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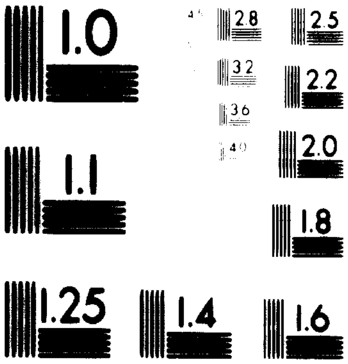
1 OF 6



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Atkins Planning

A report for the
United Nations Industrial Development Organisation

Technological innovation and its implications for long range planning of the Iron and Steel Industry in Brazil

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United Nations Industrial Development Organisation

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Technological innovation and its implications for long range planning of the Iron and Steel Industry in Brazil

1972

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CONTENTS

SECTION A

CHAPTER 1 - THE PRESENT AND PLANNED INDUSTRY

CHAPTER 2 - RESOURCES AND TRANSPORT

CHAPTER 3 - EVALUATION OF THE EXISTING IRONMAKING FACILITIES

CHAPTER 4 - EVALUATION OF THE EXISTING STEELMAKING PLANT

Page

CHAPTER 5 - EVALUATION OF THE EXISTING CASTING AND ROLLING FACILITIES

CHAPTER 6 - EVALUATION OF WORKS PRACTICE AND PERFORMANCE

SECTION B

CHAPTER 7 - IRON ORE PROCESSING

CHAPTER 8 - CONVENTIONAL COKEMAKING

CHAPTER 9 - 'FORMED' COKEMAKING

CHAPTER 10 - BLAST FURNACE IRONMAKING AND ELECTRIC SMELTING

/contd.

CHAPTER 17 - ROLLING OF FLAT PRODUCTS

CHAPTER 18 - ROLLING OF NON-FLAT PRODUCTS

CHAPTER 19 - TUBE AND PIPE MAKING

CHAPTER 20 - COATINGS

CHAPTER 21 - THE PRODUCTION OF SPECIAL STEELS

CHAPTER 22 - MINIWORKS

CHAPTER 23 - POLLUTION

CHAPTER 24 - AUTOMATION

CHAPTER 25 - ENERGY REQUIREMENTS

CHAPTER 26 - LOCATION OF IRON AND STEELWORKS

CHAPTER 27 - TRENDS IN PRODUCTION OF STEEL

CHAPTER 28 - PRODUCT DEVELOPMENT

Page

CHAPTER 29 - COMPETITION WITH OTHER MATERIALS

CHAPTER 30 - TRENDS IN CONSUMPTION OF STEEL

CHAPTER 31 - TRENDS IN INTERNATIONAL STEEL TRADING

SECTION C

CHAPTER 33 - EXPANSION OF THE INDUSTRY

CHAPTER 34 - IMPLICATIONS FOR CASTING, ROLLING AND FINISHING IN BRAZIL

CHAPTER 35 - IMPLICATIONS FOR IRON AND STEELMAKING IN BRAZIL

CHAPTER 36 - IMPLICATIONS FOR STRATEGIC PLANNING IN THE STEEL INDUSTRY IN BRAZIL

CHAPTER 37 - DEVELOPMENT OF CAPABILITY FOR ENGINEERING AND PLANT MANUFACTURE

CHAPTER 38 - RESEARCH AND DEVELOPMENT

CHAPTER 39 - EDUCATION AND TRAINING FOR THE STEEL INDUSTRY

CHAPTER 40 - RECOMMENDATIONS FOR ACTION IN PLANNING THE BRAZILIAN IRON AND STEEL INDUSTRY

APPENDICES

LIST OF TABLES

LIST OF ILLUSTRATIONS

TERMS OF REFERENCE

1. Background and aim of the project

The background of the project is as follows: The Brazilian iron and steel industry, whose production by 1945 amounted to less than 200,000 tonnes per year, has since then expanded rapidly and in 1969 reached 4.95 million tonnes. Many studies and plans have been under consideration by the Government and private firms in the last few years. An important survey of the Brazilian iron and steel industry was carried out in 1966 by Booz, Allen and Hamilton Int. Inc., under the auspices of the World Bank and the Brazilian Government. On the basis of that work the Brazilian Government prepared a National Plan for the iron and steel industry, covering the period 1968 - 1977, with detailed recommendations for the period 1968 - 1972. The projects recommended for the latter period are now being implemented. Thus, the Brazilian steel production capacity, estimated to be 5.1 million tonnes of ingots in 1967, should be increased to 7.7 million tonnes by 1973 - 1974. On the other hand, it is expected that the apparent steel consumption in the country will grow at a rate of at least 10.5 percent per year in the next decade. This forecast is based on the minimum rate of growth of the GNP planned by the Government for the period of 7 per cent per year and on the elasticity of steel production relative to the GNP, which was 1.5 in the last 15 years on the average. Accordingly, the apparent consumption of steel which amounted to approximately 5.1 million tonnes of ingots in 1969, should increase to some 15.5 million tonnes by 1980.

To satisfy this increasing demand an expansion of the Brazilian iron and steel industry will be required, beyond that contemplated in the plan already available. This will be necessary not only because of the impossibility of importing steel in the amounts that will be required, but also because of the favourable conditions prevailing in Brazil for development of the steel industry, especially the well-known availability of some of the largest reserves of first quality iron ore in the world. In fact, it is necessary to study the feasibility of expansion of the Brazilian iron and steel industry, not only to satisfy the local market but also for eventual export. Accordingly, plans for expanding the steel production capacity may involve the addition of 10 - 15 million tonnes per year of new capacity until 1980, to reach an overall capacity of some 20 million tonnes per year by 1980.

The Government is concerned with the preparation of the corresponding studies and plans but, among other elements for decision, it will be necessary to have a good evaluation of technological trends for the world iron and steel industry and of the corresponding implications for the Brazilian iron and steel industry. The information needed includes the technological and economic aspects of processes and equipment for iron ore preparation, reduction, steelmaking, rolling, product-mix choice and quality control.

The aim of the Project is to provide the Government with basic information which will in a short time lead to the full use of installed capacity through technological improvements; and which will be essential for planning the long range expansion of the Brazilian iron and steel industry along optimum technical and economic lines.

The study will be concerned with the development of the primary steel industry, that is to say, the manufacture of primary rolled steel products and only such secondary products as tubes, forgings, coated sheets, which are normally made by works that produce the primary products. The extraction, beneficiation, export and pre-reduction of iron ores will only be discussed insofar as it is related to the development of the Brazilian iron and steel industry.

2. Responsibilities of the contractor

Having in mind the Background and Aim of the Project as stated in article 1.1, the Contractor shall undertake and carry out the specific objectives and tasks stated below.

A. Technological survey and evaluation of the Brazilian iron and steel industry

Under this Section A the Contractor shall:

(i) Make a survey and evaluation which shall cover the existing plants, processes and products, as well as the planned expansions and the establishment of new ones.

(ii) Assess from technological viewpoint, the types and characteristics of equipment, processes and products followed by the evaluation of their technical and economic adequacy and performance, with comparisons with practices in use in the most modern and efficient plants elsewhere.

(iii) Pay special attention to indices of performance and point out technological shortcomings if any.

This survey, assessment and evaluation shall be based on information, data and studies made available by the Government, complemented by direct sampling on a selective basis. The end result shall be a clear presentation, analysis and evaluation of the technological status of the Brazilian iron and steel industry as it is now and based on existing plans, as it will be by 1975, with special attention to the possible increase of production and/or productivity and possible quality improvement, in a short time, by technological modifications.

The Contractor shall provide under A (i), (ii) and (iii) of this section, a broad assessment of, and recommendations for, the iron and steel industry as a whole, rather than a detailed assessment of the individual works that make up the industry, although reference to these shall be made to illustrate situations and recommendations.

B. Study, presentation and analysis of the main technological alternatives open to the modern iron and steel industry

In this study the Contractor shall indicate the significant trends in the evolution of iron and steel technology, covering all processing, from ore to final steel industry products. The analysis of technological possibilities and trends regarding nature, characteristics and applications of products of the iron and steel industry shall receive as much attention as is usually devoted to the consideration of problems related to reduction, steel-making, ingotting and rolling.

Competition of 'non-steel' products shall be carefully considered.

Such factors as technological options, size of installations, international trends in the location of installation, for pre-reduction and /or for steel-making, relative to sources of raw materials and to market, shall be considered.

The potential for, and role of, developing countries in the future of the world iron and steel industry and trade, shall be pointed out.

The economic aspects relevant to the comparison and evaluation of technological options shall be considered.

Emphasis shall be placed on the study of factors and aspects of large tonnage iron and steel production and trade "big steel" but the role of "mini-steel" plants shall also be examined, it being understood that by "mini-steel" plants it is meant here the variety of smaller steel plants, of a capacity up to some 200,000 tonnes per year whose existence is justified to satisfy certain "speciality" markets for tool steels, alloy steels, special sections or certain limited local markets for which supply from other sources proves to be difficult because of transportation costs, and keeping in mind that even in developed countries "mini-steel" plants have a very important role.

C. Indication and analysis of the implications of the technological, financial and economic trends in the world's iron and steel industry for the long-term planning of the Brazilian iron and steel industry

The Contractor shall indicate and analyse the implications of the technological, financial and economic trends in the world's iron and steel industry for the long-term planning of the Brazilian iron and steel industry taking into account the factors of production such as raw materials, energy, transportation, equipment, refractories, 'know-how', man power; the various processes and equipment to be used; the intermediate and final products to be delivered by the industry; the Brazilian export potential; the location and size of new installations; the relevant financial and economic aspects; with particular recommendations for action.

These recommendations shall be, in form and in essence, such that they will be useful to the Government and Brazilian enterprises to plan the expansion of their iron and steel industry up to 1980, and shall consider the Government targets as indicated in article 1.1, it being understood that location and size of new installation, as well as the financial and economic aspect, can only be discussed and recommended in a preliminary way, pending further detailed and specific studies.

The study under this Section C shall also include analysis and recommendations for action leading to the development of full local capability in iron and steel engineering, plant design, equipment design, equipment construction, research and development of new processes and products and training of specialists.

ABBREVIATIONS

It should be noted that SI units have been used throughout this report except where convention dictates otherwise. All costs have been given in US dollars.

CONSIDER	:	Conselho Consultivo da Industria Siderurgica
BISRA	:	British Iron & Steel Research Association
BSC	:	British Steel Corporation
OECD	:	Organisation for Economic Co-operation and Development
IBS	:	Instituto Brasileiro de Siderurgia
ABM	:	Associacao Brasileira de Mateis
AISI	:	American Iron and Steel Institute
API	:	American Petroleum Institute
BSI	:	British Standards Institute
ECSC	:	European Coal and Steel Community
EEC	:	European Economic Community
EFTA	:	European Free Trade Area
COMECON	:	Council for Mutual Economic Aid
LAFTA	:	Latin American Free Trade Association
PETROBRAS	:	Petroleo Brasileiro S.A.
IRSID	:	Institut de Recherche de la Siderurgie, France
CRM	:	Centre de Recherche Metallurgique, Belgium
NML	:	National Metallurgical Laboratory, India
USA	:	United States of America
US	:	United States
UK	:	United Kingdom
USSR	:	Union of Soviet Socialist Republics
W. Europe	:	Western Europe
BF	:	Blast furnace
BOF	:	Basic oxygen furnace (LD)
BOI	:	Blast furnace output index
TFS	:	Tin free steel
DRTP	:	Double reduced tinplate
QT	:	Quenched and tempered (steels)
PCQ	:	Plain carbon quenched (steels)
CRGO	:	Cold rolled grain oriented (sheet)
EA	:	Electric arc furnace
SL-RN	:	Stelco Lurgi - RN Corporation (proprietary process)
HyL	:	Hojalatay Lamina (proprietary process)
D/R	:	Direct reduction
Semis	:	Semi-finished products - usually slabs, blooms or billets, sometimes also ingots
R & D	:	Research & Development
GDP	:	Gross domestic product
GNP	:	Gross national product
FOB	:	Free on board
BSS	:	British Standards Specification
PVC	:	Polyvinylchloride
DC	:	Direct current
DCF	:	Discounted cash flow

approx. : approximately
c. : approximately
p.y. : per year
% : percent
cf. : refer to
qtr : quarter (calendar)
$: US dollars
¢ : US cents
Cr$: Brasilian cruzeiros
mm : millimetre(s)
m : metre(s)
km : kilometre(s)
mm^2 : square millimetre(s)
m^2 : square metre(s)
m^3 : cubic metre(s)
Nm^3 : cubic metres at normal temperature and pressure
g : gramme(s)
kg : kilogramme(s)
t : tonne(s)
lb : pound(s) weight (Imperial measure)
tpy : tonnes per year
tpd : tonnes per day
kg/cm^2 : kilogrammes per square centimetre
tonne/km : tonne kilometres
mtpy : million tonnes per year
MVA : megavolt-amps
kVA : kilovolt-amps
MW : megawatts
kW : kilowatts
kWh : kilowatt hours
TJ : terajoules
GJ : gigajoules
MJ : megajoules
kJ : kilojoules
MN : meganewtons
kN : kilonewtons
kcal : kilocalories
hr : hour
hp : horsepower
°C : degrees centigrade
C/H : carbon to hydrogen ratio
IPI : (State tax)
ICM : Imposto de Custo Mercadoria (Federal tax)

PREFACE

In June 1971 Atkins Planning were commissioned by the United Nations Industrial Development Organsiation to carry out a study of the implications of technological innovation for long range planning of the iron and steel industry in Brazil. The terms of reference for the study are set out immediately preceding this Preface. They state that the aim of the study is "to provide the Government with basic information which will in a short time lead to the full use of installed capacity though technological improvement, and which will be essential for planning the long range expansion of the Brazilian iron and steel industry along optimum technical and economic lines".

The study was carried out by a team of planners with metallurgical, engineering and economics backgrounds working partly in Brazil and partly at the Consultants' home office in Epsom. In the UK, the team were able to make use of the resources of the British Steel Corporation's laboratories (formerly known as BISRA) for advice on new technologies and research and development. At appropriate stages of the work the team was augmented by two 'top strategists' of international repute, Sir Maurice Fiennes and Mr. John L. Young, who have also continued to act as advisers throughout the preparation of the report.

The study as envisaged in the terms of reference had three distinct phases: the first concerned with the evaluation of the present industry and its existing expansion plans; the second, the technological alternatives open to the modern iron and steel industry; and the third, the implications of technological and other trends for the long-term planning of the Brazilian iron and steel industry. The work on the first phase was carried out in Brazil where an interim report was produced on that aspect of the work. At the same time the work on the second phase was in progress in the UK and interim reports were produced on these aspects also. CONSIDER staff were closely associated with the work of both phases and a consultative committee including, among others, representatives of the Instituto Brasileiro de Siderurgia and the Associated Brasileira de Metais, was set up to advise the team on the wider issues of the Brazilian steel industry. The reports on both phases were presented in Brazil at a meeting with CONSIDER, the consultative committee and the top strategists. The conclusions of these reports were then further developed as part of the third phase, and their implications for the Brazilian iron and steel industry and supporting industries were assessed and discussed at a second meeting in Brazil which was attended by CONSIDER, the top strategists and the technical representative of UNIDO. The subsequent work of producing a final report covering all these phases has been carried out at Epsom, again with active assistance from the top strategists.

The report deals with the subject matter in the same order as the terms of reference stipulate for the study itself. The opening chapters - Chapters 1 to 6 - cover the Brazilian Steel Industry as it is today (mid 1971) and its existing plans for expansion. Chapters 7 to 32 record the review of world technology. The concluding chapters - Chapters 33 to 40 - deal with the implications of technology on the future planning of the Brazilian industry. In following this arrangement, we have allowed conclusions and recommendations to arise naturally in the text as each facet of the subject is treated. To facilitate identification of these we have prepared a brief summary in which these conclusions and recommendations are highlighted and cross referenced with the relevant chapters and articles in the main body of the report. The top strategists have prepared a foreword to the report in which they express some views on the probable solution that the Brazilian steel industry will adopt as a result of rigorously planning their future expansions in the light of world technological developments.

This Foreword and Summary together with the Preface, the Terms of Reference, and a list of abbreviations, form the introductory material to the report. The main text of the report is supported by a number of appendices, dealing with details of certain aspects and including a list of references.

FOREWORD

BY

THE TOP STRATEGISTS

We were appointed as "Top Steel Strategists" to collaborate with Atkins Planning in the preparation of this report and, in addition to our two short visits to Brazil, we have helped wherever possible by commenting on the drafts which preceded the report as now submitted. Reports of this nature necessarily run to considerable length and we thought it might be helpful, both to UNIDO and CONSIDER, if we were to prepare a foreword setting out our broad view of the situation covered by the Terms of Reference.

While we do not think we have differed from Atkins Planning on any important issue of substance, we emphasize that the summary which follows represents our agreed personal view; and it relates primarily to strategy - the aspect upon which we were presumably expected to advise.

1. General observations

The effectiveness of a steel industry - or of any industry, for that matter - cannot fairly be judged solely by figures of capacity and output, supplemented by a cursory inspection of its plant and a few hours talk with the staff in a few locations. It is also important to know whether the industry as a whole and its principal components earn a reasonable return on the investment, when operating at internationally competitive price levels and at wages levels which are socially acceptable; and by a 'reasonable' return, we mean one which will stimulate the supply of new capital for further investment. Information of this kind was not available to us and there was neither time nor opportunity to ascertain it. Without such information judgements can be at fault. We were required primarily to examine the technological status of the Brazilian iron and steel industry, but technology cannot be divorced from economics when considering whether a particular enterprise is efficient or not. We make the point because future development and investment decisions are unlikely to be better than the information on which they are based, so that an organized flow to the centre of reliable and comparable data about the performance of the industry is of cardinal importance.

Moreover, in considering the future of the steel industry, it is necessary to remember that the manufacture of steel is not an end in itself: it is a means to an end, namely to provide the raw materials for a wide range of engineering and consumer goods industries. If these are to be competitive in the domestic market, as they must be, then steel must be available at competitive prices; and this, for a healthy steel industry, means competitive costs. The same, of course, applies to exports, whether of steel or of engineering goods made with it. Thus, in considering technological options, it is essential to have regard not only to what is possible, but to what is economic. If to say this is to point the obvious, it is because some of the so-called new technology which is currently publicized is far from proven and may well be uneconomic in the Brazilian context if and when it is. It is probable that, at least in Brazil's present stage of development, reliance on traditional processes which are well proved and established, but incorporating the most up-to-date engineering, will offer the best dividends.

Finally, so far as these general observations are concerned, it should be recorded that while Brazil is exceptionally well endowed with iron ore, manganese, limestone and refractory materials, all of which are quite conveniently located, she is very short of good reductants which are, of course, essential for smelting iron ore to liquid iron. The bulk of the reductant must be imported unless or until new deposits are discovered and developed. Also, the estimated availability of indigenous scrap (which is an important raw material source in most steelmaking processes) is such as to impose practical limitations on the extent to which Brazil's great electrical energy potential can be employed economically to expand steel production. While it is now practical to supplement scrap in the electric furnace by feeding pellets of metallized ore, i.e. reduced pellets, the economic price of such pellets is of major importance. Their production in Brazil from Brazilian ore inevitably re-introduces the problem of importing suitable reductants at economic prices.

These are among the main ingredients of the problem of designing a 20 million tonnes per year steel industry for 1980. It is only necessary to say that if some other countries much less well endowed can and do make steel economically, then the Brazilian problem is perfectly capable of solution. Indeed, there is no reason why she should not become one of the low cost producers of the world.

2. The flat product sector

The Brazilian industry has already made its decisions to meet the demand situation expected by 1980, and there is little which Atkins can add which is of a strategic character. The following observations are pertinent, however.

(a) Steps must be taken to improve blast furnace performance which, in general, is not up to international standards on the figures given to us. Figures are given in the report with practical suggestions on what should be done (Chapter 3, Article 3.3). We think this should be treated as urgent because of the significant savings in Brazil's import bill for coking coal, quite apart from the potential savings in production cost. Apart from this, most of the improvements which seem possible are operational matters which are the province of good management more than anything. Steps are seemingly being taken to improve the information systems which lie at the root of good management. The establishment of uniform costing systems is an important objective (Chapter 6, Article 6.2).

(b) The heavy investment in new wide plate mills will, of course, only pay off if continuous attention is given to the development and growth of the plate consuming industries, particularly shipbuilding.

(c) It should be said that, although the developments at the strip mills (iron and steelmaking as well as the mills themselves) would appear nearly adequate to meet the estimated demand for strip mill products in 1980, the total tonnage will be produced from three separate semi-continuous hot strip mills. One modern fully continuous mill would be capable of rolling the lot and still have some capacity in hand. It would also produce strip of better quality; and as the entire production would be centred in one plant instead of three, the conversion cost would be appreciably less. The existing situation, which is not in line with that in industrialised countries, is, of course, historical and cannot now be changed, but it serves to show that a piece-meal approach to strip mill products is incompatible with the economic growth targets which Brazil has set for herself.

The next hot strip mill in Brazil must surely be a modern, powerful, fully continuous mill which is capable of exploiting the full possibilities of mill automation. It may be required sooner than is generally realised if the demand for strip mill products accelerates as it has done in some other rapidly developing countries. Additional capacity is, in any event, estimated to be necessary quite soon after 1980, which means that construction of a new mill should begin perhaps in 1977 or '78, Its planning should begin much sooner; and certainly not later than 1974 (Chapter 34, Article 34.1).

As to the location it is certain that, in economic terms, it is better to expand existing steelplants to their maximum potential before building new ones. It would seem that the fairly extensive switch of emphasis of both Usiminas and Cosipa to plates, plus some other limiting factors, preclude the further development of these plants as strip producers much beyond current plans. There are, of course, many factors to be taken into account in any such decision but, prima facie, the balance of advantage would appear to support a policy of replacing the 26 year old hot strip mill at CSN by a modern mill on an adjacent site. It is pertinent to observe that by 1980 the existing CSN hot mill will be about 34 years old and may well be due for retirement, notwithstanding the expenditure on it currently being incurred. The full development of the new BOF shop to 3 x 200 tonnes - 2 melting, 1 re-lining - should produce about 4.5 million tonnes of liquid steel per year. A modern hot strip mill on normal average product mix should absorb this tonnage if well operated.

The ironmaking facilities currently planned at CSN will also support steelmaking on this scale.

(d) Of cold mills, it is only necessary to say that any new mills will of course incorporate the most up-to-date engineering available at the time, and this also applies to the considerable range of auxiliary equipment - and it will be a matter for judgement to decide the extent to which, for example, batch annealing should be replaced by continuous annealing. It seems likely that there will be a need by 1980 for further cold rolling and processing capability for sheet products as distinct from tinplate. How and where this should be furnished is a matter for detailed study, and the planning must be done in plenty of time. We can offer the general comment that these expensive assets are economic only when they are kept full of steel. It is normally practical to transfer balancing tonnages of slabs or hot rolled coils from one plant to another with this object in view, and this should form one element of the study.

(e) In the event that a new tinplate plant becomes necessary - and this seems likely, notwithstanding the impact upon tinplate of other packaging materials - it is not necessary to build it at the same site as the hot strip mill serving it. It is entirely practicable to ship hot rolled coils to a convenient location, preferably accessible to major customers in the canning industry, for cold rolling and processing. We think a new tinplate plant should incorporate facilities for the production of tin-free steel; and probably also for double-reduced tinplate (Chapter 34, Article 34.1).

(f) Viewing the flat products programme as a whole, the major process decisions (e.g. new large blast furnaces, enlargement and new construction of BOFs, phasing out of open hearth shops etc.) are quite in line with modern practice elsewhere. So is the decision to develop the continuous casting of slabs but, while continuous casting is undoubtedly here to stay for the production of plates, the position is rather different where strip mills are concerned. The reasons are given in the report, but it is sufficient to say here that 100 percent continuously cast slab feedstock for a hot strip mill is not yet generally considered feasible. Most new strip plants recently built or under construction provide for a combination of ingot practice and continuous casting (Chapter 15).

3. Structural sections

The consumption of these in relation to total steel consumption appears low in Brazil in relation to other countries. It is clear that many Brazilian structures are of reinforced concrete, but there is room for conjecture on the extent to which this is due to relatively low availability of structural steel. At all events there is no heavy structural mill in Brazil and the only medium structural (and rail) mill, which is at CSN, is really obsolete, although it was up-to-date when it was built about 26 years ago and there are many such still in operation elsewhere. This mill is not designed to roll universal beams, or H-beams and sections with parallel flanges, which are increasingly in demand for structural engineering. If experience in other comparable countries is a guide (Canada, Australia, Mexico, South Africa, for example), there should be a place in Brazil for a universal beam and structural mill as a basis for a more extensive structural engineering industry; and certainly its feasibility should be examined. Prima facie, it would be difficult simply to replace the CSN mill with another on the same site, and a universal beam mill should preferably form part of a new steelmaking complex. By the time this could be built, it may be that the whole of the steel make at CSN will be required to feed a new strip mill and it might then be found convenient to phase out structurals and rails from CSN and make them on a new modern mill elsewhere. Such a mill might well be semi-continuous, and it should be so engineered that its output potential can be increased as demand grows. Experience suggests that a mill of this type should be capable of rolling universal sections up to 500 mm or perhaps 600 mm. Sections over this size can be more economically made by welding plates, unless the market demand for them is large enough to warrant the substantially higher cost of a larger mill.

However, fabricating heavy sections from plates cut from greater widths as rolled can be expensive in terms of yield. A saving of 4 to 5 percent in yield can be achieved by fabricating universal plates, i.e. plates rolled accurately to controlled width and edge. There is currently no universal plate mill in Brazil, and the case for one should be considered. Experience elsewhere suggests that 1,000 mm is the maximum economic width normally required for this purpose from universal plate, and this is within the compass of a 2-high mill. Some such plate can, indeed, be rolled on a universal beam mill, although it is open to question whether this is the best way to utilize the mill.

4. Tubes and pipe

Most of Brazil's production has hitherto been seamless tube and although there was little information on the subject or opportunity to investigate, it seems fair to deduce that seamless tube has been used in many applications where cheaper qualities of pipe would be adequate. The electro-weld tube plants now being installed at Mannesmann will go some way to correct this, but we were surprised to find that there is no continuous butt-weld pipe plant in Brazil or, apparently, planned. Common steel pipe, usually produced by the Fretz-Moon process, forms a large part of the market in most steel producing countries; and while the economics of this and other processes depend upon the volume of production, there is a case for a specific study of the whole tube and pipe market in Brazil, upon which a strategy should be based for the further development of this highly specialised sector of the industry. Seamless tubes were the only category mentioned in the Technometal report; and it is necessary to know what the future may be for other types, because the answer may well have an impact on the planning of billet and narrow slab production.

5. Other non-flat sector products

We have deliberately referred to structural sections, tubes and pipe before turning to the highly important remainder of the non-flat sector. It is first desirable to distinguish between what are usually called 'special' steels on the one hand and 'common' steels on the other, even though the dividing line is not precise. What we saw of the 'special' steels sector suggested that the Brazilian companies concerned with the non-flats part of it are efficient and, through their overseas connections, well advised. It is reasonable to suppose that these companies will continue to do what their customers require of them. They would be helped presumably by better arrangements for the collection, segregation and processing of scrap and this is dealt with fully in the report (Chapter 13, Article 13.4). One area worth exploring is whether there would be benefit by pooling some of the activities of the alloy steel makers in such a way as to justify the installation of a high precision rod mill designed to roll relatively short runs of high value steel. Such a development took place in the UK in recent years, and even if it is not immediately practical, it seems important to ensure that the alloy steel sector of the industry does not become too fragmented.

As regards the non-flat common steel sector, there is much to be said. This sector has grown up as a result of natural forces which were often localised in character. Plants have been built to serve local, short term needs; and while it does not necessarily follow that they are uneconomic on that account, they have not as a rule been established with the long term future of Brazil's rapidly expanding economy in mind. In consequence, this sector is, by modern standards, much too fragmented and much of the equipment is obsolete. The report recommends that the prospects of rationalising some of the smaller firms, especially around Sao Paulo, should be examined, but the potential benefits can only be assessed by a study in depth.

The main question, of course, is what next? Virtually all the "common non-flats" pass through the stage of "semis", mostly billets, which are then rolled or re-rolled on different types of finishing mills to produce different products, perhaps in different locations, e.g. merchant bars, specialised sections, wire rods, narrow strip, hoop or skelp for pipe-making etc. A significant tonnage of billets will also go into forgings and stampings for a variety of trades. We were not given sufficient information to make an accurate or reliable appraisal of the demand by 1980 for all these products, and it has therefore only been possible to give the roughest indication of the finishing mills which may be required to produce them. What is significant at this stage is the likely demand for billets, because if the supply is inadequate there will be no point in building new finishing mills anyway, unless large tonnages of billets are to be imported.

The figures given to us indicate that there will be a need for a further 2.3 million tonnes or thereabouts of billets over and above existing capacity by 1980. This equates to about 2.7 million tonnes of liquid steel (assuming 85 percent yield) and the major question is to decide the technology route or routes which should be employed to produce it; and it is important to have this figure in mind because the technological options for a production of 2.7 million tonnes are different from those suitable for, say, 0.27 million tonnes.

As the report shows, the main steelmaking process route options are :

- blast furnace/BOF:
- scrap based electric arc, possibly supplemented by a partial pre-reduced pellet feed, if available;
- direct reduction iron making, followed by electric arc steelmaking.

The process options for converting liquid steel into billets are :

- casting ingots and rolling to blooms and then to billets;
- continuously casting blooms and rolling to billets;
- continuously casting liquid steel direct to billet sizes.

It is not the purpose of this foreword to repeat what is written in the report, but without hesitation we recommend:-

(1) That where, as apparently in North Eastern Brazil, there is an appreciable local arising of scrap, then that scrap should be used locally in so-called "mini" steelworks using electric arc furnaces to produce a strictly limited product range. It would be wrong to transport such scrap over long distances, and right to use it locally to satisfy local demand where it exists. It is important to realise that the economics of a "mini" steelworks rest on the availability of cheap scrap, which in turn means local scrap of which the price is not inflated by heavy transport costs. Such a works must also produce a strictly limited product range, e.g. reinforcing bar; and there must also be a local market so that the price of the finished product is similarly not inflated by heavy transport costs.

(2) That the great bulk of the required 2.7 million tonnes of steel should be made and converted into billets in a new steel plant on a green-field site, using Brazil's own natural metallic source through the blast furnace/BOF route.

(3) That while it is possible a detailed feasibility study will produce a different economic answer, we are strongly attracted to the second of the process options above, for converting liquid steel to billets, i.e. casting blooms and rolling to billets. Only by this option is it possible to combine:-

   (a) the economies of scale achievable by using iron produced in a large modern blast furnace to make steel in large, say 200 tonne, oxygen converters be they BOF or OBM;

   (b) the advantage of better yield from liquid steel to sale billet by the use of continuous casting rather than ingot practice; and the scope for sequential casting where the order book is suitable;

   (c) the flexibility offered by rolling to the various sizes and shapes required by customers from what can well be a single bloom size. Frequent changes of moulds are inimical to the efficient operation and smooth flow of production from a continuous casting machine, and recent developments in the USA have shown the tremendous economic possibilities in large scale billet production by sequential casting from large BOFs through a four strand continuous caster, using a single mould size for blooms subsequently rolled to billet sizes. It is known that the plant in question has already cast eighteen 200 tonne heats entirely into $7\frac{1}{2}$ inch (190mm) blooms representing a production of 3,600 tonnes rolled into billets within a 15-hour period, and these figures may well have been exceeded by the time this report is read (Chapter 15, Article 15.2).

It should be possible to build such a plant in stages, if this proves necessary, and the detailed studies should indicate the possibilities in this respect.

Again without attempting to repeat the report, we offer the following summarised observations in support of these recommendations:-

i) If Brazil is to have an additional 2.3 million tonnes of billets by 1980, the plant must start operations not later than the beginning of 1978 at the latest. Construction would need to start early in 1975. It may take at least two years to carry out the feasibility study, select the site, do a vast amount of engineering, organise finance, place contracts and make a host of decisions. This work will need to start, therefore, early in 1973, that is within the next 6 months.

ii) Progress has been made in direct reduction of iron ore in recent years, but the plants so far designed are still on a relatively small scale and are only economic in the context of 400/500,000 tonnes per year outputs. To achieve 2.3 million tonnes of billets by 1980 through these routes would involve the construction of five to six new steelworks. We do not believe this to be possible within the time scale envisaged and, as shown in the report, the cost of steel would be higher.

iii) With the probable exception of HyL, most of the direct reduction processes are still involved in technical troubles and, without prejudice to their future, we do not believe that Brazil should at the present time commit her future wholesale to them. To do so would be to take unacceptable risks.

iv) It remains to be seen how the SL/RN kiln at Piratini operates on local coals. Even if satisfactory, the production of 2.7 million tonnes of liquid steel would require a total of 20 kilns or more. It is known that the SL/RN process is involved in technical problems elsewhere.

v) Of the natural gas processes,it is necessary to point out that Brazil is short of that commodity, at least at present. The true economics of reformed naphtha as a substitute can only be estimated at present, because no such plant is known to be in operation. However, it would seem that with naphtha at $3 a barrel, the cost of liquid steel would be increased by at least 13 percent in comparison with natural gas at the price at which Usiba expects to buy it - and even then about 50 percent of the charge would be scrap.

iv) Of scrap, it is only necessary to say that the estimates suggest that the scrap arising in Brazil will be nowhere near enough to support steelmaking by the electric arc process on the scale envisaged. It is possible, of course, to import scrap or to start or expand a ship breaking industry, but it seems absurd to adopt such a course when Brazil possesses her own metallic source - one of the largest group of deposits of high grade iron ore in the world. While it is technically feasible to feed reduced pellets (metallized ore) to the electric arc furnace as a supplement to scrap, the economics to Brazil on a large scale have yet to be established.

Location

It is not our province to recommend sites, but we can re-assert the dictum that the economy of steelmaking rests upon the ability to assemble high grade and cheaply won raw materials at low cost at a point which is accessible to markets. In other words there is a fundamental problem of optimising transport costs; and even then there will almost certainly be a need for compromises to reconcile the optimum with practical site availability, water and power availability, and so on. Prima facie, it seems to us that any new plant should be built either upon or adjacent to the iron ore mines, or on the coast at or near one of the iron ore export outlets. The fact that coastal sites are popular in many countries is not necessarily a criterion for Brazil, because the basic reasons may be different. In Brazil, it is necessary either to haul coal by rail to an inland site, or iron ore, also by rail or slurry pipeline, to a coastal site. Prima facie, there would seem to be attractions in sea-borne coal meeting domestic ore on the coast if it proves possible to find a site in close proximity to one of the existing or developing iron ore export outlets. Amongst other advantages, the ships which export ore can often return with foreign coking coal as currently happens in the Vitoria area. Such a situation would also be favourable to exports of steel if the harbour facilities are adequate or can be made so at reasonable cost; but, of course, low transport cost accessibility to domestic markets is also a crucial factor. In theory, one would think that Brazil's long coastline could be exploited in this context, and that to a considerable extent an over-loaded internal transport system could be relieved by a well organised and economic coastal shipping system. Also, shipping billets by sea to north-eastern coastal ports in support of potential local re-rolling mills may well be a sound way of helping to promote industrialization in those regions. Nevertheless, the internal transport links from a coastal steelworks to the existing main industrial areas of Brazil would require the closest scrutiny, as this would be an important element in any decision.

The possibility of siting a new integrated steelworks in a remote area, with the object of stimulating industrial development in parts of Brazil where the economy is differently based, is a subject on which we cannot comment. Such matters are mainly political, and we are concerned in this report primarily with the economics flowing from technological options.

The cost

The report gives figures for model steelworks (Appendix 3). We cannot comment on these, except to say that there can be so many variables that a detailed feasibility study is the only means of arriving at a reliable estimate; and the infrastructure costs - a highly important ingredient - can only be estimated for specific situations. Widely differing global figures for constructing new steelworks on greenfield sites have been quoted by various authorities in recent years, and perhaps they should all be treated with some reserve because they often relate to varying contents. If, however, we take US$ 235 per annual tonne of billets (equivalent to $200 per tonne of liquid steel converted to billets) as a figure for converting Brazilian iron ore to billets through the blast furnace/BOF route, casting blooms and rolling to billet size, then the cost of a 2.3 million tonne billet plant would be about $540,000,000 plus infrastructure costs. There would, of course, be a need for further investment in finishing mills, which can either be at the same site or elsewhere. We believe, however, that if a new universal structural mill is to be built, there would be a good case on general economic grounds for siting it within the billet complex as a parallel operation.

Even if the plant can be built for $180 per annual tonne of billets, equating to about $415,000,000, the investment will still be very great. The inter-action between the public and privately owned sectors of Brazilian steel is not our business, but it does appear to us that the money can hardly be raised without a very considerable degree of State backing and involvement. In the event that a large part would need to be financed by foreign loans, such backing would be indispensable. The problems are well known in Brazil and do not call for advice from us. It is possibly worth saying, however, that in countries like the UK, where there is a mixed steel industry structure, the fact that the nationalised sector is both a supplier (of semis) to, and a competitor (in some finished steel products) with the private sector, is a frequent source of friction. With this experience in mind, it may be helpful to suggest that if in Brazil the State is to become the major supplier of billets, perforce and perhaps unwillingly, then the rolling and sale of finished products should be left to the private industry. It has been suggested that a new billet plant could be set up by the co-operative endeavour of a group of private steel companies. This might well be a good solution, but it seems likely to hinge on whether the financing of such a project is practical.

Finally, so far as the common non-flat sector of the Brazilian steel industry is concerned, we regard it as urgently necessary to commission a full feasibility study of a 2.3 million tonne billet plant. In doing so we think that CONSIDER, as the agent who would presumably commission the study, should indicate specific areas where practical sites should be investigated and should, as far as possible, limit the terms of reference to specific technological options; if the recommendations in this report are accepted, there is no point in doing the work all over again.

6. Special quality flat products

Several countries today are still suffering from the effects of insufficient vision when their stainless sheet facilities were first established. The extent to which Brazil evades this trap depends upon her willingness to establish facilities with a long term future accepting that they may be uneconomic in the short term. We think, however, that this problem can be mitigated, and that probably the cold rolling and heat treatment plant should be installed at the first stage. These can be fed by Brazilian ingots (or pressure cast slabs), hire rolled into hot rolled strip on Brazilian or foreign semi-continuous hot strip mills as opportunity offers, or contracts can be arranged. As the domestic market grows, Brazil should then install her own hot rolling facility, probably starting with a modern Steckel type reversing mill, with hydraulic gap control and automatic gauge control, with provision in the layout to convert the mill into a semi-continuous plant as demand grows further. Recent developments in the production of stainless steel ingots or slabs should be carefully evaluated, e.g. BOF or argon-oxygen de-carbonising in comparison with the hitherto conventional electric arc furnace process.

7. Peripheral subjects

We certainly think that Brazil, with her ambitious plans and enormous future, should put herself in a position to design her own steel plants, though we think it quite wrong that she should seek to make herself self sufficient in equipment design. There is plenty of engineering ability already in Brazil, but in the last resort people only learn how to design a steelworks by actually doing it. The investment in modern steelworks is so enormous, however, and the stakes so great, that there is really no substitute for experience; and this is why we believe that Brazilian consulting engineering firms should be encouraged to ally themselves with overseas firms having the necessary experience.

Equipment design is another matter. As time goes on, it becomes even more international and no country can expect to start successfully on its own ab initio. The obvious course, in our judgement, is to encourage the conclusion of licence agreements which make the most modern technology available to Brazil. Let Brazil improve upon it if she can; and sell her improvements to the rest of the world.

The manufacture of iron and steelmaking equipment within the country is, of course, desirable as a general proposition, but once again it is necessary to distinguish between what is possible and what is economic. We doubt, for example, whether it would be economic for Brazil to lay down the very heavy foundry and machine shop facilities which are necessary for hot and cold strip mill stands. It would be better to import these in the foreseeable future, since there is a considerable world over-capacity for their production, and Brazil has many claims upon her available stock of capital. On the other hand, capacity for producing the less heavy types of rolling mills should be encouraged if it is at present inadequate; and the same applies to structural engineering and the making of fabrications from heavy plate.

The production of steel mill rolls was quite impressive, and we believe the present manufacturers are likely to expand their facilities as occasion demands.

* * * *

In conclusion, it may be said that the steel industries of most of the industrialized countries are a mixture of plants which are good, bad or indifferent; so if the Brazilian industry contains some which are less than perfect, this need cause no serious dismay. Every such industry has evolved in the context of the political and economic environment existing at the time when the various investment decisions were made; and most entrepreneurs would doubtless admit that, if they had their time over again, there are many things they would do differently.

With all the advantages of hindsight it appears to us (and we believe knowledgeable Brazilians might agree) that much of the existing steel industry in this vast and fascinating country has been based on too tentative and rather small scale premises. This is very understandable in the context of the past, but we believe the future calls for a modified attitude. With an economy which is now obviously being managed and directed by firm and skilful heads and hands, which have set ambitious targets for economic growth and are determined to achieve them, and with some excellent resources available (although, alas, not apparently in reductants), the scope for a great surge forward in steelmaking becomes apparent. So far as practical, therefore, there is now a need for a "maxi" rather than a "mini" approach, save in special situations.

Investment decisions must, of course, be prudent, but Brazil seems to us to be a maxi proposition in so many respects and must make her decisions with a corresponding degree of confidence in her future.

We are glad and privileged to have been associated with this study, and we look forward to the next executive decisions with lively anticipation.

Sir Maurice Fiennes

John L. Young

November, 1972

SUMMARY AND RECOMMENDATIONS

Section A of this report is summarised in Article 1, Section B in Article 2 and Section C in Article 3. In order to make clear the context of the recommendations they have been included in this Summary and underlined; the relevant main report references have also been given.

1. The existing industry, its performance and possible short term improvements (Section A)

1.1 Structure of the industry

For the purposes of examining the implications for the long range planning of the iron and steel industry in Brazil, we are not only concerned with the industry as it exists today but also with developments which have been sanctioned (up to October 1971) and which will, therefore, be implemented in the next few years - say, by 1980.

The present structure of the industry is broadly as follows:-

Type of works	Number of works	Output in 1971 (millions of tonnes)
Non-integrated	6	
Semi-integrated	25	5.7 steel
Integrated	16	
Pig iron from small charcoal furnaces	approx. 65	0.7 iron*

In terms of finished product output, 55 percent of the 1971 production was flat products, the remainder being non-flat. The flat product output is produced by three large companies (CSN, Usiminas and Cosipa), whereas the non-flat output is produced by 44 works of capacities ranging from 4,000 tonnes per year to 500,000 tonnes per year. In 1971, 97 percent of the industry's output was

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(* Output primarily used by foundry industry.)

produced in the "steelmaking triangle" of Sao Paulo, Belo Horizonte, and Rio de Janeiro.

The existing (1971) finished product annual capacity of the industry is 4.9 million tonnes and on the basis of the developments now sanctioned this will have increased by 1980 to 9 million tonnes. The major part of this increase will take place in the flat product sector:-

	Capacity (millions finished tonnes)	
	1971	by 1980
Flats	2.3	5.3
Non-flats	2.6	3.7
Total:	4.9	9.0

The Government has a majority shareholding in seven steel companies which includes the three flat product companies and four non-flat product companies (Acesita, Cofavi, Cosim and AFP). The rest of the industry is privately owned and the two biggest non-flat companies (Mannesmann & CSBM) have predominantly foreign ownership.

The major part of the research and development activity at company level is carried out by CSN and Usiminas, whilst at national level it is carried out by Associacao Brazileira de Mateis (ABM), and Instituto Brazileiro de Siderurgica (IBS), together with several universities. Several companies have significant personnel training programmes and a number of the larger companies have technical "know-how" agreements with some major foreign steel producers.

1.2 Ironmaking

There are at present some 6 modern slot-type coke oven plants and one "beehive" type. These will be increased by 3 to a total of 10 by 1975. The three flat producers will each have installed one new plant by 1975. Coke is now produced from a blend of imported and domestic metallurgical coals (some 20 to 30 percent). The output achieved from the existing installations, at some 0.7 to 0.8 tonnes per cubic metre per day, is close to the output achieved by world leading cokemakers. The main opportunity for improvement in Brazil lies in reducing present cokemaking costs, by using selective preparation to permit the use of some non-coking coals in the coal blend - up to 40 to 50 percent has been used at some plants. Further investigations should be made into the maximum proportion that can be used under Brazilian conditions. (Chapter 3, Article 3.1).

By 1975 Brazil will have some eleven sinter plants ranging from capacities of 100,000 tonnes per year to 2.5 million tonnes per year. Seven of these plants are of the continuous type fed with coke breeze and the remaining four are semi-continuous fed with charcoal fines. The outputs of the continuous plants range from 23 to 36 tonnes per square metre per day and of the semi-continuous, 12 to 27 tonnes per square metre per day; of these the high outputs are in line with good modern practice. The lower output levels can be increased by improving the sizing and mixing of the sinter plant feed. (Chapter 3, Article 3.2).

There are at present 27 blast furnaces in operation and by 1975 there will be 31. In 1975 some 87 percent of the pig iron output will be from coke practice on larger hearth diameter furnaces (10 to 12.5 metres) and 13 percent from charcoal practice on smaller hearth diameters. Present burdens use high grade indigenous lump ore and sintered fines. The use of sintered fines will increase and soon oxide pellets will be included in burdens. The blast furnaces operating on coke have blast furnace output indices ranging from 44 to 58, which compare unfavourably with good modern practice, whereby outputs of 100 are achieved; they also have coke rates which lie between 460 and 635 kilogrammes per tonne of hot metal, which are high by world best standards. The blast furnaces operating on charcoal also have outputs which fall short of today's achievements.

Improvements in the output indices of the coke practice furnaces may be achieved by :-

(a) Removing fine materials of less than 10 mm from the burden, by providing adequate screening facilities prior to charging the furnace.

(b) Carrying out metallurgical tests to determine the optimum particle size of the burden materials, and applying the results.

(c) Using 100 percent sinter burden.

Reductions in coke rates may be achieved by :-

(a) Using direct fuel oil injection, particularly since Brazilian fuel oil has a very low sulphur content. A rate of 60 kg per tonne of hot metal should be attempted.

(b) Making provisions for the use of an oxygen enriched blast.

(c) Using higher blast temperatures and top pressures.

For charcoal practice furnaces the output indices can be increased by improving the composition and sizing of the burden, and charcoal consumption rates can be reduced by fuel and charcoal fines injection. (Chapter 3, Article 3.3)

1.3 Steelmaking

In 1971 some 6.0 million ingot tonnes were produced. On completion of the present development plan, steelmaking capacity will be about 10.8 million tonnes per year, 67 percent of this capacity being BOF, 24 percent electric arc and the remainder open hearth. The capacity increase in the flat sector will be by the BOF process whilst that in the non-flat sector will be primarily by the electric arc process. The electric arc plants will be able to use some sponge iron as a feedstock when the new SL/RN and HyL direct reduction plants come into production.

The existing BOF plants achieve tap-to-tap times varying from about 57 minutes for the 25 tonne vessels to 35 minutes for the 70 tonne vessel, although a 75 tonne vessel is operating on an 80 minute tap-to-tap time, primarily due to shortage of hot metal. Oxygen consumption (ranging from 70 normal cubic metres per tonne for small vessels to 50 cubic metres for large vessels) for the large vessels compares well with modern practice. Refractory consumption (some 3.75 kg per tonne and 400 heats per lining) could, because of the high intrinsic quality of the refractories, be reduced. In order to achieve high performance levels the following should be ensured:-

Satisfactory material flow through plant;

adequate supplies of hot metal;

adequate supplies of scrap;

adequate supplies of oxygen;

casting facilities capable of receiving maximum output of molten steel;

improvement in quality of refractories. (Chapter 4).

For the open hearth furnaces outputs are in general low (some 4 tonnes per hour for 20 to 60 tonne furnaces and 27 tonnes per hour for 200 tonne furnaces), primarily due to inadequate scrap handling and charging arrangements. These should be improved. (Chapter 4).

For the electric arc furnaces outputs range from 0.5 tonnes per hour for furnace capacities up to 4 tonnes to 8 tonnes per hour for 40 tonne capacity furnaces. Outputs vary a great deal due to varying conditions in hot metal and cold scrap charge, plant layout and supporting ancillary services. Power consumptions ranging from some 600 to 700 kWh per tonne are high by modern standards, primarily due to poor quality and low density scrap.

Improvements should be made in scrap purchasing, sorting and baling procedures, together with furnace charging procedures. (Chapter 4).

1.4 Casting and rolling

The present predominant use of ingot casting will have changed by 1975 when the flat product sector will begin to produce a large tonnage of continuously cast slabs and the non-flat sector will considerably increase its production of continuously cast billets. The number of machines installed will have increased from 3 to 9 and heat sizes will be some 150 to 200 tonnes instead of 15 to 40 tonnes.

The large flat product mills which roll both plate and strip operate significantly under capacity due to shortage of steel, leaving finishing equipment standing idle. Over half the flat product mills were commissioned prior to 1955.

There are some 72 mills in total in the non-flat sector, including 41 primary mills, 30 general mill complexes and 1 medium heavy section mill. Mill yields vary so much from one plant to another due to different product mixes and methods of operation that it is not possible to generalise about output achievements. Nevertheless, opportunities exist to increase outputs by minor investments in shears, cooling beds and reheating furnaces and rationalisation of product mix - the area of investment depending on the particular mill. (Chapter 5, Article 5.2).

1.5 Efficiency of plant and labour and quality control

In general ironmaking, steelmaking and rolling plant tend to operate at some 40 to 80 percent of their rated capacity. Since the data used was based on rated capacities assessed some time ago, plant efficiencies may have been overstated rather than understated. Mill efficiencies could be improved by alterations in maintenance methods and the provision of spare parts. Steelmaking plant efficiencies could be significantly improved by reducing the periods when hot metal is not available. (Chapter 6, Article 6.1).

The industry at present employs some 82,000 people and produces about 6 million ingot tonnes. Labour productivity tends to be somewhat higher (some 84 to 130 ingot tonnes per man per year) in the integrated flat product sector than in other sectors (on average some 60 tonnes per year per man). Clearly there is scope for productivity to be increased, and training schemes should be introduced into those works which presently have none. Also, action needs to be taken at university level to encourage more graduates and technical college students to enter the steel industry. (Chapter 6, Article 6.1).

As regards product quality, international standards are at present used but discussions concerning the production of a comprehensive national standards system are now taking place. Quality control is presently undertaken by only a few companies with adequately staffed and equipped departments. In general, quality control needs to be improved, as indicated by consumer complaints, and advice should be obtained on this. (Chapter 6, Article 6.1).

To improve performance the best international engineering, operational and managerial assistance - particularly in the non-flat sector - should be obtained. In the case of consulting assignments, the consultants recommendations with regard to achievable standards of performance should be precisely specified. The industry should seek advice on what should be done to improve quality. (Chapter 6, Article 6.1).

Existing management information systems are inadequate and advice should be obtained on establishing an industry-wide uniform system of reporting and cost control. (Chapter 6, Article 6.2).

Opportunities for rationalisation of production, particularly in the common steel non-flat sector, should be closely examined. (Chapter 6, Article 6.3).

The potential for Brazil of new manufacturing processes should be carefully evaluated. (Chapter 6, Article 6.4).

2. Technological and commercial trends in world iron and steel industry (Section B)

2.1 Iron ore processing (Chapter 7)

The proportions of lump ore, sinter fines and pelletising fines used are dictated both by the characteristics of the ores available and by commercial considerations. There is an increasing demand for higher grade raw materials and the mean grade of lump ore remains more or less constant, but the consumption of concentrated and agglomerated fines is rapidly increasing.

By 1980, consumption of sintered fines in Europe is expected to rise to about 140 million tonnes per year and consumption of pellets to 30 million tonnes. In Japan, an early increase in agglomerating capacity is expected, to reduce Japan's dependence on Australian lump ore. In the United States consumption of pellets has increased by 200 percent and in Canada by 600 percent in the past ten years, during which period sinter consumption was unchanged. These trends are expected to continue.

The practice of superfluxing sinter, whereby all the required lime is added to the sinter by blending iron ore fines with finely crushed limestone and coke breeze, is expected to grow considerably.

The trend in sinter plant development is towards larger continuous travelling grate plants, of which the largest are at present five metres wide with grate areas up to 500 square metres. The majority of plants achieve outputs of some 35 to 40 tonnes per square metre per day.

Unit sizes of pellet plants now exceed two million tonnes per year capacity, and some large North American installations consisting of a number of units have capacities of some ten million tonnes per year. The main technical developments involve the cold bonding of pellets as an alternative to firing, but the pellets need four to five weeks to reach full strength and do not travel so well as fired pellets, so their use is likely to be limited to situations where a minimum of handling is required. The largest plant now operating is in Sweden, its capacity being 1.5 million tonnes per year.

2.2 Cokemaking (Chapter 8)

The rising cost of metallurgical coke has stimulated a great deal of research and development work concerned with optimum coal blends for coking. The decreasing sales of by-products has also stimulated greater interest in methods of cost reduction.

There is a trend towards using coal blends which contain about 27 percent volatile matter since this tends to give optimum results. Selective crushing to obtain more uniform particle size is now used in France, India and the USA, and should in many situations reduce overall process operating costs.

Drying and preheating the coal charge not only results in an increased output but also creates the opportunity to increase the proportion of weakly coking coals in a blend without any reduction in coke quality. A further suggested result of preheating, not confirmed by all tests, is to reduce the sulphur content of the coke. Where pollution control is essential we expect the pipeline charging of preheated coal, now used in the USA, to be adopted in preference to the smokeless charging car method.

In order to raise the capacity of ovens, there have been increases in both length and height of ovens. Some difficulties have been experienced particularly with the 7 metres high ovens operating in Japan, but the trend to higher ovens appears to be well established and most new ovens are now 6 metres. Oven lengths are not expected to increase much beyond the now current 15 metres.

Efforts are also being made to increase the output, as well as the capacity, of coke ovens. High density silica bricks have been used and are said to increase the carbonisation rate by some 20 percent. A similar increase has been achieved by having a thinner oven wall.

2.3 "Formed" coke (Chapter 9)

Formed coke is made from carbonised or partly carbonised non-coking or weakly coking coals and has been developed as an alternative to using metallurgical coke as the principal reductant. The required mechanical properties are provided by briquetting before or after carbonisation. Most development has taken place on three processes - the Bergbau-Forschung (BBF), the Food Manufacturing Corporation (FMC), and the Sapozhnikov processes. The BBF, developed in Germany, and the Sapozhniknov process, developed in the USSR, both use some coking coal which simplifies the processes somewhat in comparison with the FMC process for which the charge can be entirely non-coking. Formed coke can be made with properties similar to those of conventional coke. One advantage of formed coke is the ease with which briquette size and shape can be controlled, thus influencing the voidage characteristics of the burden. Blast furnace performance trials are not yet readily available. The indications are that formed coke can be used as a substitute for metallurgical coke with little effect on the coke rate and its use will, therefore, primarily depend on the relative costs of the two materials. The commercial production of formed coke is likely to be adopted in countries which have no suitable coking coals but do have non-coking coals of suitable analysis.

2.4 Blast furnace ironmaking and electric smelting (Chapter 10)

Blast furnaces are now being built with capacities of up to 11,000 tonnes per day, and the size of blast furnaces is not likely to increase any further. The process is used for about 99 percent of the world's iron production, and in future development trends are likely to involve efforts to achieve further reductions in coke rates and increases in throughput.

Coke rates have fallen from some 1500 kg per tonne of hot metal in 1920 to around 500 kg per tonne of hot metal in 1970. The most rapid decline was achieved during the years 1958 to 1964, when oil injection was first used, leading to a total fuel rate of about 500 kg per tonne of hot metal. The effect of oil injection on furnace productivity is such that it can be justified on all blast furnaces where coke costs more per tonne than oil. Gas injection is used to a limited extent (mostly in the USSR), and there are some locations where acceptable non-coking coals can be mined and transported at a price which justifies coal injection, although the injection is likely to be in the form of an oil/coal slurry.

Improvements in furnace practice can be achieved by oxygen enrichment, high blast temperature and high top pressures. Most large modern blast furnaces are designed to incorporate oxygen enrichment but more interest is now shown in high blast temperatures, at around 1200 to 1250°C.

Burden preparation, involving the charging of smaller and more uniform sizes of lump ore and sinter, can increase productivity significantly, as can the replacement of lump ore by pellets.

Where marginally increased outputs are required from an existing blast furnace, reduced pellets can be used; for every ten percent metallisation of the Fe burden, an increase in production of some six percent accompanied by a decrease in coke rate, also of about six percent,can be achieved.

Due to the fact that the blast furnace can only be an efficient desulphuriser at the expense of higher coke rates and higher metal temperatures, desulphurisation is now normally done externally to the furnace, which is operated at a consistent hot metal temperature.

There are two established electric smelting processes, both developed in Norway; of these Elektrokemisk has economic advantages over the Tysand-Hole. The Tysand-Hole has a low shaft electric furnace into which lump ore and sinter and coke or charcoal are continuously charged and produces liquid pig iron which can be converted to steel by the BOF steelmaking process. However, consumption of electricity is rather high (at some 2200 kWh per tonne of hot metal), which has led to the development of the Elektrokemisk process which involves the electric smelting of a prereduced iron ore charge with non-coking coal or charcoal and limestone.

2.5 Direct reduction ironmaking (Chapter 11)

Direct reduction processes generally use fuels other than coke and produce sponge iron. The development of many different processes has enabled relatively small scale non coke-using steel plants to be established in a number of countries.

Several of these processes use natural gas, liquified petroleum gas or straight run naphtha. The aim of perfecting a fluidised bed process using ore fines has encouraged development of gaseous processes, but difficulties associated with the fluidised bed have resulted in four of the five significant processes using pellets or lump ore.

The HyL process has four reactors to reduce lump ore or oxide pellets to some 87 percent metallisation using natural gas as the reductant. This process was developed in Mexico where natural gas was cheap at 1.5 cents per therm and has proved a commercial success. Where natural gas is not so cheap, part of the gas may be replaced with oil. Naphtha can also be used but this requires a somewhat more complex plant.

The Midrex process also uses natural gas and is continuous in operation, reducing oxide pellets to over 92 percent metallisation. Three plants are presently operating but the process has not yet been commercially proven.

The Armco process is metallurgically similar to the Midrex process but is a batch process. The first plant is under construction and is expected to be in production in 1973/74.

The Purofer process also reduces lump ore or pellets in a shaft furnace, using reformed natural gas; it is a batch process like the Armco, and the first plant is under construction.

The Orinoco HIB (High-iron Briquette) is the only fluidised bed process to be developed for large-scale commercial operation. The process is continuous and reduces iron ore fines of less than 0.6 mm by means of a reducing gas. One plant is operating in Venezuela.

There are also direct reduction processes which use solid fuel as the reductant. The most important is the SL/RN process, which is claimed to be capable of producing 97 percent metallisation in high grade ores and uses a charge of sized lump ore or oxide pellets together with non-coking coal. Two main types of problem have been encountered with this process - one associated with the physical and chemical reactions and the other with instrumenting and monitoring temperature profiles in the long kilns. Although it was hoped that the process would operate satisfactorily on any quality of coal, certain characteristics - particularly the ash fusion temperature of the coal - have in practice been found to be important.

2.6 Hot metal steelmaking (Chapter 12)

The advantages of the basic oxygen furnace process (BOF) have brought about a rapid decline in the use of the open hearth process, presently accounting for some 30 percent of world steel production, and the Bessemer (Thomas) process, which accounts for only 5 percent of world production.

Sizes of BOF furnaces have progressively increased, 350 tonnes being the largest in operation at present. Since two 300 - 300 tonne furnaces will have sufficient output for a five to eight million tonnes per year capacity steelworks, there is no strong incentive to increase furnace size, especially since this can raise material handling problems and difficulties in matching continuous casting capacity. The most common plant configuration is two furnaces operating out of three, but there is a trend towards three-out-of-four operation.

Reduction in tap-to-tap times has been the most significant development in recent years. The designed BOF cycle time has been reduced from 1 hour to about 40 minutes and with the full development of on-line computer control, and improved materials handling, the cycle time of furnaces of over 100 tonne capacity may be reduced to 25 minutes.

The Thomas process continues to be used in some West European countries to handle high phosphorous ores, although no new plants have been installed since 1955. Increasing interest is being shown in the development of bottom blown processes, such as Q - BOP and CBM. Certain advantages over the BOF have been claimed.

Although the open hearth process is technically very flexible in that it can handle hot or cold charges with almost any mix of hot metal, pig iron and scrap, and produce a very wide range of steels, the conversion cost is some 50 percent more than the BOF process. Recent attempts to improve performance have centred on the use of oxygen and the Tandem furnace. Oxygen injection can result in a 15 to 25 percent gain in productivity with a decrease in fuel costs of 15 to 20 percent. The bottom blowing technique is also now being applied to open hearth furnaces.

The main development in the future is likely to be in continuous steelmaking using, say, a WORCRA type process, resulting in a continuous process chain from the blast furnace through to the continuous casting plants. The WORCRA process, developed in Australia, involves the counter flowing of metal and slag. The IRSID process, developed in France, has metal continuously introduced at the bottom of a chamber blown with an oxygen lance, the slag-metal emulsion flowing through an opening into a decanting chamber where the slag and metal separate. Both processes have operated on a pilot plant scale, but are unlikely to achieve commercial scale within the next ten years.

2.7 Cold metal steelmaking (Chapter 13)

The main process used in bulk cold metal steelmaking is now the electric arc and new developments are directed towards increasing unit outputs and reducing electricity consumption.

The main development has been in increased power ratings and ultra high power (UHP) furnaces now have power ratings of 250 to 400 kVA per tonne of capacity; smaller furnaces may have 500 kVA per tonne. These high power ratings result in tap-to-tap times of $2\frac{1}{2}$ hours when making common steels from scrap, with single slag practice and oxygen lancing. High power ratings impose heavy loads on a power system and voltage smoothing equipment has been developed to alleviate the problem. A further solution developed in Sweden and meriting consideration in certain circumstances, employs two furnace shells, one fitted with an electrode roof and the other with gas burners; this results in electricity consumption being reduced to around 330 kWh per tonne.

Hydraulically powered shearing and baling machines and specialised fragmenting plant have been the main developments in scrap handling. Heavy scrap cutting by large shears with blades of four metres have allowed squeeze boxes to be omitted. Light scrap is now normally baled into weights of up to seven tonnes and one special press makes 60-tonne bales. A new development for light scrap involves press forming into a log followed by shearing.

The Proler fragmentising plant for car hulks and domestic appliances is well proven but needs a large supply of scrap. Fragmentation followed by magnetic separation is not always capable of reducing car bodies to an acceptable residual copper level of 0.2 percent. The ripper-shredder has given better results and can reduce copper levels to 0.12 percent.

Turnings,which are the least acceptable form of scrap because of oil and non-ferrous contamination, can be briquetted, but continuous roll forming processes are now under development. Oil can be removed by drying or centrifuging with 95 percent effectiveness, and a new method involving naptha rinsing and recycling has recently been developed.

Although the electric arc furnace can also be operated on any percentage of reduced pellets - given not less than 85 percent metallisation - it is not usual to operate with more than 80 percent pellets, 20 percent scrap. Using reduced pellets, the furnace can be charged continuously and the power input increased; although electricity consumption increases, improvements in productivity of about 12 percent can be achieved due to smoother and faster melting and decreased charging time. If ultra high power is used, the cycle time of large furnaces can be further reduced to significantly under two hours. The use of reduced pellets also reduces electrode consumption and oxygen consumption during refining, and because of the lower impurity level in the charge, cleaner steels are made.

2.8 Casting (Chapter 15)

The choice lies between ingot and continuous casting. For the production of killed and semi-killed steels for strip and plate production, and for common bar production up to one or two million tonnes per year, continuous casting is generally the more economic choice.

The main developments in ingot casting have been in the materials handling aspect with ingots being cast in moulds travelling on bogey units which circulate continuously from the casting bay to the combined stripping and mould preparation bay.

Adoption of continuous casting has taken place steadily over the last twenty years and there is now some 50 million tonnes of capacity in existence. By means of ladle preheating, efforts have been made to increase the capacity of a given machine, otherwise restricted by the maximum allowable ladle pouring time of some 70 minutes. Casting speeds for slabs are generally in the range 1000 to 1500 mm per minute, speeds increasing with reducing cross-sectional area. The maximum number of strands in use is now eight for billets and blooms and four for slabs, and a number of back-to-back machines have been designed to overcome the limitation of a large number of strands in one machine. Due to the high solidification rates and small cross sections, compared with those of ingot casting, the continuous casting of other than a fully-killed steel is difficult, but is being achieved in the USSR.

A significant development in continuous casting is "non-stop" or "continuous continuous" casting whereby ladle after ladle is cast with only momentary stops.

In order to solve the problem of single machines needing a complete range of moulds in order to produce a range of sizes, variable geometry moulds have been designed for slabs; these have yet to be made entirely successful.

Future developments are most likely to lie in the direction of a horizontal mould machine and pressure pouring which involves pressuring the steel in the ladle and forcing it up a refractory lined tube into the mould.

2.9 Rolling (Chapters 16 to 18)

The three main factors which have to be taken into account when specifying rolling mills are product range, dimensional accuracy and required capacity. Capacity and range of rolled products compete for priority, the present trend being towards specialisation and a more limited range of products. As more specialist mills become justified by increased product demand, the multi-product mill has to roll an increasingly varied selection of products.

Most of the large capacity slabbing mills now being built are universal mills with driven vertical rolls in close proximity to the horizontal rolls. This type of mill produces slabs with good square edges and also requires tilting facilities on only one side of the mill. Developments have involved the automatic positioning of ingot buggies, tandem rolling techniques and slab cooling systems which have reduced scale losses and the amount of cooling yard space.

The main development in blooming mills has been the use of automatic pre-set programme controls - also applicable to slabbing mills.

Modern high production billet mills now have, say, ten alternative vertical and horizontal stands with lateral take-off for the larger sections. Extensive finishing departments for automatic inspection and non-destructive testing are now often dictated by market requirements.

"Continuous" forging of billets at fairly low outputs can be achieved by the use of swing forges. However, certain processing problems still have to be solved.

The demand by shipbuilders for wider plate has stimulated the building of four-high plate mills up to four metres in width, equipped with back-up roll bending devices for the control of lateral gauge, shape and crown. The use of plate for structural sections has prompted the building of universal plate mills. The plates can be coiled or transferred flat to cooling banks which have equipment to maintain straight edges on the plate which is then ready for welding without further preparation. Plate less than one metre in width can be rolled more cheaply on two-high plate mills.

The increasing demand for better quality strip, that is strip of more accurate and uniform gauge, better surface finish and metallurgical properties, has been met by installing more roughing stands (five or more) in the hot mill, more finishing stands (usually seven) and by using automatic gauge control and on-line computers. Strip mill power inputs have increased considerably. Slab reheat furnaces now have more heating zones (five zones) and walking-beam traversing gear and discharge extractors have been developed. At the exit end of the mill, laminar flow water cooling between the last finishing stand and the coiler is now used and additional coilers are placed some 40 metres away from the mill for very thin gauges. The need of smaller developing countries for a low-cost small-ouput mill has received a great deal of attention; a wholly satisfactory solution has not as yet been found, although the Steckel mill and Sendzimir planetary mill can be suitable choices in certain situations.

Cold strip mills now generally have five or six instead of three of four stands. Most development has taken place in gauge control methods. Hydraulic roll gap control is employed giving greater accuracy and speed of response than electric screw down systems. Much progress has also been made with on-line computer control. For small-scale plants, strip can be successfully rolled in a single-stand reversing mill and the Sendzimir cluster mill is particularly suitable for the cold rolling to thin gauges of special quality sheets, in particular stainless steel.

Heavy structural mills now being built are mostly universal mills which give a structural section of better section module than earlier standard shapes. These mills can also be designed to roll rails, sheet piling sections and universal flats or plates of limited width. An interesting development is the present construction by the British Steel Corporation of a continuous medium section and light beam mill with a capacity of some 500,000 tonnes per year. A continuous or semi-continuous mill is the usual choice where long rollings of a particular section are economic, but where this is not so, duplicate stands are often provided.

Rail mills have not changed greatly in recent years, although one new development of note is a system patented by the French company, de Wendel et Cie, in which rails are rolled on a universal beam mill. Nevertheless, it is more usual to keep the rolling of rails separate from other structural sections.

Merchant mills with annual capacities of up to 500,000 tonnes have been considerably improved with stiffer stands, better bearings, increased rolling speeds and devices to reduce roll changing time.

The speed of wire rod mills has increased up to 50 to 60 metres per second for 5.5 mm rod. High finishing speeds, together with greater accuracy, have been achieved by the development of the "no-twist' finishing block in which the last ten reductions or so, are made by pairs of rolls mounted at right angles to each other. The demand by wire drawers for greater consistency of physical properties has been met by the "Stelmor" system of controlled cooling. Also heavier coils have been demanded and this has been achieved by rolling 5.5 mm rod from 80 mm or 90 mm billets (instead of 48 mm) this requires more rolling stands in the mill. The trend towards rolling 12 metre long billets has necessitated the redesign of reheating furnaces.

2.10 Tube and pipemaking (Chapter 19)

The production of welded tubes and pipes has increased much more than seamless tubes. Whereas a plant for welded tube can have an annual capacity of, say, 2,000 to 20,000 tonnes, an economically-sized seamless tube plant will have an annual capacity of at least 100,000 tonnes.

Large welded tube from 300 to 2500 mm diameter may be produced in a spiral tube mill from hot rolled coil. Tubes from 12.5 to 100 mm diameter are generally produced on a longitudinal welded tube mill in which the feedstock, strip, is progressively formed into a tube shape through a series of rolls.

Seamless tubes are produced from heated billets or blooms which are first pierced. After piercing the partially formed tube is further processed in two or three-roll mills.

The problem of high die wear in extruding tubes has largely been overcome by the use of graphite lubricants, although the process is normally used only for high value products such as high alloy and stainless tubes; the Ugine-Sejournet process, which uses glass lubrication of the work piece, has made possible the large-scale production of extruded tubes.

A variety of methods may be employed to finish tubes. Stretch-reducing is carried out in a mill with 12 individually motored stands. A burnish can be imparted to the surfaces of a tube by a reeling mill. Correction of the shape and size of tubes can be done by pressure expanding; or the diameter and thickness of tubes can be reduced by hot and cold drawing and where a high diameter reduction is required cold reducing can be employed.

2.11 Coatings (Chapter 20)

The protection of thin flat products with tin and zinc is still the most common form of coating but newer materials such as chromium and plastic are gaining in importance.

Production rates of tinning lines are now some three times as fast as they were ten years ago, and feedstock descaling is generally now done with hydrochloric acid to sustain the high line speeds. Cold reduction is undertaken on five- or six-stand four-high mills and continuous annealing is now more usual than batch annealing, although the latter is still generally used for drawing quality steels.

The "Ferrostan" or "Halogen" processes are used for tinning, the former accounting for about 70 percent of world capacity. However, the more costly Halogen process is faster (eleven rather than eight to nine metres per second) and there is an increasing trend towards its adoption. Double reduced tinplate, developed to provide a high strength, low thickness and low cost sheet, is growing rapidly in importance.

Tinfree steel is beginning to contend with tinplate, due to its comparatively low cost. Tinfree coatings which use ultra-thin layers of chromium and chromium oxide are interchangeable with tinplate for most applications. Production lines are now usually dual purpose tinplate and tinfree.

Hot-dipping is still the most commonly employed method for galvanising but the more costly electrogalvanising, which produces a very thin coating, has certain uses. Faster lines (1.6 instead of 0.5 metres per second) are now installed and coating thicknesses are controlled by air or steam jets.

Organic coatings are laid on a hot-dip galvanised base and combine the attraction of a coloured finish with the corrosion resistance of a galvanised finish. Modern lines run at some one to three metres per second and either employ PVC-plasticols or acrylic resins. The liquid-based processes (about 80 to 90 percent of capacity) are likely to grow more rapidly than those based on pre-formed strip of which "Stelvetite" is an example.

Aluminium coatings have been developed to provide high temperature corrosion resistance, whilst lead coatings find application in automobile petrol tanks.

2.12 Special steels (Chapter 21)

The bulk of the special steels made are the austenitic stainless (AISI 300 series) which have an appreciable nickel content. Although still made primarily in electric arc furnaces, certain qualities have been made in bulk by the BOF process.

Addition of alloying elements is made either in the ladle or in the furnace - usually the latter for large quantities of alloying elements such as copper or nickel. The alloy content left in the liquid steel is affected by the degree of oxidisation of the steel when tapped, the amount of slag remaining in the ladle and the time in the process cycle when alloy additions are made.

Deoxidisers such as silicon and aluminium are added to prevent or reduce carbon monoxide release during solidification of the steel. Particular care has to be taken in the use of deoxidisers where a very clean steel is required.

As an alternative to deoxidising by chemical methods, vacuum degassing was developed particularly to cope with the increasing quantities of hydrogen resulting from basic, rather than acid, open hearth steelmaking. A number of different processes have been developed which fall into four categories - ladle, steam circulation or ingot degassing. A cheaper method than vacuum degassing has been developed termed gas flushing, in which argon is bubbled through the steel in the ladle.

The removal of non-metallic inclusions may be done by careful refining and vacuum degassing. Slag washing by the Perrin process although primarily intended to remove sulphur and phosphorous also effectively reduces inclusions.

If steels with high performance figures for creep, tensile strength, fatigue resistance, or strength are required, special techniques have to be used. Vacuum melting and vacuum remelting can be used to make very pure alloy steels. Electroslag refining produces a steel which is isotropic in its physical properties and the remaining inclusions are consistently small and evently distributed.

Two recently developed processes are plasma arc melting and electron beam melting, the latter reducing inclusions to an extremely low level.

As an alternative to casting special steels in a vacuum chamber, oxygen pick-up may be prevented by shrouding the metal stream with an inert or reducing gas. Most special steels can be continuously cast but protection from the atmosphere during casting is most important.

The main differences between rolling special and ordinary steels lie in the extra power requirement and the fact that continuous and semi-continuous mills are not appropriate, due to the small lot sizes - often only two tonnes - of special steels.

The Steckel single-stand reversing hot strip mill is often used for stainless strip; the gauge variations, which used to be experienced, can now be ruled out by the use of hydraulic precision gap control. For cold rolling stainless strip the Sendzimir cluster mill is used.

2.13 Miniworks (Chapter 22)

The main advantages of miniworks, invariably employing scrap melting in arc furnaces and continuous casting, are the utilisation of cheap scrap, the minimisation of transport and selling costs by serving a local market, and the minimising of overheads by producing a very limited range of products and using relatively simple low capital cost plant.

The capital cost per annual product tonne is lower than that attributable to a similar product in a large integrated works. A miniworks can be built for between $120 and $180 per annual product tonne; some have been built for less than $100. Careful matching of furnace and casting capacity with rolling capacity, together with the minimum provision of workshops, stores, laboratories, etc., achieves a low unit capital cost. A miniworks can also be brought up to full production in perhaps half the time it takes to build an integrated works. The cost of scrap will constitute about $29 per tonne in a total production cost, including all financial charges, that should be approximately $100 per annual product tonne. Clearly the commercial results achieved by a miniworks will thus be very sensitive to scrap prices.

The most important future development is the degree to which pre-reduced products will be substituted for scrap. This will enable continuous charging to be practised and reduce power and electrode consumption. It has been estimated that pre-reduced material will be competitive with scrap when 90 percent metallised material is about $5 per tonne more than scrap. The relative prices of coke and electricity will also have a significant commercial impact on miniworks developments.

2.14 Pollution (Chapter 23)

Carbonisation of coal in coke ovens generates a large volume of tars and dusts which can present a considerable pollution problem. It is now common to equip coal charging cars with mechanical or venturi wet scrubbers or to use a more refined system employing pipeline charging of ovens and a central wet scrubbing plant.

The handling and treatment of dry raw materials produces large quantities of dust. Dust suppression may be simply effected by a water fog technique or by the enclosure of dust producing areas and fitting exhausters and dust arresters.

In blast furnace operation the main problem is the treatment of gas before it is burnt; this is normally done by wet scrubbing which leaves a contaminated water to be purified.

Steelmaking emits large quantities of fine iron oxide fume and dust. In BOF steelmaking, where 1.5 percent of total charge weight can be dust, electrostatic precipitators or venturi scrubbing are used to control emission.

In rolling, the major contaminant is the scale and oil extracted by the cooling water; clarification or flocculation and pressure filtration of the water is necessary, depending on the degree of purity required.

In strip processing, the major problem lies in the treatment of the spent pickle liquors which are high in acid content; considerable effort has been put into developing processes to recover the acids.

2.15 Automation (Chapter 24)

The main benefits of automation are improved product quality, increased process yield and better plant utilisation. Integrated schemes are now being designed and built to enable all operations of an organisation to be controlled by hierarchical computer systems.

Automation of raw material preparation can begin at the initial weighing and batching of raw materials. Sintering has been automated and attention is now being given to pelletising.

Partial automation has been achieved in many coke oven installations.

Complete automation of the blast furnace has not as yet been achieved due to the complex nature of the physical and chemical processes involved. Nevertheless, many modern steelworks have at least one furnace fitted with the necessary instrumentation, computers and actuation equipment for fully automated control; the systems operating the burden blending and the hot stoves are operational but the main furnace systems are still under manual supervision.

Automation of BOF steelmaking can be used to control oxygen volume for a given charge weight and steel quality and quantity. In electric arc steelmaking, the control system can be used for continuous monitoring of the power consumption to adjust the electrode position so that steady power inputs are maintained below penalty levels.

Automation of soaking pits maximises throughputs and minimises heat inputs, while automation of reheat furnaces enables the feedstock to the rolling mill to be provided at the required temperature. The main application of automation in rolling has been in the gauge control in hot and cold strip mills.

The most rapid developments are taking place in the production of robust and reliable instrumentation for measuring change from pre-set values. Control demands beyond the capacity of human reactions clearly require automation.

Total automation of steelworks is not likely to be implemented for many years.

2.16 Location of steelworks (Chapter 26)

Location decisions will depend on both the technological factors (e.g. operating and transport costs) and politico-economic factors. The main technological factors are:-

(a) Size and location of market

(b) Availability and location of raw materials

(c) Location of any existing steel industry

(d) Availability of various forms of energy

(e) Existing transportation network

(f) Availability and location of infrastructure

(g) Availability of skilled management and operatives

(h) Available processes

Each location decision has to be considered on its merits and in the light of the conditions which obtain locally.

2.17 Trends in the production of steel (Chapter 27)

The two main factors causing change in the pattern of world steel production are the increase in the size of the production units and the pattern of supply and use of raw materials.

Whereas works of one million tonnes capacity were previously considered large, economic works of ten million tonnes capacity are now being built. The advent of the BOF process with its simpler and faster operation, together with large blast furnaces and reliable continuous casting plants have made these large capacity increases.

The major change in the pattern of supply of raw materials has been the use of imported foreign ores. The decision to site a works on the basis of the lowest total cost of transport now often results in the establishment of a large coastal works. The availability of coking coals caused a great deal of concern in the early 1960's but the developments in processing coals now make it possible to use other qualities of which there are much larger resources.

One trend of significance is the growing interest in establishing bulk steel, semi-finished product works close to the ore source and transporting the semi-finished product close to the market for rolling.

2.18 Product development (Chapter 28)

A very wide range of steels with special properties has been developed in recent years to meet specific needs.

Corrosion resistant common steels have been developed to resist marine corrosion, for example low carbon steels with large additions of manganese, and atmospheric corrosion by the addition of one half percent of copper.

Cheaper heat treatable steels are the plain carbon quenched (PCQ) and quenched and tempered (QT) steels.

The development of low carbon stainless steels of good weldability and workability will appreciably extend the use of stainless steels.

The demand for steels for high temperature service has increased the use of ferritic steels and high alloy Cr.Ni steels for temperatures above, say, 600°C.

Steels for low temperature use (cryogenic steels) are the recently developed QT steels.

Steels with special machining properties contain sulphur, lead or more recently tellurium.

Special cold working properties are achieved by the use of "maraging" steels containing 18 percent nickel and five to ten percent of other alloying elements.

Hard wearing properties can be obtained by surface hardening treatments such as hard surfacing or flame hardening or by the use of bimetal, a material comprising steels of different qualities.

2.19 Trends in consumption of steel (Chapter 30)

Economic growth has been achieved by countries through a number of different routes, which reflect the growth of different industries of different steel intensiveness. Although there is no strong link between the rate of growth of steel consumption per head and population growth there is a relationship between the rate of growth and the actual level of consumption since a fast rate can more easily be achieved starting from a low consumption level. Typically, therefore, compound growth rates of steel consumption per head from the period 1938 to 1968 have been of the order of 2 or 3 percent for those countries with steel consumptions per head in 1938 of 100 to 300 kg, and of the order of 7 to 8 percent for those countries with consumption per head in 1938 of from 20 to 90 kg.

"Elasticity" of steel use (i.e. the compound growth rate of steel use per head divided by the compound growth rate of GDP) varies considerably from country to country, from 2.3 in Italy and 2.0 in Spain to 1.0 in the UK and 0.4 in France. The high elasticity in Italy was associated with large exports of consumer durables together with a shift in employment from agriculture to manufacturing, whereas the low elasticity in France was due to the major share of agricultural output in the GDP growth.

The initial development period of a predominantly agricultural country creates a steel demand which is largely in the non-flat products - rails, sections and reinforcing bar. This demand tends to be met by small scale re-roller and semi-integrated plants. Mechanisation of manufacture and distribution accompanied by urbanisation promotes a big increase in demand for a large range of steel products. Later, the effect of income distribution on urban standards and the mass demand for consumer durables determines the timing and location of the installation of large flat product works.

2.20 Trends in international steel trading (Chapter 31)

In 1970 about 100 million tonnes of steel products were traded internationally out of a total production of about 590 million tonnes. A part of this trade, about 23 million tonnes, was conducted within community trading areas such as the EEC. The three major traders, who account for 72 percent of the international trade, are the EEC, Japan and the USA. In plate, Belgium/Luxembourg exports about 87 percent of her production, Sweden exports 40 percent of her wire rod production and Germany, France and Japan export about 30 percent of their sheet and tinplate. Only the USSR is self-sufficient in steel and any large scale steel producer needs to compete with Japanese and EEC steelmakers.

In general, real domestic prices of steel (after correction for movements in the whole price index) have been falling over the past decade, reflecting investment in steel capacity of some 800 to $1000 million per year during the period 1958 to 1968. Export prices, which have fluctuated considerably in the short term reflect marginal production costs but in the long term must reflect total costs. The practice of differentiating between home and export prices, particularly within the EEC, is diminishing. The basing point system of pricing is economically desirable since it encourages works to concentrate their sales within their zones of influence, thus reducing unnecessary transport costs.

Profitability of investment in steel tends to be called good or bad depending on the social values of the Government and business community concerned rather than on industry comparison between countries. In general, though, a gross return(profit before tax, interest and depreciation) on total assets of some 12 to

13 percent appears to be appropriate to a modern iron and steel industry when the technology has been consolidated. Differences in gearing, interest rates, taxation and depreciation policies result in different allocations of the gross return when expressed as net profit available to equity shareholders. For example, whilst gross returns on total assets in both Germany and Japan in 1968/69 were roughly similar (at about 12 percent) the net returns on shareholders funds were some 13 percent in Japan and 8.5 percent in Germany.

2.21 Role of the developing countries (Chapter 32)

Whilst world crude steel production has increased by 69 percent (i.e. from 350 to 590 million tonnes) in 1960 to 1970, steel production in the developing countries has increased by 180 percent (10 to 28 million tonnes). Nevertheless, 96 percent of the world's production is still made in the developed countries. There is a growing opinion that future large scale production may be split into two sectors, one for basic steelmaking to produce slabs, blooms or billets, situated close to the ore reserves and the other for rolling these into finished products located near the markets. Those countries with large ore resources would have an important role to play in the development of such projects. The large capital investment, human resources and training required to achieve a rapid transformation from a mining based industry to a manufacturing one is likely to require close co-operation, and possibly partnership, with the interested developed countries.

3. Long term planning for the Brazilian iron and steel industry (Section C)

3.1 The market and industry capacity in 1980 (Chapter 33)

The report made by Technometal in 1969 forecasts a Brazilian demand for flat products in 1980 of almost 5.8 million tonnes (actual consumption in 1969 was just less than 1.8 million tonnes) and for non-flat products, nearly 5.7 million tonnes (actual consumption in 1969 was 1.9 million tonnes). An allowance for exports has been fixed by CONSIDER at 12.5 percent of the forecast home demand, which will be 1.4 million tonnes in 1980 on the basis of the 11.5 million tonnes home demand forecast. The production capacity required by 1980 will be the sum of the Brazilian demand, the export potential and a contingency allowance for market fluctuations (also fixed at 12.5 percent of Brazilian demand) making a total of 7.2 million tonnes of flat products and 7.1 million tonnes of non-flat products.

The expected capacity of the industry in 1980 has been calculated on the basis of the existing facilities, excluding those due to be closed down, but including such new installations as CONSIDER had authorised by September 1971. It is also assumed that the capacity will reflect the recommended short term improvements described in Section A and the improvements implicit in the technological trends described in Section B. The estimated flat product capacities (in millions of tonnes per year) in 1980 will, on this basis, be as follows:-

Hot metal	12.13
Liquid steel	9.58
Slabs	6.65

Plate	1.95
Hot strip	4.90
Cold strip	2.53

Non-flat product capacities (in millions of tonnes per year) will be:-

Hot metal	1.65
Sponge iron	0.32
Liquid steel	3.68
Blooms	0.50
Billets	3.27
Wire rod	0.80
Bars	1.65
Light sections	0.30
Medium sections and rails	0.73

Production capacity for special steels is so sensitive to product mix that the forecasts can only be approximate:-

	Flat products	Non-flat products
	(millions of tonnes per year)	
Liquid steel	0.04	0.61
Rolled products	0.04	0.52

3.2 New rolling and semis capacity required (Chapter 34)

The capacity shortfall in tinning will by 1980 be some 500,000 tonnes per year and in cold rolling of tinplate 400,000 tonnes per year. In addition to the cold strip for tinplate there will also be a shortfall of some 300,000 tonnes per year in the production of cold rolled sheet, which would probably be best met by a four-or five-stand tandem mill. (Article 34.1)

The shortfall in capacity for hot rolled strip, whether sold as hot finished or supplied as feedstock for cold mills, will be some 900,000 tonnes per year in 1980. Although a fully continuous strip mill would not be justified for 1980, it could possibly be required by the mid 1980's. (Article 34.1) For plate there is no anticipated shortfall in capacity up to 1980.

Capacity shortfall for slabs is some 1.4 million tonnes per year by 1980, which is probably best met by new continuous casting capacity. (Article 34.1).

The capacity shortfall in 1980 for wire rod will be about 800,000 tonnes per year, which is likely to be provided by installing two specialist wire rod mills. (Article 34.2).

For merchant bars the capacity shortfall will be 1 million tonnes per year met either by one, or perhaps two, specialist merchant mills, or by mills to roll both wire rod and merchant bar. (Article 34.2).

For light sections the capacity shortfall of some 160,000 tonnes per year is unlikely to justify installing another mill. (Article 34.2).

There appears to be no absolute shortfall for medium and heavy sections, but the installed plant cannot produce heavy universal or parallel-flanged sections. The planning of a universal beam will, however, need to take account of the growth in demand beyond 1980, as the shortfall prior to 1980 is unlikely to justify the installation of such a mill.

It appears that there will be a considerable shortfall in capacity to produce seamless tubes and this also requires further examination. (Article 34.2).

For blooms and billets the shortfall is of the order of 0.5 million and 2.3 million tonnes per year respectively. Whether this requirement is met by ingot casting and rolling or continuous bloom casting and rolling or continuous casting of billets needs further study. (Article 34.2).

In special steels a considerable shortfall in capacity will occur by 1980 - some 200,000 tonnes per year in flat products and some 500,000 tonnes per year in non-flat. The former will require the installation of two or three small mills, probably of the Sendzimir cluster type, while the non-flat products will mostly be produced on conventional bar mills, some with facilities for normalising or slow cooling. The merits of hire rolling of ingots against continuous casting of special steels should be studied. (Article 34.3).

3.3 New iron and steelmaking capacity required (Chapter 35)

More precise statements can be made about the size of plant, the type of process and the works location in the flat product sector than in the non-flat, where the influence of scrap availability on location is much more marked.

The choice between hot metal and scrap based routes will depend on scrap availability which should be the subject of detailed study. (Article 35.1).

After making a number of assumptions, which are fully described in Chapter 35, the difference between the capacity required in 1980 and the existing plus planned new capacity in the flat product sector is as follows:- (Article 35.2).

	Million tonnes per year
Steelmaking	0.11 surplus
Ironmaking	3.80 "
Sintering	2.29 deficit
Cokemaking	0.65 "

The overall capacity deficit in sintering reflects a situation of surplus capacity at CSN with deficits at Usiminas and Cosipa. Taking into account the increases in demand that will occur following 1980, there will be a need for the provision of large additional sintering capacity. An alternative possibility would be to build a large pelletising plant at either Usiminas or Cosipa which could meet the demand for agglomerated burden at both plants. These options need further examination. (Article 35.2).

In cokemaking the overall deficit of 0.46 million tonnes per year reflects a small surplus at CSN and a deficit of 0.70 million tonnes per year at Usiminas.

In the non-flat product sector, the capacity shortfall for making liquid steel for billets and blooms in 1980 will be between 3.1 and 3.7 million tonnes per year. None of the present works is suitable for expansion, so that a new works will be required.

In the flat product special steels sector, a large proportion of the shortfall in capacity for the manufacture of liquid steel will be of high carbon or low alloy types which can be made in conventional bulk steelmaking plants, but new plants will be required for stainless and high alloy steel. (Article 35.4).

In general, therefore, the flat product sector will meet its requirements principally by attention to operational performance, while the non-flat and special steel sectors will require the construction of new plants. The additional capacity in the non-flat sector may be provided by one or more of the following process routes:-

Blast furnace - BOF steelmaking
Direct reduction - electric arc steelmaking
Scrap based electric arc steelmaking.

For the blast furnace - BOF - continuous casting process route, design limitations primarily applying to continuous casting make it impracticable to cast billets with more than 100 tonne capacity ladles. This tends to limit the steelmaking furnace to 100 tonnes capacity with preferably two furnaces working out of three or, increasingly, three out of four. The maximum practicable capacity, therefore, of a blast furnace - BOF - billet casting works is about 3 million tonnes per year. If, on the other hand, billets are rolled from continuously cast blooms then this constraint does not apply.

One of the advantages of the direct reduction - electric arc route, namely the ability to handle iron ores which would cause problems in a blast furnace does not apply to Brazil whose indigenous ores are all suitable for blast furnace use. Although the need to import coking coal for use in the blast furnace would appear to give direct reduction a comparative advantage, there is no major supply of cheap natural gas in Brazil for an Hyl process, and the high ash content of Brazilian coals militates against the SL/RN process; moreover, the absence of cheap electricity weighs against electric smelting. Thus a comparative cost examination indicates that in Brazil there is not, in general, any strong cost advantage in choosing direct reduction and exceptional changes in costs would have to occur in order to make direct reduction competitive with the blast furnace at outputs of more than 1 million tonnes per year.

For cold metal steelmaking, the choice of process route will be the scrap based electric arc furnace. Additional electric arc steelmaking up to a capacity of about 1.5 million tonnes per year by 1980 needs to be considered. However, scrap availability is likely to limit capacity to about half a million tonnes per year. (Article 35.5).

Unless considerable changes are made in the types of product produced it will also be necessary to construct substantial new special steelmaking facilities, most of which would be electric arc furnaces. An accurate market assessment of the demand for the many different types of special steel is particularly important in this area. (Article 35.4).

In planning the various expansions in capacity that will be required, it is recommended that note should be taken of the following technological developments. (Article 35.5).

In BOF steelmaking	- reduction in tap-to-tap time - ladle addition of alloying elements - fume control - three-out-of-four furnace operation
In bottom blown oxygen steelmaking	- the development of processes such as Q-BOP, OBM and SIP
In electric arc steelmaking	- reducing tap-to-tap times by ultra high power input - double furnace refining
In blast furnace ironmaking	- improved burden composition - trend towards 100 percent sinter or agglomerated burden - reduction in coke rate - oil injection techniques - developments in gas injection - the use of higher blast temperatures - the use of high top pressure - the use of reduced products in the burden
In sintering and pelletising	- the trend towards the production of self-fluxing and super fluxing sinter - developments in oxide pellet firing processes
In cokemaking	- selective crushing of coals in the blend - drying and preheating the coal blend - increased rates of carbonisation - developments in formed coke production
In direct reduction ironmaking	- the progress of the HyL, SL/RN and Midrex processes should be carefully monitored.

3.4 Strategic planning for the Brazilian steel industry (Chapter 36)

The structure of the flat products sector will be determined by the following factors:-

(a) An estimated shortfall in capacity in 1980 of some 900,000 tonnes per year is expected to increase, possibly rapidly, in the early 1980's.

(b) The next hot strip mill should be a fully continuous mill of at least 3 million tonnes capacity. The location of the mill is an important matter for further study. The future of the existing hot mill at CSN, which by 1980 will be 34 years old, calls for consideration. (Article 36.1).

(c) There is expected to be a shortfall by 1980 in tinplate and cold rolled sheet production.

In the non-flat sector, the main points for consideration are:-

(a) Processes to be employed.

(b) Unit sizes of plant to be installed

(c) Location of plant

(d) Timing of decisions

Direct reduction costs are such that we envisage additional steelmaking capacity will be divided between the blast furnace - BOF processes and the scrap based electric arc furnaces. The balance between the two will depend largely on the availability of scrap. (Article 36.2).

Most of the existing non-flat production capacity is located in the Minas, Rio de Janeiro and Sao Paulo regions, which is also where the major part of the increased demand in 1980 will arise. To meet the demand for 3 to 4 million tonnes per year of hot metal, three different approaches need examining:-

An integrated works on an inland site
An integrated works on a coastal site
Dispersed production.

A final choice needs to be based on careful evaluation of the precise nature of the market demand, transport costs and other economic and commercial factors. (Article 36.2). Coastal sites are generally more favoured than mine-based sites.

On the assumption that a single large blast furnace will supply the total demand for additional hot metal based steelmaking, and that it needs to be commissioned by 1980, then preliminary engineering would need to be done in 1973/4 preceded by any special studies recommended in this report. (Article 36.2)

The structure of the special steels sector cannot be fully determined without a more extensive study of the market requirements for special steels - especially stainless and grain oriented silicon sheet. (Article 36.3).

To ensure the smooth overall expansion of the industry, it is also necessary to ensure that such items as raw materials, reductants and refractories, which are common to all sectors, are available in the appropriate quantity and quality. (Article 36.4).

3.5 Development of capability for engineering and plant manufacture (Chapter 37)

We have considered how Brazil can develop a full capability for the whole sequence of operations involved in the engineering, design and construction of an integrated iron and steelworks.

It is suggested that CONSIDER might take the initiative in encouraging two or three of the leading Brazilian consulting engineers rapidly to develop their technological ability either by recruitment abroad or by seeking association with experienced foreign firms. Alternatively CONSIDER could itself promote the formation of a small experienced study team. (Article 37.1).

The availability of engineers of the right experience is most often the limiting factor in steelworks construction. The planned scale of expansion in the Brazilian steel inudstry is such that the demands which will be made on it must undoubtedly exceed the engineering resources available and a substantial degree of external assistance must be obtained. (Article 37.2).

There exists the capability in Brazil for undertaking the civil engineering design and construction for the type of projects envisaged in this report. In structural engineering the merit of continuing to import heavy steel structures needs to be examined. (Article 37.3).

A full local capability in plant and equipment design is not recommended as an immediate objective. Initially the best equipment designs available from world sources should be used. (Article 37.4).

There is a strong case for developing immediately those parts of the plant and machinery construction industry which supply plant to other sectors of the economy as well as the iron and steel sector - for example electrical switchgear and mechanical handling equipment. Other sectors which should be expanded at an early stage are refractory bricks and roll suppliers. (Article 37.5)

In the medium and heavy plant manufacturing industries Brazil already has a production capability and it would be in the national interest to expand the annual output of these industries. We recommend that Brazil should equip herself to supply most of the lighter machinery required such as blast furnace blowers, small turbo-generators and rolling mill equipment - all of which can be made in machine shops equipped with 10 or 20 tonne overhead cranes. Heavier items such as rolling mill stand castings can be manufactured in only relatively few foundries in the world and facilities for manufacture within Brazil cannot be justified. In overhead cranes for steelworks Brazil is already virtually self-sufficient. (Article 37.5).

Mill rolls of most kinds are now being made in Brazil but production will, of course, need to be expanded to meet the steel development programme. (Article 37.6).

Most of the commonly used transformers, motors and switchgear can be supplied by the existing private industry. In the case of the main drives and control gear for large reversing mills and for continuous mills we recommend that they are imported, although the possibility exists of manufacturing under licence. Similarly the variable speed motors required for roller tables should be made in Brazil under licence. (Article 37.7).

3.6 Research and development (Chapter 38)

The major consideration is the level of resources which should be devoted to research and development in the iron and steel industry. Expenditure on research and development by world steel companies varies a great deal and the level of expenditure tends to correlate with the type of product rather than with the level of output. We estimate that an appropriate target for research and development allocation in Brazil in 1980 would be in the range of $15 million to $25 million, implying some 2,400 men employed on these activities - that is some 2 percent of the total workforce. (Article 38.1).

In general, we recommend that the principal emphasis should be on development rather than research and that the pace of basic research should be allowed to evolve naturally as inventive talent becomes available. (Article 38.2).

Research and development effort is at present developed through individual companies. A central co-ordinating and sponsoring body could do much to prevent wasteful duplication of effort and impose overall shape and direction on the country's research, although the activities of such a body should not in any way be directed so as to prevent any company from pursuing research independently. (Article 38.3).

It is particularly important that Brazil derives the maximum benefit from research and development work undertaken in other countries, and it is, therefore, essential to have a communication network which will monitor research and development carried out abroad and ensure that this information together with the results of Brazilian research and development are channelled to those who need to use it. (Article 38.6).

Further, it is important that selectivity and concentration of effort should be practised in research and development. The amount of effort devoted to each area must be sufficient to maximise the chances of making a significant contribution to the industry. (Article 38.6).

Topics which are recommended as particularly suitable for a Brazilian research and development effort include (Article 38.6)

Sintering	- development and use of superfluxed sinter - savings in coke breeze
Cokemaking	- selective crushing of cheaper coal blends - formed coke manufacture
Direct reduction	- development of the HyL, SL/RN and, possibly, Midrex processes

Steelmaking	- methods of improving operating performance - the use of reduced pellets in electric arc furnaces - developments in the OBM process
Continuous casting	- introduction of technology being developed in the USSR for continuous casting of rimming steels.

3.7 Education and training for the steel industry (Chapter 39)

Establishing industrial capacity in a developing country makes great demands on the whole range of infrastructural institutions of which education is probably one of the most important.

The capability for achieving the desired degree of training at all levels of operation and management in the industry already exists in Brazil; it requires mobilising to service the particular requirements of the steel industry.

We recommend that the steel industry should make an immediate detailed study of its management and skilled and semi-skilled labour requirements during the next ten years. This information should then be used to plan education programmes in the various centres of learning. (Article 39.5)

3.8 Recommendations for further action in planning the Brazilian iron and steel industry (Chapter 40).

The following additional action is recommended as a result of the analysis of the implications for Brazil of world technological trends in the iron and steel industry:

- An advisory panel should be set up to monitor and appraise world-wide plant design trends (Article 40.1)
- The industry should make use of specialised planning consultants, to leave Brazilian planners greater freedom for analysis and evaluation of strategies (Article 40.1)
- The industry should supplement its own manpower resources at times of peak design effort by using engineering consultants (Article 40.1)
- Detailed studies should be put in hand as follows: (Article 40.2)

  a market/product evaluation for packaging materials;
  a detailed survey of pipe and tube products;
  a detailed survey of medium and heavy section demand;
  an evaluation of different locations for a continuous hot strip mill, and tin plate plant;
  a study of scrap availability and utilisation;
  a study to determine the steelmaking policy for the non-flat product sector;

a study of feedstock sources for special steelmaking;
a review of mill capacity in the non-flat sector in relation to steel qualities and products required;
a study of the economics of rolling stainless and other special steel sheets;
a study of product standards and quality;
a study to specify performance indices appropriate to the industry;
an evaluation of the technical characteristics of transportation which are of importance to the steel industry;
a study of the availability of fuel and reductants, with special reference to formed coke.

- The specification of performance indices for the industry should be completed at an early stage. (Article 40.3)
- The strategy once established, must be continually reviewed and revised. (Article 40.3).

SECTION A

TECHNOLOGICAL SURVEY AND EVALUATION OF THE BRAZILIAN IRON AND STEEL INDUSTRY

CHAPTER 1 - THE PRESENT AND PLANNED INDUSTRY

1.1 The composition of the industry

The Brazilian iron and steel industry comprises some 113 works ranging from very small pig iron producers and re-rollers to large integrated works. Of these, forty-three works represent nearly the whole steel product manufacturing capacity of the industry. A list of these works, together with four new works which are now under construction, is shown in Table 1.1. This table sets out the type of manufacturing facilities available at these works, the description of steel products which could be produced and their finished product capacities.

In addition, there are over sixty small ironmakers producing pig iron in charcoal blast furnaces on a semi-continuous basis, and a number of small iron foundries and re-rolling works. The potential production capability for pig iron from these small charcoal furnaces has proved useful in the past during the periods of peak demand for steel, and it is considered that these enterprises will continue to function in the future. Their output in 1970 was approximately 700,000 tons and their potential output is believed to be higher. There is no detailed information on their production facilities and future development plans. It is not possible, therefore, to analyse this sector, although it is considered likely that it will largely supply the foundry industry with only marginal output being supplied to the steel industry. We also believe that investigation into the best use to be made of the pig iron produced by these small ironmakers - including the potential for export - would be of considerable value.

The map in Figure 1.1 indicates the locations of the 43 major works and the 4 new works under construction. Of these, there are 16, including the 4 new works, shown individually on the map; the remainder are all in the "steelmaking triangle" of Minas Gerais, Rio de Janeiro and Sao Paulo, which have been marked on the map, and the works within each of these three areas have been listed at the foot of Figure 1.1. The works have been designated by the abbreviated titles generally accepted in the industry.

The industry has three types of works : integrated, semi-integrated and re-rollers or non-integrated works. The integrated works are classified as having ironmaking, steelmaking, and rolling facilities, while the semi-integrated ones have steelmaking and rolling facilities but no ironmaking. In Table 1.2

TABLE 1.1 - LIST OF COMPANIES WITH PRODUCTS AND BALANCED CAPACITY OF FINISHED PRODUCTS

	Enterprises	PRODUCTS																						
				Pig Iron			Steel Ingots				Flat Products			Non Flat Products										
				Blast Furn.							un-coated			Bars		Shapes								
		Sinter	Coke	Coke	Charcoal	Electric smelting	Open-Hearth	BOF	Electric	Bessemer	Hot	Cold	Coated	Common Steels	NonCommon Steels	Light	Medium	Heavy	Rails and accessories	Rods	Common Wire Rods	Seamless Pipes	Balanced capacity *1,3 finished products (tonnes) 1969	Expected capacity *4 finished products (tonnes)
1	Cosipa	o	o	o				o			o	o											511,000	1,701,000
2	CSN *5,8	o	o	o			o				o	o	o	o		o	o	o	o				1,065,400	1,767,000*8
3	Usiminas	o	o	o				o			o	o											703,000	1,855,000
4	Acesita *5				o	o			o	o	o				o								96,000	166,000
5	Açonorte								o											o	o		42,000	115,000
6	Aliperti				o		o		o					o	o					o			185,000	185,000
7	Anhanguera								o						o								75,000	75,000
8	Aparecida								o						o								33,000	83,000
9	B. Mansa	o			o		o	o								o	o			o	o		190,000	190,000
10	C.B. do Aço						o									o							14,000	14,000
11	CBUM	o			o		o							o		o				o	o		48,000	48,000
12	CIFA *2													o	o						o		60,000	60,000

* for explanation, see the notes on Page 6.

TABLE 1.1 - LIST OF COMPANIES WITH PRODUCTS AND BALANCED CAPACITY OF FINISHED PRODUCTS (cont.)

Enterprises		PRODUCTS																					Balanced capacity*1,3 finished products (tonnes) 1969	Expected capacity*4 finished products (tonnes)
				Pig Iron			Steel Ingots				Flat Products			Non Flat Products										
				Blast Furn.							un-coated			Bars		Shapes								
		Sinter	Coke	Coke	Charcoal	Electric smelting	Open-Hearth	BOF	Electric	Bessemer	Hot	Cold	Coated	Common Steels	Non Common Steels	Light	Medium	Heavy	Rails and accessories	Rods	Common Wire Rods	Seamless Pipes		
13	Copalem *2													o	o	o				o	o		27,000	27,000
14	Cofavi								o					o		o	o			o	o		31,000	170,000
15	Cobrasma *10								o						o								36,000	36,000
16	Coferraz								o											o			34,000	34,000
17	Comesa								o											o			8,000	8,000
18	Copala								o											o			4,100	4,100
19	Cosim		o		o		o		o					o						o		o	162,000	162,000
20	Cosinor								o											o			21,000	21,000
21	CSBM	o			o		o	o						o		o				o	o		475,000	548.000
22	Dedini						o		o					o						o			99,000	99,000
23	Eletrometal								o						o								4,100	4,100
24	Fi-El								o											o	o		25,000	25,000

* for explanation, see the notes on Page 6.

TABLE 1.1 - LIST OF COMPANIES WITH PRODUCTS AND BALANCED CAPACITY OF FINISHED PRODUCTS (cont.)

Enterprises		PRODUCTS																						
				Pig Iron			Steel Ingots				Flat Products			Non Flat Products										
				Blast Furn.							un-coated			Bars		Shapes								
		Sinter	Coke	Coke	Charcoal	Electric smelting	Open -Hearth	BOF	Electric	Bessemer	Hot	Cold	Coated	Common Steels	NonCommon Steels	Light	Medium	Heavy	Rails and accessories	Rods	Common Wire Rods	Seamless Pipes	Balanced capacity *1, 3 finished products (tonnes) 1969	Expected capacity *4 finished products (tonnes)
25	Guaira								o					o						o			20, 000	20, 000
26	Itaunense								o											o			23, 000	23, 000
27	Lafersa				o		o													o	o		16, 000	16, 000
28	Lanari				o		o							o		o				o	o		30, 000	60, 000
29	Mannesmann				o	o		o	o					o	o							o	245, 000	265, 000
30	Metropolitana								o					o	o					o			29, 000	29, 000
31	Minasfer *2																			o	o		19, 000	semis only fed to Pains
32	Montepino *2														o	o				o	o		77, 000	77, 000
33	Pains				o		o													o	o		33, 000	80, 000
34	Plangg								o							o							800	800
35	Riograndense								o					o		o				o	o		178, 000	178, 000
36	Saad						o													o	o		60, 000	60, 000

* for explanation, see the notes on Page 6.

TABLE 1.1 - LIST OF COMPANIES WITH PRODUCTS AND BALANCED CAPACITY OF FINISHED PRODUCTS (cont.)

	Enterprises	PRODUCTS																						
				Pig Iron			Steel Ingots				Flat Products			Non Flat Products										
				Blast Furn.							un-coated			Bars		Shapes								
		Sinter	Coke	Coke	Charcoal	Electric smelting	Open -Hearth	BOF	Electric	Bessemer	Hot	Cold	Coated	Common Steels	NonCommon Steels	Light	Medium	Heavy	Rails and accessories	Rods	Common Wire Rods	Seamless Pipes	Balanced capacity *1.3 finished products (tonnes) 1969	Expected capacity *4 finished products (tonnes)
37	Sto. Amaro								o											o			2,400	2,400
38	São José								o							o				o			71,000	71,000
39	S. Olímpia								o					o									42,000	42,000
40	S. Antonio *2																			o			3,600	3,600
41	S. Estéfano								o							o							4,400	4,400
42	S. Tereza *2															o							12,000	12,000
43	Villares								o						o								37,000	37,000
44	Siderama				o			o								o					o		nil	40,000
45	Piratini *6		D/R						o					o	o						o		nil	60,000
46	Usiba *6,7		D/R						o					o									nil	280,000
47	Cosigua *9								o											o	o		nil	224,000
	TOTAL																						4,851,800	8,982,400

* for explanation, see the notes on Page 6.

TABLE 1.1 - LIST OF COMPANIES WITH PRODUCTS AND BALANCED CAPACITY OF FINISHED PRODUCTS (cont.)

Notes

1. Balanced capacities of finished products taken from Technometal report. 'Brazilian Steel Market' - Volume 1.
2. For re-rolling plants, mills output are given.
3. In 1969 the combined capacity of the non-flat product works in terms of rolling mill capacity was some 544,000 tonnes higher than the total of the balanced capacities shown, and some 221,000 tonnes higher in terms of steelmaking and roughing mill capacity; these cannot be utilized since they exist in different works which do not have a balanced steelmaking to rolling mill capacity.
4. The expected capacity finished product tonnages are based upon completion of projects approved at September 1971
5. CSN includes 200,000 tonnes and Acesita 60,000 tonnes of non-flat products in 1969 capacities. Approved developments increase these tonnages to 350,000 and 100,000 tonnes respectively.
6. D/R indicates a direct reduction process.
7. First stage of Usiba is for billets only.
8. The CSN production figures include the tonnes of tinplate which will be available in 1976/1977 when the new tinning line comes into operation, and 240,000 tonnes of semis.
9. First stage only.
10. The total production of COBRASMA is forgings for industry.

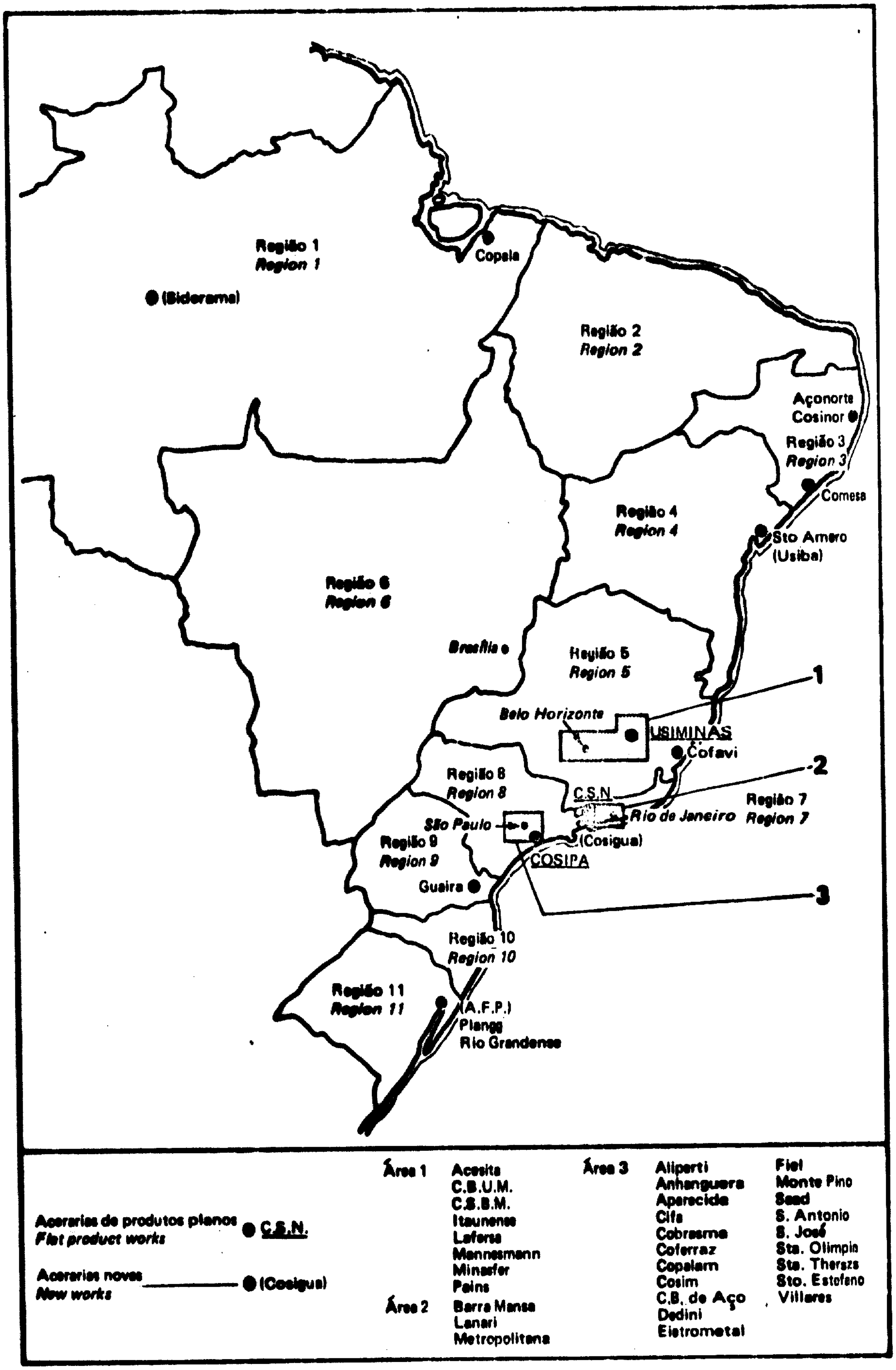

FIGURA 1.1 – LOCALIZAÇÃO DA INDÚSTRIA SIDERÚRGICA BRASILEIRA

FIGURE 1.1 – LOCATION OF BRAZILIAN STEEL INDUSTRY

the forty-seven works are classified under these headings and also by location.

TABLE 1.2 - CLASSIFICATION OF STEELWORKS IN BRAZIL

Region	Number of Works - by Type				Output(3) in 1971 (million ingot tonnes)
	Integrated	Semi-Integrated	Non-Integrated	Total	
Minas Gerais	7	1	1	9	2.2
Rio de Janeiro	3	2(2)	-	5	1.8
Sao Paulo	3	13	5	21	1.5
All others	3(1)	9	-	12	0.2
Total	16	25	6	47	5.7

(1) These works are under construction
(2) One of these works is under construction
(3) Estimated from IBS data for first nine months of 1971.

It is also possible to categorise these works by their production - respectively of flat and non-flat products. The situation is not clear-cut, as Companhia Siderurgia National (CSN), which is primarily a flat product works, also produces medium sections and rails, while the non-flat producer Companhia Acos Especiales Itabira (Acesita) also makes flat products in special steels. For ease of reference, however, we have adopted the terms "flat product sector" and "non-flat product sector" as descriptions which cover only the major activity of each works in that sector - thus the "non-flat product sector" does not include CSN, in spite of their sections capacity.

The flat product sector of the industry consists of three large integrated works which together accounted for 55 percent of the output in 1971. These works are Companhia Siderurgia National (CSN), Usina Siderurgia de Minas S.A. (Usiminas), and Companhia Siderurgia Paulista (Cosipa) located in the Rio de Janeiro, Minas Gerais and Sao Paulo regions respectively.

The non-flat product sector of the industry comprises, in contrast, a large number of smaller works of sizes varying from 4,000 tonnes to over 500,000 tonnes of ingot production capacity per year. These works, including the plants under construction in this sector, have been classified in Table 1.3 by size, type and product.

TABLE 1.3 - DISTRIBUTION OF WORKS IN NON-FLAT PRODUCT SECTOR

Annual Capacity Ingot Tonnes (Thousands)	Type of Works	Number of Works - by Product		
		Common Steels	Special Steels	Tubes
Under 25	Integrated	1		
	Semi-integrated	8		
	Non-integrated	3		
	Total	12		
25 to 100	Integrated	4	1	
	Semi-integrated	11	3	
	Non-integrated	3	-	
	Total	18	4	
100 to 300	Integrated	5		
	Semi-integrated	3		
	Non-integrated	-		
	Total	8		
300 to 500	Integrated	1		1
	Semi-integrated	-		-
	Non-integrated	-		-
	Total	1		1

Although about a quarter of these works lie outside the main steelmaking 'triangle shown on Figure 1.1, most of the production originates within it.

1.2 Present output and planned capacity

The output of the industry in 1971 amounted to nearly 6 million tonnes of ingot steel, of which nearly 97 percent was produced in the Sao Paulo, Belo Horizonte and Rio de Janeiro triangle. Action to spread the industry over a wider area is being taken, as demonstrated by the construction of the three new integrated works outside this triangle. These works are, however, relatively small. The breakdown of the 1971 output by sector and location is given in Table 1.4. These figures demonstrate the industrial importance of the Minas Gerais and Sao Paulo regions.

Development of an industry is a continuous process so that a review of the position at any point in time must of necessity present an incomplete picture. For the purpose of this investigation, only those developments sanctioned by CONSIDER* up to September 1971 have been included as part of a firm development programme, which will, on this basis, increase production capacity from the 4.9 million product tonnes shown in Table 1.1. to a total of 9.0 million tonnes of fini-

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* Cf. Article 1.4 below.

TABLE 1.4 - DISTRIBUTION OF OUTPUT IN 1971

Flat product sector		Non-flat product sector	
Company	Output (millions of ingot tonnes)	Region	Output (millions of ingot tonnes)
Usiminas	0.9	Minas Gerais	1.2
CSN	1.6	Rio de Janeiro	0.2
Cosipa	0.6	Sao Paulo	1.0
		All others	0.2
Total	3.1	Total	2.6

shed products. Priority in this programme has been given to the flat product sector, of which current plans will increase capacity by 130 percent, compared with only 42 percent for the non-flat sector. The result is illustrated in the table below, which shows the proposed capacities in both flat and non-flat products once the programmed development is completed, together with the existing capacities in these two sectors.

Sector	Annual finished product capacity (millions of tonnes) Existing	Planned
Flat product	2.3	5.3
Non-flat product	2.6	3.7
Total	4.9	9.0

The development will chiefly involve the installation of new facilities, and existing facilities will also be improved by additional equipment or by re-engineering plant. The main items of the new facilities are discussed in the following chapters.

After the completion of the current development programme, the regional distribution of finished product capacity will be approximately as follows:

Region	Annual finished product capacity (millions of tonnes)
Minas Gerais	3.1
Rio de Janeiro	2.4
Sao Paulo	2.8
All others	0.7
Total	9.0

It can be seen that over 90 percent of the total production capacity will still be within the main steelmaking triangle, but at the same time the total production capacity of the other regions will be increased by well over 100 percent.

1.3 Product diversity

In order to assess the diversity of the industry, it was necessary to establish certain product groups and identify how many and what type of works were manufacturing the different products. This analysis has been summarised in Table 1.5.

TABLE 1.5 - PRODUCT DIVERSITY 1969-1971

Products group	Number of Works - by Type			Total
	Integrated	Semi integrated	Non integrated	
1. Plate, sheet, coil only.	2	-	-	2
2. Plate, sheet, coil, coated products, medium heavy profiles, rails.	1	-	-	1
3. Special plates, bar, rod, shapes.	1	-	-	1
4. Light sections, bar, rod, shapes	4	7	3	14
5. Rod and bar only	3	15	3	21
6. Special steels, bar, rod, shapes.	-	3	-	3
7. Tubes and bar, rod, shapes.	2	-	-	2
TOTAL OF PLANTS	13	25	6	44

1.4 Organisation of the industry

The Government, private enterprise and foreign investors have all contributed to the growth of the Brazilian steel industry. In the early years, development and involvement were only loosely co-ordinated but in recent years a more ordered pattern of growth has been taking place. In support of this developing industry, a number of organisations and institutions have been set up to provide guidance and assistance to the industry on such matters as planning and development, finance, commerce, and technological research, training and "know-how".

The role of government

In concert with world trends, the Brazilian government's role in the steel industry has developed in recent years into a responsibility for shaping the industry to suit the total economy of the country. To this end, the Conselho Consultivo da Industria Siderurgica (CONSIDER) was created to act, until recently, in a consultative capacity to the Minister of Industry and Commerce on matters relating to the iron and steel industry. This organisation has now been restructured and given more substantial terms of reference. These are :

(1) To formulate and co-ordinate iron and steel industry policies;

(2) To establish the criteria for granting governmental incentives to the steel sector;

(3) To establish the general guidelines for the commercial and financial policy of state-controlled steel companies;

(4) To authorise the application of accelerated depreciation for top-priority steel projects;

(5) To authorise, by delegation of the Customs Policy Council, the granting of tax exemption to imported capital goods intended for projects which are considered top-priority;

(6) To programme investments in the steel sector and co-ordinate the consequent allocation of the necessary public funds;

(7) To grant priority to projects for building new plants and for the expansion or modernisation of existing steelworks where such projects are eligible for official financing;

(8) To execute or contract, through its Executive Secretariat, the sectoral studies necessary to the planning of the Brazilian steel industry.

"CONSIDER will also collaborate with the interministerial Price and Customs Policy Councils to formulate the prices and customs policy for the steel sector. It will also advise the Bureau of Foreign Markets of the Bank of Brazil and the Central Bank of Brazil as to which machinery and equipment should be imported for the steel projects already approved and the external credits to be obtained for such projects."

The establishment of CONSIDER demonstrates a rationalisation of the many duties and functions which the Government has found it necessary to assume in connection with the Industry, and separates these from the function of ownership.

Ownership

The Government has a majority share-holding in seven steel companies. These include the three flat product works. CSN has been financed directly by the Treasury, while Usiminas and Cosipa are supported by government funds through the Banco Nacional de Desinvolvimento Economico (BNDE). The main shareholders of Usiminas are BNDE, the State Government of Minas Gerais and a consortium of Japanese interests; BNDE are the majority shareholder. In the case of Cosipa, the equity is held by BNDE, the State Government of Sao Paulo and the national Treasury.

The Government's participation in the non-flat sector of the industry embraces four companies: Acesita, Cofavi, Cosim and AFP. The Government has acquired Acesita, Cofavi and Cosim as an emergency measure in order to prevent closure of these works. Government support of the fourth company, AFP, acknowledges the commercial risks and potential technological benefits inherent in investing in an enterprise based on an emergent process, in this case SL/RN direct reduction ironmaking.

The other company (Usiba), based on direct reduction is not financed by the Government but has its backing through the majority shareholder, SUDENE, which is a planning and administrative organisation created by the Government for the development of the north-east of Brazil. SUDENE acts as the trustee for private investment in these developments.

A possible development which is under consideration is the co-ordination of all the state-owned companies under a holding company, entitled Siderurgia Brasilia (SIDERBRAS).

The rest of the industry is in private hands. A few companies have been set up by foreign investors, and although their equity is now mainly Brazilian owned, foreign interests still have the largest individual holdings in the two biggest non-flat companies, Mannesmann and CSBM.

Research and development

Technological investment in support of the industry takes place at two levels - company and national.

At the company level, the research staffs and laboratory facilities at CSN and Usiminas are the only establishments of any significance in the industry. There are plans for expanding these but as is usual with works research facilities, the activities are largely confined to inspection and quality control procedures, and to solving problems arising in the works. Some capacity for applied research projects is,however, planned into the expansions.

The national and state institutions of importance to the steel industry are the Associacao Brasileira de Mateis (ABM), the Instituto Brasileiro de Siderurgia (IBS) and several of the universities.

The ABM is a learned society of international standing. It stimulates technological interchange by means of meetings and publications at national and regional levels in both ferrous and non-ferrous metallurgical fields. The society has published over 1,000 papers and ten books since 1944. It also sponsors scholarships.

In contrast, IBS has been established and financed by the steel industry itself to provide a commercial information service. Market intelligence and information on price trends are typical of the service provided.

Most fundamental research is restricted at present to the universities. With many calls on their resources, it follows that the contribution to steel is small. There is also the research organisation known as Centro Tecnico

Aeronautical e Spacial, which concentrates on basic research in metallurgical fields. Its work is related to the exacting needs of the aerospace industry which usually anticipate the needs of general engineering by one or two decades. Research on steels by this organisation may thus be regarded as a long term investment.

There are also several consulting engineering companies capable of executing development projects. A current example is a project for a long distance iron ore slurry pipeline system.

Training and "know-how"

Several steel companies have personnel training programmes and technical "know-how" agreements with major foreign steel producers. These include two of the integrated flat product companies, the special steel producers and a number of the larger companies in the non-flat section of the industry.

CSN has an agreement with the United States Steel Corporation. In addition, the Company runs and staffs local technical colleges to provide trained personnel in grades ranging from technician to graduate engineer. Training has been a strong feature of CSN's policy for many years, so that the industry as a whole has benefited from a supply of trained personnel.

The long term agreement between Usiminas and the Nippon Steel Corporation is similar to the CSN - USS agreement. Cosipa has no set training programme and organises programmes when the need arises. Most training is arranged internally but individual technicians and engineers are selected for further training and education abroad.

The companies engaged in special steel production generally seek co-operation with well-known foreign manufacturers. For instance, Anhanguera is now operating in association with SKF of Sweden. Like most agreements it provides for the training of Brazilian personnel by SKF staff and for the exchange of technical "know-how" in mutual fields of experience. AFP - a company which is going to produce special steel products - has an agreement with AB Bofors, also of Sweden. The works of this company is still under construction, but the company is already arranging to train people locally and in Sweden. Villares also have agreements with Crucible Steel and with the Ohio Rolls Corporation of the US.

Of the other steel producers in the non-flat product sector, Mannesmann operates a continual training programme for all levels of operatives and engineers. It is company policy to send a selected number of personnel abroad for training and experience, usually to the company's parent works in Germany. New developments in technology are constantly reviewed by the Mannesmann group as a whole and this information is made available to all subsidiary companies. CSBM has an overseas training scheme for engineers and some production personnel. The company also operates a technical training programme in-house for works operatives and technicians.

CHAPTER 2 - RESOURCES AND TRANSPORT

Although this Section is concerned with the present state of the Brazilian industry, it is convenient in considering resources and infrastructure requirements, to minimise repetition in Section C by looking at the situation up to 1980 in this Chapter.

In order to meet the needs of the Iron and Steel industry in 1980 it will be necessary to secure greatly increased supplies of raw materials, fuel and electricity and to make sure that adequate transport facilities are available for the handling of feedstock and finished products. It will also be necessary to ensure that labour and management are trained in adequate number and well in advance of the building of new plants. The following articles discuss the resources and transport systems in terms of quantity, technological characteristics, location and exploitation.

2.1 Feedstock

Iron ore

Brazil has some of the most extensive and highest grade iron ore reserves in the world. The country's known reserves of high grade (above 64 percent Fe) hematite ore alone amount to about 4,500 million tonnes.

The largest and best known ore deposits are situated in the State of Minas Gerais in an area known as the'iron quadrilateral'. There are reserves of potential ores known to exist in many other States. The estimated reserves are given in Table 2.1, but these do not include large high grade deposits recently found in the State of Para.

TABLE 2.1 - RESERVES OF IRON ORE DEPOSITS
(millions of tonnes)

Location	Reserves
State of Minas Gerais	29,830
State of Mato Grosso	10,050
State of Amazonas	200
States of Bahia, Sao Paulo, Parana, Santa Catarina, etc.	130
TOTAL	40,210

At present, the principal mining activities are centred in the State of Minas Gerais, accounting for almost all of the national iron ore production. Although by the end of this decade iron ore reserves in other States will be exploited, the bulk of the supplies required for the Brazilian steel industry may still be obtained from the mines in Minas Gerais State. By 1980 some of the reserves in this State should be extensively developed not only to supply the home industry but also to provide an even larger proportion of the production tonnage for export markets.

At the present time, one works in the flat product sector and several steelworks in the non-flat sector obtain their iron ore supplies from their own captive mines. The iron content of the supplies is generally above 64 percent. By 1980 several of these steelworks should expand their ironmaking facilities and therefore will require increased iron ore supplies. These organisations have made provisions for additional production facilities at the appropriate mine to sustain the increased demand for iron ore.

There are several mining companies operating independently of the steel companies in Brazil. They supply part of their production to the home steel industry and export the rest. The two main such companies are Companhia Vale do Rio Doce (CVRD) and Mineracao Brasileiras Remiedas (MBR).

In 1970, CVRD produced about 23 million tonnes of iron ore products; of this amount approximately 21.8 million tonnes were exported, and the rest sold to the home market. By 1975 this company envisages producing about 56 million tonnes of ore and adding to their existing oxide pellets production capacity at about that time, a 3 million tonne unit to produce a total of 5 million tonnes of pellets per year. The iron content of the company's products is generally above 64 percent.

MBR is a private company and its mines came into operation only recently. In 1970 the company produced about 2 million tonnes, of which approximately 50 percent was supplied to the home industries and the rest was exported. The company envisages producing about 13 million tonnes of high grade ore (65 percent Fe plus) in 1975.

Because of the nature of some iron ore deposits in Brazil and the friable characteristics of iron ores mined from these deposits, it is most likely that sized lump ore for ironmaking will be used only to a limited extent. To achieve performance levels from ironmaking facilities, comparable to those denoted in Appendix 1, the industry will have to procure predominantly iron ore fines which would need to be agglomerated by sintering prior to charging into blast furnaces. The use of oxide pellets in blast furnaces will, or course, have to be considered as this type of material becomes available from home resources. One of the new works which is now under construction in the non-flat sector of the industry will procure oxide pellets for use in direct reduction ironmaking facilities.

Scrap

The availability of iron-bearing scrap in Brazil over this decade is a matter of considerable conjecture, since it is not a well documented subject. Recently, however, IBS prepared a report giving the estimates of scrap availability in

Brazil up to 1980. On the basis of this report, and taking into account the possible effects of technological trends in the manufacture of steel products, we have estimated that by 1975, 1980 and 1985 the annual arising of scrap excluding circulating scrap within the steelworks, will be of the order of 2.1, 3.3 and 5.0 million tonnes respectively. The estimated proportions of process and capital scrap for each period are shown in Table 2.2

TABLE 2.2. - PROJECTED SCRAP AVAILABILITY IN BRAZIL

(millions of tonnes)

Source	Annual availability		
	1975	1980	1985
Process	0.8	1.3	2.2
Capital - home goods	1.0	1.6	2.4
- imported goods	0.3	0.4	0.4
TOTAL	2.1	3.3	5.0

Process scrap refers to scrap generated by secondary industries during the course of production of goods from finished steel products. Capital scrap is the most diverse form of scrap and is recovered from replacement of machinery and capital goods such as railways, motor vehicles and ships.

The most important source is capital scrap. Arisings of capital scrap are a function of conditions some 20 years earlier when the rate of growth of the economy may well have been different from today. However, the estimates presented in Table 2.2. indicate that capital scrap will arise in significant proportions during the period considered. The estimated availability of capital and process scrap in different regions is shown in Figure 2.1; most scrap arises within the steelmaking regions, and the small amounts arising in outlying regions is too remote to be useful in any but small local works.

Although the arisings of capital scrap will be in significant quantities, its collection in an organised and properly classified fashion will demand extensive services from the scrap merchants. At the present time there are many scrap collecting companies operating in Brazil; only a few of these companies have some scrap processing facilities, and these are highly labour-intensive and non-mechanised. The industry has no corporate representation. In many respects this situation has led to circumstances in which the availability of the material is not secured, and the quality and price are far from stabilised.

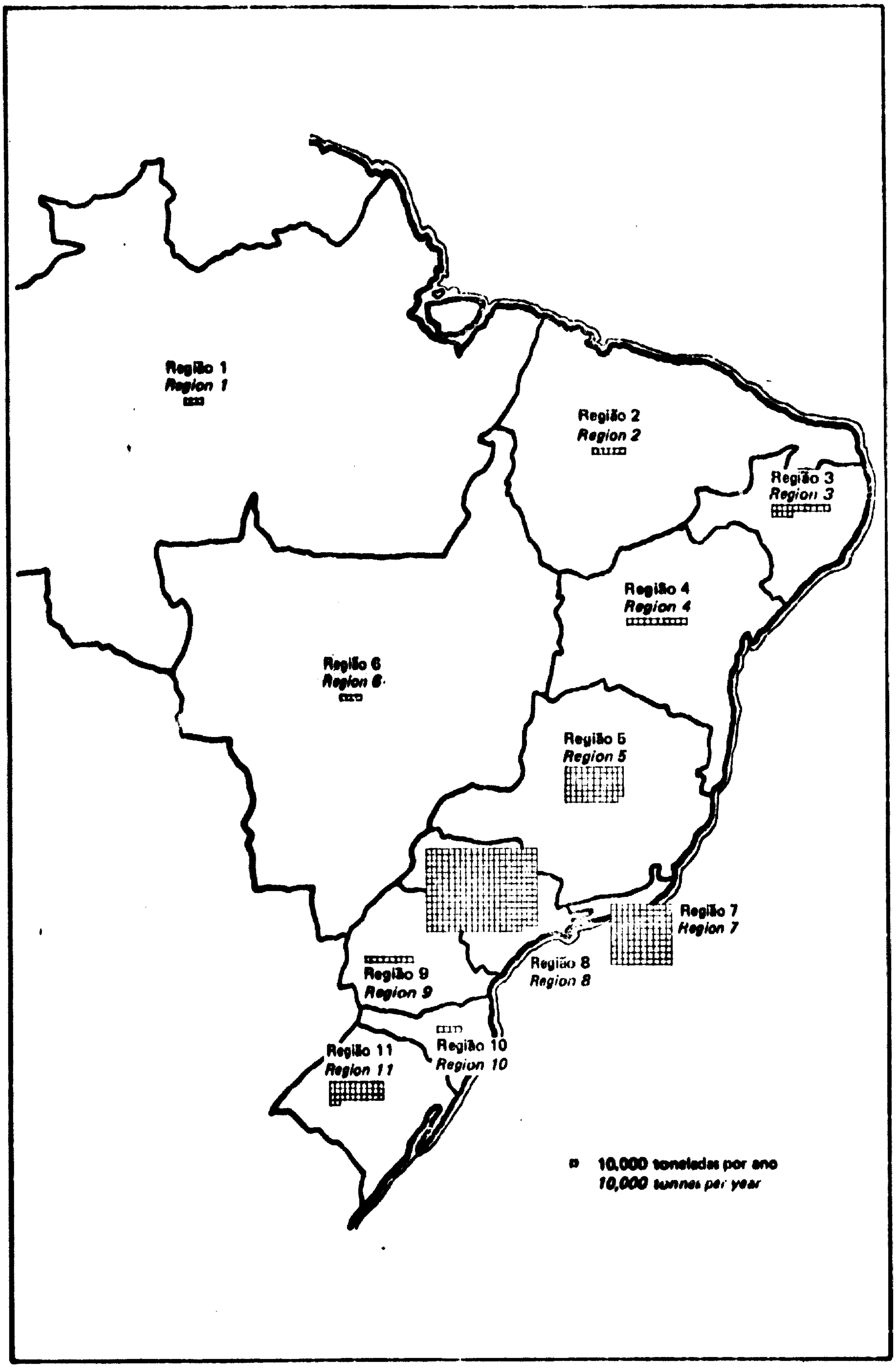


FIGURA 2.1 – PADRÃO REGIONAL DE PROCESSO E SUCATA BASILAR PREVISTOS EM 1980
FIGURE 2.1 – REGIONAL PATTERN OF PROCESS AND CAPITAL SCRAP ARISING 1980

Although in the short term the smaller scrap collecting companies can make an important contribution there will be a need in the longer term for organisations with large scale collecting and processing facilities. The promotion of this re-organisation will not only establish the regular availability of the material and economics of scale of operation, but will also guarantee the quality of materials despatched to the steel industry.

The main contribution of larger organisations would be the negotiation of commercial policies with the steel industry, particularly on such issues as supply and demand conditions, schedules of scrap specifications and price structure.

Pig iron

In Chapter 1 it has been mentioned that there are over sixty small ironmakers producing pig iron in charcoal blast furnaces on a semi-continuous basis. The majority of these ironmaking facilities are situated in the State of Minas Gerais, and although it is considered that they will continue in the future to make a useful contribution,the individual production units are small. It is therefore considered that these companies should not be regarded as forming part of the strategic plan.

2.2. Coal and charcoal

By 1980 the demand for coking coal will be significantly higher than the quantity required today. The demand for non-coking coals may also rise because these materials may be required for the operation of solid-fuel based direct reduction processes and, possibly, for the production of 'formed coke'. The demand for charcoal is not expected to alter significantly. The availability and supply situations of these fuels are discussed below.

Coal

The known reserves of coal deposits in Brazil amount to about 3,300 million tonnes. The deposits are mostly located in the State of Rio Grande do Sul, Santa Catarina and Parana. The estimated tonnages of these reserves are given in Table 2.3.

TABLE 2.3. - RESERVES OF BRAZILIAN COAL
(millions of tonnes)

State	Estimated reserves
Rio Grande do Sul	2,022
Santa Catarina	1,205
Parana	37
Total	3,264

Other coal deposits are known to exist in the regions of Piaui, Tocantins-Araguaia, Rio Fresco and Alto Amazonas, but both the extent and accessibility are unknown.

The Brazilian coking coal deposits are mainly situated in the State of Santa Catarina. The nature of these deposits is such that the production of coking coal will always be associated with the extraction of a certain proportion of non-coking coal. The coal seams are composed of thin bands of coking and non-coking coals and waste materials; this condition does not permit mining different types of coal selectively.

The characteristics of typical Brazilian coals are given in Table 2.4.

TABLE 2.4. CHARACTERISTICS OF TYPICAL WASHED COALS

Characteristics		Coking Coal	Non-coking Coal
Moisture	-%	10.0	7.0 - 8.0
Ash	-%	18.5	30.0 - 45.0
Sulphur	-%	1.8	2.0 - 3.5
Volatile matter	-%	30.0	22.0 - 24.0
Fixed carbon	-%	51.5	44.0
Calorific value	-L/C cal/kg	6,800	4,800 - 5,500
Swelling index		2.5 - 4.5	-

The data in this table shows that the Brazilian coals are of poor quality. This is primarily due to the high ash content, which is over 50 percent in the as-mined state. Since the ash forming matter is widely and intimately dispersed throughout the mass of coal, the washed coking coal supplied at present to the steel industry contains over 18 percent ash, even after enrichment by coal preparation.

At present several mining companies are exploiting the coal deposits of Brazil. Most of these are small, but there are nineteen principal companies and the majority of these operate more than one mine. Thirteen of these companies are operating mines in the State of Santa Catarina, three in the State of Rio Grande do Sul and three in the State of Parana.

The production of national coal in 1969 was as follows:-

State and coal type	Production - million tonnes	
	Run of mine coal	Washed coal
Rio Grande do Sul		
Non-coking coal	1.0	0.9
Santa Catarina		
Coking coal)	3.7	(0.8
Non-coking coal)		(0.5
Parana		
Non-coking coal	0.4	0.3
TOTAL		
Coking coal)	5.1	0.8
Non-coking coal)		1.7

At present, the Brazilian coal mining industry supplies annually about 0.8 million tonnes of coking coal to the steel industry. This amount represents about 33 percent of the total requirements of the industry. It is reported by the Brazilian authorities that in 1980 the supply of national metallurgical coal will still only amount to about 1.5 million tonnes.

In the very near future, only a nominal supply of non-coking coal will be required for the SL/RN direct reduction ironmaking plant of Acos Finos Piratini. The company will have a coal washing plant, which will prepare coal obtained from a mine adjacent to the works, to produce about 65,000 tonnes for metallurgical use.

The industry now uses a small quantity of non-coking coal primarily for steam raising and, for this purpose, will continue to procure from indigenous sources although the tonnage purchased is unlikely to be increased by 1980.

Charcoal

At present about 90 percent of the national charcoal pig iron production comes from the Minas Gerais State. The supply of charcoal required for this production is either obtained from the steel company's own, or from locally situated carbonisation plants. It is unlikely that this situation, both from the point of view of charcoal pig iron production and charcoal supply, will change by 1980. If it is assumed that by the end of this decade a maximum of about 2 million tonnes of charcoal will be required to satisfy the total demand of all blast furnaces producing charcoal pig iron in Brazil, then it will be necessary to maintain afforestation, permanently, of an area of about 400,000 hectares within the vicinity of these blast furnace installations.

2.3 Fuels and electricity

The potential sources and availability of fuel oils, natural gas and electricity are discussed below.

Fuel Oil

Brazilian reserves of crude oil are estimated to be only about 850 million barrels (115 million tonnes). The deposits which are being worked are situated in Bahia, Alagoas and Sergipe, and these yield, in total, about 60 million barrels (c. 8 million tonnes) per year.

There are several petroleum refineries operating in Brazil, located in Bahia, Guanabara, Rio de Janeiro, Minas Gerais, Sao Paulo, Rio Grande do Sul and Amazonas. The total processing capacity of these refineries is stated to be 250 million barrels (c. 35 million tonnes) of crude oil per year. (In 1969 these refineries produced about 170 million barrels of petroleum products).

The Brazilian refineries process both indigenous and imported crude oil. Nearly two-thirds of the imported crude oil comes from middle-eastern countries.

One of the important properties of Brazilian fuel oils is that their sulphur content is lower than that of most of the oils from international sources. For this reason, Brazilian fuel oils are ideally suited for blast furnace injection.

Natural Gas

The present reserves of natural gas which have been discovered in Brazil are comparatively small. A recent estimate by PETROBRAS puts them at approximately 25,000 million cubic metres. To put this estimate in perspective, it is approximately equivalent to the current annual consumption of petroleum fuel in Brazil. It is therefore clear that with only the existing known reserves in Brazil it will not be possible to sustain any long term major industrial demand from the steel industry.

However, a supply of about 200 million cubic metres per year of natural gas will be made available to Usiba for use in their HyL direct reduction ironmaking plant. This company's plant is now under construction and has been founded on the basis of a supply concession from PETROBRAS for as long as supplies of natural gas continue.

Naphtha

Liquid naphtha is a light distillation product of crude petroleum. Its importance as a resource is that it can be reformed to produce a reducing gas suitable for use in the gas-based direct reduction ironmaking plants. However, it is more expensive than natural gas.

Liquid naphtha is produced at a number of Brazilian refineries located in Bahia, Rio de Janeiro, Minas Gerais, Sao Paulo and Rio Grande do Sul. At present a total of about 3.5 million tonnes per year is available and it is expected that, by 1975, this tonnage will rise to about 5 million tonnes per year.

Electricity

The present installed capacity for electricity generation in Brazil is over 10,000 MW. The regional electricity generating capacity is shown in Table 2.5.

About 77 percent of the installed capacity is hydro-electric, the balance being thermal. It has been stated that, by 1974, the installed capacity will be increased by 65 percent to give a total installed capacity of about 17,000 MW. At the present time the national supply situation is such that only about 50 percent of the generating capacity is now utilised.

A pilot nuclear generating station is now under construction at Angra dos Reis. This plant will have a capacity of 500 MW.

ELETROBRAS (Centrais Eletricas Brasileiras SA) is the state controlled holding company for many individual regional generating enterprises. ELETROBRAS together with Grupo Light SA control about 64 percent of the total installed capacity.

TABLE 2.5. - REGIONAL ELECTRICITY GENERATING CAPACITY

Region	Present installed capacity - MW			Planned Capacity by 1974-MW
	Hydro	Thermal	Total	
Northern States	676	337	1,013	2,220
Minas Gerais	2,329	35	2,364	3,525
Espirito Santo	59	31	90	206
Rio de Janeiro	886	217	1,100	1,500
Guanabara	-	237	237	637
Sao Paulo	2,655	723	3,378	5,683
Parana	131	127	259	548
Santa Catarina	96	157	253	385
Rio Grande do Sul	237	377	614	1,147
West Central	785	69	855	1,208
TOTAL	7,854	2,307	10,163	16,891

2.4. Process materials and water

The production of crude steel and finished products requires a number of different types of process materials and a great deal of water. With the development of the steel industry the demand for these will also increase, although it is unlikely that this will impose any serious constraint. Water is not considered to be a problem; the supply of other materials is discussed below.

Fluxing materials

The principal fluxing materials used by the steel industry are burnt lime, limestone, dolomite and fluorspar. Limestone and dolomite will be needed mainly at the sinter plants to produce self-fluxing sinter but, where necessary, they may be used as fluxing agents in the blast furnace burden. Burnt lime, produced by calcination of limestone, will mainly be used in the steelmaking operation.

Brazil has extensive reserves of limestone and dolomite deposits, and there is an abundant supply of these materials in all steel producing areas. At present, the majority of the steel companies procure these materials from their own captive mines and it is expected that this procurement policy will continue in future.

Ferroalloys

The steel industry will require supplies of different types and grades of ferroalloys for the production of common and special steels. It is estimated that in 1980 the total requirements of the industry will be about 0.2 million tonnes; about 25 percent of this amount will be required for special steel production.

Currently, ferroalloy production capacity in Brazil is nearly 120,000 tonnes of which ferro-manganese accounts for just over half and special ferroalloys about 8,000 tonnes. However, it has been stated that by 1975 the production capacity for special ferroalloys will be nearly doubled, and that the capacity for common ferroalloy production will be increased by about 20 percent.

In 1970 the demand for high carbon common ferroalloys was almost satisfied by national producers. On the other hand most of low carbon and special ferroalloys were imported. Bearing in mind the growth rate of the ferroalloy production industry and the steel industry's requirement for ferroalloys in 1980, it is apparent that the production facilities for ferroalloys will have to be increased significantly by the end of this decade if large scale importation of these commodities is to be avoided.

Refractories

In 1980 the steel industry will require approximately 0.9 million tonnes of refractory products, of various types. About 10 percent of this tonnage will be basic refractory products required for steelmaking furnaces; the remainder will be mainly non-basic types for lining all other types of furnaces, blast furnace stoves, ladles,hot metal mixers and similar retaining vessels, as well as the flues, or stacks, through which hot gases are conducted.

In 1970 the Brazilian refractory industry had, in the past years, produced some 0.4 million tonnes of refractory products. This tonnage nearly satisfied the total national demand for refractories, and only about 10,000 tonnes of refractory products were imported. About 85 percent of the tonnage produced was supplied to the steel industry.

There are several refractory manufacturing companies operating in Brazil. Of these, three companies, namely Magnesita SA, Ceramica Sao Caetano, and Industrial Brazileiro Artigos Refractories, account for nearly 90 percent of the national production; some steelworks also have facilities for refractory manufacture. Of all the companies, Magnesita SA is the most important, since this company is currently satisfying nearly 80 percent of the total Brazilian market for basic refractories. This company is fully aware of the projected development of the steel industry, and has a programme for development of production facilities to keep pace with the needs of the steel industry.

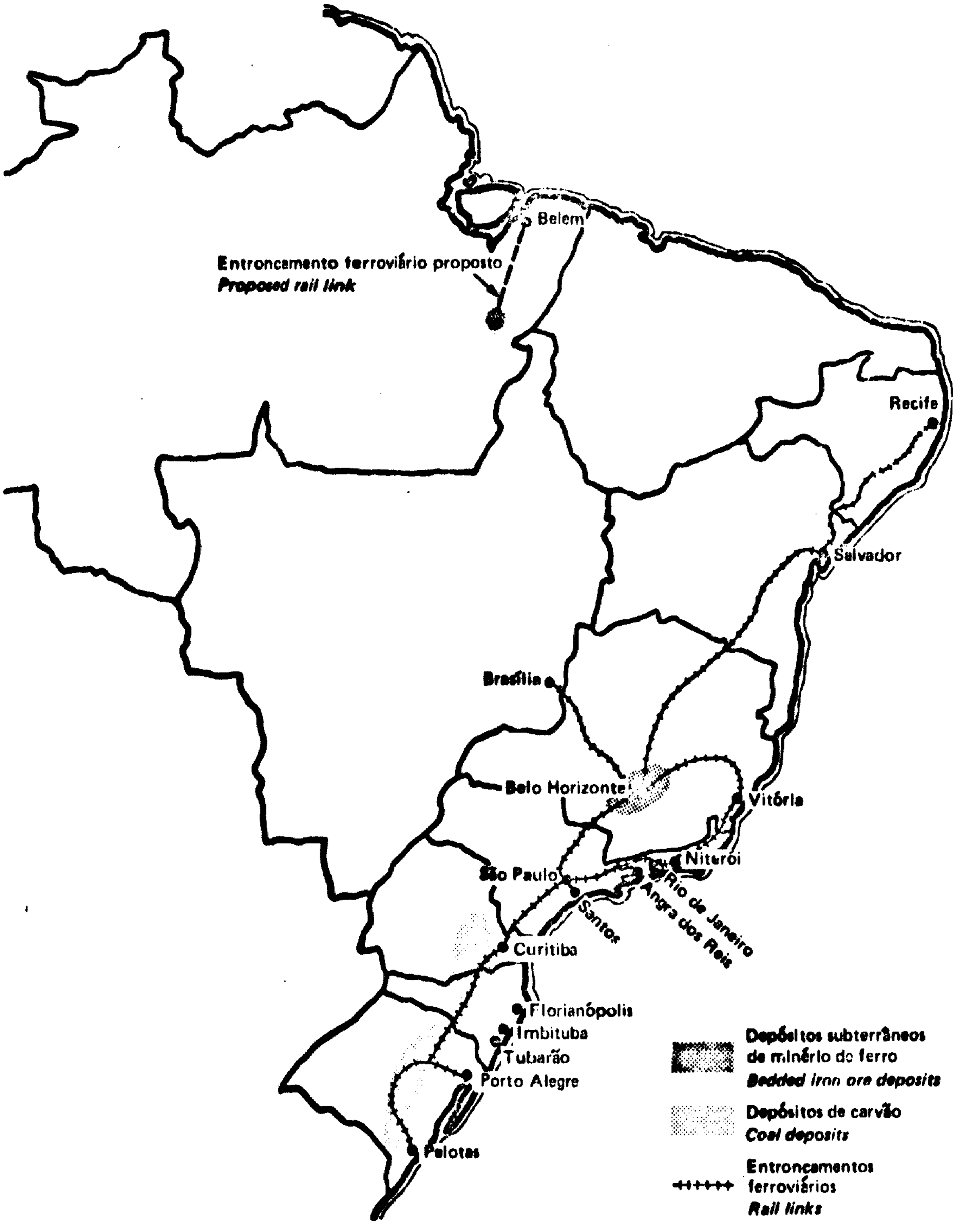
In general, the quality of most refractory products manufactured in Brazil is good. However, it is most encouraging that the industry - and particularly Magnesita SA - has already a major research and development establishment. It has already been proposed by Magnesita SA that the facilities of this establishment should be extended to provide better services in quality improvement and new product development.

2.5. Transport

By 1980 the quantities of various types of raw materials and finished products which will have to be transported will have greatly increased. The expected increase in demand on transport infrastructure in relation to the services that were provided to the industry in 1970 is given in Table 2.6.

During the past years over 95 percent of the total tonnage of materials, which have been either consumed or produced by the industry, have been transported within a regional triangle. This triangle includes the states of Rio de Janeiro and Guanabara, Sao Paulo, and Minas Gerais, together with Espirito Santo. Although the development of the steel industry will affect regions beyond these states, the effect on transportation networks will be relatively small. It is anticipated that in 1980 approximately 90 percent of the movement of materials will take place within the regional triangle. In quantitative terms this means that nearly 50 million tonnes of raw materials and finished products will be transported within this area.

The extent of the principal rail and road systems, together with the location of principal ports, are shown in Figure 2.2. At present, railways are mainly used for raw material transportation, and more than half of the total finished products are transported by road haulage. The transport of indigenous coking coal from southern Brazil is partly by ship and partly by railway.



Distances

Rail—Belo Horizonte—São Paulo approx **905** km
Rail & Sea- Tubarão--São Paulo 500 km sea 40 km rail
Rail—Usiminas--Vitória 325 km
Rail—Usiminas-- São Paulo 900 km
Rail—Usiminas—Rio de Janeiro 400 km
Rail--Usiminas—Belo Horizonte 120 km
Rail & Sea--Tubarão—Rio de Janeiro 800 km sea 95 km rail

Ports	Low water depth access Channel	Harbour size	
		Width	Depth
Vitória	13 m	330 m	13 m
Rio de Janeiro	12 m	250 m	12 m
Santos	8.5 m	350 m	5-10 m
Angra dos Reis	14 m	430 m	8 m
Imbituba	A.a	350 m	8.5 m

FIGURA 2.2 – FACILIDADES EM TRANSPORTE
FIGURE 2.2 -- TRANSPORT FACILITIES

TABLE 2. 6. - INCREASE IN DEMAND ON TRANSPORT INFRASTRUCTURE 1970 to 1980

Material	Material consumption or production million tonnes per year		Expected increase in demand %
	1970 (1)	1980(2)	
Iron ore	6.5	19.0	192
Coking coal	2.0	9.0	350
Non-coking coal	-	0.1	-
Charcoal	1.4	0.6	(-43)(3)
Purchased scrap	2.0	4.0	100
Ferro-alloys	0.1	0.2	100
Fluxing agents	1.3	5.0	285
Other materials	1.0(4)	2.0(4)	100
Finished products	4.2	14.7	250
Total	18.5	54.6	195

Notes: (1) Extracted from RFFSA report 1970 and other publications

(2) Estimated tonnages - for preliminary indication only

(3) Percentage decrease in demand

(4) Estimated quantities

Railways

The most important railway lines serving the steel industry are the central regional division of Rede Ferroviaria Federal SA (RFFSA) - a state controlled organisation - and the narrow-gauge Vitoria-Minas line owned by CVRD. The central region division handles considerable amounts of raw materials and finished products in one direction and more predominantly coal and oil by-products in the other direction. The central division network has a nominal cargo handling capacity of 18 million tonnes per year. Both rolling stock and track improvements are in hand, and it is stated that by 1974 this capacity should

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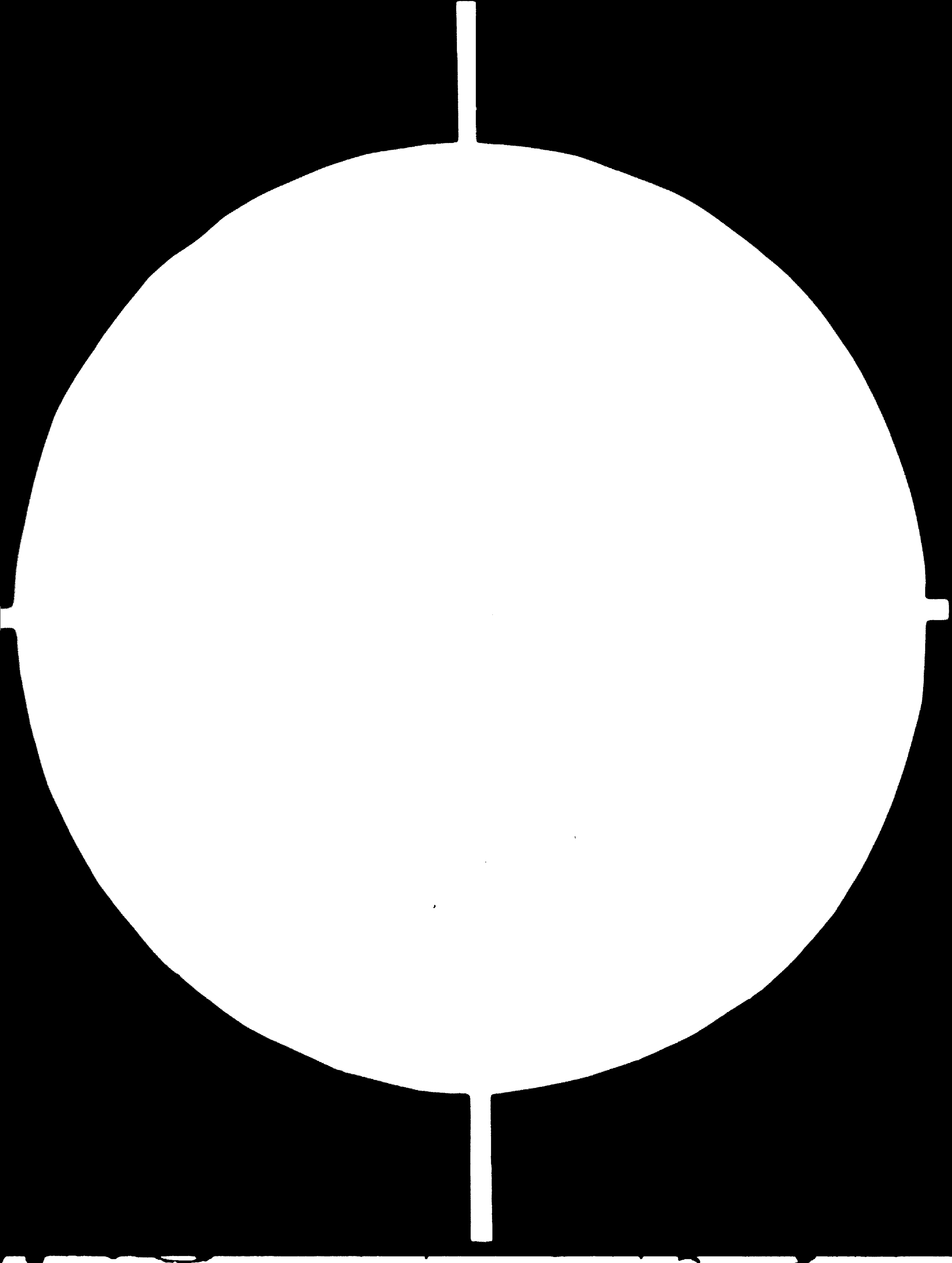

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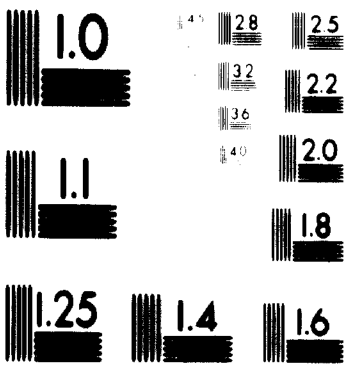

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NATIONAL BUREAU OF STANDARDS
STANDARD REFERENCE MATERIAL 1010a
(ANSI and ISO TEST CHART No 2)

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reach 32 million tonnes. By 1980, the quantities of raw materials and finished products which will have to be transported within the area of this division are estimated to be as follows:

		Million tonnes
Iron ore		8.0
Coking coal		2.0*
Charcoal		small
Purchased scrap		0.5
Ferroalloys		small
Fluxing agents		2.2
Other materials		1.5
Finished products		9.0
TOTAL	approx.	23.0

* Mainly from ports to steelworks

In addition to the above 23 million tonnes, it is reported that this division will handle about 24 million tonnes of iron ore for export. Thus, excluding the facilities required by other industries, the total tonnage of cargo will amount to more than 47 million tonnes. Even if one allows for the fact that not all the cargo is moved in one direction, the requirement is far in excess of the 1974 nominal capacity of the division network. It is clear, therefore, that an investment will be required to provide adequate facilities to service the demands of the expanded iron ore and steel industries. RFFSA has a projected investment programme up to 1980. In this programme, allocations have been provided to match the requirements of the expanded steel industry. The significance of these allocations in terms of total requirements needs to be carefully scrutinised and attention must be given to ensuring that the resource allocations and investment programmes of the state-controlled railway organisation can take full account of the expansion of the steel industry, through joint discussion.

At the present time the railway freight cost is high, but this is believed to be due to the low traffic density; the situation is likely to change in the foreseeable future, although it should be remembered that because of difficult topographical conditions, the freight cost may not always be comparable with railways operating elsewhere.

The Vitoria-Minas line is mainly used for transportation of iron ore for export, but it also handles steel products from Usiminas to Vitoria and coking coals from Vitoria to the steelworks. At present this is the only rail link with the Usiminas works, which is thus without a direct rail link with the markets in Rio de Janeiro and Sao Paulo. This Vitoria-Minas line is believed to have the highest traffic density in Brazil.

Roads

The importance of the road network - particularly in the Sao Paulo, Rio de Janeiro and Minas Gerais regions - is that the bulk of finished products from the steel industry is delivered by road to consumers. The road haulage freight cost is competitive with that of railways and it is for this reason, coupled with a greater degree of flexibility of operation, that the industry is able to use the road system to such an extent.

The road network within the regional triangle now extends to about 410,000 kilometres, of which only about 7 percent is asphalted. By 1975 it is reported that a further 5,000 kilometres of asphalted roadway will be built.

With a substantial increase in national industrialisation by 1980, the road haulage system will undoubtedly play a dominant role. Although the steel industry will continue to use road haulage to move finished products to consumers, it is likely that the proportion of the total tonnage which will have to be moved by road in 1980 might be reduced. Obviously, this will largely be dictated by the services offered and freight costs charged by the railways.

Port facilities

There are several ports situated along the coastline of Brazil with sufficient depth of water to be of service to the steel industry.

Port Vitoria is used for importing coal and exporting iron ore and finished steel products. Recently a new port has been built at Tubarao, close to Vitoria, with facilities primarily provided for large-scale iron ore export. Angra dos Reis and Rio de Janeiro are used for importing coal; Rio de Janeiro port also has a specialised iron ore loading terminal and there is a new ore terminal being built at Angra dos Reis. At Santos coal from southern Brazil and overseas, and indigenous iron ore are received, the latter being discharged at Cosipa works which is joined to the port by a canal. Imbituba is used for shipping Brazilian coal.

Development programmes to provide improved facilities at some of these installations have been considered. It is reported that by 1974 approximately $100 million will be invested in these ports and other installations situated at Parangua, Recife, Belem and Itaqui.

CHAPTER 3 - EVALUATION OF THE EXISTING IRONMAKING FACILITIES

The characteristics of existing and planned plant in the Brazilian iron and steel industry, the operating practice and performance of these plants, and the possibilities for short-term improvements are all examined in this and subsequent chapters. Each process area is dealt with in turn, divided between the chapters as follows: cokemaking, sintering and ironmaking in this chapter; hot metal and cold metal steelmaking in Chapter 4; casting, rolling, finishing processes and special processes in Chapter 5.

The plant items have been classified by size and age, and any interlinking of items within a process area has been noted. The information on plant, and more particularly on practice and performance was supplied to us by the individual works; while it has been subjected to critical examination, it is clearly not possible for us to vouch for the accuracy of the data on the basis of the limited visits made to works in Brazil. Moreover, the necessary information was not available from all works — the number of plants from which data was available is noted in the various tables.

The variations in performance across the Brazilian steel industry are considerable; in some cases, there is scope for a general improvement in the performance of the whole industry, while in others, there are opportunities for improvement in specific companies. It should be understood that the information given below on plant performance refers to the industry as it was in 1969 — in many cases, companies may thus already be implementing the recommendations we have made for short-term improvements.

The information received also indicates that the industry is operating on two levels — those works which compare well with good average world practice, and those works operating noticeably below this level.

3.1 Cokemaking

Nearly all metallurgical coke for blast furnace ironmaking is produced by modern slot-type coke oven installations. There is, however, one small cokemaking plant using 'beehive' ovens for the production of blast furnace coke. The number of slot-type coke oven battery installations is indicated in Table 3.1 - including those which are part of the current development programme.

TABLE 3.1 - SLOT-TYPE COKE OVEN BATTERY INSTALLATIONS
(number of installations)

Annual battery capacity of coke - thousand tonnes	Year of commissioning				Total (1975)
	Before 1940	1940/ 1955	1955/ 1970	1970/ 1975	
200 - 300	-	-	5	-	5
300 - 400	-	2	-	-	2
400 - 500	-	-	-	3	3
500 - 600	-	-	-	-	-
600 - 700	-	-	-	-	-
700 - 800	-	-	-	-	-
Total	-	2	5	3	10

Three new coke oven batteries - one at each of the flat products works - are being installed as part of the expansion projects. Two of these installations will have 6 metre high ovens, whereas the third battery will be equipped with the traditional ovens of 4 metres height. The existing ovens, all with similar basic dimensions, are all abont 4 metres high. It is envisaged that the small producing units such as the 'beehive' ovens may be closed when the new oven batteries come into operation.

The coke is currently produced from a blend of imported and domestic metallurgical coals, the latter making up 20 to 30 percent of the mix. The domestic coals are of poor quality, as discussed in Chapter 2 Article 2.2. However, present indications are that approximately the same tonnages of domestic coal will be available for cokemaking in the future, so that it will contribute a progressively lower proportion to the blend as the total production increases.

The performance of the existing cokemaking plants has been assessed on the basis of coke production per unit volume of oven per day. All the plants in operation are essentially of the same design. Calculations of output from the information available indicate that the three plants operate within the range of 0.7 to 0.8 tonnes per cubic metre per day which indicates a uniform level of performance throughout the industry. It also compares favourably with the world's leading cokemakers, who achieve an output rating between 0.9 and 1 tonne per cubic metre per day. (See Appendix 1).

Possibilities for short-term improvements

Since the coke outputs are already at a reasonable level, the main opportunity for short-term improvement in cokemaking lies in reducing the production costs. This in turn means reducing the cost of coal, which accounts for nearly 100 percent of the total cokemaking costs. It can be done by using a certain proportion of non-coking coal in the coal blend by selective preparation, which has been discussed fully in Chapter 8. In the world at large, proportions of up to 40 or 50 percent of non-coking coal have been used, and we recommend careful investigation into the maximum proportions possible in Brazilian conditions.

If the price differential between non-coking and coaking coals is approximately $5 per tonne, the use of a proportion of 50 percent non-coking coal in the blend would result in a saving of approximately 10 percent in the cost of coke.

3.2 Sintering

Sintering of iron ore is carried out by continuous strand or semi-continuous Greenawalt type machines. The characteristics of existing sinter plant installations, together with the plants which are planned for the current development programme, are recorded in Table 3.2.

TABLE 3.2 - SINTER PLANT INSTALLATIONS
(Number of installations)

Annual capacity of finished sinter thousand tonnes	Year of commissioning				Total
	Before 1940	1940/ 1955	1955/ 1970	1970/ 1975	
CONTINUOUS					
700 - 900	-	-	2	-	2
900 - 1100	-	-	1	1	2
1100 - 2000	-	-	-	-	-
2000 - 2500	-	-	-	3	3
SEMI CONTINUOUS					
50 - 100	-	1	-	-	1
100 - 150	-	-	2	-	2
200 - 250	-	1	-	-	1
TOTAL	-	2	5	4	11

The continuous sinter plants which are in operation at the flat products works, are all of modern design. The plants proposed in the expansion plans of these works will have larger capacities.

Semi-continuous sinter plants are in operation at the non-flat products works. Expansion of some of these installations is also envisaged in the development programme. Semi-continuous sinter production has certain limitations incompatible with modern steel plant operations, but it is expected that these installations will stay in effective operation producing charcoal sinter as long as the present coke procurement policy remains unaltered.

The sintering plants use coke breeze in the continuous plants and charcoal fines in the semi-continuous installations. It has been indicated that some plants currently using semi-continuous machines will, following their expansion, change to continuous machines. This will mean that some continuous machines will be operating with charcoal fines because sufficient coke fines will not be available.

The performances of sintering operations have been assessed on the basis of specific output which is defined as production of sinter in tonnes per square metre of grate area per day. Both continuous and semi continuous machines are compared on the same basis.

The range of specific output of the sinter plants is tabulated in Table 3.3.

TABLE 3.3 - SINTER PLANT PERFORMANCE

Type of machine	Number of machines		Output tonnes/m^2/day
	Installed	Analysed	
Continuous	3	2	23 - 36
Semi-continuous	3	3	12 - 27

Possibilities for short-term improvements

The output of one of the continuous machines - 36 tonnes/m^2/day - is the equivalent of world best practice, and thus is exceptionally good. The other machine is working only at an average level of performance. (See Appendix 1). The semi-continuous charcoal based machines have a wide range of output characteristics. It has been stated that the low performance machines operate with an extremely varied sinter burden and do not have raw material sizing and grading facilities. These differences would explain the variation of the production ratio from the best performance on this type of plant, which is good in comparison with world practice.

We recommend that attention is paid to the physical quality of the feed materials. By improving the sizing and mixing of the feed, more consistent sinter will be produced with a consequent reduction in the generation of recirculating fines which will raise output levels. Sinter plant development is discussed in Chapter 7 (Article 7.2.).

3.3 Blast furnace ironmaking

The blast furnace ironmaking operation in Brazil can be divided into two types of practice: coke and charcoal. In 1971, approximately 3.7 million tonnes of pig iron were produced using blast furnaces operating within the Brazilian steel industry.

An inventory of blast furnace ironmaking installations is given in Table 3.4.

TABLE 3.4 - BLAST FURNACE INSTALLATIONS
(Number of installations)

Furnace Hearth Diameter Meters	Year of commissioning				Total (1975)
	Before 1940	1940/ 1955	1955/ 1970	1970/ 1975	
COKE PRACITCE					
Below 7.0m	-	-	1	-	1
7.0m - 9.0m	-	2	3	-	5
9.0m - 10.0m	-	-	-	-	-
10.0m - 12.5m	-	-	-	3	3
CHARCOAL PRACTICE					
Below 2.0m	3	-	3	-	6
2.0m - 3.0m	-	7	-	1	8
3.0m - 4.0m	-	1	2	-	3
4.0m - 5.0m	-	4	1	-	5
TOTAL	3	14	10	4	31

Note: All furnaces have been included at original start-up date. Major rebuilds have not been included. Only furnaces in the 47 plants listed in Table 1.1 are included.

Nearly two-thirds of total pig iron production was obtained from coke based furnaces and the rest from charcoal furnaces. After the completion of the present development programme, the blast furnace ironmaking pattern will change significantly, reducing the proportion of charcoal iron from 32 percent to 13 percent. This changing pattern of iron production is shown in Table 3.5.

The coke based blast furnaces have the larger diameters and are in operation at the flat products works. They were the economic size of furnace at the time they were installed - many of them before 1955 - but they are now small by the standard of modern installations. However, the three new furnaces being installed for the expansion of the three flat products works will be large furnaces of between 10 and 12.5 metres diameter.

The charcoal based furnaces have, as usual, smaller hearth diameters. Recently only one charcoal blast furnace has been installed at a new integrated works and proposals for building any more are not being put forward although some of the very small diameter charcoal furnaces operating in the country may be rebuilt to larger hearth diameters.

TABLE 3.5 - IRON PRODUCTION PATTERN

Basic reductant	Output of pig iron			
	1971 production [1]		Blast furnace ironmaking capacity on completion of present development programme [2]	
	million tonnes	%	million tonnes	%
Coke	2.5	68	9.6	87
Charcoal	1.2	32	1.4	13
Total	3.7	100	11.0	100

1. Estimated from IBS quarterly statistical information

2. Blast furnace capacity only. Actual iron make will be lower owing to limited sinter plant and/or cokemaking capacity.

Operating practice

The blast furnace operations are based upon the use of high grade indigenous lump ore and sintered fines. The use of sintered fines in the blast furnace burden will increase due to the physical characteristics of the indigenous ore which is friable and breaks down within the blast furnace. In the expansion plans of the large integrated works additional sintering plants have been included to ensure adequate production facilities. In future a proportion of oxide pellets will also be included when the pellet making facilities in Brazil are expanded sufficiently to supply the domestic as well as the export market.

The performance of blast furnace ironmaking installations is shown in Table 3.6. In the presentation, criteria such as the blast furnace output index, the output rating and the corrected fuel rate (coke or charcoal as appropriate) to produce one tonne of liquid pig iron are used; these are defined in Appendix 1.

The blast furnaces operating on coke have an output index range of 44 - 58, which is accounted for by the differing characteristics of the lump ore and sinter feedstock being used. Both the output index range and the output ratings are lower than good world practice levels, which are respectively over 100 for the output index and 2.5 tonnes of hot metal per cubic metre per day for the output rating.

The range of coke usage indicates a deviation of approximately 10 percent up or down and this is again accounted for by the variations in raw materials and

TABLE 3.6 - IRONMAKING PLANT PERFORMANCE

Blast furnace Hearth diameter	Number of furnaces		Blast furnace output index (BOI)	Output rating tonnes hot metal/m^3 day	Corrected fuel rate kg/tonne hot metal	Coke/Charcoal rate kg/tonne hot metal
	Installed	Analysed				
COKE PRACTICE						
7.00 to 8.0m	5	5	44 - 58 (51)	1.0-1.4 (1.17)	635 - 701 (655)	460-635 (538)
CHARCOAL PRACTICE						
Below 3.0m	13	9	19 - 38 (29)	0.35	634 - 960 (845)	630-960 (778)
Above 3.0m	9	8	13 - 35 (17)	0.53-1.1 (0.9)	686 - 843 (746)	642 - 843 (752)

Note: 1. Only charcoal blast furnaces at plants included in Table 1.1 have been included.

2. Figures in brackets (....) are averages.

operating conditions. The coke rates are higher than the world standard of about 450 kg per tonne of hot metal for furnaces operating with a fuel oil injection rate of approximately 60 kg per tonne of hot metal.

The charcoal furnaces have been divided into two sections - above and below 3.0 metre hearth diameter. In both cases, the output index of the various furnaces are widely different and the charcoal usage figures also cover a wide range. It is considered that these wide differences can be attributed to the varying physical properties of raw materials used, the works facilities available for raw material preparation, the method of operation and management.

A modern charcoal furnace is expected to operate at a charcoal rate of 525 kg/tonne of hot metal with a fuel oil injection rate of 40 kg/tonne, charcoal injection of 60 kg/tonne and output rating of 1.6 tonnes/m^3/day. It can be seen that the performance recorded in Table 3.6 does not meet these standards.

Possibilities for short term improvements

(a) Coke practice furnaces

We recommend that some action should be taken to improve the output index and output rating of the blast furnaces tabled above. This should include an attempt to improve burden preparation by such means as:-

(i) Remove fine materials of less than 10mm from the burden by providing adequate screening facilities prior to the furnace charging.

(ii) Carry out metallurgical tests to determine the optimum particle size of the burden materials, and apply the results.

(iii) Consider using 100 percent sinter burden.

Burden preparation has been discussed in Chapter 7 with respect to iron ore. Its importance to the blast furnace operation (which is discussed in Chapter 10) is that the efficiency of furnace operation is related to the particle size distribution of the burden materials. Improvements in burden preparation must therefore be made to achieve full benefit from operational improvement techniques. An immediate increase of furnace productivity of 10-15 percent can be expected from an operation using prepared burden over that using unprepared burden under the same operating conditions.

Consideration of an all-sinter practice is recommended because the nature of some Brazilian ores results in an accumulation of fines during the handling of the burden prior to charging, and during the metallurgical operation. The adoption of all-sinter practice will lead to consideration of the use of self-fluxing or super basic sinter. The precise burden composition offering the greatest improvement can only be determined by specific trials in each case. The merits and demerits of self-fluxing and superfluxed burdens are discussed in Chapter 7.

It is also important that some reduction in the coke rate should be achieved. If the average coke rate of 538 kg shown in Table 3.6 could be reduced to 475 kg, the saving of more than 60 kg per tonne of hot metal would effect a reduction of approximately 5 percent in the cost of iron. It should be possible to reduce the coke rate by such means as:-

(i) Using direct fuel oil injection, particularly since Brazilian fuel oil has a very low sulphur content. A rate of 60 kg per tonne of hot metal should be attempted, although it may not be possible to achieve this in every case.

(ii) Making provisions for the use of an oxygen enriched blast.

(iii) Using higher blast temperatures and top pressures.

These techniques have been discussed in greater depth in Chapter 10.

On the basis of the information available to us, we believe that injection of 50 kg of fuel oil per tonne of hot metal and a blast temperature of 1050°C will be attainable levels in most cases. Any improvements beyond these levels must be investigated with respect to the facilities available as they may require major plant modifications and also the use of oxygen injection. We cannot, without further detailed study, indicate the balance between oil injection and oxygen enrichment, or the top pressures which might be attainable in specific cases. It is our opinion, however, that application of these techniques after study could raise the average output index of the coke based blast furnaces to over 70, with the larger and recently rebuilt furnaces attaining an index of 80 or more.

(b) Charcoal practice furnaces

The output index of the charcoal practice furnaces is also low and some improvements can again be expected by improving the composition and sizing of the burden. Charcoal consumption rates are high and this could be reduced by fuel injection and charcoal fines injection.

3.4. Other ironmaking processes

At present electric smelting furnaces are in operation at the steelworks of Mannesmann and Acesita, where these furnaces are in use in conjunction with charcoal blast furnaces. In 1971, about 0.15 million tonnes of pig iron was produced from these furnaces.

There are two electric smelting furnaces at Mannesmann; each has an electrical rating of about 17 MVA. These furnaces have been operating since 1956. The existing 17 MVA furnace at Acesita was installed in 1963. At this works a second smaller furnace with a rating of 4,000 kVA is now being erected. It is intended that this smaller furnace will be used for the production of ferro-alloys. No further increase in this type of production is envisaged.

The two electric ironmaking furnace installations work under considerably different conditions in that one unit operates intermittently due to a mixed programme and inadequate power supply and the other unit operates as a regular production plant. An examination of the power consumption figure for the continuously operating furnace indicates that it operates on an acceptable power consumption basis of 2,100 kWh per tonne. The other furnace operates at a power consumption figure of about 20 percent above the larger unit.

Two direct reduction ironmaking plants based upon the SL-RN and HyL processes are at present in the course of erection. The industry as a whole will be scrutinizing the operations of these two plants, particularly the operation of the SL/RN plant using indigenous coals, to determine the future role of this process in Brazil.

Direct reduction

Two direct reduction plants are under construction during 1971 and should be commissioned by 1973. The details of these are as follows:

Company	Type of Equipment	Rated annual output of sponge iron
Piratini	SL/RN	65,000 tonnes
Usiba	HyL	260,000 tonnes (at 86% Fe, equal to 220,000 tonnes Fe)

The industry as a whole will be scrutinising the operations of these two plants, particularly the operation of the SL/RN plant using indigenous coals, to determine the future role of this process in Brazil. (Cf. Chapter 11).

CHAPTER 4 - EVALUATION OF THE EXISTING STEELMAKING PLANT

4.1 Plant characteristics

The steelmaking processes employed in Brazil are open-hearth, BOF, and one small Bessemer converter. In 1971 approximately 6.0 million ingot tonnes were produced. Nearly all of this tonnage was produced by open hearth, BOF and electric arc installations, with only a nominal amount from the Bessemer plant which it is understood will cease production by 1972. After the completion of the present development programme, the steelmaking production pattern will change significantly, as indicated in Table 4.1.

TABLE 4.1 - STEEL PRODUCTION PATTERN

Steelmaking process	Tonnage and percentage			
	1971 Production		Capacity on completion of present development programme	
	million tonnes	%	million tonnes	%
Bessemer	0.1	1	-	-
Open-hearth	2.4	40	1.0	9
BOF	2.2	37	7.2	67
Electric Arc	1.3	22	2.6	24
Total	6.0	100	10.8	100

An inventory of steelmaking installations is given in Table 4.2.

TABLE 4.2 - STEELMAKING FURNACE INSTALLATIONS
(number of installations)

Type of furnace and rated furnace capacity Tonnes	Year of Commissioning				Total
	Before 1940	1940/1955	1955/1970	1970/1975	
BESSEMER					
40 - 60	-	1	-	-	1
Total	-	1	-	-	1
OPEN HEARTH					
Less than 20	4	-	-	-	4
20 - 40	5	3	5	-	13
40 - 60	-	7	4	2	13
200	-	8	-	-	8
Total	9	18	9	2	38
BOF					
Less than 20	-	-	2	-	2
20 - 40	-	-	2	1	3
40 - 60	-	-	-	-	-
60 - 80	-	-	4	-	4
80 - 100	-	-	-	4	4
100 - 200	-	-	-	4	4
Total	-	-	8	9	17
ELECTRIC ARC					
Less than 5	-	5	6	-	11
5 - 10	1	8	6	-	15
10 - 20	-	7	10	1	18
20 - 40	-	3	8	2	13
40 - 60	-	-	4	3	7
Total	1	23	34	6	64

It can be seen there are a large number of open-hearth furnaces, which are working in both integrated and semi-integrated works. The open-hearth shop of CSN is being replaced by a BOF steelmaking shop and will close completely as soon as the new shop has reached a satisfactory production level. Their use in other integrated works will probably cease once new BOF steelmaking facilities are installed. The use of open-hearth furnaces in smaller semi-integrated works is different in that they will most probably be economic to operate for some time to come. Some of the more modern installations may be able to benefit from new developments in oxygen injection, discussed in Chapter 12.

The development of electric arc furnace practice has followed world developments, and the only changes expected to the existing situation would be the repowering or rebuilding of the older and smaller units. The last remaining Bessemer furnace is part of a Duplex operation, which is suitable to the current circumstances, but will in due course be replaced by a BOF installation. In general, the existing plant - including many of the BOF furnaces - was commissioned some years ago and is therefore small in size and does not have the benefits of scale associated with a modern BOF furnace.

4.2 Operating practice

The hot metal processes are predominantly open-hearth and BOF, although much of the non-flat production is from scrap based electric arc furnaces. Open-hearth and electric arc furnaces are also operating on all cold charges.

The development plans of the large flat product plants will increase the tonnage of BOF steel considerably, while the closure of the only large open-hearth shop will reduce the open-hearth tonnage. The operations of electric arc furnaces using hot metal will remain dependent upon the availability of scrap.

In the non flat sector of the industry a large proportion of the plants will continue to use both open-hearth and electric furnaces on cold practice, but generally the expansions in this sector propose the use of electric arc furnaces. The open-hearth shops will continue to operate with varying scrap to pig iron ratios. There will be two electric arc shops using directly reduced sponge iron as a cold feedstock, when the SL/RN plant of AFP and the HyL plant of USIBA come into production.

Basic oxygen steelmaking (BOF)

In the BOF installations of the flat products sector, the process being used is in line with normal plant operations using approximately 20 percent of the metallic charge as scrap. In the smaller installations for non-flat production, there are certain variations to suit the local conditions; scrap proportions as low as 10 percent and as high as 40 percent are used in particular cases as expedients to meet these conditions.

The performances of the various BOF steelmaking operations at present in operation are shown in Table 4.3. The comparison has been made on the basis of output in tonnes per hour, tap to tap times, and consumption of oxygen per tonne. (See Appendix 1).

TABLE 4.3 - BOF STEELMAKING PERFORMANCE

Nominal capacity of vessel	Number of furnaces		Output in tonnes per hour	Tap/tap time (minutes)	Oxygen: normal cubic metres per tonne
	Installed	Analysed			
13.5 t	2	-	-	-	-
25 t	2	2	26.3 - gross	57.0	70.0
40 t	2	2	63.0 - average	42.0	-
70 t	2	2	120.0 - average	35.0	56.0
75 t	2	2	56.0 - minimum	80.0	50.0

The operations of the BOF units appeared to be generally competent, but local shortages of liquid iron and other differences in operating conditions have caused a wide range of heat times - some of the tap to tap times in the table are exceptionally long. One plant is operating at a low level of performance due to hot metal shortage and another is operating with a scrap preheating technique which lengthens the heat time by up to 20 minutes; in each case these are reactions to prevailing conditions. The stated consumption of oxygen also varies considerably, but in the best case compares favourably with world practice; during visits to the plants, oxygen flow-rates and blowing times were discussed and observed to be generally at normal levels. The limited information on refractory consumption indicates an average of 3.75 kg/tonne with an average lining life of approximately 400 heats, which could be better in view of the quality of the dolomite and magnesite refractory materials reported to be available in the country, although it compares well with world good practice. It may be possible to improve the brick quality or the furnace lining techniques used.

The existing plants have every opportunity of working at the high performance levels achieved internationally but to maintain good utilisation of the furnaces it is important to ensure good management practice and the best balance of facilities. Among the many possible steps, the following are typical: check that the materials flow through the plant is satisfactory; ensure adequate supplies of hot metal; ensure adequate supplies of scrap; ensure adequate supplies of oxygen; provide casting facilities capable of receiving the maximum throughput of molten steel; increase the lives of furnace linings by improvements in the qualities of refractory bricks.

Open-hearth steelmaking

The performances of the various open-hearth furnace installations, in terms of gross annual output, expressed as tonnes per hour, are shown in Table 4.4.

TABLE 4.4 - OPEN HEARTH STEELMAKING PERFORMANCE

Furnace nominal capacity tonnes	Number of furnaces		Gross output tonnes per hour
	Installed	Analysed	
Below 20 t	1	1	2.3
20 t-30 t	16	12	1.9 - 5.4 (3.4)
30 t - 40 t	10	10	2.8 - 4.3 (3.9)
*60 t	4	4	4.0
*200 t	8	8	26.8

* Note: the furnaces in the 60 tonne and 200 tonne capacity groups are respectively in single steelmaking shops.

The open hearth furnaces work under greatly varying conditions of hot and cold charge, plant layout and supporting ancillary services, especially scrap charging. The spread of the output figures over the whole range of nominal furnace capacities confirms the effect of these different conditions. All of the furnaces seen during the works visits are oil fired which should give good melting rates but in most cases scrap handling and charging arrangements are inadequate and cause long charging times. The low gross output results together with the low utilisation figures indicate either that furnace major repair times are extensive or that furnaces are deliberately kept in reserve after repairs. There are several instances of open-hearth furnaces being held in reserve as an operating insurance and to balance hot metal and scrap availability.

Electric arc furnace steelmaking

Electric arc furnaces generally operate on conventional cold charge practices, including the use of oxygen, and in one instance the preheating of scrap external to the furnace is practised. The proposed new arc furnaces have high power transformer ratings in accordance with modern plant specifications.

The performance of the various electric arc furnace installations has been shown in Table 4.5. The operating performances have been compared on the basis of gross annual output, expressed as tonnes per hour, and electric consumption as average kWh per tonne.

The performances of the electric arc furnaces which have been included in the table show a spread of results very similar to the open hearth furnaces. In this respect it must be remembered that the steelmaking shops often combine these two processes and they are each affected by the greatly varying conditions of liquid metal and cold scrap charge, plant layout and supporting ancillary services. The power consumption of the furnaces expressed as kWh per tonne must vary according to the furnace charge and type of steel being produced but generally these figures are high in comparison with, for example, the leading

TABLE 4.5 - ELECTRIC ARC STEELMAKING PERFORMANCE

Furnace nominal capacity (tonnes)	Number of furnaces		Gross output tonnes per hour	Power consumption kWh/tonnes
	Installed	Analysed		
up to 2 t	8	2	0.42 - 0.64	780 - 720
3 t - 4 t	7	3	0.24 - 0.68 (0.46)	630 - 850 (-)
4 t - 5 t	nil	-	-	-
6 t - 10 t	17	9	1.57 - 3.28 (2.8)	556 - 727 (638)
10 t - 15 t	10	3	(3.95)	-
16 t - 25 t	3	-	-	-
26 t	1	1	5.06	848
27 t - 34 t	3			
34 t - 44 t	5	4	5.4 - 8.8 (8.0)	572 - 664 (595)

Note: The low number of furnaces analysed is in many instances due to the information being available on a shop basis which could not be separated for the individual furnaces.

US electric arc steelmakers, whose consumption ranges from 400 to 500 kWh/tonne for carbon steel and 500 to 600 kWh/tonne for alloy steel. Some works are suffering from local power shortages which can seriously affect their performance, particularly as they are usually the first industrial companies to be shut down in power cut situations. The scrap is often of low density and poor quality which could affect both power consumption and refractory consumption due to multiple scrap charges during the heat and the resulting physical damage.

Vacuum degassing

Up to 1971 Villares was the only company operating a vacuum degassing plant. This was commissioned in 1968. In the expansion plans for the 1975 production, one other plant has been proposed. The details of installed vacuum degassing plants in 1975 would then be as follows:

Company	Type of Equipment	Heat Size
Villares	ASEA	20 - 30 tonne
Piratini	ASEA/SKF	15 - 40 tonne

Possibilities for short term improvements

The existing BOF plants have every opportunity of working at the high performance levels achieved internationally but to maintain good utilisation of the furnaces it is important to ensure good management practice and the best balance of facilities. Among the many possible steps, we recommend the following: check that the materials flow through the plant is satisfactory; ensure adequate supplies of hot metal; ensure adequate supplies of scrap; ensure adequate supplies of oxygen; provide casting facilities capable of receiving the maximum throughput of molten steel; increase the lives of furnace linings by improvements in the qualities of refractory bricks. Developments in BOF steelmaking are described in Chapter 12.

For both electric arc and open hearth furnaces, it is considered that materials handling problems are the main cause of the output levels, which are low by comparison with world good practice. (See Appendix 1). Improvements again depend on good management, and we recommend that attention be paid to such factors as improved scrap purchasing, sorting and baling procedures; scrap preparation and handling; improved furnace charging procedures. Such measures as these should lead to cuts in tap to tap times and so raise the commercial outputs of the plants. Developments in open-hearth steelmaking have been considered in Chapter 11. Electric arc steelmaking is discussed in Chapter 13.

CHAPTER 5 - EVALUATION OF THE EXISTING CASTING AND ROLLING FACILITIES

5.1 Casting and primary rolling

The casting process predominantly used in Brazilian steelworks is conventional ingot casting, followed by primary rolling, although a large number of smaller steelworks produce small ingots which are suitable for rolling directly on the finished product mills without the need of primary rolling facilities.

Ingot casting procedures can be subdivided into three significant areas. Firstly the large flat products plants have modern conventional equipment for producing and handling ingots; secondly in the non flat sector there are plants using various casting techniques to produce ingots of up to about 4 tonnes which suit the limitations of their primary mill; thirdly there are the plants using uphill casting methods to produce small ingots only, which are fed directly to the mills as billet making feed stock. In addition continuous casting of billets is practised at two works, for the limited production of normal carbon steels.

On completion of the development plans for 1975, the flat products sector will start to produce a large tonnage of continuously cast slabs, and the non flat sector will considerably increase its production of continuously cast billets. The adoption of continuous casting by the special steels manufacturers is unlikely to be considered until their expansions go beyond their present primary mill capabilities. The continuous casting plants proposed by the flat products works are intended either to supplement existing primary rolling facilities which are being fully utilised or to avoid the need for additional expensive primary mill equipment.

The existing and planned continuous casting installations are listed in Table 5.1.

The ingot casting and primary rolling mill facilities which are in operation in the larger plants will almost certainly remain in operation for some years although the additional capacity required for expansion plans will most probably involve the building of continuous casting plants, which would be the modern solution to meet the casting requirements. Some of the small companies producing billet size ingots for rolling directly on the secondary mills are also considering the installation of continuous casting plants to replace their ingot casting procedures; this is a trend which is likely to develop. (Cf. Chapters 15 and 16).

TABLE 5.1. - CONTINUOUS CASTING PLANTS

Company	Number of machines	Number of strands per machine	Heat size (tonnes)	Product (mm)
EXISTING				
Non flat products				
Riograndense	2	2	15	120 x 120
Dedini	1	3	40	125 x 125
PROJECTED				
Flat products				
CSN	1	2	200 (960,000 t/y)	150 x 1260 150 x 1055 150 x 850 150 x 790
Usiminas	2	2	150 (600,000 t/y)	160 x 910 250 x 1750
Pains	1	2	25	80 x 80 120 x 120
Cofavi	1	2	15	80 x 80
Usiba	1	6	120	80 x 80 160 x 160
Cosipa	Planned for 1975 - 1980			

For ease of reference, both the primary and secondary rolling mills are listed in Table 5.2 below, which includes existing installations, those under construction and mills planned for 1975.

TABLE 5.2. - ROLLING MILL INSTALLATIONS
(number of installations)

Type of mill	Year of commissioning				Total
	Before 1940	1940/ 1955	1955/ 1970	1970/ 1975	
FLAT PRODUCTS					
Primary mill	-	2	1	-	3
Plate mill	-	2	1	2	5
Hot strip mill	-	2	1	-	3
Cold mill	-	2	1	1	4
Special plate mill	-	1	-	1	2
NON FLAT PRODUCTS					
Primary mill	1	9	14	1	25
Intermediate mill	2	10	15	1	28
Finishing mill	2	12	17	1	32
Continuous mill	-	-	1	3	4
Seamless tube mill	-	1	1	-	2

Note:
1. The original Acesita special steels flat products mill is expected to remain available for individual rollings.
2. Semi-continuous mills are included with the finishing mills.
3. Temper mills and skin pass mills are not included in the Table.
4. The welded tube mill of CSBM (Companhia Siderurgica Belgo Mineira) has not been included. The narrow strip mill of CSBM has stopped operation.

5.2 Secondary rolling

The rolling mill installations have developed in a pattern in which it is common for several types of product to be supplied from each plant. The large flat products mills are of conventional design in the context of small-scale operations in a developing country, all three combining plate and strip production. The plant of CSN also incorporates a medium-heavy section mill.

Since these mills are being used to roll both strip and plate, they suffer the attendant loss of economies due to finishing equipment standing idle. Moreover they are not kept fully occupied, due to lack of steel, and are not therefore operating at their economic load factor.

Over half the flat product mills were commissioned prior to 1955, and no significant changes are envisaged in the intermediate and finishing mill arrangements of this sector.

In the smaller plants of the non-flat product sector primary and intermediate mills provide materials for several separate finishing mills. Seamless tube production is restricted to two plants, although in both plants tubes are not the only mill product. Some of the mills in this sector were commissioned prior to 1940, and many of them were installed with the emphasis on hand operation. There are proposals at works engineering level to rebuild the older, run down and inefficient mills, and the expansion schemes indicated in Table 5.2. include modern continuous and semi-continuous mills which will provide operational advantages as well as close tolerances of final products.

The mill practices used in the various sectors of the industry are considered to be essentially in line with operating practices elsewhere, (See Appendix 1). The mills have generally been supplied by recognised world manufacturers and the layouts of mills, heat treatment facilities, coating lines, and finishing lines closely follow conventional layouts.

Performance of flat product mills

Table 5.3 shows the operational results, in terms of the tonnes of product per hour from the different mill equipment, for the three large flat products mill complexes.

TABLE 5.3. - FLAT PRODUCTS MILL PERFORMANCE

Type of mill	Number of mills		Tonnes per hour
	Installed	Analysed	
Primary mills	3	2	175 - 242
Plate mills	3	2	25 - 80
Hot strip mills	3	2	123 - 180
Continuous cold mill	2	1	90
Semi continuous cold mill	1	1	33

Note: The figures are given as provided by the industry and we were not in a position to check their accuracy.

With the possible exception of the hot strip mills which are similar in design and duty, the figures available for the mill installations are not suitable for direct comparison purposes. In addition to the basic differences of the rolling programmes some slabs are purchased, in one instance due to steel shortage, which prevents a direct rolling balance comparison. However, with the exception of CSN, the flat products mills are generally working at capacities and utilisations well below design; this situation should alter when the expansion projects are completed and the mill complexes come into more balanced operation.

Performance of non-flat products rolling mills

The various types of mill in the non flat sector have been arranged into similar groups and the operations compared on the basis of gross tonnes of product per hour. The results are shown in Table 5.4.

TABLE 5.4. - NON FLAT PRODUCTS MILLS PERFORMANCE

Type of mill	Number of mills		Gross output
	Installed	Analysed	
Primary mills	41	1 5	71 10 - 28 (-)
Medium heavy section mill	1	1	50
General mill complexes Below 25,000 t	7	7	3.6 - 7.3 (5.5)
25.000 - 100.000 t	14	11	5.66 - 15.0 (8.7)
Above 100.000 t	9	3	20.7 - 22.6 (21.4)

Note: Only a small number of Primary Mills were analysed because it was not possible to separate the performance from the overall mill operations. The figures used are those given by the industry, and we are not in a position to check their accuracy. Figures in brackets (...) are group averages.

The mills in the general non flat area operate with widely different product rolling programmes. The grouping of annual tonnages tends to bring the mill complexes into approximately similar product mix groups. The mills of capacity below 100,000 tonnes per year producing light sections, rod and bar are fairly widely spread in gross output figures which would be expected from the range of of possible product mixes. The ranges of production also reflect the pattern of utilisation of equipment and manpower from which the indication is that many of these mills work at close to full capacity. Some mills are working with purchased semi-finished materials due to a shortage of steelmaking capacity at the plant.

It is not possible to comment on the mill outputs without referring to details of the mill construction and layout and attempting to rationalise product mixes. Mill yields from ingot or billet to finished materials are also widely variable which again is due to product mix and methods of operation.

Possibilities for short-term improvements

There are always opportunities to extend mill capacities by minor investments in such items as shears, cooling beds and reheating furnaces; by rationalisation and simplification of the product mix from any one mill; and by planned maintenance. The exact remedy, however, is unique to each mill, and it is not possible to comment on the entire range of possible mill improvements; we recommend that specialists in mill layout should be consulted for each case. (Cf. Chapter 17 and 18).

5.3 Tubemaking

There are two seamless tube mills now in operation. The smaller of the two was installed in the period 1940 - 1955 and the larger was commissioned between 1955 - 1970. The processes utilised are extrusion for up to 100 mm diameter tubes and rolling up to 275 mm diameter. Only the larger of the two works is fully equipped with finishing end equipment suitable for the production of all types and specifications of tubes as well as fabricating facilities for some tubular products. (Cf. Chapter 19). It should be noted that these plants manufacture other products in addition to tubes.

Because of the difficulty of obtaining comprehensive information about the large number of small plants contributing to the total production of welded tubes, we have been forced to exclude these from detailed consideration. Of the larger operations, however, it is reported that the welded tube mill of CSBM (Companhia Siderurgica Belgo-Mineira) will be closed down in the near future, while a new welded tube mill is under construction at Mannesmann.

5.4 Coating processes

The continuous coating lines of the CSN works are the only coating plants for flat products installed in Brazil. At the present time two electrolytic tinning lines and two hot dip galvanising lines are in operation, but two additional electrolytic tinning lines and a continuous galvanising line are included in the development plan for the period up to 1975. The new coating plants will include all the necessary modern ancillary equipment and some modifications are being made to the existing lines to increase production and efficiency. (Cf. Chapter 20).

5.5 Finished products

Within the broad categories of flat and non-flat products, the various items have certain generally applicable dimensional ranges which are shown in Tables 5.5 and 5.6.

Dimensional limitations

Although the industry is capable of providing the vast majority of the range of products required by the consumers, there are certain dimensional limitations.

With regard to flat products, the main dimensional constraints are width. Plates are at present limited by the maximum mill size of 2.7m, but the installation by 1975 of the plate mills at Cosipa and Usiminas will increase the mill size to 4.0m.

In the non flat sector of the industry, dimensional limitations do not appear to

TABLE 5.5. - FLAT PRODUCT RANGE

Type of mill	Dimensional Range	
PRIMARY MILLS	**Slabs**	1.2 - 1.65 m maximum width 200 - 400 mm thickness 5.50 - 7.0 m length
PLATE MILLS	**Plates**	1.2m, 1.6m and 2.7m width 6.00mm to 78.0mm thick 10.6m to 12.5m maximum length
HOT STRIP MILLS	Hot Rolled Strip	1220, 1600 and 1829mm max. widths 1.52mm to 9.5mm thickness 12 t, 13t, and 10 t maximum weight
COLD STRIP MILLS	Cold Rolled Strip	1310 and 1660 maximum widths 0.30/0.38 to 2.66mm thickness 18 t and 21 t coil weight max.

TABLE 5.6. - NON FLAT PRODUCT RANGE

Type of mill	Dimensional range
PRIMARY MILL	
Billets	Up to 150 x 150 mm square - common size
Blooms	220 x 220 mm square 180 x 300 mm.
SECTION MILLS	
CSN	Rails TR25, -TR57, 24.7 - 56.9 Kg/M 100 x 100 mm - 150 x 150 mm Universal sections 90 x 40 - 380 x 85 mm Channel 75 x 60 - 510 x 175 mm Joist 65 x 65 - 200 x 200 mm Angles
OTHERS	Sections up to 125 mm maximum dimension Flats 3 mm to 25 mm thick up to 100 mm wide Squares up to 125mm Bars up to 150mm dia Angles up to 100mm maximum dimension Reinforcing bar up to 37.5 mm diameter Wire rod down to 5 gauge (5.5 mm diameter)
TUBES	Up to 150mm and 250 mm diameter Maximum length 6.0m
WIRE	0.2mm to 4.8mm diameter

introduce any serious constraints. At the present time the industry is capable of producing medium sections up to 500mm from the mill of CSN. However, should the demand for larger dimension structural steel sections increase it would be necessary to consider additional production facilities either in the form of new rolling mills or welded fabrication shops.

Steel quality limitations

The manufacturing facilities available by 1975 will be capable of producing virtually all qualities of steel. In addition, many of the companies in the industry have technical know-how agreements covering all aspects of steel qualities, with internationally reputable steelmakers such as United States Steel, Crucible Steel, "Bofors," Nippon and SKF.

As the industry has the necessary plant and equipment and the access to technical process expertise, steel quality should not be a long term constraint on the industry.

Products beyond plant capability

Table 5.7 shows the actual tonnage for 1969 and the estimated tonnages for 1975 of those materials which must be imported because there is no facility for producing them in Brazil. The figures in Table 5.7 have been extracted from the total import statistics, but in many cases the official classification does not permit an exact definition of product or tonnage. Only products of which more than 100 tonnes per year are imported have been shown. It is considered that all the products in the table will continue to be imported in 1975, with the exception of the wide cold rolled strip. The 1975 tonnage estimates have been calculated by assuming the same growth as for the general internal steel demand, this being 11 percent per year compound increase on the 1969 import figures.

It should be noted that the total steel imports in 1969 are recorded at approximately 500, 000 tonnes. In principle,the industry had the ability to manufacture all but the products in Table 5.7 which total only 100, 000 tonnes. The other imports can be explained in terms of price, quality, delivery, order size, government policies and trading agreements.

The 1969 tonnages do not warrant immediate major capital investment in any one product. These imports are however, a reflection of the fact that the Brazilian industry lacks the following plants:

- a modern stainless steel strip plant
- a facility for grain-oriented transformer sheet
- a narrow hot and cold strip facility, say 600 mm, primarily for special qualities.
- a heavy structural mill, preferably a modern Universal beam and section mill, capable of rolling universals up to 600 mm.
- a skelp or narrow hot strip plant up to, say, 300mm
- a high precision rod mill for alloy steels.

The implications of these shortcomings on the longer term planning for the industry are considered in Section C; and appropriate recommendations are made.

Product tolerances and the effect on plant items

Customer requirements tend increasingly to demand greater tonnages of finished products within close tolerances. The total number of rolling mill installations can be subdivided into broad categories to give an indication of the tolerance of the finished product.

The groups listed in Table 5.8. below are essentially based upon product types,

TABLE 5.7 - PRODUCTS BEYOND PLANT CAPABILITY

(tonnes)

Product definition and quality	Tonnage imported 1969	Expected tonnage to be imported 1975
SEMI FINISHED		
Alloy Steels	400	750
FLAT PRODUCTS		
Alloy steel plates	570	1.070
CR Sheet and coil above 1.5m width	tonnage not obtainable	28.000
Stainless alloy flats	14.000	nil
Grain oriented sheet and non oriented sheet	12.400	23.200
Other alloys	1.000	1.870
Narrow special steel strip	3.100	5.800
COATED SHEETS		
Out of range tinned sheets	13.200	24.690
Other coatings	2.900	5.420
NON FLAT		
Rock drills	2.000	3.740
Large profiles and piling	13.500	25.250
TUBES		
Special steel	840	1.570
Special steel extruded	730	1.300
Galvanised + 230mm	7.400	13.840
Total excluding CR sheets	72.040	108.500
Total including CR sheets	-	136.500

divided into tolerances by commercial grading, such as automobile materials and reinforcing bars. The number of works in each group is also shown.

TABLE 5.8.- EFFECTIVE PRODUCT GROUPS

Group	Description	Number of Works
1	Flat products	3
2	Tubes	2
3	Special steels - high tolerance	4
4	Non special steels - high tolerance (automobile)	4
5	Non special steels - normal commercial	16
6	Non special steels - low tolerance (re-bars)	14
	Total	43

It is felt that no significant changes will occur in the special product group numbers 1 to 4. The demand for products such as reinforcing bars manufactured in the remaining two groups, representing thirty installations, will remain high, and it is unlikely that any pressure for improving the product tolerances will be imposed on these mills. However, any new mill installations will automatically fall within the high tolerance groups.

CHAPTER 6 - EVALUATION OF WORKS PRACTICE AND PERFORMANCE

Members of Atkins Planning and the two top strategists retained to advise us visited a number of companies - mainly in the Sao Paulo-Belo Horizonte-Rio de Janeiro triangle. This was not a full survey of the industry, and the information obtained is not adequate to form a basis for categorical generalisation about the industry. Nevertheless an assessment of performance in quantitative terms was possible as a result of our analysis.

Discussions with top management and with department heads revealed an awareness in many companies of such opportunities for improvement as have been noted in earlier chapters. Although in several cases active steps have already been taken to implement these, there appear to be other areas of concern to management of which the importance was not always fully appreciated. We have identified four such areas - the performance gap, management information, rationalisation and the role of new manufacturing processes. In the following articles, current works practice and performance in Brazil is discussed in the light of these topics.

6.1 Performance gap

It is to be expected that within an industry which includes three large integrated works, several medium size works and a large number of smaller plants, the performance of these plants will differ considerably. An indication of the rather wide range of performance has been given and discussed in the previous chapters. In this respect Brazil is no different from many industrialised countries. As in these countries, the objectives of management must be to bring the works at present operating at the lower end of the performance range up to the standard of the stronger companies, and the stronger companies up to the standards of good world practice. We have noted that Brazil has some metallurgical problems - principally the poor availability of suitable coking coals - which are special to her own operations. However, these cannot be seen as major problems when compared with those of other countries which make steel successfully, and they should not be allowed as reasons for failing to achieve high standards of performance.

The performance gap, or the margin by which the industry fails to achieve its potential in terms of quantity, quality and cost of production, is primarily a function of process yield, use of plant capacity, manpower productivity and quality control; we have also considered the impact of management services, training, and technical support services.

Process yields

The process yields of the various process areas are shown in Table 6.1. The figures have been provided by the various works and it has not been possible to establish whether they have been calculated on a common basis. The range of yields, however, is generally relatively small and the yields follow an expected pattern.

TABLE 6.1 - PROCESS AREA YIELDS

Process area	Number of Works		Material	Product	Process yield percentage
	Installed	Analysed			
Blast furnace ironmaking					
Coke practice	3	3	Fe in ironbearing charge	Hot metal	90 - 92
Steelmaking					
Open hearth		6	(Metallic charge	Liquid steel)	87 - 94
Electric arc	26	9			78 - 95
BOF	5	4			88 - 90
Rolling					
Plate	3	2	Slab	Plate	83 - 85
Hot strip	3	2	Slab	HRC *	96
Cold strip	3	2	HRC *	CRS *	96 - 97
Billet	41	7	Ingot	Billet	85 - 96
Bloom		3	Ingot	Bloom	91 - 96
Rod	28	6	Billet	Rod	88 - 95
Bar		5	Billet	Bar	86 - 94

Note: The above yield figures were provided on the basis of individual works assessments and were not prepared on a common basis. The figures, therefore, cannot be used for direct comparison purposes.

* HRC - hot rolled coil; CRS - cold rolled sheet.

Methods of achieving short term improvements in process yields have been recommended in Chapters 3 to 5, but they may be briefly restated, as follows:-

i)	In ironmaking	- improve burden preparation methods
ii)	In steelmaking	- use more consistent practices to improve casting techniques and surface quality
iii)	In rolling	- simplify the product mix and ensure that roll life is at a maximum.

Use of plant capacity

The effectiveness with which the existing capacity of the industry is being used can be assessed by comparing the present outputs of the various process areas with their theoretical capacities. The information required for this review was obtained from the series of reports for Instituto Brasileiro de Siderurgia which surveyed the industry, and has been summarised in Table 6.2.

TABLE 6.2 - PLANT USE - 1969

Description of plant	Number of plants		Plant use percentage
	Plants installed	Plants analysed	
BLAST FURNACE			
Coke practice	3	3	75 - 157 (122)
Charcoal practice	10	7	47 - 102 (77)
STEELMAKING			
Open hearth	13	8	48 - 104 (81)
BOF	5	5	37 - 158 (87)
Electric arc	26	10	54 - 96 (74)
ROLLING			
Plate	4	4	12 - 83 (46)
Strip Hot	3	2	32 - 55
Strip Cold	3	2	53 - 110
CSN-heavy section	1	1	42
Light section and bar (common)	18	5	41 - 158 (72)
Bar (non common)	13	8	32 - 65 (49)
Rod	27	14	31 - 131 (66)
Tube	2	2	76 - 97 (86)

Note:
1. Plant use is taken as a percentage of the rated total output.
2. Figures given are range of use percentage values and group average.
3. Plate and strip are produced on the same mills.
4. The Usiminas cold strip mill is a reversing mill of lower capacity.

In preparing this table it became clear that the rated capacities from which the use percentages were calculated were, in many instances, the plant manufacturers' ratings; this accounts for the apparent anomaly of plant use percentages exceeding 100. For the purpose of establishing a comparative analysis of use, however, it is only necessary to consider a set of capacities which are based on common parameters.

It can be seen that the range of use for all process areas is very wide, and that on average the industry is operating at a point below the desired level.

The mills are in general operating at a low rating, although this can often be attributed to a lack of feedstock supplies, and it should be remembered that mills are frequently capable - on basic design considerations - of output above the required tonnages. Nevertheless, it seems that the methods of operation and the handling of maintenance and spare parts are contributing significantly to this low level of use.

Similarly, in the steelmaking units, there are a number of conditions such as shortage of hot metal and the special operating practices designed to overcome the shortage of hot metal which, together with general maintenance problems, contribute to low levels of use.

Some plants are operating at rates which give good plant use, but typical performances tend to approach the lower figures and this is, therefore, an area where efforts to improve on current practice would result in substantial improvements overall.

Manpower productivity

Process areas within the works have been analysed to establish the number of staff in each grade - management, skilled and unskilled workers. The process areas have been divided into groups of similar types of operation for the purpose of the analysis. The details are given in Table 6.3.

The accuracy of the division of staff into the grades shown depends upon the interpretation of the individual works management; although the numbers in each group may therefore not be strictly accurate, the area totals should be acceptable for comparison purposes.

The range of the number of employees and the division into various categories show a very wide spread. This is to be expected from the wide difference of operations even within similar groups of plants. Generally, management supervisors account for approximately 10 percent of the staff.

The average figures for skilled and semi-skilled workers tend towards the higher end of the range of numbers normally employed, which indicates a generally low effective use of manpower. This is supported by the analysis of manpower productivity shown in Table 6.4.

In order to investigate the manpower productivity within the industry, we used the criterion of ingot tonnage produced per year per man employed. Information relating to two-thirds of the total list of companies was available and these results have been grouped according to the nature of the works. The details are given in Table 6.4.

TABLE 6.3 - MANPOWER - NUMBERS EMPLOYED

Process groups	Number of plants		Totals	Management supervisors	Skilled workers	Unskilled workers
	Installed	Analysed				
IRONMAKING						
Coke practice	3	1	761	79	382	300
Charcoal practice	13	3	107 - 459 (230)	1 - 37 (13)	7 - 237 (82)	99 - 185 (135)
STEELMAKING						
550.000 t and 800.000 t		2	389 - 505	34 - 44	199 - 268	156 - 193
20.000 t to 150.000 t	35	18	24 - 395 (169)	1 - 53 (7)	3 - 115 (32)	15 - 543 (148)
ROLLING						
Group 1		11	65 - 516 (227)	1 - 24 (5)	2 - 80 (23)	46 - 506 (198)
Group 2	38	3	466 - 913 (635)	24 - 131 (83)	4 - 389 (197)	175 - 497 (355)
Group 3		2	1247 - 1582	91 - 94 (93)	651 - 1229 (693)	259 - 505 (377)

Notes: 1) Rolling mill groups = 1, up to 35.000 t

2,35.000 to 100.000

3. approximately 500.000 t,

2) Figures in brackets are group averages.

TABLE 6.4 - MANPOWER PRODUCTIVITY

Plant description	Number of plants		1969 Average gross output ingot tonnes per man per year	
	Existing	Analysed	Range of output	Average
INTEGRATED				
Flat products	3	3	84-130	101
Non flat products[1]	8	6	29-99	61
Tubes	2	2	38-58	-
SEMI-INTEGRATED				
Common steels	22	13	18-127	51
Special steels	3	3	20-63	29
NON-INTEGRATED[2]				
Common steels	6	3	85-113[3]	95[3]

Note:
1. Non integrated plants are rerollers only.
2. Acesita is included with non-flat products.
3. Ingot equivalent.

The output per man per year of the integrated works producing flat products, ranges from 84.0 to 130.0. This range is larger than expected, and may be due to the fact that two of the works included in this analysis have significant numbers of employees engaged in semi-social activities.

The non-flat integrated plants have a very wide range of outputs per man year. It should be noted that whilst the higher figures can be attributed to economies in scale of productivity, the range indicates that a number of works are not as manpower effective as might be expected.

The two tube works included in the analysis are different in output and product range, and the difference in output figures is to be expected.

The large number of semi-integrated works producing common steel non-flat products have a particularly wide range of values for output per man year. This is also to be expected from the many different product mixes and product levels in this group, but it does seem that labour employment in this sector is too high.

In the special steels sector, the one plant which has recently been built to produce only special steels shows a good economy of labour. The other two works are older and do not specialise to the same extent in special steel finished products.

The non-integrated rerolling plants have a small range of output figures, indicating a close similarity of operation.

Quality control

The industry has largely developed in close collaboration with overseas companies, and its major customers are directly connected with overseas manufacturing organisations. This consumer relationship is particularly noticeable in the automobile industry where, for instance, Volkswagen and Mercedes Benz specify to the DIN standards and General Motors, Ford and Chrysler specify to USA standards. The result is that both European and USA standards systems are being used by the industry.

The use of established and internationally recognised standards has been beneficial in that it has avoided the expenditure of time and effort required to establish a comprehensive national system. In effect the steel companies operate within the standards of their largest customers.

The Brazilian National Standards are at present only in an embryo stage, but the work of producing a comprehensive national standards system is under discussion. A small number of standards for the physical properties of steel products have been drawn up, although they are not universally adhered to.

From a marketing point of view the existing pattern of operations may be satisfactory as long as the scale of operations is small and manufacturers are linked to single or limited numbers of customers. This pattern is bound to change with the growth of industry and the requirement for a comprehensive standards system will become apparent. The system will be essential for marketing and sales operations not only in an expanded Brazilian industry but also in the export markets of Latin America and elsewhere. It is important, however, to use an existing international or foreign national set of standards as the basis and, if necessary, adapt it for Brazilian conditions, rather than to incur the effort of creating a new set of standards.

It is also important to improve the level of quality control achieved during the production process, in order to ensure that the product output meets whatever standards may be set. It must be remembered that quality control is closely interrelated with process yields, and that any attempt to improve one must not be at the expense of the other.

Most companies undertake some degree of quality control on both the metallurgical and physical aspects. However, only a few companies appear to have suitably staffed and equipped departments to carry out these functions, and only in a limited number of works are efforts being made to establish and operate quality control departments. From discussions and visits it has appeared that the quality control functions are not proving fully effective and the industry as a whole is not devoting sufficient of its resources in the way of management, engineers and facilities to this function. Certainly this subject is frequently raised by the consumers, who generally require better standards. While the establishment of a fully integrated control system is essentially a long-term objective, nevertheless, whatever attention is given to quality control will yield some immediate benefits from a marketing and sales point of view.

Management services and training

A broad review of the management and technological services available to the industry has been made. To a certain extent, these services are available in the large integrated works and specialist steel product manufacturers, but there are a large number of works where management services and technical departments are virtually non-existent.

Production scheduling, stock control and planned maintenance are functions of operations research which are given attention in some of the works, but the industry as a whole is not yet employing sufficient staff and personnel to provide these services. This may be due to the lack of suitable personnel and training facilities.

With regard to personnel training, there are schemes to train engineers and operators both "on the job" and overseas, but this is limited to those works which are modern or more technically oriented, and there are a number of works which do not have training schemes, but seem to rely on the larger works for trained and experienced staff. The number of people receiving management training appears to be relatively small, to the extent that they do not seem to have the impact on the industry that it needs.

Technical services

Research and development is at present being undertaken as part of the technical agreements with overseas companies. Development units are being set up and equipped in some of the works, and are undertaking some production and applied development research. Fundamental research is not carried out at the moment and reliance is being placed on the established facilities of the overseas collaborators.

The application of computers, automation and process control techniques is beginning to develop, and the importance of these services is realised by management and operators. Efforts are being made to investigate these technologies in overseas countries by visits and training periods, with a view to increasing their application in the industry.

Recommendations for narrowing the performance gap

In the present state of development of the iron and steel industry throughout the world, the most economic method of closing the performance gap is to obtain the best international engineering and operational (including management) assistance, from companies with established records of success. We did find during our visits and discussions that this was being done, but we found an uneven application across the Industry. In particular, the non-flat sector working in common steels lagged behind the special steel and flat product sectors. Some of the assistance was being obtained in the form of licence agreements and some in the form of specific consulting projects. In the latter case where the consultants were involved directly with production, we felt that management did not always insist on the consultants specifying with an adequate degree of precision the standards of performance which they believed were capable of being met. Neither was there always an indication of the time by which the management of the steel companies should expect to achieve these performances with the plant modifications and staff changes which were suggested.

It must be the aim of all production staff and plant managers to get the best performance out of their existing plant. This is especially true of the immediate future before any major plant improvements and modifications are due to become operative. It should be understood that the assessment of performance of a steel company or industry should be based not only on quantity of production, but also to a great extent on quality. The assessment of quality requires close detailed study beyond the scope of the short time scale of our visit, but we did obtain some evidence of inadequate quality in the flat product sector. While this could be attributed to local reasons, we would make the point that the achievement of good quality should normally precede the expansion of the works to obtain greater outputs. Good quality is often a function of the plant, equipment and facilities available and we would expect that there are some difficult situations causing problems at the present time which modest marginal capital expenditure would be sufficient to overcome. External professional advice can be very effectively used to identify and resolve such problem areas.

In view of the importance of improving performance in the short-term, so that future expansion of the industry will be more soundly based and thus more likely to be successfully implemented, we recommend immediate attention to the various suggestions which have already been made in the preceding chapters.

As has been stated, it is not possible within the scope of this report to do more than indicate the broad areas where improvements could be achieved quite readily. Matters such as attention to burden preparation, improvement in coke rate and achieving consistency in casting practice, will quickly repay the detailed study needed for their implementation.

Where consultants are retained to advise on these matters, they should be required to be specific in their recommendations; this, in turn, means that the consultants must be briefed with clearly defined terms of reference. We recommend also that detailed studies be undertaken to establish appropriate maintenance schedules as a matter of urgency. Shortages of feedstock should also be investigated, although these will tend to become less of a problem as capacities become more nearly balanced under the influence of improved performance, and in the light of the expansion programme.

In general the outputs per man year indicated in Table 6.4 are low, but it is appreciated that they are the natural result of the evolution of the industry and of the relatively unskilled or inexperienced labour. However, the proportion of the total cost per tonne of finished products represented by the labour element is estimated to be between 15 and 20 percent, which is not excessive by world standards.

It would therefore seem that opportunities for reducing operating costs by increasing the productivity of manpower are limited, although the cumulative saving across the industry of even 5 percent of the wages bill would provide a substantial budget for training purposes. By handling this at industry level, there is an opportunity for all companies, both large and small, to benefit. While technical training is naturally acknowledged to be of importance, training of personnel for management functions must not be overlooked and we recommend that it is given similar priority.

During our discussions we have gained the impression that there is a significant gap between the different levels of personnel with respect to training. There is a plentiful supply of semi-skilled and unskilled workers in the country, but it appears that there is a serious shortage of skilled personnel. A further shortage exists at middle management level, which is probably due to a shortage of technical college education in Brazil. A shortage of university trained personnel suitable for the iron and steel industry is also apparent, although the total number of graduates from the universities with engineering training is quite large and the number of graduates of all disciplines is very large. The major recruitment for all management positions in the steel industry appears to come from the few major companies who operate internal and overseas training schemes.

We recommend that urgent action is taken at university level to encourage more graduates and technical college students in the technical and management disciplines to join the steel industry, and so provide more engineers and technicians in the middle grade of responsibility.

Finally, in our consideration of the performance gap we recommend that immediate attention be given to improving inspection procedures and quality control, and that studies should also be put in hand for the establishment of a fully-integrated control system in the longer term, as recommended in Chapter 40.

6.2 Management information

It is axiomatic that the quality of management decisions is dependent upon the quality of the information on which they are based. This is especially true of the steel industry where many complex factors have to be taken into consideration.

It is apparent that management in the Industry recognises that existing information systems are inadequate because external professional advice is already being sought and given to improve them.

We attach great importance to the continuous monitoring of performance because the effort to reduce costs and overmanning and to raise quality must be continuous. Recommendations by consultants and advisers need to be put into effect and the predicted results achieved; this can only be done if the results of improvements are continually measured.

The three major flat product companies are perhaps the most forward in employing external advisers, yet we have noted differences in performance between them that cannot be explained solely in terms of raw materials, processes or location. In making our comparisons and in trying to ascertain the reasons for these differences, we are conscious, as we have stated earlier, that our data may be unreliable; this is one reason for stressing the importance of a systematic method of reporting, and preferably a uniform system of reporting including a uniform method of cost determination and comparison, to be adopted by the Industry generally. A uniform system of reporting provides not only a day to day means of monitoring individual works performance, but provides a basis for inter works comparison. This has advantages at both company and national level. For the individual company it provides a reliable basis for assessing one's competitive position. At national level, it provides the necessary information whereby central agencies such as IBS and CONSIDER can promote the health of the industry and ensure a sound basis for investment.

Recommendation

We recommend, therefore, that the Industry, under the leadership and guidance of CONSIDER, give urgent thought to the development and adoption of uniform systems of performance measurement and reporting.

6.3 Rationalisation

Better understanding of the works operations through an adequate reporting system and improvements in performance will together lead to a rationalisation of works facilities in detail. In this article, we wish to discuss the wider implications of product and process rationalisation which affect the individual company's relationship with the market and with its competitors.

To remain competitive, rationalisation and diversification of the product range have to be kept in balance. On the one hand, rationalisation keeps production and inventory costs low, while diversification enables the company to ride the vicissitudes of the market.

The possibilities for rationalising production in the Brazilian steel industry need to be investigated thoroughly, on the basis of the individual circumstances of the many steel companies; although outside the scope of this study, some consideration has been given to the problem.

The three large works producing flat products are already effectively rationalised to suit market requirements, as they are at present. This does not, however, remove the need for continual reappraisals of the market as it develops.

The production of tubes can be treated in the same way as the flat sector, and does not need further rationalisation at present.

The non-flat products sector should be considered under two headings - special products and common steels. The former are, again, like the flat products sector, well suited to the present market. The common steels sector includes two groups of works which can be distinguished by the quality of their products and product range, as illustrated in Tables 1.5 and 5.8 above.

One group concentrates on the production of rod and, to some extent, bars and is also generally only capable of producing the lower tolerance products. This group we feel will continue in operation until economic and commercial pressures compel them to close or modernise.

The second group of works is more varied in their production abilities, with product ranges of shapes, flats, rods and bars. There are larger companies in this group which have undertaken or planned rationalisation programmes, involving relatively large capital expenditures, which appear logical in the context of the present development plan.

Recommendation

We recommend that the smaller companies in the second group referred to above should consider what opportunities for rationalisation are open to them, in particular:-

i) In steelmaking, they should review the possibility of operating a communal steelplant to feed a group of individual mills.

ii) In marketing, they should consider group arrangements which would permit a rationalisation of mill product mix.

6.4 The role of new manufacturing processes

It is necessary here to distinguish between processes which are new to Brazil and those which are new in a world context. Those new to Brazil can be accepted and assimilated using external know-how and technological assistance as discussed in Article 6.1. Processes which are 'per se' new must be dealt with in a different fashion.

Direct reduction is, perhaps, the outstanding 'new' process at the present time. We have noted that it features in many of the development plans put forward by the non flat product sector. In fact, two plants, incorporating the HyL and SL/RN processes, are currently under construction. As the initials imply, these are proprietary processes subject to licence agreements. Information on the economics and performance is in consequence restricted, so that it is not easy for management trying to compare different processes to form a satisfactory judgement. Also most companies do not possess sufficient resources to carry out an exhaustive evaluation and decisions are thus liable to be made on subjective rather than objective grounds.

Recommendation

We recommend, therefore, that the needs of a company should be assessed by an independent adviser or consultant, and in the event of a 'new' process being proposed, that management should make sure it has full understanding of the amount of development work and expense it may be committed to. Failure to realise this results in conflicts between the process licensor and the user with losses in production and delays in resolving the development troubles. It must always be remembered that pioneering a new process can be expensive and failure may be disastrous; if it is decided to follow this line of development, every precaution should be taken to facilitate the introduction of the new process and to minimise the risk of development problems. The chapter on direct reduction processes, Chapter 11, illustrates the dangers inherent in adopting new processes while they are still only in the development phase.

SECTION B

STUDY, PRESENTATION AND ANALYSIS OF THE MAIN TECHNOLOGICAL ALTERNATIVES OPEN TO THE MODERN IRON AND STEEL INDUSTRY

CHAPTER 7 - IRON ORE PROCESSING

7.1.Trends in iron ore preparation

Iron ore is normally transhipped from mine to steelworks in one of these forms: lump, fines (for sintering) or oxide pellets. The form used is largely dictated by the natural characteristics of the particular ore body, for the reasons given in the following paragraphs. It is therefore appropriate to comment on the changing world pattern in the availability of ore in each form before considering the trends in the methods of burden preparation for the ironmaking process.

The greater part of the world's iron ore resources available for exploitation are in metamorphosed and recrystallised rocks derived from sedimentary origins. The occurrence of these is very widespread but the average grade of schists of this type is less than 30 percent Fe, except under favourable conditions where natural concentration processes have taken place to produce upgraded deposits. In some instances the Fe grade of the ore is as high as the upper sixties. The iron ore available from such a mine is usually lump material. The fines caused by degradation during the winning, sizing and transporting of the ore are usually separated out by screening; alternatively ore may be sold as "run of mine" (ROM) ore.

Where natural processes have not given rise to such high grades, it is modern practice to concentrate the ore prior to ironmaking. Concentration is usually done at the mine, the amount and type of processing being largely dictated by the natural grain size of the ore. Where the grain size is comparatively coarse, the minerals can be liberated and a concentrate made at a particle size appropriate to the sale of the product as sinter fines. Where the grain size is finer, however, the ore must be subjected to more grinding to achieve the desired degree of liberation and the resulting concentrate is too fine for sintering. An extreme example of fine grinding so far reached in the processing of iron ores is the Tilden project in Michigan, USA, where the ore has to be ground to 85 percent minus 25 microns. The only successful method of agglomerating concentrates made in this manner is by pelletizing.

On a world-wide basis the proportions of lump ore, sinter fines and pelletising fines used are dictated both by the characteristics of the natural ore bodies and commercial considerations. During the first half of the twentieth century the average grade of the iron ores mined rose steadily, reaching a peak in the mid-fifties. Since about 1955, however, the trend has reversed and the average grade of ores mined is now falling, though very slowly. On the other hand, ironmaking processes are making use of progressively higher grades of raw material feed. Thus, although the world demand for iron ore is rising, the usage of lump ores remains more or less constant, and consequently the consumption of concentrated and agglomerated ore fines is increasing rapidly. This is illustrated in Figure 7.1, which shows the world production of lump ore, sinter fines and pellets over the period 1950-70 and forecasts the trend to 1980. In Table 7.1, the change in the relative use of lump ore and agglomerated products is also indicated, together with estimates for 1975.

TABLE 7.1. - RELATIVE USE OF PROCESSES OF IRON ORE PREPARATION

(Expressed as a percentage of total iron ore consumed)

	1964	1970	1975 (Estimates)
Lump Ore	47	49	43
Pellets	9	15	24
Sinter	44	36	33

Source: U.N.I.D.O.

There have been other estimates of future trends in the use of iron ore preparation processes, for example a recent forecast (Mineral News, VIII, Issue 5, Sept. 1972) that the consumption of pellets will increase from 115 million tonnes in 1970 (16.3 percent of total iron ore consumption) to 150 million tonnes (18 percent) in 1975, about 240 million tonnes (22 percent) in 1980 and 310 million tonnes (25 percent) in 1985.

Present world production capacity for pellets is approximately 145 million tonnes (Figure 7.2). The USA leads in the production of pellets, with a current capacity of 58.5 million tonnes. Table 7.2. shows the regional distribution of pellet plant capacity.

Regional practice

The world trends in the changing blend of lump ore, sinter fines and pellets supplied to the iron and steel industry is not necessarily reflected in the principal established ironmaking regions because each has developed using different ore resources. For example, the principal importing regions of Western Europe, Japan and the USA show markedly different trends in burden preparation practice.

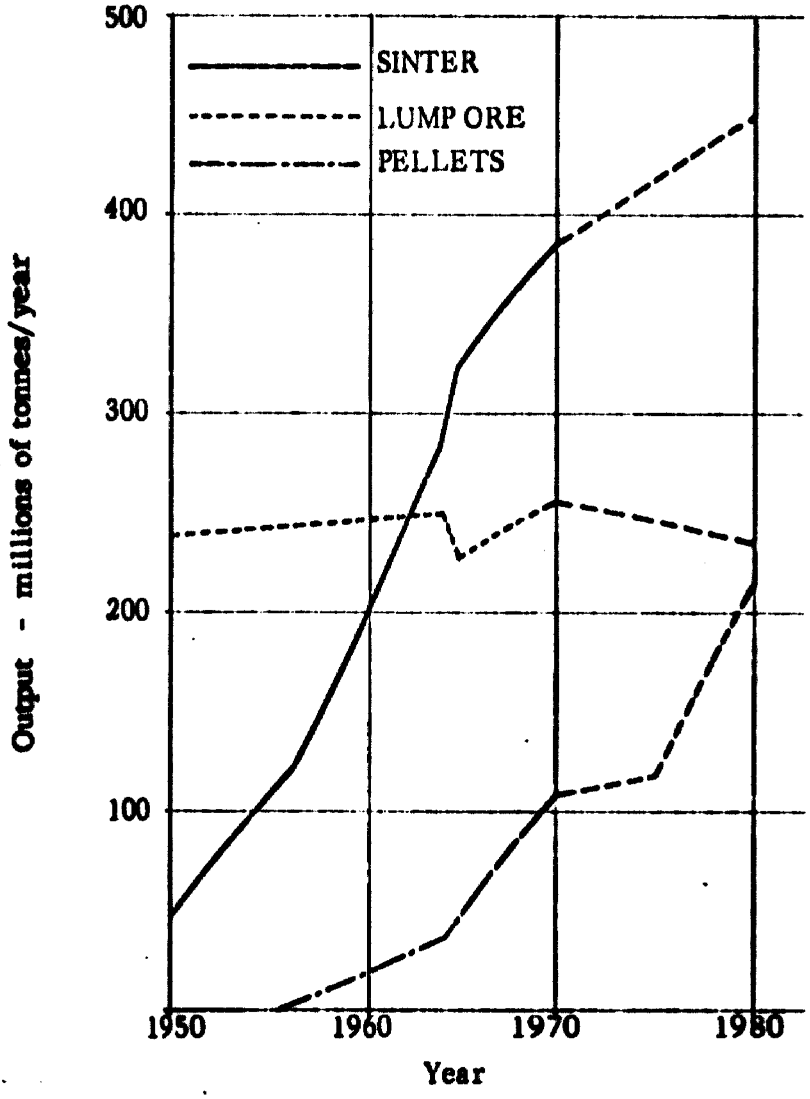

FIGURE 7.1 - WORLD PRODUCTION OF LUMP ORE, SINTER AND PELLETS. (COMPILED FROM VARIOUS SOURCES).

TABLE 7.2. - WORLD PELLET PRODUCTION

Region	Capacity (Million tonnes/year)
USA	58.5
Canada	21.4
Europe	
USSR	18.5
Sweden	4.5
Norway	0.6
Italy	0.4
W. Germany	0.4
Finland	0.3
Yugoslavia	0.2
France	0.1
Others	
Australia	11.0
Chile	9.5
Japan	6.0
Peru	3.5
Brazil	3.0
Argentina	2.5
Liberia	2.0
Morocco	0.9
Philippines	0.8
India	0.5
TOTAL	145.0

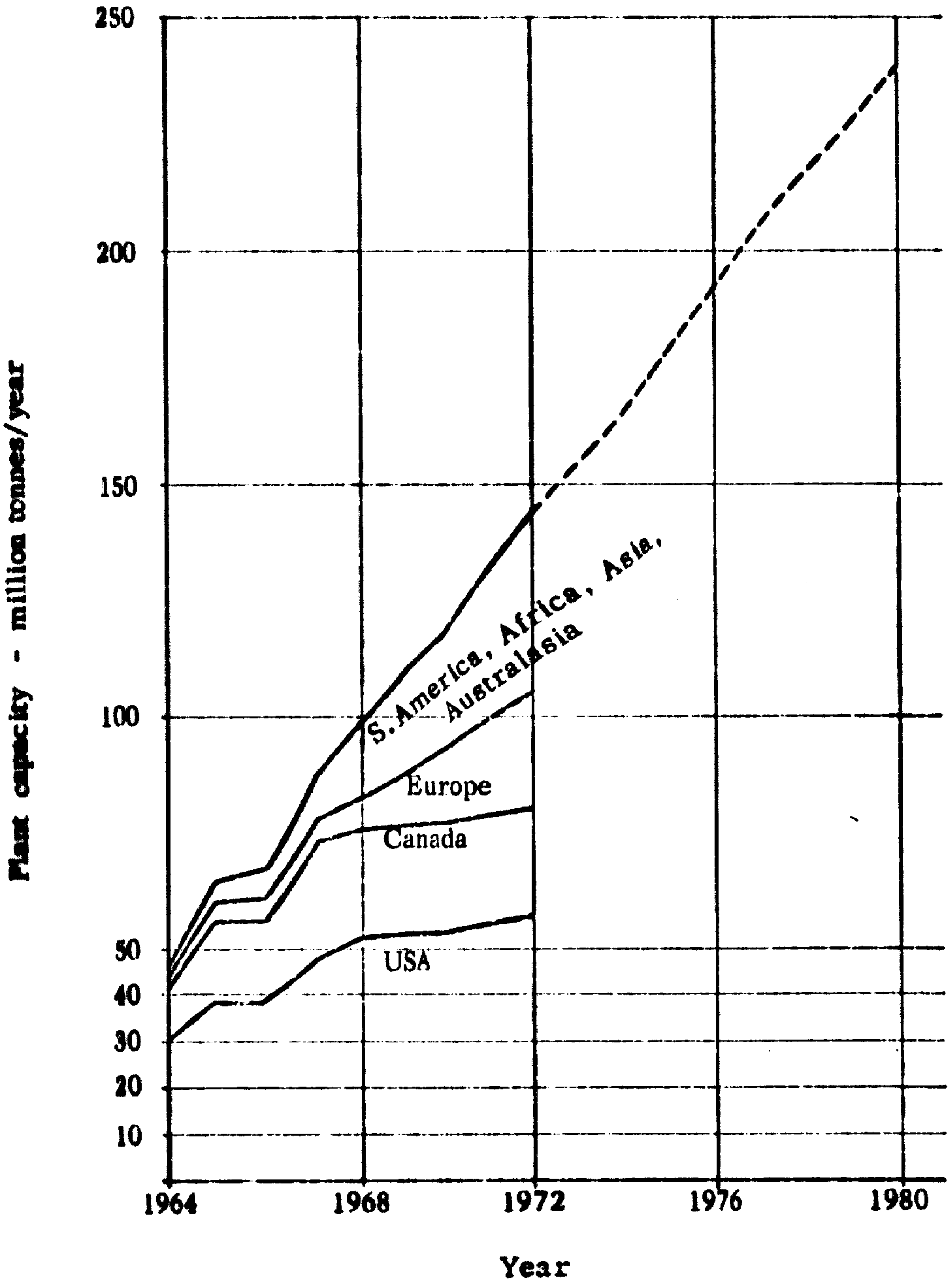

FIGURE 7.2 - WORLD PELLET PLANT CAPACITY (COMPILED FROM VARIOUS SOURCES)

(a) Western Europe

A characteristic of the West European steel industry is the considerable capacity of sinter plants already in existence, largely as a result of the traditional dependence on local ores which have low Fe contents. A change to high grade imported ores has enabled increased outputs of liquid iron to be achieved from existing sintering and ironmaking facilities. In consequence this sinter capacity is sufficient in most of Western Europe to agglomerate enough fines to satisfy the demand for a number of years to come, a fact which is reflected in a price differential between lump and fines equivalent to the operating costs of sintering. As existing sinter capacity within the region is filled up, the prospects are that additional plants will be built. By 1980, the total size of the West European market for high grade imported ores is likely to increase almost two-fold, largely at the expense of domestic ore production. Authoritative forecasts for 1980 indicate that the usage of lump ores will have fallen to less than 50 million tonnes per year, while pellets will have grown to about 30 million tonnes per year. Consumption of sintered fines is forecast to rise to about 140 million tonnes per year, accounting for almost two thirds of the iron ore used. However, there is some evidence that concern over pollution may be influencing European Steelmakers in favour of pellets, rather than sinter. A West German mill is at present planning to conduct trials in a large blast furnace with pellets constituting 80 percent of the total iron ore charge. Spanish steelmakers are also considering the import of pellets.

(b) Japan

The Japanese steel industry has shown a phenomenal rate of growth in the last decade, annual output of crude steel having risen from 22 million tonnes in 1960 to 92 million tonnes in 1970. The total supply of iron ore and its sources, have undergone an equally dramatic change. Imports of ore and concentrates from Asia and Latin America in 1960 totalled 14.9 million tonnes and in the same year Japanese sinter plant capacity was 10.5 million tonnes per year. By 1970, imports of ore to Japan had reached the order of 100 million tonnes per year, Australia being by now the principal source. By that year, sinter plant capacity had increased to the extent that it was capable of absorbing nearly 50 million tonnes of ore fines. The growth of Japanese sinter plant capacity is shown in Figure 7.3. The pause in growth of capacity over the years 1962 to 1965 is thought to reflect the anticipated future dependence on Australian lump ore. However, once production began, fines arising from the mining operations were offered on the market at a price that justified the provision of sinter capacity to use these. In consequence in the fiscal period 1971-72, the Japanese steel industry used as blast furnace charges about 22 million tonnes of lump, 80 million tonnes of sinter and 14 million tonnes of pellets. However, although there are vast known reserves of iron ores in the world, the sources of high grade sintering fines available to Japan are comparatively few - Western Australia, South Africa, Brazil, India and Guinea - which may restrict the future growth of sinter capacity. It is estimated that by 1980 fines and concentrates for sinter and pellet plant feed may make up about half of the raw iron-bearing materials imported, the balance comprising a gradually decreasing proportion of quality lump and a correspondingly growing proportion of pellets.

The demand for pellets is thus likely to grow considerably within the next decade, partly to facilitate pollution control. Many Japanese steel mills already have their own pellet plant. The installed capacity has been growing steadily during the 1960's but the rate of growth has increased dramatically since 1970, as illustrated in figure 7.3. Seven more pellet plants of 2 to 3 million tonnes capacity each are planned for operation by 1975, thereby more than doubling the present capacity.

Japan's shift towards the use of pellets as blast furnace feed is encouraging the erection of new pellet plants in W. Australia, India, Angola, Ivory Coast, Alaska, Liberia and South Africa.

Nevertheless, a recent report quoted in "Mineral News" suggests that the Japanese are finding the use of pellets less advantageous than sinter feed on grounds of both economy and quality. It is understood that the Japanese now believe that desulphurisation can be achieved at very low cost at the sinter plant ; if this were to be substantiated the trend towards the use of pellets in Japan might be reversed.

(c) The USA and Canada

The steel industry in the USA has shown a very slow growth pattern over the past decade. Informed opinion considers that this pattern will continue because the national steel consumption per capita is approaching its ceiling. Consumption of iron ore at US steel plants grew from 102 million tonnes in 1960 to 129 million tonnes in 1969. In contrast, Canadian ore consumption is modest by comparison, the quantity used in 1969 being only 9.3 million tonnes.

Iron ore production in the USA has grown more rapidly over the same period with a distinct change in type of product taking place. The quantities of run-of-mine ore and screened lump supplied have actually fallen, sinter fines have remained at about the same level, whereas pellets have risen three-fold. The same trends have been exhibited to a more marked degree in Canadian ore production, where the output of pellets has risen seven-fold in seven years.

The pattern of development of sintering and pelletizing in the USA reflects the sources of the ores used and their type. The growth of pelletizing coincided with the development of the use of concentrates derived from the Lake Superior taeonites. Pelletizing capacity in Canada has been expanded in response to this threat to sales of lower grade Canadian concentrates despite the fact that this entails the regrinding of materials that are otherwise suitable for sintering.

The trend through the sixties is shown in Figure 7.4. Sinter plant output in both countries was essentially constant throughout the period but

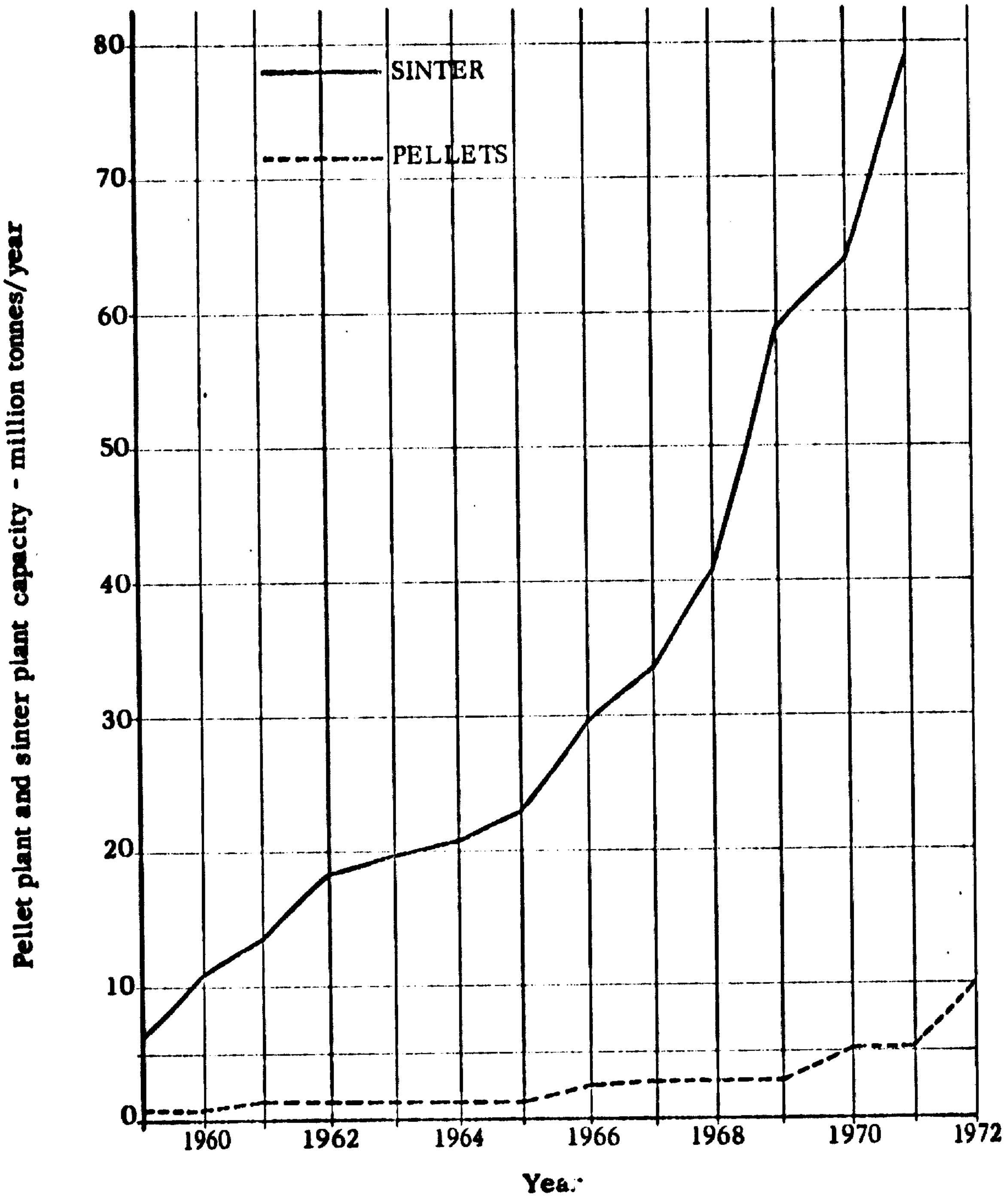

FIGURE 7.3 - JAPANESE PELLET PLANT AND SINTER PLANT CAPACITY

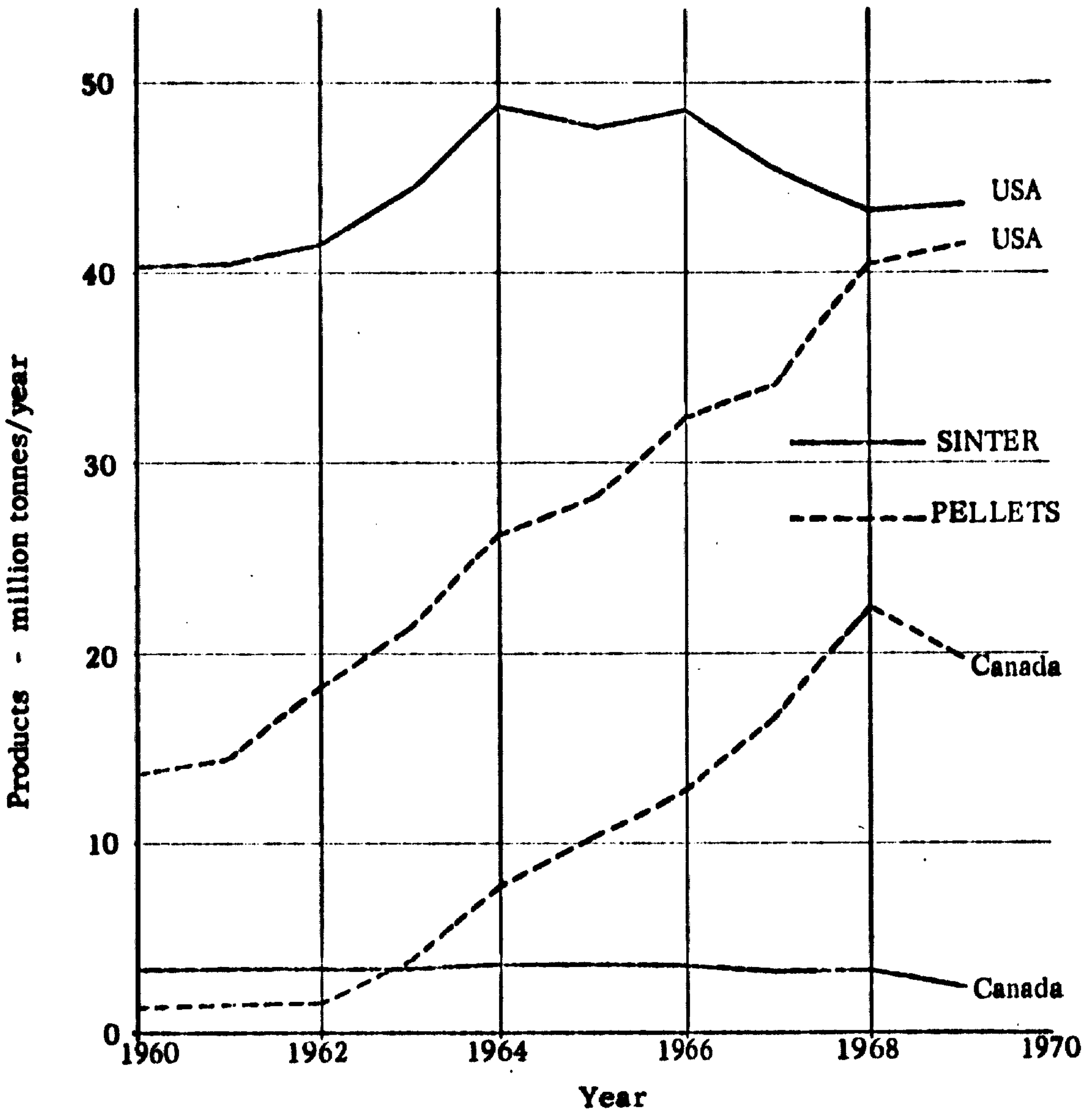

FIGURE 7.4 - AGGLOMERATED PRODUCTS IN USA AND CANADA

may tend to decline in the future due to increased public concern over air pollution, especially in the USA. Pellet production has grown strongly, and as more fine-grained taconite ores are exploited in the USA this growth will continue. The US Bureau of Mines estimates that by the year 2000 the whole of the USA output of iron ore will be sold as pellets. Canadian output of pellets will continue to grow in relation to the level of its exports to the USA because of the lack of sinter plant capacity there. The proportion of Canadian ore marketed as sinter plant feed will depend closely on the level of Canadian exports to the Japanese and European markets.

Ore shipping

One of the major factors contributing to the world-wide availability of high grade ores and concentrates has been the fall in shipping costs that has occurred in the last twenty years. The typical size of iron ore bulk carriers has increased rapidly in that time from 10,000 tonnes deadweight in the early fifties to 70,000 tonnes deadweight now, with larger carriers of over 100,000 tonnes deadweight already employed on certain routes. Some iron ore loading ports are being developed to take still larger carriers up to 150,000 tonnes deadweight although the number of ports capable of receiving such ships is limited. The development of unloading facilities is also taking place. The economies of scale provided by these large carriers have enabled freight rates to be reduced so far that ores are now available from any source to any market. For example, Brazilian ores have been shipped to Europe for less than $2/tonne, and West African ores to Japan for just over $3/tonne.

Another factor which contributes to lower shipping costs is the growing tendency to transport solids in slurry form by such techniques as the Marconaflo system*. The system extends the convenience and economics of handling solids in slurry form to the loading and unloading of ships. In addition to slurry system installations at the mine for beneficiation, and subsequent pipeline transfer to the loading jetty, there are a number of slurry unloading facilities, installed or planned, for feeding concentrates to pelletizing and sinter plants.

Among the more important examples of the Marconaflo system are the Marcona pelletizing plant in San Nicolas, Peru; the pelletizing plant of the Oregon Steel Company, Portland Oregon which uses concentrates shipped from San Nicolas (where it is loaded as slurry) or from Tasu, British Columbia (where it is loaded as dry filter cake) - in either case unloading is by the slurry technique ; and the Waipipi Ironsands Limited mining and benefication operation which incorporates a slurry shiploading system for bulk shipping of ironsands to Japan.

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* "Marconaflo and its use in new mineral developments" M.J. Fraser and L.P. Connolly CHEMTECH, February 1972, No. 116.

The system is also used in a 52-mile pipeline carrying iron ore in Tasmania in a 250-mile coal line in the South Western USA and in other similar applications.

The system is currently under consideration for developing the Kudremukh iron ore deposit in Mysore, India. In this case, the proposed scheme involves transport from the mine to a slurry pond at Panambur by a 36-mile pipeline. Since the waters at Panambur are shallow it is proposed to load into 200, 000 deadweight ton vessels anchored 10 miles offshore, through a 40-inch pipeline.

The world-wide availability of high grade ores made possible by low transport costs, coupled at the present time with a potential over-capacity in the mines, has led to ore treatment in some countries not primarily to increase the iron content but to improve the quality of their product by removing undesirable impurities. The growth of pelletizing in Canada has already been mentioned, and another example is Swedish ores. These have been sold in the past principally as high grade lump ore with rather high phosphorus values, but in consequence of competition from low phosphorus ores from outside Europe, some of the Kiruna ores are now subjected to a concentrating process aimed not so much at improving their iron content as to reduce the level of phosphorus they contain.

Use of self-fluxed and superfluxed burdens

The ironmaking process requires that the burden should contain a fluxing material, besides the iron ore itself and the appropriate reductant. The usual flux, capable of forming a slag with the silica in the ore is lime, CaO, which is normally added to the process as crushed limestone, $CaCO_3$.

When lump ore is used, the lime addition is normally in the form of lump limestone, charged to the blast furnace at the same time. The charging of limestone, as such, to the blast furnace adds to the heat requirement of the process since a certain amount of heat must be provided to convert limestone to lime. From this point of view, basic sinter has an advantage because the $CaCO_3$ is converted to CaO during the sintering process using coke breeze or other fuels instead of expensive metallurgical coke. Basic sinter is made by blending iron ore fines with finely crushed limestone and coke breeze prior to sintering. The practice of superfluxing, that is, adding <u>all</u> the required lime to the sinter, is a recent development. With some iron ore it has not proved possible to achieve satisfactory sinter strength when high basicities are used but recent developments, particularly in Russia, have shown that under some circumstances sintering produces a continuous skeleton of crystalline matter in the sinter which actually increases strength. Improved reducibility can also result from the high content of easily reducible calcium ferrite and because there appears to be a smaller proportion of iron oxides combined with the silicates. The use of superfluxed sinter results in small decreases in sinter plant output together with small increases in blast furnace output. A disadvantage of superfluxed sinter is that it has an increased tendency to pick up sulphur during the sintering process. The applicability of superfluxing practice can only be determined by plant trials and may be influenced by the inherent particle size distribution of the particular ores and limestone.

The practice of superfluxing of sinter is expected to grow considerably over the next few years. Nevertheless, we believe that the problems involved in predicting exactly the fluxing requirements of a blast furnace burden, and the need to be able to make small changes in it in the course of controlling the process, will result in a small quantity of flux still being charged direct to the furnace.

The addition of fluxing materials to a pellet mix leads to the formation of weaker pellets. The friable product which usually results is difficult to handle and transport without considerable degradation. At the present time therefore, it is normal practice to charge unfluxed pellets directly to blast furnaces along with lump limestone, as is done with lump ore. However, development work to overcome this problem is now in hand, and it is our opinion that commercial production of fluxed oxide pellets will be introduced by the end of this decade.

Sizing of the burden

The size specification of lump ores is becoming increasingly tight. A 1964 contract for the supply of lump from Australia to Japan was based on a specification of 100 percent less than 150 mm, 80 percent over 6 mm. Subsequent contracts have been based on size ranges of 100 mm to 6 mm and, more recently, of 30 mm to 6 mm.

There are indications that, in the present 'buyer's market' in iron ore, pressures are developing to narrow the range still further to one of 25 mm to 8 mm, or even 25 mm to 10 mm. Such a tight size restriction on lump ore will mean that the ore producers will have increased quantities of fines to dispose of. Degradation in transit of both lump ore and pellets gives rise to further fines at the steelworks, so that despite the strong growth in the use of pellets in recent years, sinter will be the main burden form throughout the next decade.

7.2. Sinter plant development

There are three principal types of sinter plant: the continuous travelling grate, sinter pans and rotary tables. Pans and rotary tables have only been used in smaller installations on account of their flexibility to frequent changes of feed and intermittent operation, but no new installations are likely. The continuous travelling grate plant with a capacity of 0.3 to 0.4 million tonnes per year is more suited to large-scale operations and on present trends will almost invariably be the type of machine selected for use.

In this process, a feeder mechanism deposits a uniform layer of charge comprising a mixture of iron ore fines, coke breeze, limestone fines, return sinter fines, on the pallets forming the travelling grate. These then convey the charge under the igniter where the surface is heated to incipient fusion. The ignited charge then advances over a series of windboxes from which the air is drawn by fans. The rate of travel of the pallets and the volume of air drawn through the charge are controlled so that the zone of combustion reaches the grate bars at the point where the pallets leave the final windbox. Beyond the end of the travelling grate the sinter is crushed, hot screened to remove fines and then air cooled. The cooled sinter is screened again before use, and all fines are returned for re-sintering.

The dimension of a sintering machine usually referred to is the area of grate exposed to the windboxes. One of the design factors contributing to the growth in the effective area of a machine is an increase in the strand width. The largest machines currently in use are 5 metres wide, with grate areas of up to 500 m^2. Figure 7.5 shows how the size of plants has grown in Japan during the past decade. Design and development costs rather than technological restraints have governed growth. The large number of plants built by one supplier (marked by crosses in Figure 7.5) accounts for the very rapid increase in the last five years, and it may be assumed that still larger plants will be constructed in the future. The main factor affecting the design of larger units is the maintenance of uniformity of air-flow over the width of the strand.

Outputs of sinter plants vary,* the range being from 30 to 45 tonnes of sinter per square metre of effective grate area per day, the majority of plants achieving 35 to 40 tonnes per square metre per day. Increases in productivity have been obtained in Japan by the use of increased suction pressures on the windboxes, introduced initially to combat decreasing permeability of the sinter bed due to the rising proportion of fine concentrates used in the mix. Productivity is also increased by using post-ignition heating of the top surface of the sinter bed, from which the sinter has been found to be up to 20 percent more friable than sinter formed at the base of the bed. This heat is supplied by having a heating hood following the ignition furnace, to provide heated air for the windboxes.

The sintering process is relatively cheap in itself. Excluding the cost of the materials being made into sinter, namely the iron ore fines, coke breeze and limestone, the total cost ranges from about $3.5 per tonne of sinter on a one million tonnes per year operation to $2.2 on a 10 million tonnes per year plant. These costs compare with a cost of $11 to 12 for the materials processed, per tonne of finished sinter.

The material to be sintered needs to be raised to a temperature of about 1400 to 1600°C. The total heat requirement is between 1.8 and 2.7 gigajoules per tonne of sinter. The normal means of providing this hitherto has been to include fine coke breeze in the intimate mixture of particulate materials fed to the machine. This addition is such that the charge contains about 4 to 7 percent of carbon, which is ignited at the top surface of the sinter bed as it passes through the ignition furnace zone, normally fired by oil or gas.

Coke breeze has been the traditional fuel for sintering, but with improved coke rates in ironmaking, the necessary amounts of breeze may not always be available from cokemaking. In such cases supplementary fuels, either solid or gaseous, may be used, replacing up to 40 percent of the coke breeze if necessary. A wide variety of solid fuels have been tried successfully as a substitute for coke breeze. The most suitable solid fuels are those having low reactivities, low volatile contents and low ash contents, usually crushed and screened to have a top size of about 5 mm. In general the higher the fuel reactivity is above that of coke breeze, the higher will be the CO/CO_2 ratio in the waste gas resulting in a lower thermal efficiency in the sinter bed. If the fuels contain more than about 10 percent volatiles, these distil off before

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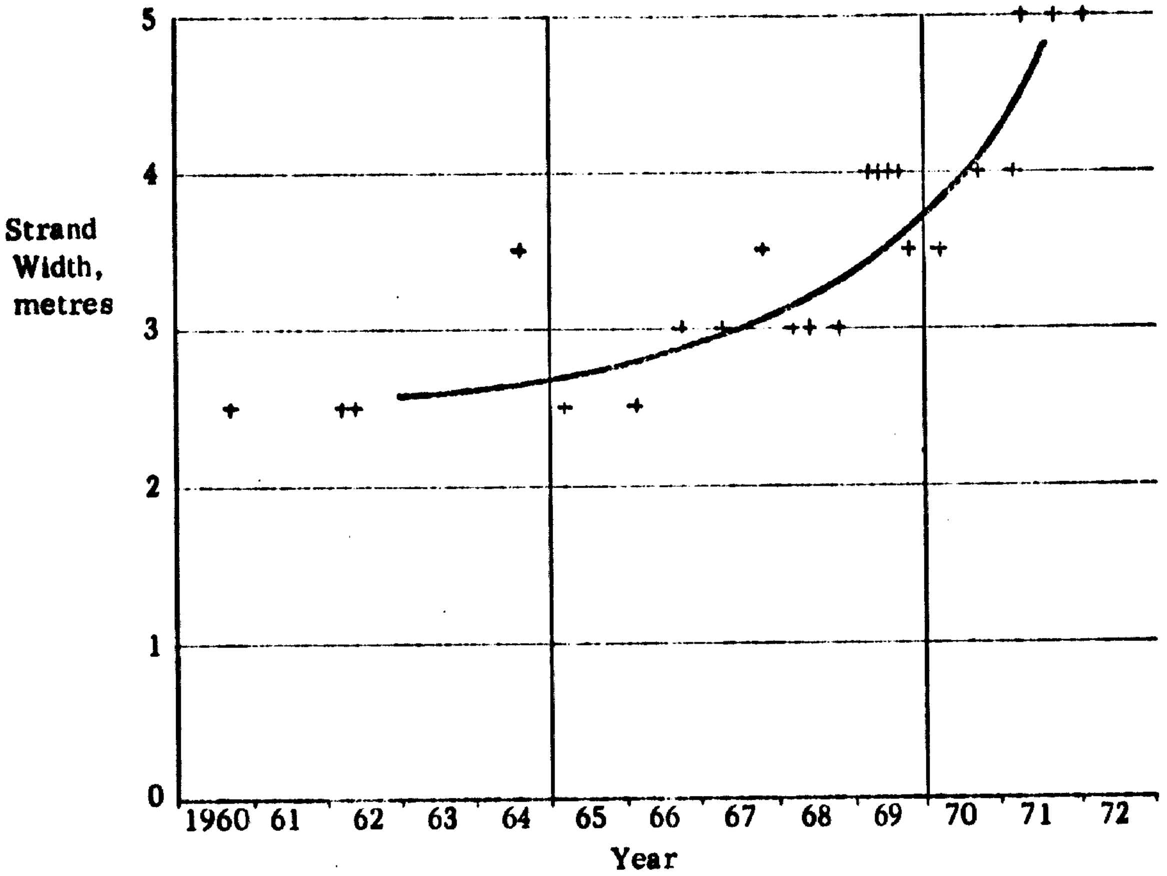
* See Appendix 1



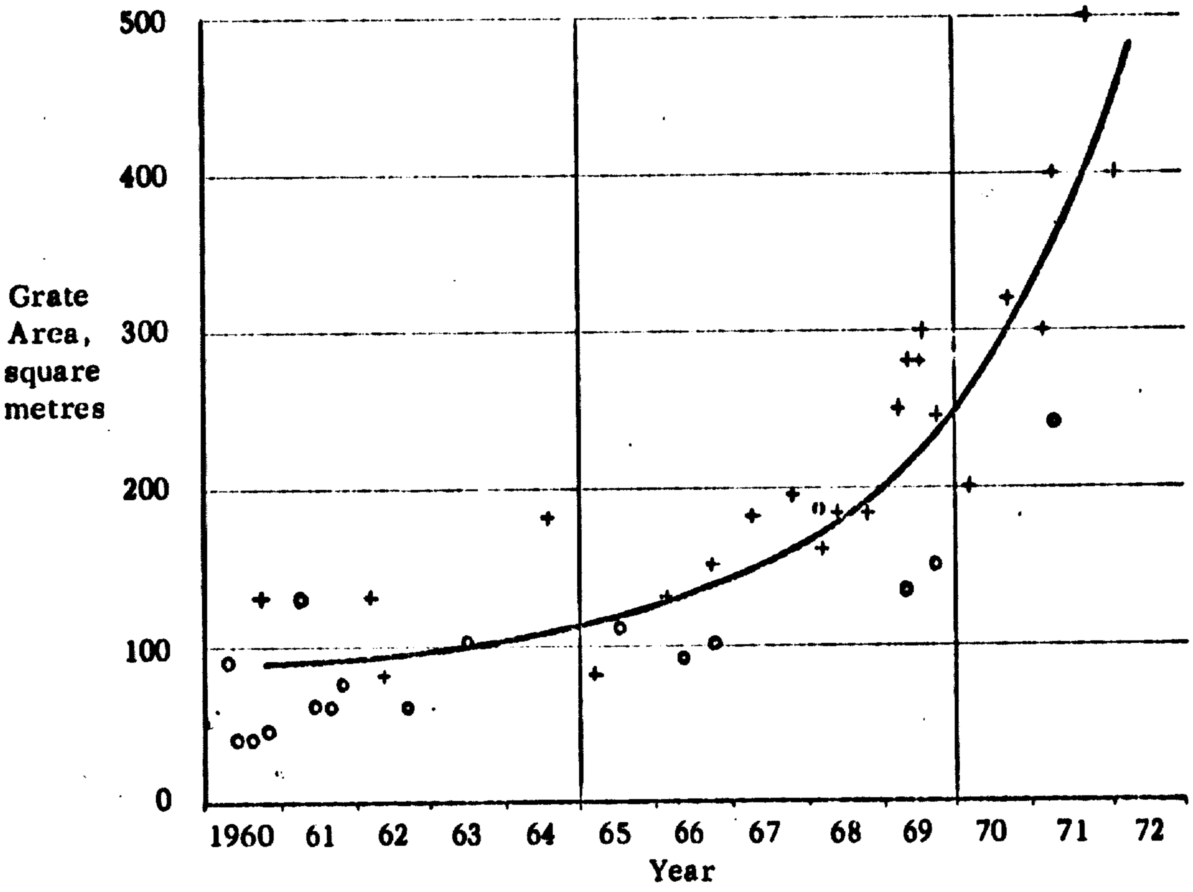


FIGURE 7.5 - GROWTH OF SINTER PLANT SIZES IN JAPAN

reaching the combustion zone proper, and the calorific value of the volatile content is partly or completely wasted in the sinter bed. High ash contents in the fuel additions are to be avoided because they require additional fluxing and also influence the coke-rate in the blast furnace operations.

Gaseous fuels, typically blast furnace gas, are used to pre-heat the air. Besides reducing the requirements for coke breeze, this improves the strength of the sinter.

7.3. Pellet plant development

Pelletizing is the process whereby very finely ground iron ore concentrates, usually in the size range of 70 percent or more finer than 44 microns, are agglomerated into balls or pellets of about 9 to 16 mm diameter. The process is carried out in two stage, balling and indurating.

In the balling stage, the fine particles of ore, usually with an admixture of a half to one percent of a binder such as bentonite, are dampened and rolled on a rotating inclined surface. The balls which are formed are soft at this stage and are generally referred to as green balls. The quality of the balls depends on the amount of water added and on other process variables that in turn must be adjusted to take account of fluctuations in the quality of the feed materials. The definition of a satisfactory ball and the interrelationships between the variables have not, as yet, been rigorously quantified. In consequence, control of the plant depends largely on the skill of the operator. An early breakthrough in the application of automation is not envisaged.

Indurating, which is the firing of green balls to form hardened pellets requires the generation of temperatures in the region of 1200 to 1300°C. There are four basic types of indurating plant: the shaft furnace, the travelling grate, the grate-kiln and the circular hearth.

The shaft furnace is a vertical refractory-lined chamber into which the green balls are charged from above. There are oil or gas-fired combustion chambers at the sides of the furnace, from which the hot gases enter the furnace and heat up the pellets. The pellets produced are cooled and screened before passing to storage. Shaft furnaces tend to be limited to a maximum throughput of 0.5 million tonnes per year, and use from 0.45 to 0.53 giga-joules of heat per tonne.

The horizontal travelling grate, one of the alternative means of indurating green pellets, is a machine very similar to that used in sintering. The pellets are conveyed by the grate through successive stages of drying, preheating, burning, recuperation and cooling, the hot air from the latter stages being fed back to the earlier stages. The heat requirement is about 0.6 gigajoules per tonne of pellets, and is usually supplied by oil or gas. Outputs of individual horizontal travelling grate machines can be over 2 million tonnes per year.

The third type of indurating plant is the grate-kiln-cooler combination machine. In this, the drying and preliminary hardening of the green balls is carried out on a short horizontal travelling grate, and the final hardening takes place in an oil-fired rotary kiln. Total heat input is of the order of 0.7 gigajoules per tonne. Hardened pellets are discharged from the kiln to a rotary cooler, being discharged at a temperature of about 200°C. The rotary nature of the hardening process helps to give a more consistent quality of product than is achieved by other methods.

The fourth system of indurating involves the use of a horizontal circular grate which, as it rotates, carries the pellets through successive zones of drying and indurating. This type of plant is still in the development stage. A version which went into operation in 1967 was taken out of service late in 1968, but it has recently been announced that another plant, of a different design by another manufacturer, is shortly to be built. It remains to be seen what results will be achieved.

An alternative to the various fired forms of pellets are those which are cold bonded. In the Grangcold pellet process the pellets are formed in balling discs in the usual way, with a 10 percent addition of Portland cement as a binder-hardener. The green pellets are very soft, with little strength in the first 30 hours, reaching some 70 percent of final strength at the end of three to six days. They take about four to five weeks to reach full strength. In this process the soft green pellets are mixed with additional ore fines to act as a cushioning material and are fed to a tall vertical hopper. The rate of withdrawal from the bottom of the hopper is regulated to allow a sufficient dwell time for the pellets to harden. The pellets are recovered from the pellets - fines mixture by screening, the fines being recycled. The largest plant currently operating is one that the Grängesberg company have built at their mine in central Sweden, with a capacity of 1.5 million tonnes per year, to supply their steelworks in Oxelösund. Cold bonded pellets do not travel as well as fired pellets so that their use is likely to be limited to locations where the journey from the pellet plant to the steelworks involves a minimum of handling and no transhipment; where the cement raw materials are readily available in the neighbourhood of the plant; and where there may be some advantage in saving fuel consumption.

Although unit sizes of pelletizing plants now exceed 2 million tonnes per year, the larger plants consist of a number of units and some North American installations have capacities in excess of 10 million tonnes per year. The trend in growth of total world pellet plant capacity in recent years has been indicated in Figure 7.2.

The cost of the pelletizing process above are the order of $4 per tonne at annual outputs of one million tonnes down to about $3 per tonne at outputs of 10 million tonnes. There is little economy in scale beyond this point, because the larger installations are built up of multiples of smaller units, and there are few savings that can be made in the ancillary materials handling equipment.

CHAPTER 8 - CONVENTIONAL COKEMAKING

8.1 Impetus to development

Conventional slot-type coke ovens are used to produce over 95 percent of the world's production of metallurgical coke. Although there are a number of small beehive coke oven installations, their contribution to the supply of coke to the steel industry is diminishing rapidly since any new cokemaking capacity required is now provided by installing slot-type coke oven plants. The discussion on technological developments is therefore centred around the cokemaking process using slot-type coke ovens.

In recent years the rising cost of metallurgical coke through the growing scarcity of supplies of prime quality coking coals has stimulated a great deal of research and development work to find out the optimum composition of coal blend for coking. Developments in this area are most significant since the cost of coal per ton of coke produced represents nearly 100 percent of the cost of coke. Work has also been done on the technological aspects of coke oven design and performance particularly to improve the efficiency of existing installations or to increase their capacity. In many instances these developments have resulted in savings in both capital and operating costs of the coke oven plant and in some cases product quality has also been improved. Wider implementation of these improvements is now taking place due to the rising production cost of cokemaking owing particularly to decreasing credits from by-product sales. Efforts have been made to improve the design of by-product recovery plant but competition from the petrochemical industry has continued to depress the revenue available to the coke oven operators from the sale of the by-products. The areas in which the most important technological advances have been made are cribed, together with the extent to which they may be expected to proceed in future.

8.2 Composition of the coking coal blend

The composition of the coking coal blend used for cokemaking is the most important single factor in determining coke quality and the cost of coke. While it is possible to use a single type of coal to make metallurgical coke, it is usually easier to achieve all the desired coke properties by blending two or more coals. The principal objectives in blending are: -

i) to improve the physical quality and uniformity of the resulting coke;

ii) to improve the yield of coke products:

iii) to increase the range of coals which may be selected for cokemaking with a view to reducing the cost of coal blend.

The third objective is obviously important to many industrial nations lacking high quality coking coals, and wishing to make full use of indigenous coals in order to reduce the need for imports.

The usual practice at coke plants is to blend small proportions of low volatile coals with high volatile coal. The use of high volatile coals tends to produce weaker cokes and gives lower yields. Low volatile coals improve the yield of coke and its physical structure, but the amount that can be used is limited because of their tendency to expand under carbonisation conditions, which may result in oven damage. They also have a higher price than high-volatile coals.

The volatile matter content of coal blends in most parts of the world lies between 20 and 30 percent, as shown in Table 8.1, but this varies according to what coals are available in each region at a competitive price. The trend to use coal blends containing volatile matter of about 27 percent will become established practice because a blend with this characteristic tends to give near optimum results, both on technological and economic grounds.

TABLE 8.1 - RANGE OF VOLATILE MATTER CONTENT AND YIELDS OF COKE IN CERTAIN COUNTRIES

Country	Volatile Matter* percent	Yield of Coke* per tonne of coal
Belgium	24 - 27	0.77
France	22 - 31	0.75
Italy	24 - 25	0.78
Netherlands	23 - 30	0.78
W. Germany	20 - 27	0.75
Japan	25 - 32	0.71
UK	24 - 32	0.71
USA	26 - 34	0.74

* Dry basis

8.3 Coal preparation

The preparation of coals by crushing, screening and mixing prior to charging into the ovens for carbonisation is common practice in cokemaking installations. However, in recent years the subject has received a great deal of attention because an understanding of the technology involved has indicated that improved coal charge preparation aids the production of good quality coke, increases oven productivity and facilitates the use of higher proportions of weakly coking coals in the coal blend. Any development resulting in the use of cheaper coals is significant since any reduction in the cost of coal will make approximately similar savings in the cost of coke.

Conventional crushing processes are generally employed for coking coal preparation and are based on the reduction of the coal to about 80 percent less than 3 millimetres in a single pass through a hammer mill. This results in a very wide particle size distribution below 3 millimetres with a large proportion of undesirable fines. The stronger, more inert, constituents of the coal accumulate in the coarser fractions, whilst the friable, easily fusible constituents are reduced to a fine particle size. The presence of coarser inert constituents in coking coals gives rise to a non-homogeneous coke with structural weaknesses and consequent low strength.

The friable components known as vitrain and clarain, are primarily responsible for the binding of coke into a strong solid mass and excessive subdivision of these components below the particle size of the 'inert' material has a deleterious effect on this binding power. To overcome this difficulty a method of selective crushing of the coal has been developed. In this method the incoming coal is screened to remove the existing material of less than, say, 3 millimetres particle size. The oversize is subjected to impact crushing and then added to the incoming coal prior to screening. The degree of crushing and recycling are adjustable to an optimum level. In this manner a more uniform particle size distribution is obtained with a pronounced reduction in the proportion of fines. The particle size distribution of the inert material is also improved.

Selective crushing may be utilised in two ways:-

(1) The same coal blend may be maintained with selective crushing, thus producing a stronger coke which results in an increased yield of usable blast furnace coke. An increase in yield of about two or three percent may be expected, which will produce roughly a similar percentage reduction in the total costs of cokemaking.

(2) The coke strength may be maintained at the same level and a larger proportion of cheaper weakly coking and non-coking coals added to the blend. The actual quantity which could be added will depend upon the characteristics of these coals.

The additional cost of preparing the coal charge by selective crushing is estimated to be about $1.0 per tonne of coke produced. It is likely that the savings which could be achieved by the reduction of the cost of coal per tonne of coke will be greater than the cost of selective crushing. Because of this economic advantage this method of coal preparation is now practised in a number of countries, notably France, India and the USA and its application should certainly be considered for existing and new installations in the future.

8.4 Drying and preheating the coal charge

The technique of drying and preheating the coal blends prior to charging into the ovens is by no means new and even in 1926 trials with coal preheated to 150°C produced a 15 percent increase in output. It offers the most important possibility for increasing the throughput of an oven by both increase in bulk density and reduction in coking time. Results vary from oven to oven and also from one coal blend to another as can be seen from Table 8.2. British tests have shown that when the moisture content of a coal blend is reduced from say 10 to 3 percent, increases in throughput of up to 20 percent can be achieved for the same flue temperatures. If, in addition to drying, the coal blend is preheated up to temperatures in the region of 200°C coke oven throughput can be raised by a further 25 to 30 percent. Preheating trials in Australia and the USA have yielded similar results, preheat temperatures of 150°C producing an overall improvement of over 25 percent in output. This was estimated to be made up from 13 percent improvement due to drying, 7 percent due to decreased coking time and the remainder due to improvements in yield of usable coke. Preheats of 300°C produced gains in output of around 35 percent. The work in the USA showed that preheating results in increased oven wall pressures during coking. At low preheats this is not a serious matter, but at the higher preheat temperatures oven wall pressures increased by up to 27 percent. This must be taken into account in the oven construction, especially in the reconstruction of an existing installation that has not been designed for this condition originally.

Increase in throughputs and possible saving in fuel costs are not the only points in favour of this technique. It has been found that coal blends containing higher proportions of weakly coking coals may be accommodated in blends without reduction in coke quality when preheating is practised or alternatively that improved coke qualities can be achieved when using good coking coals. There is usually an improvement in strength and abrasion resistance, which is particularly noticeable and is thought to result from the higher bulk densities achieved. The very substantial improvement in Micum indices (see footnote) is evident in Table 8.2.

Micum Index:	Shatter and abrasion resistance of coke as defined by British Standard Specification 1016; other national standards define equivalent indices.

TABLE 8.2 - EFFECTS OF COAL PREHEATING

Coal Blend	A		B		C		D		E	
Volatile matter (daf) %	27.1		34.9		35.2		37.0		37.6	
Swelling index	8		8½		8		7		6	
Carbon (dmmf) %	90.4		88.1		86.6		85.8		85.7	
Charge Condition	Wet	Pre-Heated	Wet	Pre-Heated	Wet	Pre-Heated	Wet	Pre-Heated	Wet	Pre-Heated
Temperature of pre heat * °C	-	190	-	180	-	180	-	190	-	170
Charge bulk density db kg/m^3	723	833	725	833	698	833	731	833	693	833
Carbonising time h	16.3	14.4	16.7	14.8	17.7	14.4	16.0	12.0	18.0	14.7
Oven throughput db kg/m^{3}h	41.4	57.9	43.5	56.4	39.4	55.6	45.7	69.4	38.5	55.7
Increase in throughput %	-	30.7	-	29.9	-	46.3	-	51.9	-	46.5
Micum indices** of coke:										
(a) M40	73.2	73.6	59.6	71.7	63.9	70.8	56.6	68.7	50.6	57.9
Increase	-	0.4	-	12.1	-	6.9	-	12.1	-	7.3
(b) M10	9.6	7.4	10.0	7.6	8.9	7.5	10.2	8.2	10.8	8.5
Decrease	-	2.2	-	2.4	-	1.4	-	2.0	-	2.3
Yield of crude liquor m^3/t charge	0.116	0.031	0.166	0.045	0.192	0.036	0.134	0.054	0.152	0.067

daf - dry ash free

dmmf - dry mineral matter free

db - dry basis

* Temperature of coal immediately after charging to oven

** As defined in British Standard Specification 1016

Source: British Coke Research Association

According to work in the USSR preheating appears to offer the additional advantage of reducing the sulphur content in the coke. Tests with preheating to 350°C led to a liberation of about double the sulphur normally released in coke-making. However the characteristic has not been confirmed by work elsewhere.

The results of the preheating trials carried out in the UK suggest that there is a small cost benefit of between \$1 and \$2 per tonne. It is thus an attractive method for increasing the capacity of an existing plant. It is however, essential to prove the performance of the coal blend used before embarking on modifications to the plant. As experience is gained it is likely that a number of coal charge preheating plants will be installed in the near future.

Charging of preheated coal

Where coal preheating is to be practised, a decision must be taken on the method of charging. This is basic to the design of the plant and also influences the pollution control of the plant.

Two main methods of charging preheated coal are in operation; the first uses a pipeline and the second a smokeless charging car. The pipeline charging method, which is now in use in the USA, has the important advantage that gas and fume discharge on charging is completely removed, and this method also has a lower capital cost than smokeless car charging. The pipeline process is, however, slower than car charging and the fluidising tendency of the method leads to a lower bulk density of the charge with lower charge weight and slower carbonising. The reduced bulk density also affects the coke properties and thus coke from pipeline charged ovens is unlikely to be as good as that from car charged ovens using the same coal blend. Taking an overall view we expect pipeline charging to be implemented in preference to smokeless cars in locations where pollution control is an important issue. In other situations there appears to be very little to choose between the two methods.

8.5 Increased oven capacity

To increase capacity, oven lengths have increased steadily and most new ovens are now approximately 15 m long. We do not expect ovens to show further significant increase above 16 m in length, because the friction and inertia of the oven charge will then be such as to require a pushing action which might physically damage the coke. In addition to this, the longer the oven wall the more difficult it becomes to ensure uniform and efficient heating.

Increases in oven capacity can be achieved by increasing the width of the oven, but this leads to decreased oven productivity due to its disproportionate and adverse effect on carbonisation rate. There has in fact been a tendency, more particularly in the USSR, to reduce oven widths from the generally agreed dimension of 0.45 metres to 0.40 metres which has enabled coke outputs to be increased by up to 5 percent through faster carbonisation.

The main trend is towards increased oven height. Although the majority of plants use 4 to 5 metre high ovens, some countries have been using ovens up to 6 metres high for some years. Most new ovens are being installed with heights of approximately 6 metres and this represents an immediate 50 percent increase in oven capacity and a similar increase in throughput over existing 4 metre ovens. It has been reported that a saving of approximately 10 percent in capital costs per unit of production results from increasing oven heights from 4 to 6 metres and the labour costs are reduced to approximately two thirds. Ovens of 7 metres are now operating in Japan. Serious consideration is also being given to the design of ovens of 8 metres. Although we believe such ovens to be practicable, we note that very little evidence on the effect on coke quality of very tall ovens is published and that several difficulties have been encountered. These difficulties include carbon deposition in the oven, non-uniform heating and lack of temperature control, accentuated by a marked linear charge shrinkage. Maintenance problems have also increased and effective door sealing has become more difficult. We consider that these difficulties, together with the increased range of bulk density within the charge, will adversely affect coke quality. Further engineering and development work must be done to overcome these problems. On the credit side, there seems to be good evidence that by-product quality is improved, probably as a result of the longer passage of gases through hot coke. In spite of the technological difficulties, the trend to increase oven heights now appears to be well established.

8.6 Increased coking rate

The present trend in the industry is to design for the fastest possible coking rate, in order to achieve savings in both unit capital charges and operating costs. Recently installations have been built to operate lateral carbonisation speeds over 30 millimetres per hour, compared with traditional rates of about 25 mm/hr. The most modern designs now provide for carbonisation at up to 35 mm/hr.

There are many factors which can contribute to an increase in the coking rate of a particular coal blend. The factors exercising the greatest influence are the carbonisation flue temperature, the thickness of chamber walls, and the thermal conductivity of chamber refractories.

With no changes in oven design, an increase in carbonisation rate of about 10 mm/hr can be achieved by an increase of a little over 200°C in flue temperature but this means operating with flues at about 1500°C. At this temperature the oven wall refractories are close to their safe operating limit under hot-load conditions. Flue temperatures have therefore been limited to about 1400°C, an increase in carbonisation rates of 10 mm/hr still being achieved by using higher thermal conductivity refractories and thinner oven walls. The thermal conductivity of high density silica refractories is about 20 percent more than that of normal silica refractories. It has been reported that the use of high density silica refractories has increased the carbonisation rate by as much as 20 percent. A similar increase has been achieved by modifying the design of the oven wall to make it thinner.

Future oven design will undoubtedly make use of all three factors to achieve the highest possible coking rate, taking advantage of any improvement in the thermal conductivity or hot-load performance of the refractories and balancing the conflicting demands of oven height and heat transfer on the wall thickness.

8.7 By-product plant

Two main options for by-product processing are open to plant operators. The first involves advanced by-product processing with a substantial capital investment, but producing high value products. The other option is to simplify the by-product plant as much as possible, consistent with the need to clean the oven gas to adequate standards and to avoid pollution beyond the legal limits. Although in the past a considerable number of plants have been built in the USA and Europe of this first type for large scale production of ammonia and other chemicals, we expect most new plants to be of the second simpler variety.

The recent growth of the petrochemical industry has resulted in a decline in the revenue available to coke oven operators from the sale of by-products, particularly ammonium sulphate. In fact, since the mid-fifties such revenues have fallen continuously in real economic terms at approximately 1.3 percent per year. Benzole will continue to be scrubbed out as there is still a ready sale for this product. Tar is normally removed anyway, and can usually be sold. Ammonia will not however be reclaimed but will be washed out of the coke oven gas and burnt. This will become well established practice over the next 10 years. Furthermore, the increasing emphasis placed on combustion flue gas control will mean that sulphur removal from coke oven gases is likely to be continued.

8.8 The future of conventional cokemaking and the economic unit

During the last ten to fifteen years, technological developments in coke oven design and operation have enabled the installation of taller ovens together with, in some instances, preheating equipment and the application of several process modifications to achieve higher productivity and a reduction in the cost of cokemaking. Although these developments have made a useful contribution to new installations, in most cases existing plants have been unable to gain the full beneficial effect.

Changes in oven practice leading to increased throughput usually require plant changes in the more intricate areas of by-product and material handling plants. This restricts the extent of the changes which can be made by modifying existing plant and in general, substantial parts of the modern developments can be incorporated only by building completely new installations. During the coming decade, however, we expect the developments discussed in this Chapter to be implemented on a wider scale, but there are unlikely to be any fundamental changes to the conventional process.

The most advanced ovens being installed towards the end of the decade will have a chamber length of approximately 16 metres, a height of 7.5 metres and a width of 425 millimetres giving an oven charge volume of 51 cubic metres. A battery of some 80 ovens of these dimensions can be handled as a single unit. When charged with a coal blend preheated to about 180°C and carbonising it at a rate of 35 millimetres per hour, such a battery would be capable of producing about 1.6 million tonnes of coke per year A plant consisting of two such batteries would be able to serve a steelworks producing 7 million tonnes of liquid steel per year.

Most of the developments discussed so far have economic benefits which are additive. However, it is not expected that the savings achieved will more than offset the increased costs of labour and pollution control and the losses in by-product revenue.

CHAPTER 9 - 'FORMED' COKEMAKING

Considerable efforts have been made during the last ten years to find an economically acceptable alternative to metallurgical coke as the principal reductant in blast furnace practice. "Formed coke' appears to be the only material which holds any promise of immediate commercial success. In consequence, most research has been carried out on processes yeilding this product, and a simple classification of non-conventional cokemaking processes is shown in Table 9.1. Leading cokemaking authorities agree that formed coke is unlikely to be superior in use to good metallurgical coke produced by the conventional methods. The aim therefore has been to develop processes that utilise cheaper coals, that are not markedly more costly than conventional cokemaking and that yield a product suitable, in the first instance, for blending with metallurgical coke without adversely affecting blast furnace performance. The trend in the use of formed coke will be determined by the availability and cost of metallurgical coking coals rather than technology now that satisfactory formed coke processes have been developed.

9.1 Formed cokemaking processes

Formed coke is manufactured from carbonised or partly carbonised non-coking or weakly coking coals, the required mechanical properties being provided by briquetting either before or after carbonisation. In recent years a considerable number of formed cokemaking processes have been described. So far only a few have been operated commercially and no single process has emerged as a 'best choice'.

The available formed cokemaking processes can be characterised by the number of heat treatment stages employed, by the degree of devolatilisation or carbonisation prior to briquetting and by whether briquetting is assisted by the addition of a binder. Processes involving cold bonding of raw coal by pelletising, followed by carbonisation of bonded material, and processes involving single stage carbonisation of raw coal briquettes, have failed to produce a satisfactory product. Processes which involve heat-treatment of raw coal followed by briquetting and then carbonising have aroused considerable interest; a number have been developed but the main methods can be illustrated by examining the salient points of three of them, each of which is receiving serious consideration and will be developed further during the next few years. These are the Bergbau - Forschung (BBF), Food Manufacturing Corporation (FMC), and Sapozhnikov processes. There are also commercial processes for producing formed coke for foundry use, but

TABLE 9.1 - SIMPLE CLASSIFICATION, WITH EXAMPLES, OF NON - CLASSICAL 'COKE' MAKING PROCESSES

Types of process		Examples	Outline
1. Direct carbonisation (no briquetting) with lump product		Wise-Salem (USA)	**Continuous carbonisation on rotary hearth**
		Nizhne-Tagil (USSR)	**Continuous carbonisation on rotary hearth**
2. Raw coal briquettes are carbonised		**Bilkenroth-Rammler** (W. Germany)	**Dried brown coal briquetted and carbonised in vertical chambers**
		Norwegian	**Crushed coal briquetted; preheated; carbonised in continuous vertical chambers**
3. Initial carbonisation is at a low temperature	**Process involves briquetting, leading to production of 'formed coke'**	**FMC (USA)**	High-volatile non-caking coal converted to char by multi-stage fluid-bed carbonisation; char briquetted with binder incorporating tar obtained in previous stage; final carbonisation in continuous vertical retorts.
	Briquettes formed from the product of an initial carbonisation	**Saposhnikov (USSR)**	Fine coal softened by rapid heating in whirlwind chamber; briquetted practically at temperature reached in first stage; final carbonisation in continuous vertical chamber ovens.
4. Initial carbonisation is at a high temperature		**Polish**	Char produced by Lurgi-Spulgas carbonisation; briquetted with binder incorporating pitch from tar obtained in first stage; subjected to mild heat-treatment in oxidizing atmosphere.
		Briqcoke (Australia)	High temperature carbonisation of poor coking coal; char crushed and briquetted with pitch binder; mild heat-treatment followed by carbonisation of briquettes.
		BBF (W. Germany)	Non-coking coal devolatilised at 600-700°C mixed with coking coal and hot briquetted. Final high temperature carbonisation in a sand bed.

we are concerned here only with formed coke suitable for the blast furnace. Foundry coke tends to be dense and is unsuited to efficient blast furnace operation.

Bergbau - Forschung process

This process, developed in the Federal Republic of Germany, uses non-coking low volatile coal and good coking coal in a ratio of about 7:3. The non-coking coal is first devolatilised at a temperature in the region of 600-700°C and the resultant hot char mixed with the coking coal at a temperature of about 450°C. The mixture is hot briquetted in a roll press to produce 'green' briquettes containing 7 - 8 percent volatile matter, the bitumen in the coking coal acting as a binder. Further carbonisation is carried out in a sand carboniser at 900-1000°C. A diagrammatic representation of the process is given in Figure 9.1. The formed coke product has a volatile content of about 1 percent. There is a 50 tonnes per day pilot plant in operation and a 300 tonnes per day plant is believed to be under construction at Essen, West Germany.

FMC process

Developed in the USA, this process, which is operated on a commercial basis, is capable of utilising any high volatile non-coking coal. The coal is first carbonised in a fluidised bed section of the plant and the tar produced is used as the binder for the char. Briquetting is achieved by roll pressing; the green briquettes are 'cured' at about 500°C and finally carbonised at about 900-1000°C in a continuous vertical retort. The formed product has a volatile content of 1 - 2 percent. There is a 250 tonnes per day plant in operation at Kemmerer Wyoming, USA. The process is shown diagrammatically in Figure 9.1.

A related process has been developed by the Consolidation Coal Company involving fluid-bed carbonising of high-volatile coal and the subsequent feeding of this char, with possibly some crushed coking coal and returned breeze, to a slightly inclined rotary kiln operating at 450°C. Pellets (12-50mm) are produced in the kiln by the rotary action and the sticky effect of coking coal or pitch. These pellets are carbonised in vertical retorts. The volatile content is below 1 percent, and physically it is said to be the equivalent of oven coke, including its resistance to abrasion. A semi-production plant using this process is under construction at Bethlehem Steel, Maryland, USA.

Sapozhnikov process

This process was developed in the USSR. High volatile non-coking or weakly coking coal is rapidly heated, only slightly de-volatilised, and then hot briquetted. The briquettes are then carbonised in continuous vertical chambers at 850°C. The final carbonisation must be carefully controlled if the high-volatile briquettes are not to be destroyed during the process. It is held that this sequence produces the nearest structural equivalent to oven coke. The process flow diagram is given in Figure 9.1. Problems have been experienced with the process itself in the operation of the first pilot plant. This plant is rated at 3.5 tonnes per hour. A second pilot plant rated at 5 tonnes per hour has now been brought into operation.

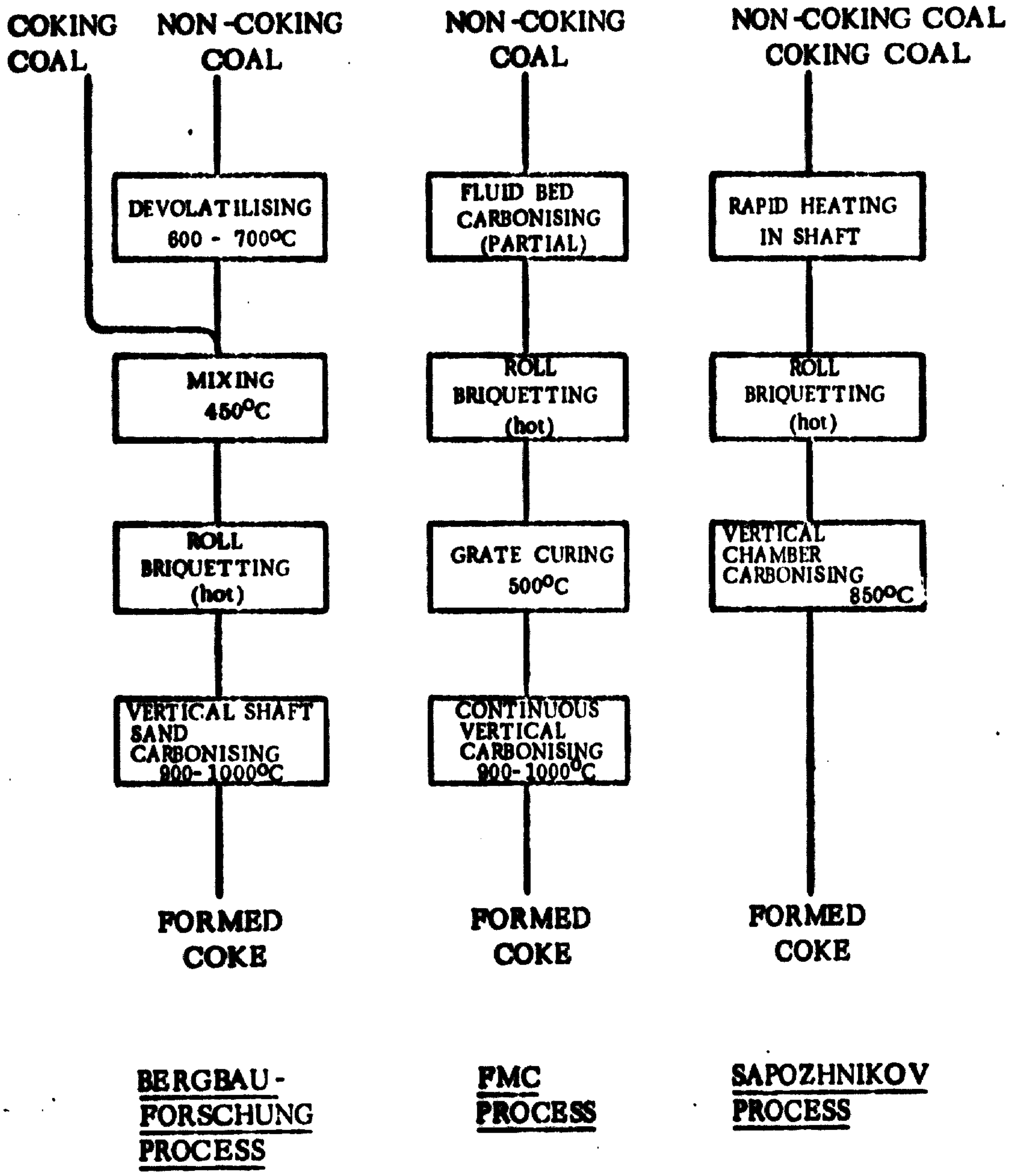


FIGURE 9.1 - FORMED COKE PROCESSES

Of the three processes two of them, BBF and Sapozhnikov, use a certain amount of coking coal. This may be considered as a disadvantage in the sense that it probably increases the cost of the coal feed, but it does appear to simplify the process itself. The FMC process, in which the whole charge can be non-coking coal seems more complex in operation and so probably has a higher capital cost.

A consideration of the advantages and disadvantages of the various processes examined to date is sufficient to conclude that carbonising, either with hot gas or sand, associated with continuous production, will be the means adopted for all future developments in which briquettes are used.

9.2 Properties of formed coke

Consideration of the properties of formed coke is best undertaken by comparing them with those of a conventional blast furnace coke. Typical physical properties of formed coke and conventional coke are given in Table 9.2.

TABLE 9.2 - PROPERTIES OF FORMED COKE COMPARED TO CONVENTIONAL COKE

Material	size mm	weight g	ash db%	sulphur db%	Porosity %	Crushing strength kg	M10	M40	Bulk density kg/m^3
Oven coke	40-100	100-500	9.4	0.86	48 - 53	300	7.5	70	450-500
BBF formed coke	47x60 x35	44	7.0	0.82	59	260	7.1	-	495
FMC formed coke	38x35 x24	19			50	380	7.7	-	480
BBF green briquettes	60x45 x31	60			35	210	9.3	83	578

db = dry basis M10 and M40 = Micum indices (to BSS 1016)

The cokes referred to in the table have similar thermal characteristics.

The bulk density determines the buoyancy of the coke in the binder. It is therefore important that it should be of the same order. The structural characteristics as represented by the crushing strength and the Micum indices are also demonstrated to be satisfactory. Other tests confirm the shatter and abrasion properties. Published figures for both BBF and FMC briquettes show that Micum indices better than

75 per cent above 40 mm, and not more than 8 per cent below 10 mm (good conventional coke) can be achieved.

Both the average size and the size range of blast furnace coke have been considerably reduced in recent years and advanced operating practice now calls for coke lumps between 20 and 65 mm, with no more than 5 per cent less than 10 mm. A great advantage of formed coke is the ease with which briquette size and shape can be controlled to influence the voidage characteristic of the burden.

Much has been written on the subject of coke reactivity but a full understanding of its role has yet to be achieved. The coke must exhibit a reactivity which is high enough to ensure rapid burning at the tuyeres but low enough to enable the coke to reach the tuyeres largely unburnt. The reactivity conditions required inside the furnace are difficult to simulate in the laboratory so that the significance of differences in reactivity performance of formed and natural coke is difficult to assess. There is evidence that the microreactivity of formed coke is higher than that of conventional coke due to its lower carbonising temperature, but this is offset to some extent by the reduced ratio of lump surface area to volume, and hence lower bulk reactivity of the regular shaped briquette. There is insufficient experience of blast furnace operation using formed coke to determine whether this difference is important.

The chemical analysis of both formed coke and conventional coke is largely determined by the analysis of the original coal. Good metallurgical coal will produce a coke with ash content below 8 per cent and sulphur below 1.0 per cent. Non-coking coals with a comparable analysis are available.

It can be seen from the above discussion that formed cokes can be made with individual properties comparable to those of conventional coke. The blast furnace operator, however, is interested in the properties of formed coke only inasmuch as they affect his furnace operation in three respects: (i) productivity, (ii) coke rate per tonne of hot metal, (iii) hot metal analysis. Such operating characteristics can only be determined by blast furnace performance trials.

9.3 Blast furnace ironmaking trials with formed coke

Those engaged at the present time on blast furnace ironmaking trials using formed coke have exhibited a certain reticence over the results of their work. While some information has been released, much of the information essential to a determination of the relative success of the trial has been withheld. This is no doubt an indication of the commercial value which the ironmaking industry attaches to formed coke.

Recently several ironmaking trials have been carried out in various countries including West Germany, the UK, the USSR, and the USA. The results of these trials have indicated that formed coke can become a substitute for conventional metallurgical coke. Some of the important aspects of these trials are described below.

The trials which were carried out in West Germany using formed coke produced by the Bergbau-Forschung process were reported to yield promising results. The blast furnace on which the trials were conducted has a 6.8 metre hearth diameter and normally, on conventional coke practice, produces between 1,250 and 1,350 tonnes of hot metal per day. The furnace operation was said to be satisfactory during the trial period, although the formed coke consumption was about 18 per cent higher than that of conventional coke. However, having allowed for the higher volatile matter and moisture content of formed coke, the corrected coke requirement* was calculated to be about 2 per cent above the normal value. The furnace productivity with formed coke dropped by about 7 per cent, but this was probably due to coke moisture fluctuations. Uncarbonised 'green' briquettes were also tried without any adverse effect. It has been suggested that if the final stage of carbonising can be eliminated then the cost of the product would be reduced by around $4 per tonne.

The British Steel Corporation have reported that their recent blast furnace trials with 3,000 tonnes of Bergbau-Forschung formed coke at the East Moors works were concluded satisfactorily. A ten year development programme is now in operation leading to the installation of a 0.25 million tonnes per year formed coke plant by 1980. A trial with FMC formed coke is planned in the near future, in order to compare the characteristics of BBF and FMC cokes.

The ironmaking trials which were carried out in the USSR used a mixture of 50 per cent conventional coke and 50 per cent formed coke. The blast furnace used in these trials has a working volume of 750 cubic metres. The results were certainly encouraging in that the furnace productivity was increased by over 4 per cent with less than 1 per cent increase in coke consumption per tonne of hot metal produced. Further tests are planned with 100 per cent formed coke as reductant in the blast furnace charge. Also, they have announced they will build a 1 to 1.5 million tonnes per year formed cokemaking plant by 1975.

The trials on the US Steel Corporation's experimental blast furnace (1.2 metres hearth diameter) using 100 per cent FMC formed coke briquettes as reductant are reported to show relatively small variations in coke rate and furnace productivity from normal operations based on conventional coke practice. Following these trials, full-scale tests were arranged at the steelworks of Armco Steel Corporation. During these tests the furnace operation was greatly affected due to high fines content of the formed coke charge. As a result of these findings, the FMC process has been modified to produce formed coke of improved properties.

9.4 The future of formed coke for the blast furnace

It is our firm belief that the blast furnace will continue to dominate iron making for the next two or three decades and the present property requirements for blast furnace solid fuel will change very little. The blast furnace trials conducted so far have shown that formed coke can be used as a substitute for oven coke and that it is likely that it will produce very little difference in blast furnace coke rate.

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* for definition see Appendix 1

Since formed coke can compete on technical grounds with conventional coke its future depends on the relative costs of oven coke and formed coke, taking into account any small differences in coke rate or furnace productivity.

At this stage published data does not permit an assessment of the costs of commercial production of formed coke, although at least ten countries are reported to have commercial or pilot plants in operation. However, from a consideration of the processing requirements it seems reasonable to suppose that the capital costs of formed coke plants are higher than those of slot oven plants, particularly since the more promising processes are multistage compared with the single stage of conventional coke oven plants. They can, however, be operated continuously and this means that their operating cost may well be lower than those of slot oven batteries. Taken together, capital and operating cost of a formed coke plant may thus be comparable with that of a modern conventional oven. The much smaller by-product yield of formed coke plants will, however, reduce the revenue from this source, although some plant operators might not regard this as a serious problem since the value of coke oven by-products is dropping, as noted in Article 8.7 The distribution of costs between centres for conventional and formed coke is set out in Table 9.3.

TABLE 9.3 - BREAKDOWN OF COKEMAKING COSTS

($ per tonne of coke/formed coke)

Cost centre	Conventional coke ovens	Formed coke plant
Coal coking blend @ 24$/t	37	-
non coking @ 20$/t	-	31
Capital charge	6	9.5
Operating costs (inc. works services)	5	4.5
	48	45
By product credits	7	4
TOTAL	41	41

The conventional plant costs are based on a 1.5 million tonnes per year installation. The formed coke costs are estimated for a plant of similar capacity. It is clear that the most significant factor in the cost of cokemaking is the cost of the coal. The price differential between metallurgical coal and non-coking or weakly coking coal is therefore crucial in determining the economic advantage, if any, of formed coke for a particular application.

The costs given in Table 9.3 are appropriate to a European site where the coal has to be imported regardless of quality. Under these conditions, the price is much the same for either type of coke. This is, however, insufficient incentive to use formed coke. At the present state of development some allowance for risk in the new process is essential. It is probable that a differential of \$4 to \$6 per tonne in favour of formed coke will be necessary to bring about large scale adoption of the process. Locations with local sources of non-coking coal may be able to show differentials of \$8 to \$10 per tonne between coking and non-coking coals. In these circumstances formed coke production should be seriously considered. Such differentials are unlikely to be general so that most installations built during the next decade will be for large coke consumers to reduce their absolute dependence on coking coal.

The growth of cokemaking capacity generally is low, being much lower than that of ironmaking capacity. The predicted annual growth in world iron production is approximately 5 percent over the next five to ten years but the fall in world average coke rate is likely to be approximately 2 percent per year. Thus the demand for blast furnace coke will only increase by about 3 percent per year. Also many coke oven installations are rebuilt rather than replaced. For example, during the years 1957/67 nearly half the coke ovens completely rebuilt in the USA were reconstructed within the original framework or rebuilt on the original pad. Many of the improvements discussed in Chapter 8 can be incorporated in the rebuilding so that a higher capacity installation results.

These factors lead us to the conclusion that commercial production of formed coke will grow slowly. It may be expected to gain ground most rapidly in those countries where two circumstances favourable to formed coke exist. First, these countries will lack suitable coking coal but possess non-coking coals of acceptable analysis. Secondly, they will have an above average rate of growth of iron and steel production with consequent demand for new coke making facilities. There may also be occasions when formed coke breeze is needed for sintering. With very low coke rates in the blast furnace and with 100 percent of the iron ore being charged in the form of sinter, the total quantity of coke breeze used in the sinter plant approaches a quarter of the coke used in the blast furnace. Formed coke breeze or perhaps carbonised but unbriquetted material should be suitable for sinter plant application; this is an area where strength is unimportant and reactivity a little less important than in the blast furnace.

CHAPTER 10 - BLAST FURNACE IRONMAKING AND ELECTRIC SMELTING

10.1 Blast furnace development

The blast furnace is firmly established as the principal method of ironmaking and today about 99 percent of the world's iron production comes from this process. The developments which are taking place in blast furnace ironmaking technology are directed towards still further cost reductions. To assess the relative importance of various aspects of the process in these developments it is necessary to examine how the costs of the ironmaking operation are made up. Table 10.1 shows a typical breakdown of the total cost of blast furnace iron at a capacity of 3 million tonnes of hot metal per year, using run of mine ore with about 64% Fe content.

TABLE 10.1 - BREAKDOWN OF BLAST FURNACE IRONMAKING COSTS

Item	$/t (hot metal)
Iron Ore - ROM ($14.5/t)	22
Coke ($41/t)	20
Other materials and all conversion costs	4
Capital charge	6
less Credits (< $0.5/t)	-
	52
Allocation of general works services and working capital	6
TOTAL	58

From this breakdown it can be seen that the largest costs are for raw materials. As discussed in Chapter 7, there has been a steady trend over the past twenty years towards raising the Fe content of the ore charged so that nowadays it is common for the burden to contain lump ore or agglomerates with Fe contents of over 60 percent. Short of charging reduced products or scrap, there is little scope for raising the Fe content of the metallic charge further. Consequently the ironbearing materials have ceased to be an important subject of study for cost reduction. On the other hand, there are still opportunities to reduce the amount of coke consumed. Both coke and its substitute, formed coke, are relatively expensive fuels besides occupying valueable space in the blast furnace. Much current development is devoted to reducing the coke rate. This work will continue.

The other costs detailed in Table 10.1 are much smaller and savings in these will have only a marginal effect on the total cost of hot metal. Nevertheless, worthwhile savings in capital cost that are reflected in the capital charges may be possible through the application of advanced technology. Higher performance materials, better understanding of the complex reactions within the furnace and the application of automation are all contributing to cost reductions due to increased productivity. (For discussion of automation in blast furnaces see Chapter 24, Article 24.2.)

It is in these two fields of technology, coke rate reduction and increased unit throughput that development trends are taking place.

10.2 Size and output of blast furnaces

The most notable trend in blast furnace development has been the rapid increase in size, which together with richer burdens has led to very big increases in output; these have been greatest in the USSR and Japan. Figure 10.1 shows the increase in best world production up to 1971, when over 8,000 tonnes per day was reported at Nagoya No. 3 furnace in Japan. In Japan there are now 23 furnaces with working volumes over 2,000 cubic meters, each producing in excess of 4,000 tonnes of hot metal per day, and there are four furnaces with volumes over 4,000 cubic meters. The biggest blast furnace in the world at present, in terms of volume, is reported to be at Fukuyama, Japan, with a working volume of 4,200 cubic meteres. This furnace has recently been commissioned and has an output of 11,000 tpd. The coke rate is 395 kg per tonne of iron with oil injection averaging 47 kg per tonne of iron. It has a 4-bell charging system. A similar unit in France is due for commissioning in 1973, while a furnace of 5,000 cubic metres is planned in the USSR. It is to be expected that within a few years a furnace of 12,000 tpd will be a reality since such furnaces are at present being seriously discussed. The following description of the No. 1 blast furnace at Nippon Steel's Oita works is typical of these larger furnaces:

> "This furnace has a daily output of 10,000 tonnes of pig iron. Its useful working volume is 4158 cubic metres with a hearth diameter of 14 metres. It has 4 iron tap holes, 2 slag notches and 38 tuyeres and has incorporated the latest evaporative stave cooling plates of the blast furnace. It will have a maximum top pressure of 2.4 atm.(35.5 psi) and a blast temperature of 1250°C.

The growth in furnace size will finally be checked by technical or operational limitations but, at the present time, there is no consensus of opinion in authoritative circles over the limiting factors. Blast penetration, uniform operation, structural problems and materials handling are all possible contenders. Operational problems arise from the difficulties of ensuring a uniform distribution of the burden over the cross-section of the furnace stack during charging, and a uniform flow of gases over the cross-section with the blast entering only around the periphery - difficulties that clearly will become more severe as the diameter increases. Structural problems arising from the increasing weight of the furnace have been overcome so far by supporting the furnace top structure on separate columns instead of on the furnace shell itself, as was common practice in some countries until very recently. Materials handling becomes increasingly difficult because in order to dispose of the iron at the rate at which it is produced in large furnaces it is necessary to use more than one tap-hole. Two tap-holes are now common on the larger furnaces and four tap-hole

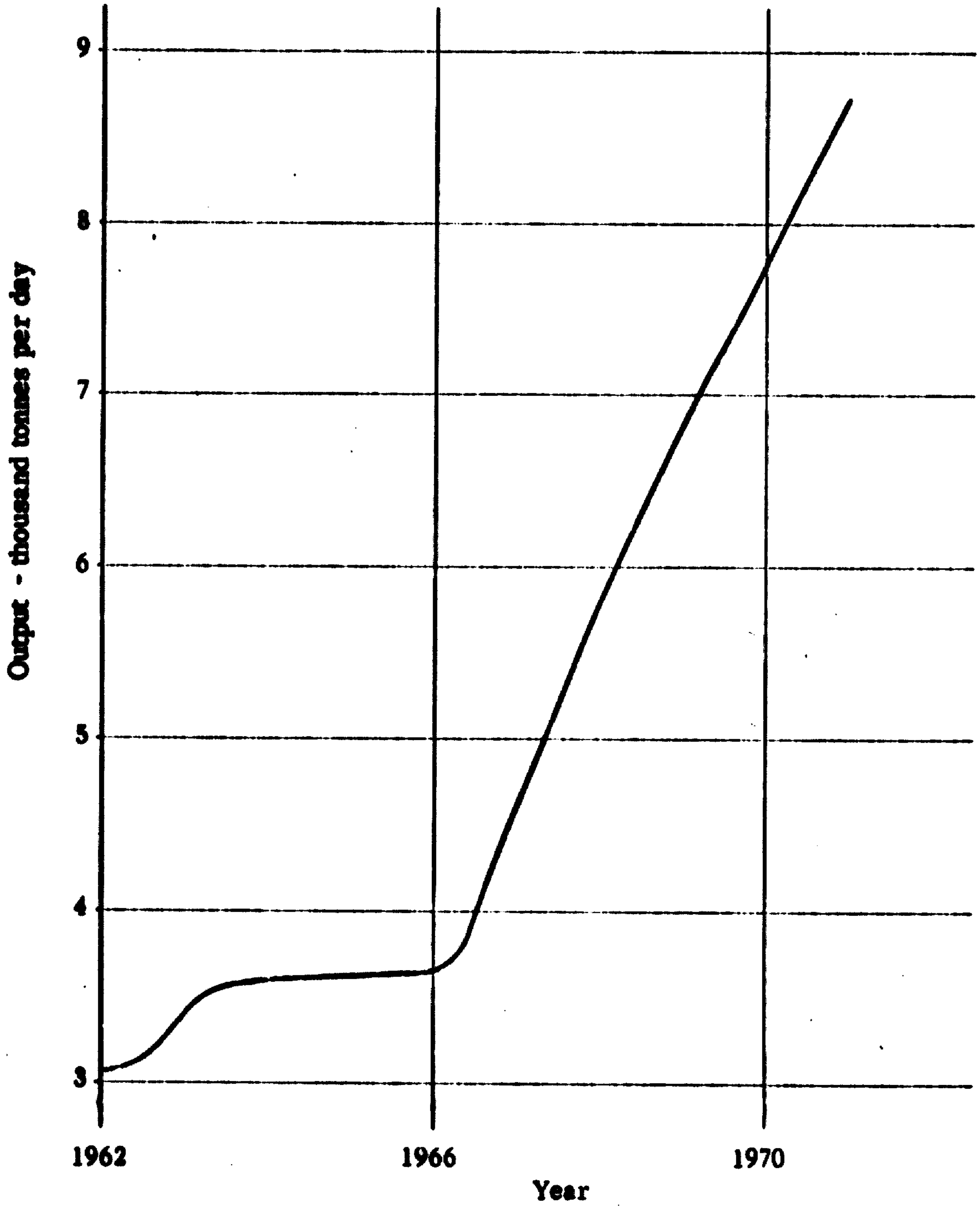

FIGURE 10.1 - BEST WORKS BLAST FURNACE OUTPUTS

arrangements are used in the very largest furnaces. Multiple tap-holes lead to a demand for more space in the cast house, which has led to a removal of the stockline bunkers to a more remote location and the practice, now almost universal in new furnaces, of feeding the furnaces by conveyor belt rather than ship's hoist. Even with this provision, disposing of both iron and slag presents difficulties; with a four tap-hole furnace the tapping of iron will be almost a continuous process. It is generally agreed that operational and engineering difficulties will not halt the growth in furnace volume until a hearth diameter of around 15 metres is reached. This should still allow a very considerable increase in output and may well enable 16,000 tpd to be achieved, the level of output the British Steel Corporation have suggested to be the limit. On the present rate of growth, it seems possible that this will be achieved by the end of the decade.

Furnace output is closely correlated with hearth diameter and furnace volume. As a rough guide, furnace output ranges between 2.5 and 3 tonnes of hot metal per cubic metre per day for modern high performance installations. However in comparing best practice in different countries account must also be taken of burden weight per tonne of hot metal and of coke rate. In Japan slag volumes of 250 kg per tonne of hot metal are normal practice on the high output furnaces. In many other countries slag volumes are often around 350 kg per tonne. This is due to the use of slightly lower grade ore, and sometimes to the need to maintain high slag volumes to accommodate the relatively high sulphur content arising from the coke. In the UK for example a coke sulphur content of 0.9 - 1.2 percent makes furnace operation at less than 350 kg of slag per tonne impracticable.

A useful index for comparing performance of large blast furnaces (see Appendix 1) is the expression

$$\frac{P(0.02B + 10)}{72(3.3D - 10)}$$

where P = Production of hot metal - tonnes per day
B = Burden weight - kgs per tonne hot metal (excluding coke)
D = Furnace hearth diameter - metres

The expression takes into account burden weight and hearth diameter but is valid only for furnaces with diameters more than 6 metres. (A modified index is available for furnaces with diameters less than 6 metres). The index is used in the UK where the average value is 70. Today an index of 100 is considered good practice by world standards and the UK steel industry is planning to achieve indices of 100 - 120 on the 10 - 12 metre blast furnaces expected to be built during the next few years. An illustration of the advanced state of the Japanese steel industry is given by the fact that in 1968 the best performance produced an index of 130 and the present-day best is about 170.

Having pointed out the extremely high outputs of best world practice, it is pertinent to observe that average furnace output throughout the world is still only approximately 1,000 tonnes per day, as Figure 10.2 shows. A continuation of the present world trend would lead to an average world output of about 1,600 tonnes per day in 1980.

Although in general terms the economies of scale favour the largest units, in practice the total capacity of the steel industry undergoing expansion also influences the size of furnaces installed. Thus the largest units are inappropriate to countries having low annual capacities. The maximum size of the furnace is set not only by the complexity of factors determining the total size of the works, but also by the fact that it may be economic to divide the iron production between two or more blast furnaces to match expansion of the ironmaking with the development of other parts of the works.

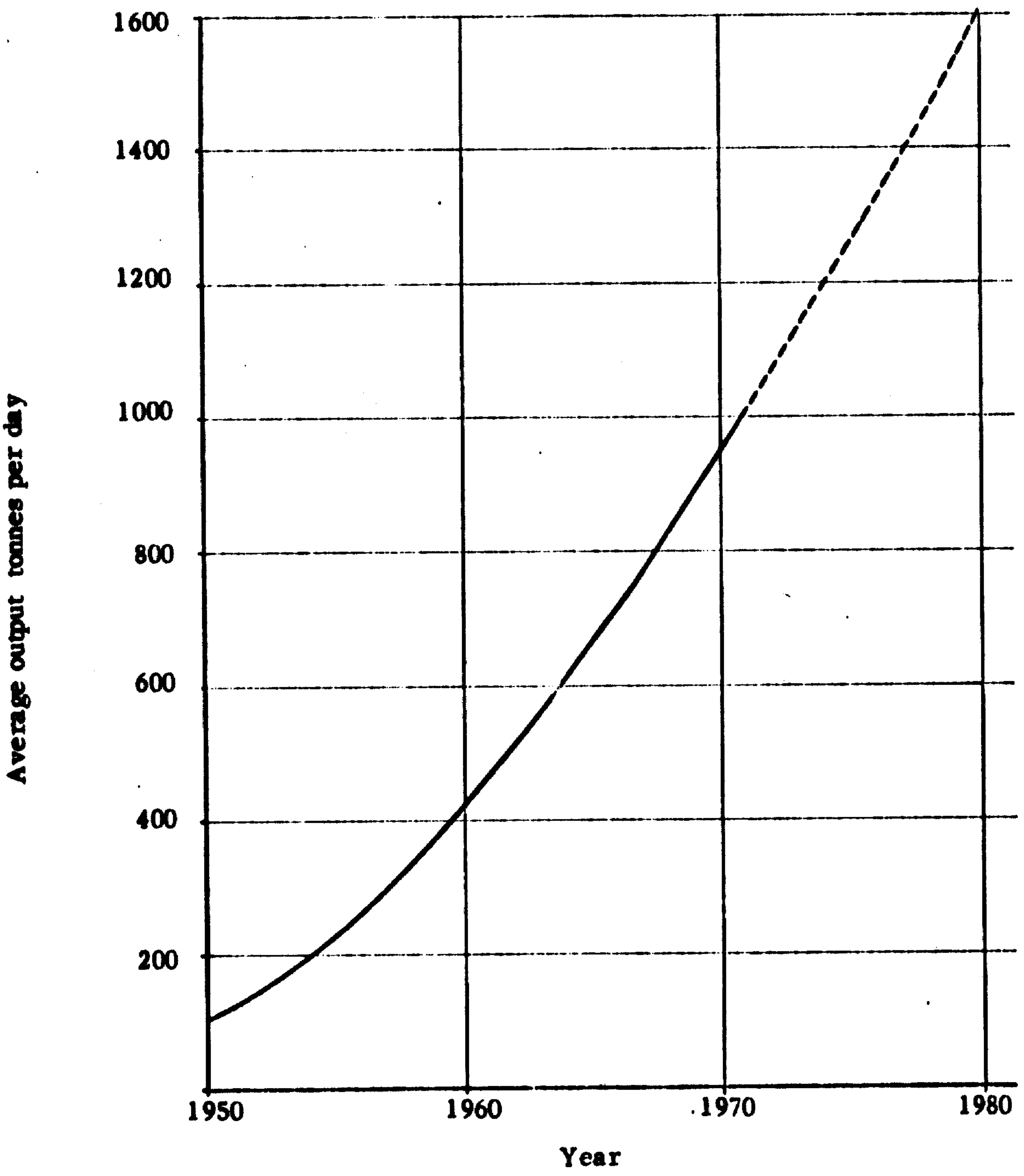

FIGURE 10.2 - WORLD AVERAGE BLAST FURNACE OUTPUT

Figure 10.3 illustrates the economics of scale of installations having one, two, three or four blast furnaces. Based on costs of a number of large modern works, there appears to be little economic advantage in producing iron in installations having outputs greater than 10 million tonnes per year. The full line in the Figure is an indication of the general level of unit conversion costs achievable at any level of output. The introduction of larger blast furnaces will lower this curve slightly especially in the band 2 to 8 million tonnes per year but is unlikely to effect the cost above 10 million tonnes per year.

Table 10.2 shows a breakdown of the comprehensive conversion costs at different levels of output. The unit costs of iron ore, coke, credits and working capital have been excluded from calculations of cost for this figure and for this comparison. To obtain total costs of hot metal, $45/tonne must be added to the comprehensive conversion costs to account for the items omitted.

TABLE 10.2 - B.F. IRONMAKING COMPREHENSIVE CONVERSION COSTS
($/tonne)

Item	Annual output - million tonnes		
	1.0	3.0	10.0
Consumable and maintenance materials	1.6	1.5	1.5
Fuel and energy	1.2	1.2	1.2
Utilities	0.6	0.6	0.6
Labour	0.7	0.5	0.4
Allocation for works services	4.0	3.3	2.8
Capital charges	7.2	5.8	4.6
TOTAL	15.3	12.9	11.1

10.3 Coke rate

Blast furnace coke rates, i.e. the quantity of coke required per tonne of hot metal production, have been falling throughout the world for many years and further reductions will be achieved. Figure 10.4 shows the change in world average coke rate and Figure 10.5 shows the situation which obtains on large blast furnaces in Japan. It is noticeable in Figure 10.5 that the coke rate fell sharply during the years 1958 to 1964. This was due at first to increased use of sinter and better furnace control. Oil injection began in 1961 and together with other improvements in furnace operation produced a sharp change in coke rate during 1961/62. From that time there has been no marked change in total fuel rate which has remained a little over 500 kg per tonne. The coke rate however has continued to fall as larger volumes of oil have been injected into the furnace and as furnace practice has continued to improve. The current world fuel rate record is about 450 kg of coke and oil per tonne of hot metal recorded in Japan. The best actual coke rate, also achieved in Japan, is 365 kg per tonne.

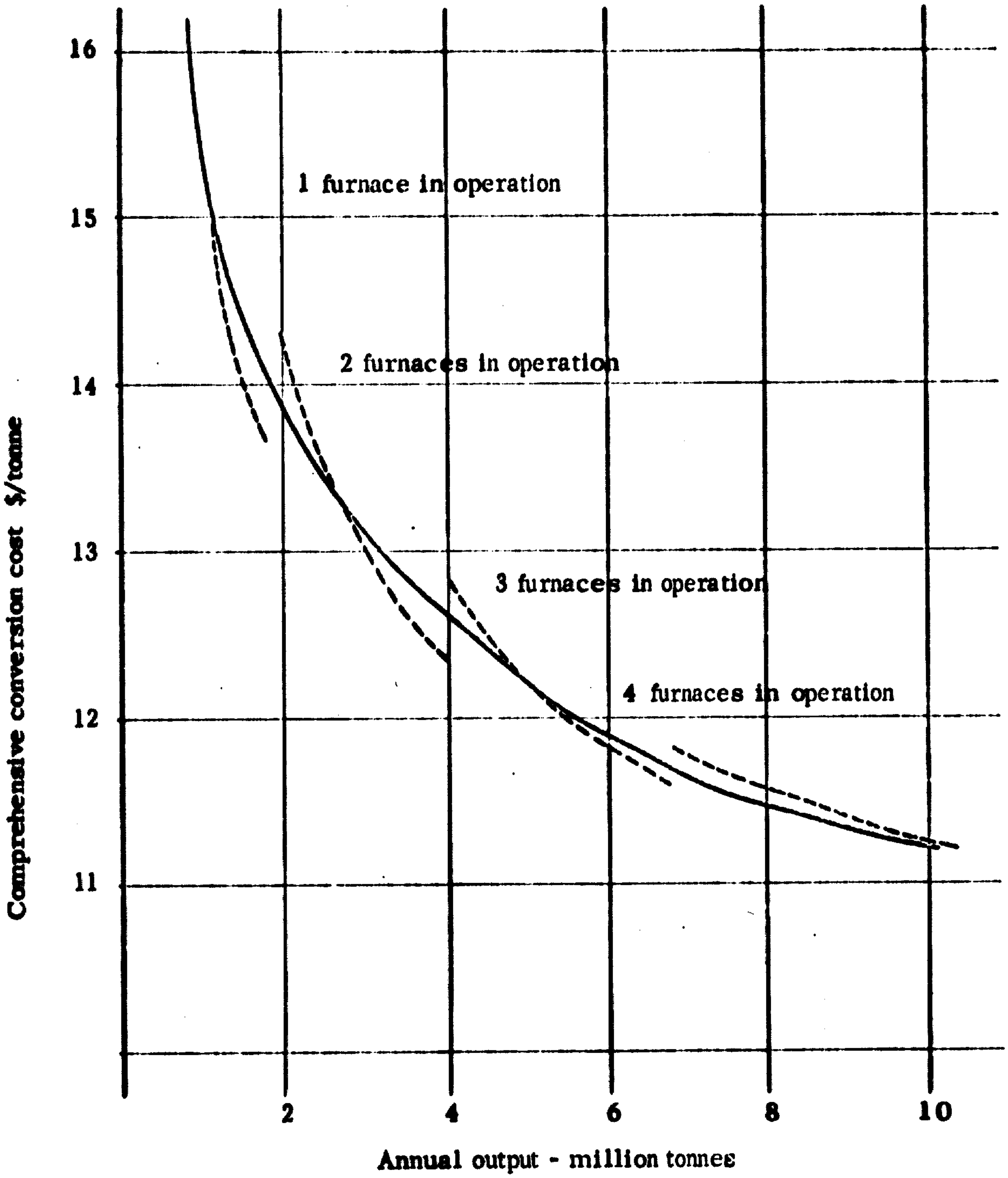

FIGURE 10.3 - TYPICAL ECONOMIES OF SCALE CURVE FOR MODERN BLAST FURNACES

Table 10.3 gives average coke rates for various countries in 1967 and also forecasts made by the Economic Commission for Europe, in that year, of coke rates in 1980. It appears as though the forecasts for Japan are pessimistic since Japanese practice on most large furnaces already lies within the range given for 1980. The same cannot be said, however, for most other countries which are improving more slowly on their 1967 performance.

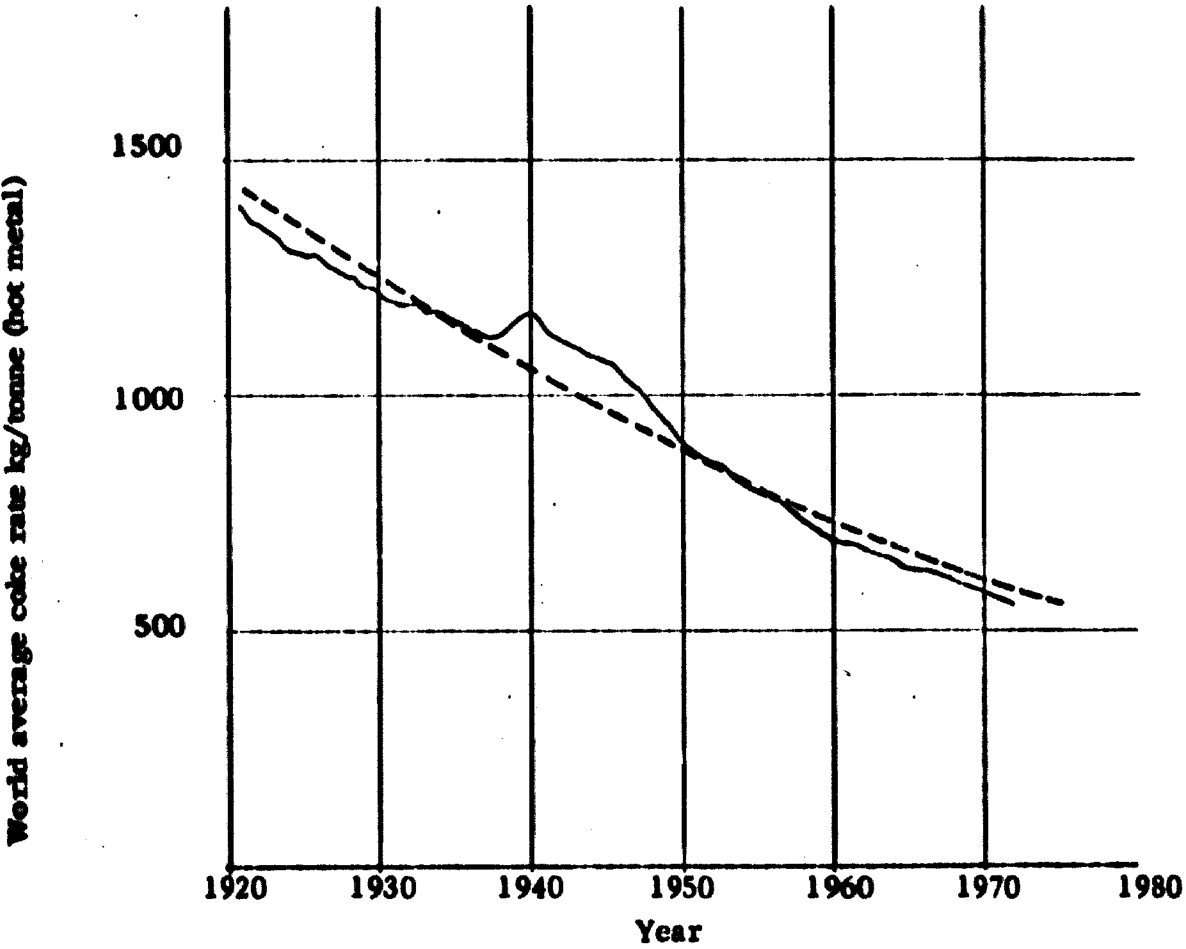

FIGURE 10.4 - WORLD AVERAGE COKE RATE

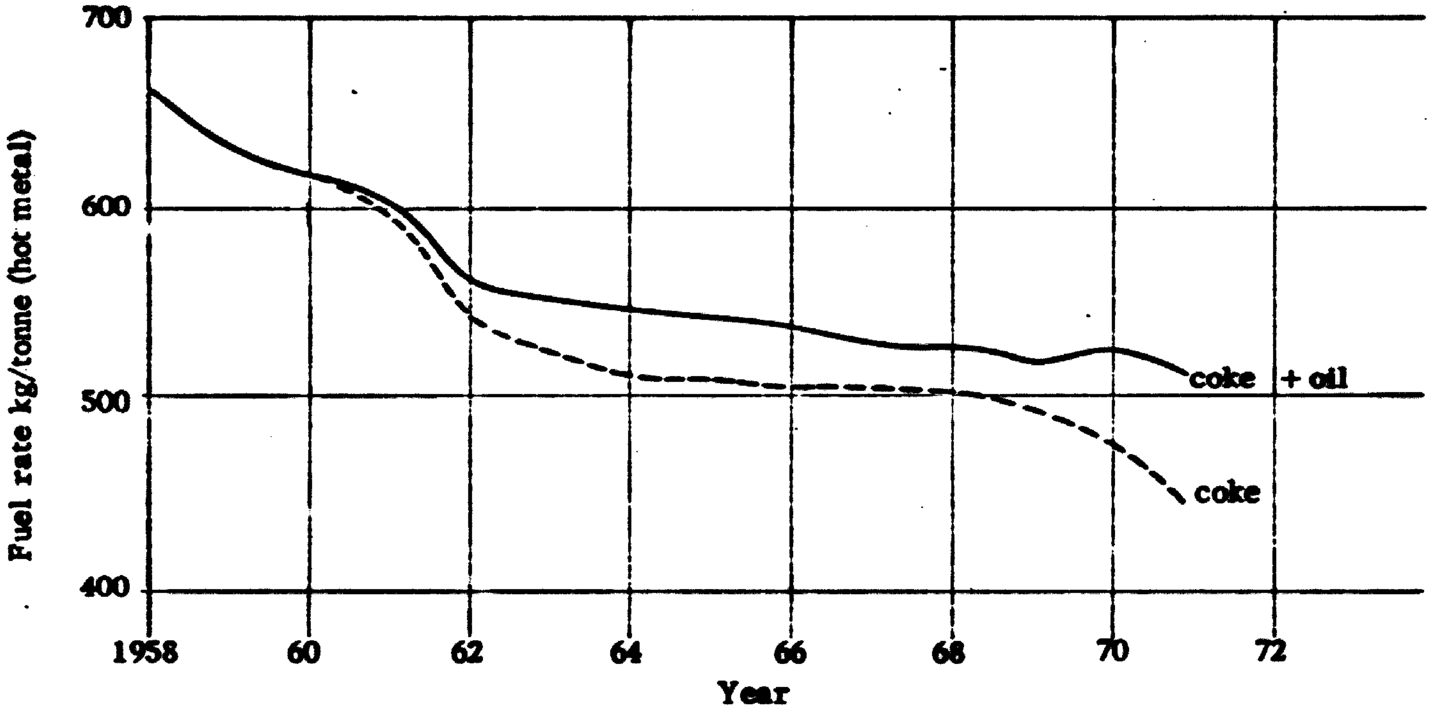

FIGURE 10.5 - TYPICAL FUEL RATES ON LARGE JAPANESE BLAST FURNACE

TABLE 10.3 - TREND OF BLAST FURNACE COKE CONSUMPTION

(kg/tonne of hot metal)

	1960	1967	1980
EEC	890	620	480 - 520
United Kingdom	825	656	490 - 530
Rest of Western Europe		660	490 - 530
USA	749	639	460 - 500
Canada		555	440 - 480
Latin America		700	490 - 530
Africa		773	490 - 530
Middle East			500 - 540
Japan	617	496	435 - 475
India		845	500 - 550
Rest of Asia		790	500 - 550
Australia		608	440 - 480
USSR	711	600	460 - 500
Other East European countries		710	480 - 520
Communist China		867	500 - 550
World		632	470 - 510

The theoretical minimum coke rate necessary to achieve adequate reduction of rich oxide burdens has been stated by Von Bogdandy to be 390 kg per tonne. A substantial part of this can be replaced by oil and in Japan it has been shown that 35 percent of the coke can be replaced by oil. The trial was conducted in 1963 and so it does not follow that at a theoretical minimum fuel rate the same replacement value would apply. Nevertheless, it is reasonable to suppose that 15 to 20 percent of the coke could be replaced by oil and this would bring the coke requirement down to around 320 kg per tonne. There have, in fact, been suggestions in the UK and elsewhere that 300 kg of coke and 70 kg of oil may ultimately be achievable.

It is our belief, taking into account the likely further improvements in blast furnace operating practice and assuming an oil injection rate of 80 kg per tonne, that the coke rate on Japanese furnaces will fall to around 360 kg per tonne by 1980. This is to be compared with a likely world average of around 500 kgs per tonne.

The most advanced large blast furnaces operating in Japan are very close to their limit of technical efficiency, and further large improvements in thermal efficiency cannot be expected. A further reduction in coke rate can be expected but it will be produced entirely by substitution of alternative fuel sources for part of the coke, as discussed in the following article.

10.4 Fuel injection

Oil injection

Fuel oil injection through the tuyeres is used in blast furnace operation more frequently than any other injection practice. In 1966 at least eleven countries were using oil injection, while today most ironmaking countries practice it, and almost all, if not all, new blast furnaces have oil injection facilities built into them. In Japan the practice of oil injection has spread to approximately 80 percent of blast furnaces and is still growing.

The quantity of oil to be injected depends on a number of factors, the most important of which are the relative prices of coking coal and oil, the replacement ratio at which oil can be substituted for coke,and in some cases, the improvement in furnace productivity.

Average oil consumption, on furnaces using injection, ranges from around 25 kg per tonne hot metal in most countries, to 40 kg in Japan. Much higher quantities have been injected in full scale trials; for example, over 100 kg per tonne hot metal were injected very successfully by Nippon Steel Corporation in 1970, and we understand that using emulsifying techniques 135 kg per tonne have been injected in German trials. Various reports predicting high coke replacement rates have been published but it seems rare for long term operational performance to exceed a rate of 1 kg of oil replacing 1.35 kg of coke; in fact some furnaces are operating at a replacement rate very close to unity. Experience has shown that prediction of the replacement rate before installing oil injection on a furnace is unreliable and in practice results are often poorer than the prediction. A typical example of the replacement rate on a large modern furnace is given in Figure 10.6. The maximum level of replacement and the point of onset of rapid fall in replacement rate depend on the furnace practice but it would be unwise to plan to achieve a replacement of more than about 1.3 without using oxygen injection and higher blast temperature.

The effect of oil injection on furnace productivity can be seen from Figure 10.7. The actual rate of increase of productivity depends among other things on blast temperature. The higher the blast temperature the greater is the amount of oil which can be injected but the increase of productivity is less. The figure refers to injection practices in 1965. With improved furnace practice, injection rates around 40 kg of oil per tonne and with blast temperature in the region of 1200°C, an improvement in productivity of 3 to 4 percent can now be expected. Special trials using high injection rates - around 100 kg per tonne - suggest that productivity improvements of 6 to 9 percent may be possible. With oxygen enrichment the productivity improves still further.

The cost of oil injection equipment is small compared to the benefits which can often be obtained from cheaper fuel substitution. Oil injection can easily be installed on existing furnaces.

The trend to increased usage of oil injection and to increased injection rates is very well established. Oil injection can be justified on all blast furnaces where

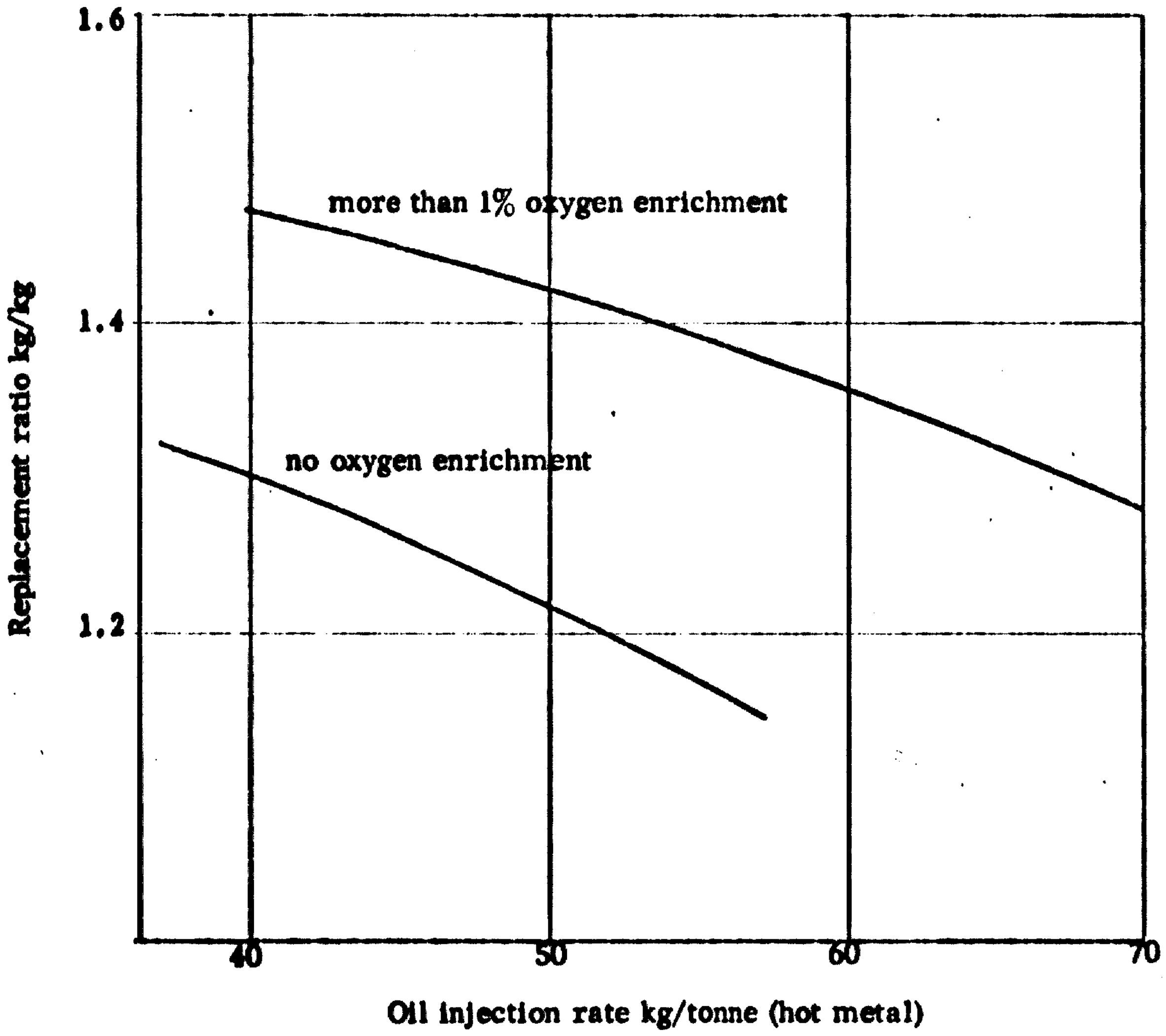

FIGURE 10.6 - EFFECT OF OIL INJECTION IN REPLACING COKE

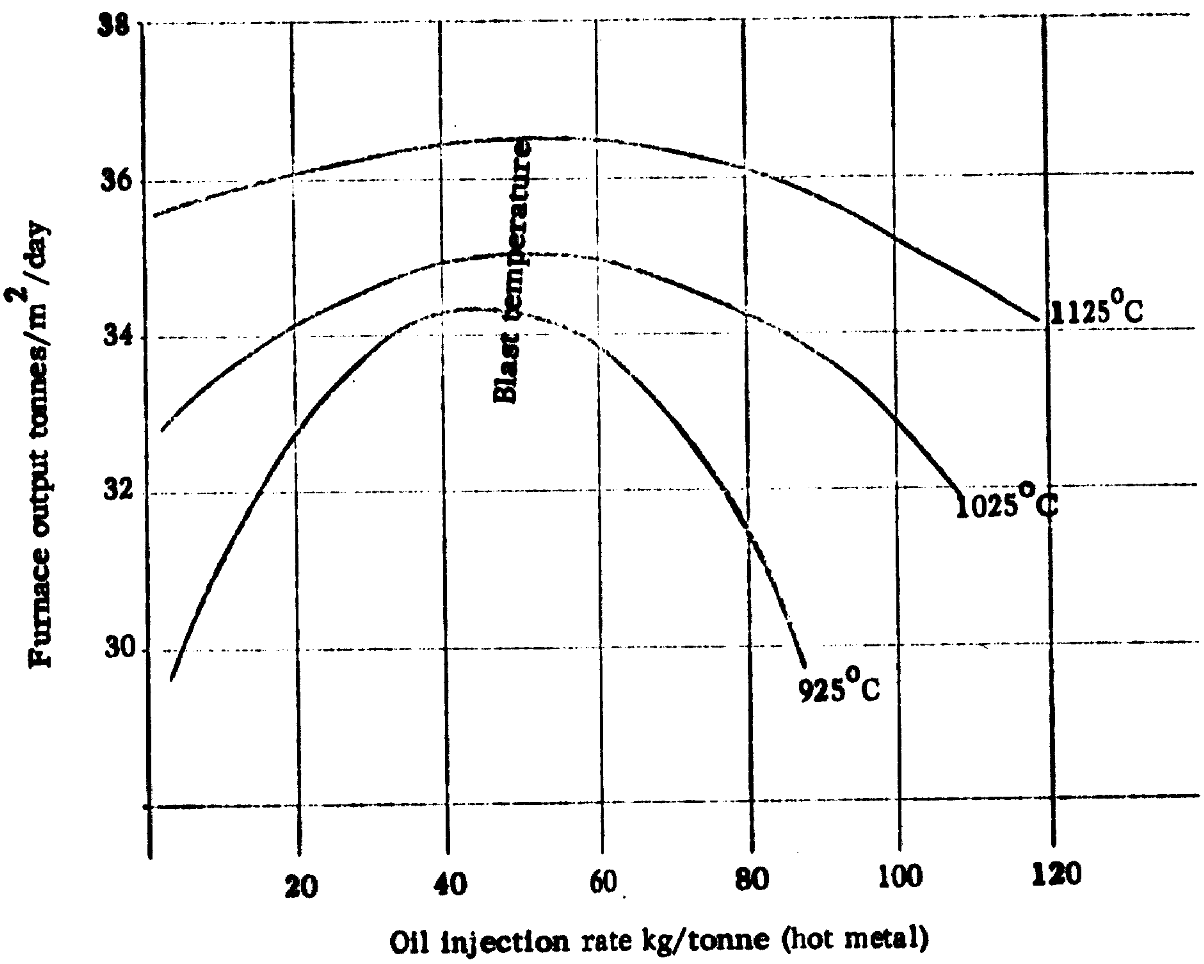

FIGURE 10.7 - EFFECT OF OIL INJECTION RATE ON BLAST FURNACE PRODUCTIVITY

coke costs more per tonne than oil. The growth of oil injection, and its effects and economic advantages, appear to be leading to an average world consumption of 50 to 75 kg per tonne. In cases where the economic advantages of oil injection are very strong, injection rates of over 100 kg per tonne will become common, assisted particularly by recent research on improving oil injection by generating an oil stream of very fine particles.

Gas injection

Injection of gas is not as common as that of oil but is widely practiced in the USSR. In 1965 80 percent of pig iron was produced there in furnaces with gas injection, mainly using natural gas. The effects of natural gas injection are similar to those of oil injection and 1cubic metre of natural gas will replace about 1 kg of coke. A lower replacement volume is achievable for coke oven gas and the improvement in productivity is also substantially lower. Table 10.4 shows the properties of injected fuels. It can be seen that the heat taken up by coke oven gas and natural gas is greater than for other injectants and a correspondingly larger increase in blast temperature is needed, more so for natural gas than for coke oven gas.

TABLE 10.4 - SOME PROPERTIES OF BLAST FURNACE INJECTANTS

	Carbon/ Hydrogen ratio (weight)	m^3/kg fuel		Heat release at tuyere KJ/kg	
		CO	H_2	to CO+H_2	Net *
Coke oven gas	2.2	0.9	2.4	5900	- 6800
Natural gas	3.2	1.6	3.0	13600	- 8400
Fuel oil	7.4	1.7	1.4	6700	- 1200
Low volatile coal	19.1	1.7	.5	8000	- 2200
Coal tar	16.5	1.8	.6	9000	- 2700
Coke	225	1.8	-	10800	- 5800

*net heat release at tuyeres is sensible heat plus heat of combustion less heat required to raise products to 1870°C.

The use of natural gas depends essentially on its availability and is a matter of the relative costs of fuel oil and gas at the works. In most locations it is too expensive. The use of coke oven gas in the blast furnace depends on the demands for coke oven gas from other sources, and is unlikely to warrant consideration except where a surplus exists.

A promising method for reducing the coke rate, developed initially at CRM (Centre de Recherche Metallurgique, Belgium) lies in combining a measure of direct gaseous reduction with the blast furnace operation. To produce metallized iron pellets or ore in a shaft furnace for use in solid form, such as for melting stock in the electric furnace, as low a temperature as possible is desirable. This helps to avoid slag formation and to simplify cooling without subsequent reoxidations. Reducing gas should be injected at a temperature of about 1,000 to 1100°C.

The objective in blast furnace injection is to save as much coke as possible, and to achieve the greatest production possible per kg of coke burned at the tuyere level. To achieve this economy, the reducing gas made outside the furnace by reforming auxiliary hydrocarbons should be introduced at the plastic seam at the temperature of the gases rising at that level (about 1550°C). In addition to doing all the necessary reducing, the gas brings in additional heat which will be used to heat all descending materials in the charge - coke, ore, flux, metallized ore and pellets - and save coke. Otherwise, it would be necessary to charge at the top, dry, preheat in the shaft, and burn at the tuyere level. This process makes it possible to charge more ore per kg of coke, thereby increasing production and reducing coke consumption.

To furnish the additional heat required to smelt the additional metallized ore (or pellets) and the gangue material being brought down into the smelting zone by the injections, it is necessary to use as much additional blast heat as available, and beyond this to use as much oxygen through the tuyeres as is needed to keep the furnace operating properly and to make iron of the desired analysis. This is known as the Raick Double Injection Process.*

Reducing gas introduced above the level of the plastic seam still leaves the necessity of heating the stock column materials descending from this level to the bottom by coke burned at the tuyere level. This coke must be charged at the top, and this limits coke saving and decreases production.

Auxiliary hydrocarbons, whether reformed outside or not, introduced below the plastic seam - even at the tuyeres - will be below the temperature of the rising gases and will limit coke saving and decrease production because coke must be burned at the tuyeres to raise the gas temperature. If the introduction of auxiliary hydrocarbons is properly done, there can be some coke saving and some increase in production. When auxiliary hydrocarbons are correctly introduced at the plastic seam there will be a possibility of a larger coke saving per tonne and a greater production increase than when introduction is made at any other location.

The use of nuclear energy to produce reducing gas for injection in ironmaking is another development which is being closely studied. Shunzo Fujiki, executive vice president of Nippon Steel Corporation, has been quoted as observing that "nuclear energy will in the not too distant future take the leading role among all conceivable energy sources" **

Reducing gases can be produced from fossil fuels, such as heavy oil, utilising nuclear heat. Helium gas, used as coolant for the atomic reactor, emerges from the reactor at about 1,000°C and can be employed in heat exchangers to crack oil into reducing gas (H_2 or $H_2 + CO$). This reducing gas is used either to produce pellets by direct reduction processes (shaft furnace or fluidized bed methods, see Chapter 11), or injected into the blast furnace to reduce the coke ratio. The helium gas is now at a lower temperature and can be employed for steam generation for electric power which can, in turn, be used to melt and refine the reduced pellets in the electric furnace.

* K.G. McGutcheon, "Journal of Metals", Sept. 1971, p. 15.

** "Metal Progress", p. 60, November 1971.

A possible arrangement for injecting reducing gas, formed by nuclear energy, to a blast furnace is shown in Figure 10.8*. In addition to the blast furnace the plant consists of a gas-cooled nuclear reactor, a reducing gas generator and a heat exchanger for recovering heat energy below 800°C. The nuclear energy can be used for the endothermic reforming of fuels to CO and H_2, and also to raise the temperature of the reducing gas up to 1,000°C.

Another example, shown in Figure 10.9, illustrates the possibility of regenerating blast furnace top gas and reinjecting it. However, as the recycling reaction proceeds, the nitrogen content in the waste gas increases, so the injection rate is limited by the decreasing gas permeability in the furnace.

The theoretical amount of heat required for heat loss in the furnace, sensible heat of iron and slag, and heat of direct reduction of SiO_2, MnO and P_2O_5 in the iron requires a typical coke consumption of 220 to 260 kg/tonne of pig iron. However, if nitrogen gas at 1500°C to 1600°C could be supplied and injected as a heat source (under the assumption that there is no hindrance of gas permeability in the furnace) the coke rate would further decrease to 130 to 190 kg/tonne of pig iron. This variation, however, could be said to be another direct reduction process (see Chapter 11) rather than a true blast furnace process. Nevertheless, it is the direct reduction effect of reducing gas injection which leads to the dramatic lowering of the blast furnace coke rate, since under these conditions no coke is required to reduce the iron.

Although many technical difficulties remain before nuclear energy can be used in iron-making on a large scale, it seems likely that at least one major installation will be operating within this decade.

Coal injection

Interest in coal injection in the blast furnace is around 150 years old. Serious interest was shown during the 1950's and 1960's, but the increasing practice of fuel oil injection during this period eclipsed coal injection as a means of conserving metallurgical coking coal. A very wide range of non-coking or weakly coking coals can be injected, the properties and analysis being not very important, with the exception of sulphur and ash content. Trends in the USA and the UK during the 1960's showed that under suitable conditions 1 kg of coal can replace 1.2 kg of coke. Many earlier trials, however, failed to achieve a replacement rate better than unity.

As long as oil injection retains its present economic superiority, there are no real prospects for coal injection. Moreover, we do not expect that within the next ten years the relative prices of coal and oil will change sufficiently to warrant a general awakening of interest in coal injection. Should that time come, however, then it is likely that coal would not be used on its own but in an oil/coal slurry. The use of oil/coal slurries containing up to 40 percent coal have been successfully tried in the past, but these have given way to oil injection. At present, however, there will be a few locations where acceptable non-coking coal can be mined and transported at a price which may justify coal injection in preference to oil.

10.5 Improvements to furnace practice

Oxygen enrichment

Oxygen enrichment is becoming more widely practised and most large modern blast furnaces are designed to incorporate it. Enrichment from 21 percent to 24 percent oxygen is a common advanced practice and in Japan a number of furnaces are operating at around 26 percent oxygen. Oxygen enrichment first became a common practice in the USSR where about one-third of iron is now made in oxygen

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* Transactions of the Iron & Steel Institute of Japan, Vol.11, No.6, 1971, p.422 & 423

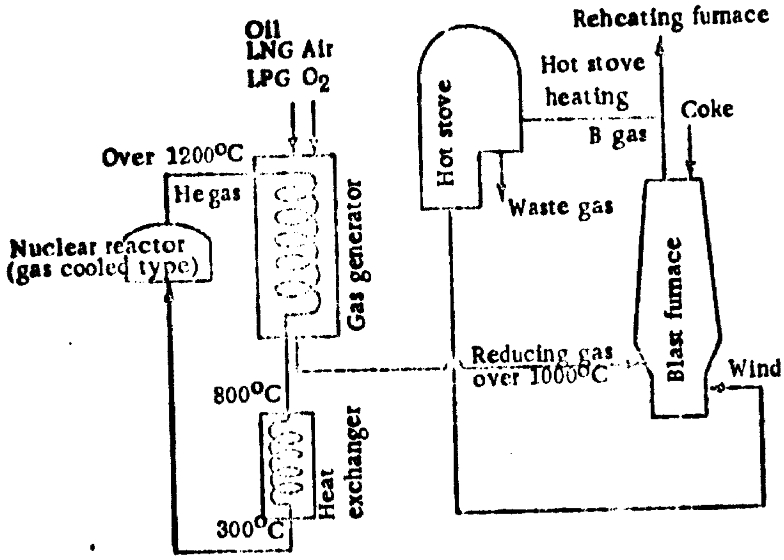

FIGURE 10.8 - AN EXAMPLE OF APPLICATION OF NUCLEAR REACTOR TO BLAST FURNACE (1). REDUCING GAS GENERATION AND INJECTION INTO BLAST FURNACE.

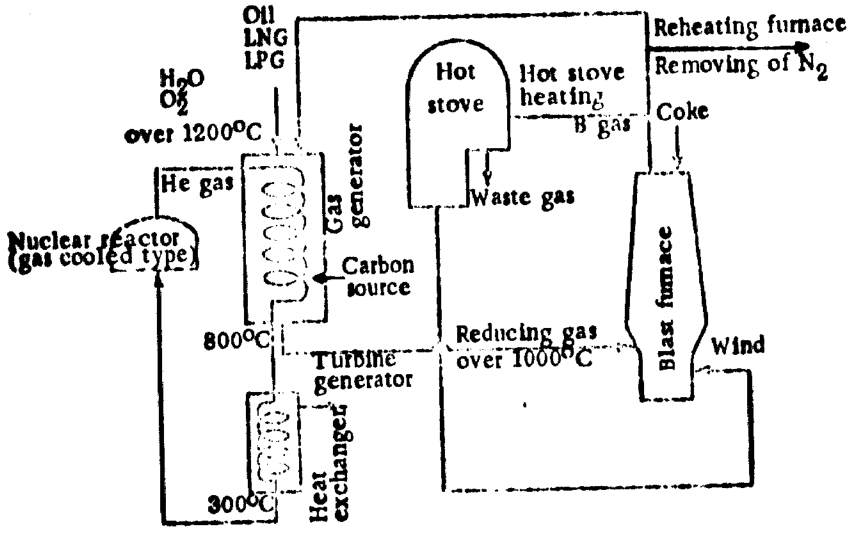

FIGURE 10.9 - AN EXAMPLE OF APPLICATION OF NUCLEAR REACTOR TO BLAST FURNACE (2). REGENERATION OF BLAST FURNACE GAS AND REINJECTION.

enriched furnaces.

Attempts to improve productivity of the blast furnace by increasing the driving rate and so burning coke faster show that a point can be reached, even with high top pressure, when smooth descent is disrupted by the buoyancy effect of an excessively high volume of gas. At this point furnace productivity begins to fall again and coke rate increases sharply. The wind volume can be reduced with oxygen enrichment, which also produces an increase in flame temperature unless compensated. When no other alterations are made to furnace practice, then an increase in oxygen content of say 2 percent, raising it from 21 to 23 percent will produce an increase in productivity of around 10 percent. However, the injection of fuel to reduce the coke rate may require oxygen enrichment to maintain proper operation in the furnace, as in the Raick Double Injection Process mentioned in Article 10.4 above.

More interest now seems to be shown in high blast temperature than in oxygen enrichment as a means of compensating for fuel injection and of controlling the furnace. We believe that the trend towards increased use of oxygen enrichment of furnaces will continue, but that enrichment rates are unlikely to grow much beyond their present levels.

A special instance has been reported* of very highly oxygen enriched blast (about 55 percent oxygen) being employed to enable the top gas from the furnace to be used directly for ammonia synthesis. The practice has now been discontinued because of a change in the requirement for ammonia.

High blast temperature

Increasing the blast temperature has always been an important method of reducing coke rate; the effect is shown in Figure 10.10. The corrected** coke rate falls by around 10 kg per tonne for each 100°C increase in blast temperature. In addition to its direct uses as a coke saver, high blast temperature can be used to compensate for tuyere zone heat loss resulting from fuel injection.

Average blast temperatures have risen steadily over the years and practice on most modern furnaces is around 1150°C, with some furnaces rising to 1300°C. The highest temperature used in prolonged operation is 1350°C. The trends in fuel injection, oxygen enrichment and other blast furnace practices indicate that few attempts will be made to use temperatures in excess of 1350°C, and that in general average practice in modern plants will be to operate at around 1200 - 1250°C over the next five to ten years.

High top pressure

The effect of high top pressure is to enable a large increase in wind rate to be achieved without disturbing smooth burden descent or increasing dust loss. It is now generally accepted that all blast furnaces can economically justify some increase in top pressure above atmospheric, and most authorities believe that all furnaces should be operating at least at 1 atmosphere top pressure. Pressures of between 0.5 and 1.0 atmosphere can usually be achieved by modification on existing furnaces, but provision for higher pressures can be made only at the design stage of a furnace. The trend towards high top pressure in Japan is shown in Figure 10.11. Since the introduction of the technique some ten years ago, it has become very widely adopted. More than two-thirds of all blast furnaces in Japan

* J. Iron & Steel Inst. of Japan 58, No.5, 637 (April 1972)

** the term 'corrected coke rate' is explained in Appendix 1.

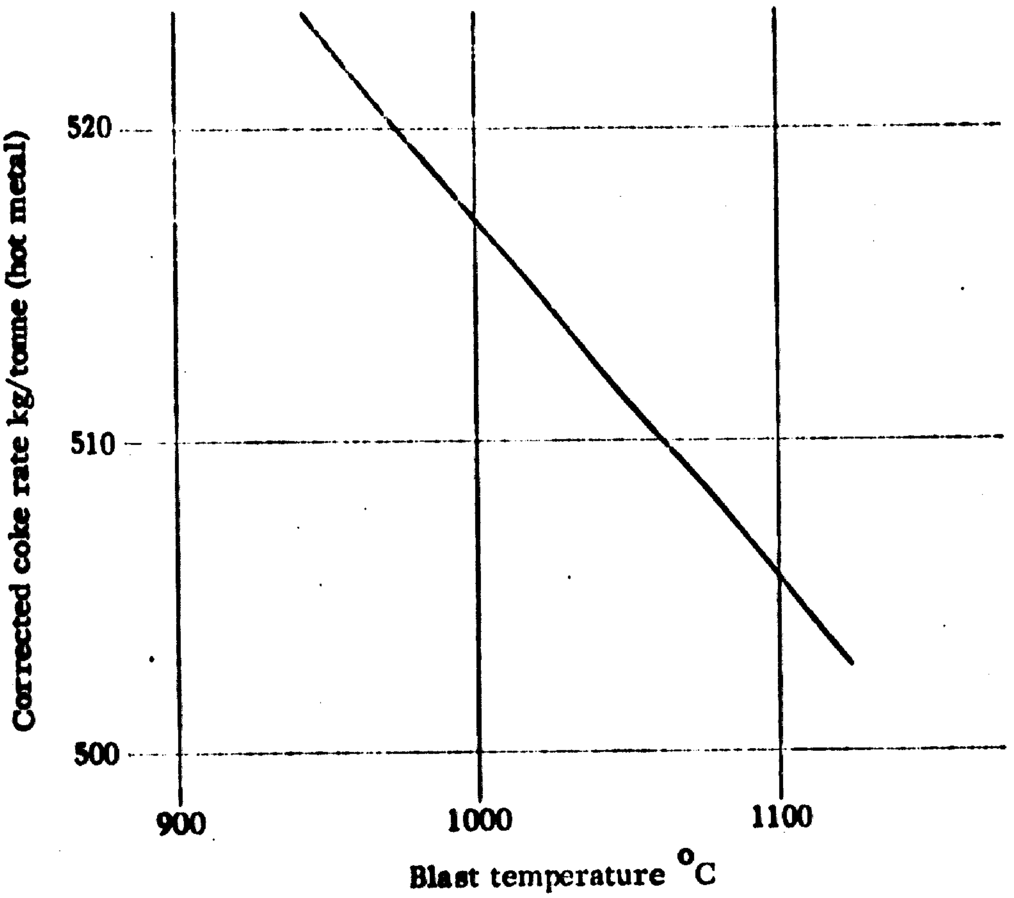

FIGURE 10.10 - EFFECT OF BLAST TEMPERATURE ON COKE RATE

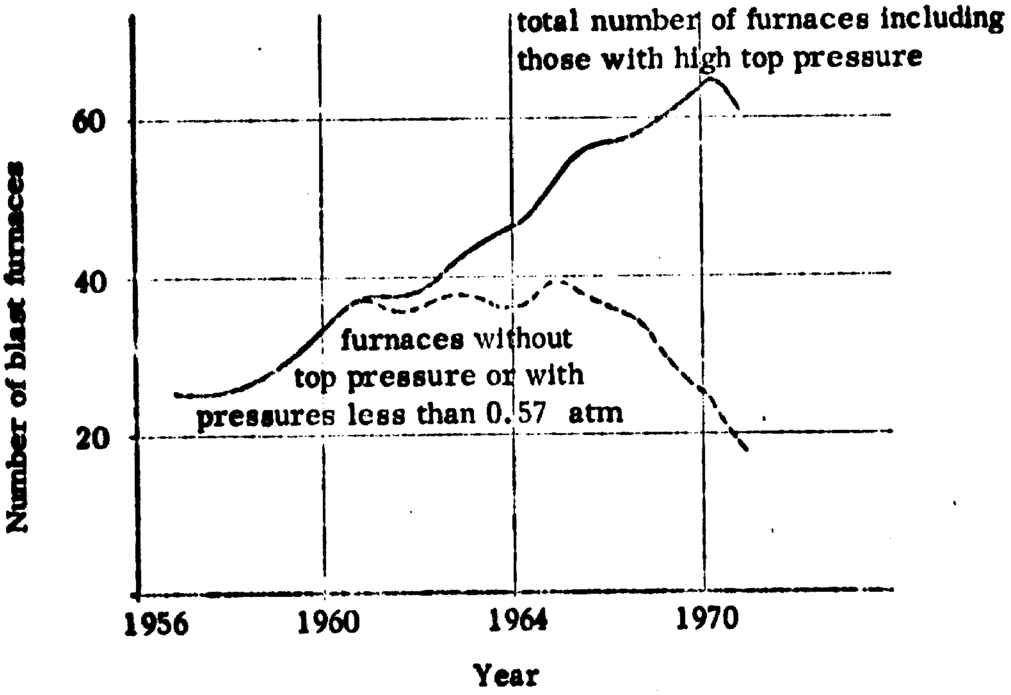

FIGURE 10.11 - USE OF HIGH TOP PRESSURE IN JAPAN

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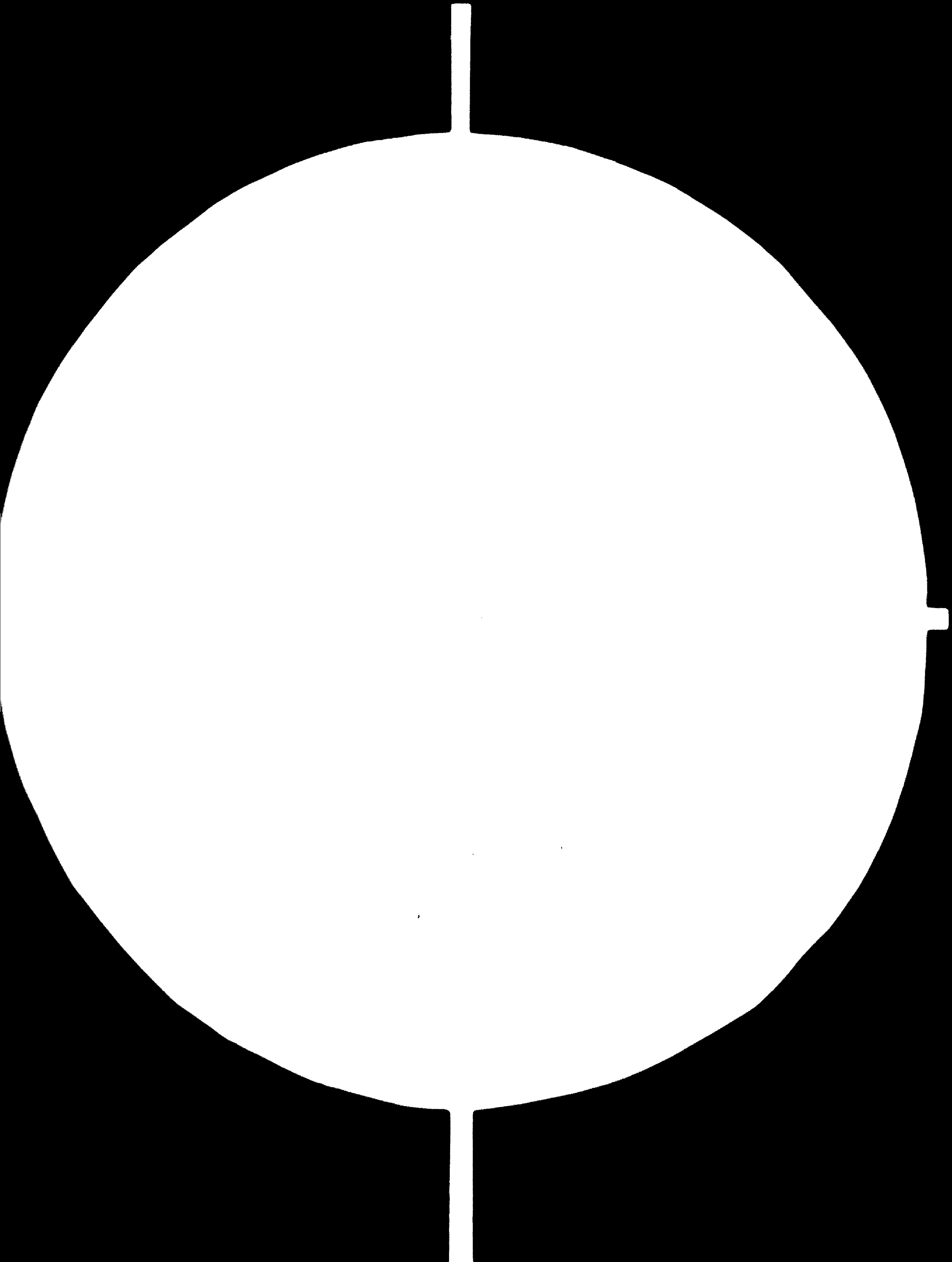

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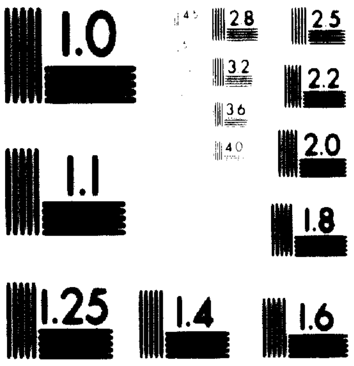

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are now using top pressure. The trend there indicates that well before the end of the decade almost all blast furnaces will employ this technique. The maximum pressure in use today is about 2.5 atmospheres although most furnaces with top pressure lie between 0.6 and 1 atmosphere. In the USSR pressures of around 1.7 atmospheres are used in several places. In W. Europe the advantages of high top pressure were not generally recognised until several years later than in Japan but its use is now becoming more common. World average top pressure is not likely to exceed one atmosphere for many years.

Top pressure has only a small beneficial effect on coke rate but produces an improvement in productivity of around 1 percent for each 0.1 atmosphere.

10.6 Effect of burden preparation

The gradual improvement in coke and burden sizing practice has produced large increases in productivity and large reductions in coke rate. The importance of sizing is now fully accepted as has already been noted in Chapter 7. The drive has been towards the use of smaller and more uniform sizes of lump ore and sinter particles in the furnace. Modern practice involves sizing to 25 to 10 millimetres but still closer limits will be used in future. The effects of sizing practice are shown in the following illustrations. Figure 10.12 shows the importance of sizing all constituents of the burden similarly. Such practice produces the largest increase in productivity. It does, however, have disadvantages, for with the trend toward decreasing particle size of lump ore, sinter and pellets, the maintaining of the coke at the same size as the ore produces an increase in coke rate due to the increased surface area of coke and consequent increased burning above the tuyeres.

The use of pellets in the burden or of carefully sized sinter, produces an increase in productivity, partly due to improved gas flow and partly due to increased surface area for reduction. Figure 10.13 shows the improvement in productivity obtained on a variety of blast furnaces in Germany and the USA by replacing lump ore with pellets in the charge, and thus making higher blast volume possible. Figure 10.14 shows the effect on coke rate of substituting pellets for lump ore in the burden. Tests have shown that the effect on coke rate of similarly sized pellets and sinter is not significantly different; although pellets effect a greater improvement in charge permeability, the bulk reducibility of the two forms of charge is roughly comparable.

It is advisable to practise rescreening of the charge immediately before charging, in order to eliminate fines generated during handling.

We expect that the range of burden particle size considered acceptable for large modern blast furnaces will gradually be reduced further, from between 25 and 10 millimetres to between 20 and 10 millimetres. Tighter specifications will also be applied to coke particles. The result of these requirements will be to cause reduced output of individual sinter and coke plants due to increased recirculation.

10.7 Use of partially reduced iron ore as a blast furnace feed

Reports of tests undertaken on both industrial and experimental blast furnaces confirm that normal smooth furnace operation is not interrupted by the addition of pre-reduced products, and that the hot metal analysis was at least as controllable as with normal charging practice. It has been pointed out, however, by Centro

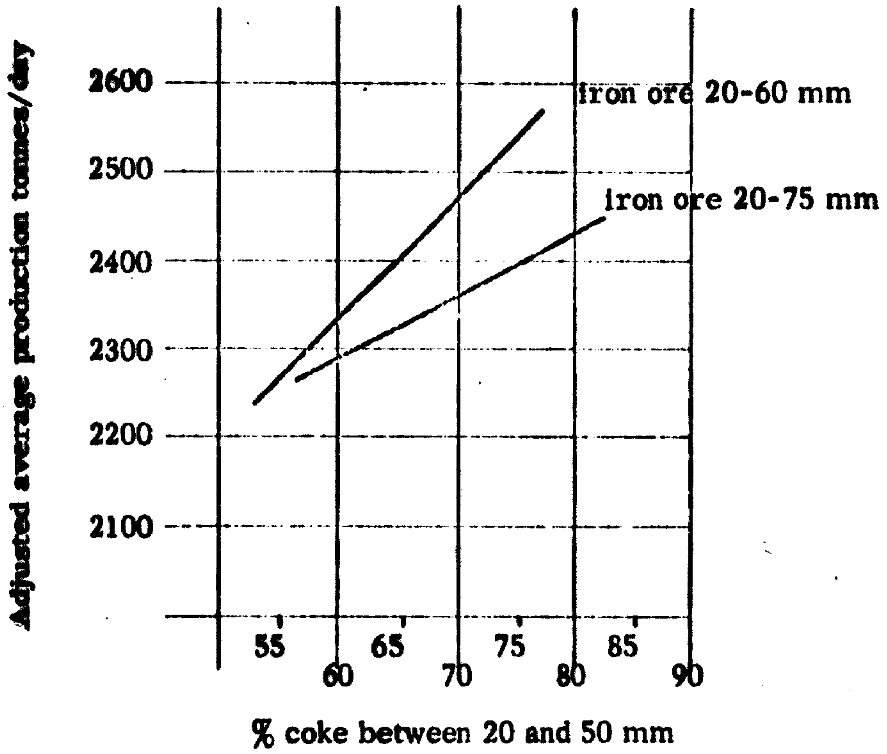

FIGURE 10.12 - EFFECT OF COKE SIZE ON BLAST FURNACE PRODUCTION

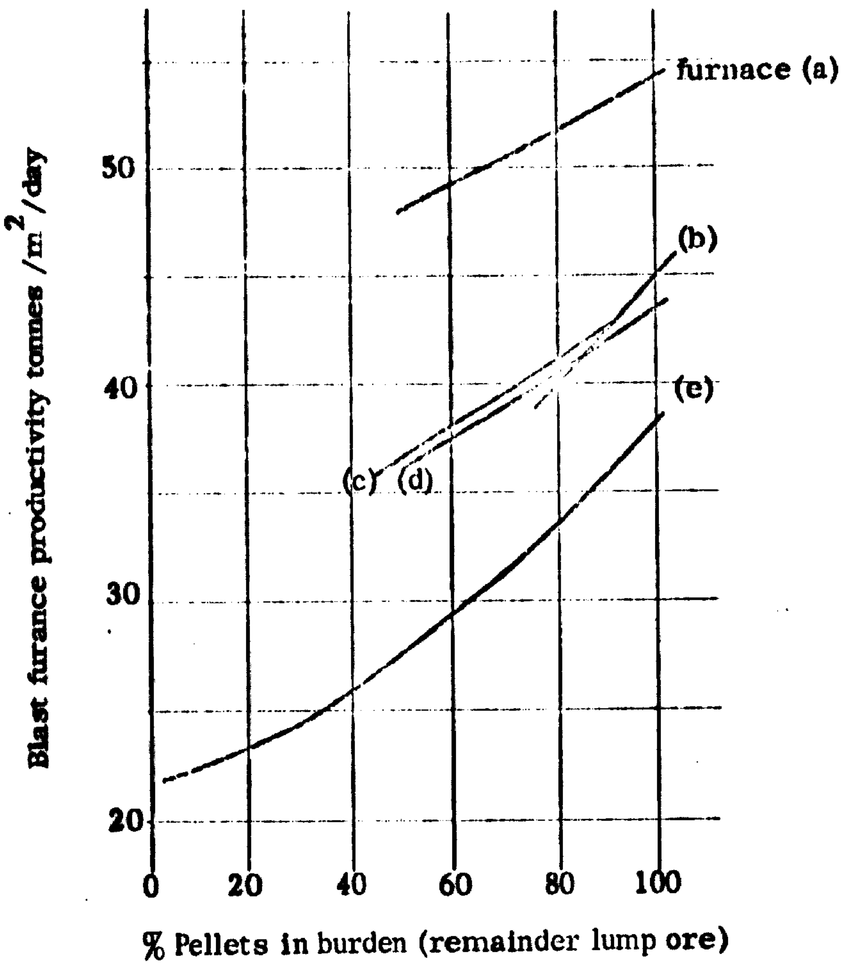

FIGURE 10.13 - EFFECT OF PELLETS ON BLAST FURNACE PRODUCTIVITY IN A VARIETY OF BLAST FURNACES

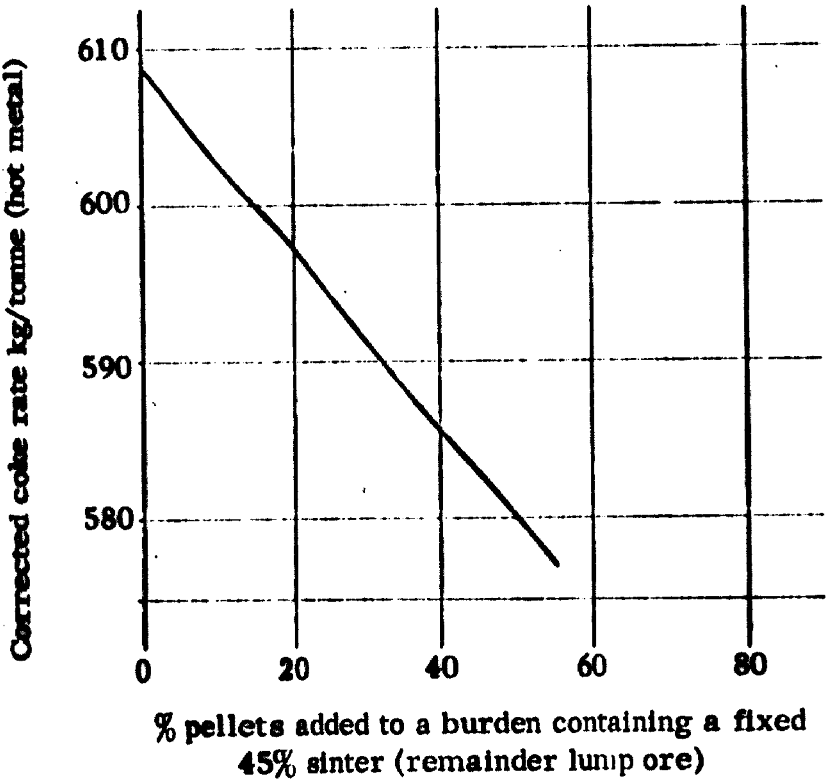

FIGURE 10.14 - EFFECT OF PELLETS ON COKE RATE

Sperimentale Metallurgica in Italy, that the cold compressive strength of North American high grade ore pellets after the onset of reduction falls sharply and rises only slightly as further reduction takes place. These findings are borne out by tests on pellets produced in New Zealand. In view of this phenomenon we find it surprising that performance trials with large quantities of reduced pellets have not reported loss of performance due to burden crumbling and high dust generation.

A new high-iron briquette (HIB) facility at Puerto Ordaz, Venezuela, is being commissioned and operated by Orinoco Mining Co., a subsidiary of US Steel Corporation *. The plant is designed to produce up to 1 million tonnes annually of 75 percent reduced HIB's having an iron content of about 86 percent for use in blast furnaces, or at a lower production rate, briquettes of 92 percent iron content for use in steelmaking furnaces.

In the HIB plant, dried Venezuelan ore is crushed and screened (-10 mesh) and then preheated in a two-stage fluidized bed to about 870°C. The preheated ore is reduced in a two-stage fluidized bed reducer operating at about the same temperature. In the first stage, ore is reduced to iron oxide (about 30 percent reduction) by the off-gas from the second stage of the reducer. Final reduction to 75 percent is accomplished in the second stage with reducing gas generated by steam reforming of natural gas. The hot reduced ore powder is then fed directly into the briquetting machines. The briquettes are cooled to about 65°C before discharge to the stockpile.

A roll-type briquetting press produces 3.8 cm. x 3.8 cm. x 1.3 cm. briquettes. The HIB's have little degradation during handling and with no significant reoxidation.

It is expected that the Puerto Ordaz plant will be in full commercial production later this year.

Characteristics of the briquettes include the ease of storing and shipping a stable, unit-sized product, with consequent lower handling costs. The process also has the advantage of producing a material of uniform quality - always 86.5 percent iron with 75 percent of the oxygen removed.

The principal effects of charging reduced product to the blast furnace are increased productivity and reduced coke rate. Individual test results show that each 10 percent of metallisation of the Fe in the burden results in a decrease in coke rate of roughly 6 percent and an increase in production also of roughly 6 percent. This effect is approximately linear to metallisation values around 80 percent, but probably begins to fall off at higher degrees of reduction.

Several attempts have been made to determine the economics of charging reduced pellets to the blast furnace. Those attempts which show that such a practice can be economical seem to make the mistake of assuming a small price premium for metallising the pellets. The economics are closely linked to the price of coke since the major effect on hot metal costs of a partially pre-reduced burden, is the saving in coke. When coke costs are low then the saving is smaller than when coke is expensive. If a blast furnace burden is pre-reduced to a metallisation around 35 - 70 percent then, provided the pre-reduction can be achieved for a comprehensive conversion cost of not more than $10 - $12 per

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* Journal of Metals, July 1972, p. 3 ; see also Chapter 11, Article 11.2

tonne of iron in the pellet, or around \$7 - \$9 per tonne of pre-reduced pellet, the process can be economical. Other calculations from authoritative sources (private communication) suggest that the saving in production costs is about $2\frac{1}{2}$ percent per 10 percent of burden metallisation. Assuming a hot metal comprehensive conversion cost of \$36 per tonne (see Table 10.1) and a burden metallisation of 30 percent, then the saving is just under \$3 per tonne. If the burden metallisation of 30 percent is achieved by having half the burden metallised to 60 percent, then the cost of pre-reducing that portion of the burden must not exceed \$6 per tonne of iron, or around \$5 per tonne of pre-reduced pellet.

Cost data for the HIB operation at Puerto Ordaz are not yet available for comparison, but taking both of the above examples, in order to secure an economic advantage it is necessary to pre-reduce the pellets for around \$6 to 12 per tonne of iron in the pellets. The present known cost of pre-reduction is considerably in excess of this and there is no prospect of it falling to a level which will warrant serious consideration of pre-reduced pellets for the blast furnace on a permanent basis in the foreseeable future. It is doubtful whether the Orinoco Mining Company would recommend a blast furnace charge of briquettes alone*.

The only occasion on which pre-reduced burdens can be seriously contemplated is when steelmaking capacity is expanded and a small increase in blast furnace output is required to provide the additional hot metal required. A practice using pre-reduced ore or pellets may then be economically justified because it delays the building of a new blast furnace.

10.8 Effect of charging limestone to the blast furnace

The penalty for charging raw limestone to the blast furnace, as opposed to charging calcined limestone together with sinter, is considerable. In the first place, the heat required to calcine 150 kg of limestone is equivalent to that produced by about 10 kg of coke. Thus at a limestone rate of 150 kg per tonne hot metal about 10 kg of coke breeze per tonne hot metal would be required to calcine the limestone in a sinter plant. In a sinter plant all the carbon is burnt to CO_2 but in a blast furnace not all the carbon is converted to CO_2, and thus if calcining is undertaken in the blast furnace a larger quantity of coke must be used. In addition to this, the economics of the blast furnace suffer in three more ways. First, the coke used must be of metallurgical quality rather than coke breeze; second, the presence of this extra coke reduces the volume of furnace available for iron ore; third, the CO_2 generated from the limestone dilutes the reducing gas in the furnace and reduces the calorific value of the top gas. It is not possible to generalise on the saving due to sintering the limestone but it is clear from the discussion above that there is a strong economic incentive to avoid charging raw limestone to the blast furnace.

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* Journal of Metals, July 1972.

10.9 Use of charcoal in ironmaking

Because of its limited application, charcoal as a reductant has received very little attention on a world scale, nevertheless charcoal blast furnaces are operating in several countries. Where small blast furnaces are to be located near local ore reserves in forested areas remote from supplies of coal suitable for blast furnace coke, then charcoal charging warrants detailed examination. For example, a small charcoal blast furnace, rated at 325 tonnes per day, is to be constructed in Thailand by 1973. The furnace will operate on charcoal and it is expected that the charcoal rate will be 565 kg per tonne hot metal with 12.5 percent of this being injected through the tuyeres as an oil/charcoal slurry. The furnace is rated at 1.6 tonnes per cubic metre per day which is comparable with the best performance of existing charcoal furnaces.

As a reductant and a fuel charcoal has proved itself satisfactory in small furnaces but it possesses several important disadvantages when compared to blast furnace coke performance in large modern furnaces. Its inherent low strength combined with a high reactivity increases the tendency to crush and burn before reaching the melting zone of the furnace. These characteristics cause disruption of the operation of the blast furnace and result in decreased productivity and increased charcoal usage. In addition to these disadvantages, the low density of charcoal results in a decrease in the volume of the furnace available to iron ore. Against these physical disadvantages may be placed the important advantage of high purity and the low resultant slag volume.

The yield of charcoal from wood is in the range 30 - 40 percent. Thus it is important to reduce the distance over which the wood must be hauled. There are economic advantages to carbonising the wood near the felling site, but this results in a varying moisture content in the charcoal, which in turn causes fluctuations in the operating characteristics of the blast furnace. The trend is, therefore, to overcome the difficulty by carbonising near the steelplant and then storing the charcoal under cover.

The adoption of planned reforestation schemes using eucalyptus trees, which can be used after eight years, has made it possible to make more use of land within the vicinity of the steelworks. The use of virgin forest has become impracticable in most cases, since the areas are sparsely populated and transport costs to the steel-consuming industries become excessively high.

It would seem that the physical and chemical characteristics of charcoal militate against its use in new large blast furnaces, and this alone is likely to lead to a decline in charcoal reduced iron as a proportion of the total production in areas like Latin America. Small and medium size works remote from deep water transport routes and deposits of coking coal, but close to extensive areas of forest with charcoal potential, would need to be evaulated carefully, particularly if there is a history of successful charcoal operation at the site. Where large works are to be constructed close to deep water, it is highly unlikely that the works could be operated economically on charcoal. The promise of further substantial reductions in coke rate of large furnaces is also calculated to swing the balance of future operation against charcoal.

Another possibility for using charcoal might be the blending of poor quality coal with charcoal in the preparation of 'formed coke', where the high purity of the charcoal might compensate for the high impurity and ash level of the coal. In this way a 'coke' of satisfactory strength might be produced in combination with local coal; together these facts might offer some economic advantage compared with imported coking coal.

The quality of charcoal iron is such, however, that there will be a continuing demand for appreciable quantities. Swedish steel owes much of its reputation to the use of high purity charcoal iron as the starting point of its manufacture.

The charcoal furnaces operating at Windowie, Western Australia, have a combined arrival capacity of 70,000 tonnes of pig iron, and over 80 percent of the output is exported through Freemantle.

Windowie charcoal iron is particularly suitable for the manufacture of spheroidal graphite cast iron or ductile iron. Uses for which charcoal iron is particularly suited include steel and paper mill rolls, ingot moulds and slag pans, malleable castings, piston rings, and in the manufacture of steel castings.

Although Windowie iron as produced in the blast furnace is very low in phosphorus, sulphur and other elements, demand for a wide range of specifications has led to the installation of a 10-ton "shaking ladle" for further purification, and, if necessary, additions to the metal.

In the ladle, the composition of the metal is controlled by injecting oxygen and various additives. As a result a pig iron of virtually any required specification can be produced within very close tolerances.

10.10 Hot metal quality of blast furnace iron

The hot metal requirements from the blast furnace are dictated by the needs of the basic oxygen steelmaking plant which requires metal of consistent analysis and temperature to be able to operate effectively at high output. The most critical single constituent of the blast furnace hot metal is its sulphur content since the BOF is an inefficient desulphuriser and is able to remove only about half the sulphur in the hot metal. It is important, therefore, to ensure that the sulphur in the hot metal is at an acceptable level. Nearly all BOF plants now require sulphur content to be below 0.05 percent for all hot metal. Many plants require all hot metal below 0.04 percent sulphur with a proportion, around 25 percent of the total, to possess a sulphur content less than 0.025 percent. The blast furnace can be an efficient desulphuriser but only at the expense of increased slag volume, higher operating temperature, higher coke rate and higher metal temperature. These facts raise costs and decrease output, in addition to which, the higher temperature produces a higher silicon content which is undesirable at the steelmaking stage. A further disadvantage is that it is difficult to make the blast furnace react swiftly to an undesirable change in hot metal sulphur content.

The simplest solution to the problem is to operate the furnace in a uniform manner and provide a consistent hot metal temperature at the same time accepting the resulting sulphur level and then desulphurising the metal between the blast furnace and the BOF. In many cases there are strong economic advantages to external desulphurising, as shown in Figure 10.15 from information published recently by one major works in the UK.

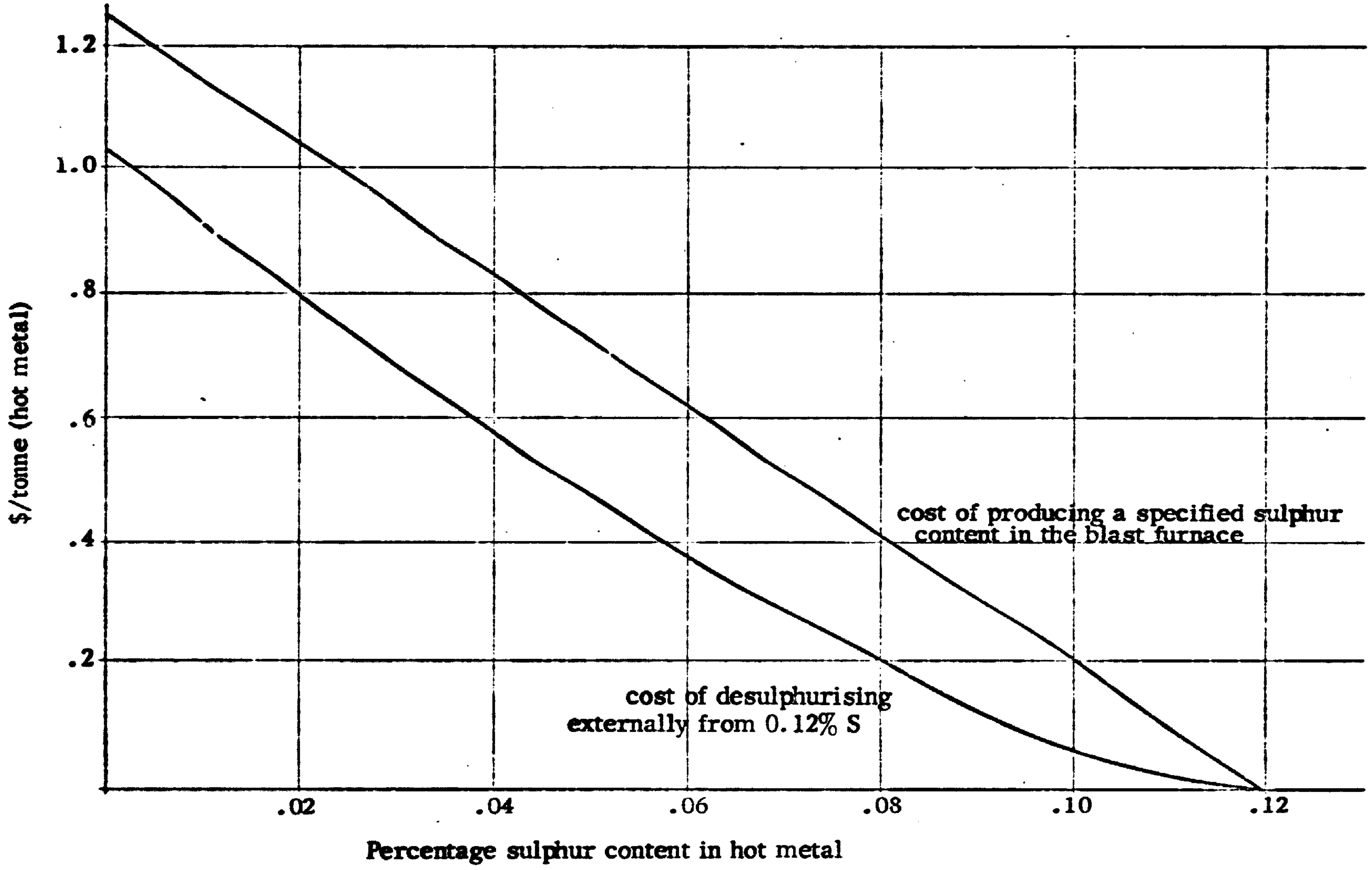

FIGURE 10.15 - COSTS OF DESULPHURISING IN THE BLAST FURNACE & EXTERNALLY (UK conditions)

Several approaches have been adopted for external desulphurisation. These fall into two main categories: (a) batch processes; (b) continuous processes. The majority of methods being developed at present are of a batch nature and desulphurising is carried out in a ladle set apart from the conventional process path. The simplest batch process involves plunging a desulphurising reagent to the bottom of the ladle using a refractory bell. The cost of reducing sulphur from 0.025 percent to less than 0.01 percent by this method is about $1 per tonne. All batch processes have the advantage that they can be easily controlled and continued to a desired point.

Continuous processes can be installed in the existing runner system of the blast furnace. The process available from Rheinstahl consists of a cylindrical vessel into which metal flows tangentially and mixes with calcium carbide fed steadily into the vessel; the slag is periodically raked off. The process is very efficient and desulphurisation from 0.12 percent sulphur to an acceptable level can be achieved for around $1.25 per tonne. In such a case, up to $2.5 per tonne can be saved at the steelmaking stage.

The advantages of external desulphurising and the growing need to operate modern furnaces in a uniform manner without regard to small variations in sulphur content will result in a growth of external desulphurising.

In situations where hot metal is unavoidably high in silicon, such as India, desiliconising can often be justified. There appear to be no prospects of a marked improvement in the currently available methods of ladle desiliconising using oxygen injection.

10.11 Electric smelting processes for ironmaking

There are two established electric smelting processes which are now operating in many parts of the world. These are the Tysland-Hole and the Elektrokemisk processes.

The Tysland-Hole process

This process was developed in Norway. It employs a low shaft electric arc furnace into which iron bearing materials, such as lump ore and sinter, and coke are charged continuously. Reduction of the ore and melting of the resultant product take place in the furnace hearth from which liquid pig iron is tapped intermittently. Metallurgical coke, a mixture of coke and coke breeze, or charcoal can be used as reductants. The process requires about 2200kWh of electricity and 350kgs of coke per tonne of hot metal when melting an iron bearing charge containing about 60 percent Fe. This is equivalent to a total energy requirement of 16 giga joules per tonne.

The largest furnace operating in Norway, has a rated capacity of over 160,000 tonnes of hot metal per year. The largest Tysland-Hole ironmaking plant, also operating in Norway, can produce approximately 700,000 tonnes of hot metal per year.

The Tysland-Hole process proved itself very successful from the time it was first introduced. It is flexible in that it can be operated at as low as 50 percent of rated capacity without affecting metal quality or greatly increasing the energy requirement. Also, the process can be adapted to produce a wide range of products, from ordinary pig iron to various types of ferro-alloys.

A major advantage of electric smelting processes is that they provide a liquid product which can be converted to steel by the BOF steelmaking process. However, they are only competitive with the blast furnace in locations where cheap electrical power is available. Costs for a 0.5 million tonne per year Tysland-Hole furnace operation in such a location are given in Table 10.5.

TABLE 10.5 - IRONMAKING COSTS OF TYSLAND-HOLE PROCESS

	Unit Cost $/tonne
Iron ore (lump) ($14.5/t)	22
Coke ($41/t)	14
Electricity (@0.25¢/kWh)	6
Other conversion costs	4
Capital charge	8
	54
Credits	-2
	52
Allocation for general works services and working capital	7
TOTAL	59

The capital cost of a 0.5 million tonne per year installation is about $42 per annual tonne of capacity. The cost of a smaller plant with an annual capacity of 100,000 tonnes is about $50 per annual tonne, whereas the cost would be about $40 per annual tonne for a larger plant with a capacity of one million tonnes. The economies of scale obtainable from Tysland-Hole plant beyond a capacity of 0.5 million tonnes are thus small.

From the cost breakdown in the table it is evident that the total cost of coke and electricity amounts to about 30 percent of the total. The process is clearly sensitive to the cost of electrical energy and this has led to the development of the Elektrokemisk process.

The Elektrokemisk process (See also Chapter 11, Article 11.4)

This process was also developed in Norway. It involves electric smelting with pre-reduction and produces liquid iron. The iron ore charge, together with non-coking coal or charcoal and a certain amount of limestone, is fed into a rotary kiln reactor heated at the discharge end by a fuel oil burner. The partially reduced product, together with the coal char, falls into an electric smelter. Complete reduction and melting of the charge take place in the furnace from which liquid iron is tapped intermittently. The quantities of electricity and coal required will depend upon the degree of reduction achieved in the pre-reduction kiln. Generally the process will require about 1400 kWh of electricity and 400 kg of coal per tonne of hot metal produced from an iron ore change containing 60 percent Fe equivalent to a total energy requirement of 14.5 giga joules per tonne.

This process has been in commercial use for liquid iron production in Yugoslavia and South Africa. The largest kiln-electric furnace unit has a rated capacity of about 70,000 tonnes of hot metal per year, although it is understood that this has now been upgraded to 100,000 tonnes per year. The capacity of the Yugoslavian and South African plants is of the order of one million tonnes of hot metal per year, but the Yugoslav kilns are no longer operating.

Ironmaking costs of the Elektrokemisk (Elkem) process are given in Table 10.6 for a plant of 0.5 million tonnes per year. Electricity is charged at 0.25 cents per kWh.

The capital cost of an Elkem plant is greater than a Tysland-Hole plant of equivalent capacity because the former is a two-stage process. The economies of scale of capital cost are, however, similar to those of the Tysland-Hole process.

The total cost of fuel and energy is significantly lower than that of the Tysland-Hole process under identical conditions. This is mainly due to the fact that the Elkem process uses cheaper coal, and also that the thermal efficiency of the process is superior.

The economic advantage of the Elkem process over the Tysland-Hole increases as electricity rates increase and makes the former the natural choice for most applications of electric smelting. Tysland-Hole furnaces are only likely to be built, in future, as extensions of existing installations.

TABLE 10.6 - IRONMAKING COSTS OF ELEKTROKEMISK PROCESS

	Unit Cost $/t
Iron ore (lump) ($14.5/t)	22
Coal ($41/t)	11
Electricity (0.25c/kWh)	3
Other conversion costs	5
Capital charges at 20%	9
	50
Credits	-1
	49
Allocation for general works services and working capital	7
TOTAL	56

CHAPTER 11 - DIRECT REDUCTION SPONGE IRONMAKING

11.1 Direct reduction ironmaking processes

'Direct reduction' is a generic term which by common acceptance is now taken to include all processes which yield reduced iron products, usually referred to as sponge iron, in the form of irregular lumps, spherical pellets or fine iron powder.

In recent years many direct reduction processes have been described. These processes have embraced a very great range of plant and every known type of reducing agent. There are many reasons and conditions which have been encountered, differing from country to country, to justify the development of these processes in such large numbers. For instance, most of the processes have been designed for outputs much smaller than those normally associated with economic blast furnace ironmaking plant, giving opportunities to establish self-contained plants in countries such as South Korea which cannot utilise the production of a large blast furnace. As the processes generally use fuels other than blast furnace metallurgical coke, certain countries have found a direct reduction process the most economic because of the local availability of an alternative energy source. Examples are the use of natural gas in Mexico and electrical power in Scandinavia. Also low-grade ores or ores with contaminants such as titania (as in the New Zealand ironsands) which cannot be used in the blast furnace burden can be exploited by employing certain direct reduction processes.

Direct reduction is a developing technology and new processes are continually being proposed or new plants built. Those processes which are actually in use, and those which appear to show promise of successful development, are listed in Table 11.1. However, we endorse the following comment from the Battelle Memorial Institute: *

> "The published literature on direct reduction is biased. Most publications deal with a limited range of subjects. These subjects include descriptions of processes, the results of chemical and metallurgical experimental work (including pilot plants), economic forecasts for new plants, and predictions about the future. Missing from the literature are reports on how and why certain plants failed and the actual costs being experienced in operating plants. Until we reach a situation where both sides of the story are equally

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* Paper presented at E.C.E. Seminar on Direct Reduction of Iron Ore, Bucharest, Sept. 1972.

well known, and the deficiencies of direct reduction are balanced against the advantages, much caution must be exercised to avoid being carried away by the vocal optimist. It may be significant that some of the organisations and individuals who have operating experience with direct reduction plants (some now defunct) make a point of avoiding open presentations such as the present Symposium.

One of the main problems is that in some cases the estimated cost of production tends to be high enough to discourage rapid acceptance on a large scale. The number of uncertainties is high.

The conclusion is that by the time that direct reduction reaches maturity as a high tonnage commercialised series of undertakings, the form of the processes and the means by which we select between them and select their raw materials will be different from the way that we know them today. Direct reduction processes as now visualised by no means represent the highest potential for their utilisation."

The wide international interest in the potential of direct reduction processes is indicated in Table 11.2, from which it will be noted that of the plants actually in operation the majority are based on gaseous reductant.

TABLE 11.1 - IMPORTANT DIRECT REDUCTION PROCESSES

Gaseous reduction processes	Solid reduction processes	Electric prereduction
HyL Midrex Orinoco (HIB) Armco Purofer	SL/RN Krupp	Elkem

11.2 Gaseous reduction processes

The gaseous reduction processes utilise natural gas as the principal source of reductant and fuel. Alternatively, they could use any of the liquified petroleum fractions or straight-run naphtha as the prime source; these would need reforming before feeding to the process, and at the present time there are no commercial plants based on reformed petroleum fractions.

The fluid nature of the reductant has encouraged development engineers to try to perfect a fluidised bed process with the ore as fines. With a growing proportion of iron ore becoming available in this form, this would appear to have considerable advantages. However, the main disadvantage of using ore fines in a fluidised bed reactor is that the ore particles tend to stick together due to the difficulty of controlling the temperature profile within the reactor,

TABLE 11.2 - THE STATUS OF DIRECT REDUCTION PROJECTS (Mid-year 1972)

Process and Location	Number of plants and annual capacity (tonnes x 10^3)			
	Operating	Starting-up	Under construction	Planned
Gaseous reductant				
HyL - Mexico; Monterrey	2-250		1-400	
- " ; Vera Cruz	1-200			
- " ; Puebla	1-250			
- Brazil ; Bahia			1-250	
Midrex - USA; Portland, Oregon	1-400			
- " ; Georgetown, S.C.	1-400			
- " ; Louisiana				1-800
- Canada; Contracoeur			1-400	
- Germany; Hamburg	1-400			
Orinoco - Venezuela; Puerto Ordaz		1-1000		
Armco - USA; Houston, Texas			1-400	
Purofer - Germany; Oberhausen			1-150	
Solid carbon reductant				
SL and SL/RN:				
- Greece; Lyrca	1-100*			
- S.Africa; Witbank	1-800*		1-200	
- New Zealand; Glenbrook		1-150		
- Korea; Inchon		1-150**++		
- Canada; Sudbury, Ontario		1-200		
- Brazil; Piratini			1-60	
- W.Australia; Hamersley				1-1400+++
- India; Goa				1-150
Krupp - S.Africa; Dunswart			1-100	
Others - Yugoslavia; Skopje		1-250+		
- Italy; Monfalcone				1-40
- India; Madras				1-1000
- Japan; Kobe Kakogawa				1-2000*
- " ; Chiba			1-250*	

Notes:		
	+	Operations halted in May 1971
	*	Partial reduction for use in iron-making
	**	For foundry iron
	++	Operation halted in November 1970
	+++	Gaseous reductant alternative (HyL) under consideration.

Source: AISE Convention, Pittsburg, September 1972("The Inevitable Magnitudes of Metallized Iron Ore" by Jack Robert Miller).

thus resulting in efficient fluidising and reduction. A measure of the difficulties encountered may be judged from the fact that four of the five processes here described use lump or pellet feed. These are the HyL, Midrex, Purofer and Armco processes. There is only one fluidised-bed process which appears to be sufficiently developed to be considered as a commercial proposition. This is the Orinoco HIB direct reduction process.

The HyL process

The HyL process developed by the Hojalata y Lamina S.A. (HYLSA) is now operating successfully on a commercial scale at the company's steelworks at Monterrey and Puebla in Mexico. This is a batch process and employs four reactors which are operated in sequence to reduce lump ore or oxide pellets. The reducing gas is produced from desulphurised natural gas in a gas reforming plant. The process is capable of producing reduced products of up to 87 percent metallisation. In producing one tonne of such product from an iron ore containing 60 percent Fe, it requires approximately 700 cubic metres of natural gas, which is equivalent to a heat input of about 20 giga joules.

The first (200 tonnes per day) plant was installed at Monterrey, and began operations in 1957. As a result of the profitability and technical success of this first unit, a second major plant, also at Monterrey, rated at 500 tonnes of Fe per day, began operations in 1960. The mechanical and process design features of the new unit were considerably modified, involving a new cooling cycle, doubling the reactor area, and the charging of 120 tonnes of lump ore compared with 15 tonnes. As a result of these changes, there were considerable major difficulties at start-up, which required extensive major modifications. It was not until December 1962 that fully stabilised and reliable performance was achieved, and this has been maintained.

After five years of successful operation at Monterrey with the second plant, Tubos de Acero de Mexico, S.A. (TAMSA) at Vera Cruz, Mexico, installed an HyL plant to produce 500 tonnes per day of total iron; it commenced operations in mid-1967 and was accepted by TAMSA in December 1967. The plant was originally designed to operate on El Encino lump ore, but in 1968 the supply of suitable El Encino lump ore was becoming depleted; the percentage of fines and magnetite reached unacceptable levels and TAMSA imported Itabira lump ore from Brazil. The reducibility of this ore was found to be substantially poorer than El Encino and to achieve design output it would have been necessary to have a substantial increase in gas reformer and compressor capacity for which the plant had not been designed. TAMSA then evaluated other lump ores, such as Mexican El Conejo, Marcona oxide pellets from Peru, and Itabira pellets from Brazil. Although the reducibility of the ores and pellets varied, the operation was completely successful and TAMSA now charges a mixture of lump ore and pellets to obtain the optimum production based on availability and economics.

In 1969 HYLSA de Mexico erected a new integrated steelworks at Puebla, Mexico, incorporating an HyL plant rated at 500 tonnes per day of total iron, processing El Encino lump ore. In May 1970 the HyL plants at Puebla and Monterrey discontinued the use of lump ore and converted to an all pellet operation, with excellent results. Production increased 32 percent, gas consumption decreased 13 percent, and metallization improved 10.3 percent. *

A number of alterations were made to the Monterrey design for the Puebla installation. The Monterrey plant has five individual steam-methane catalytic reformers. One of the basic changes made in the 1960-62 period was modification of the quenching-preheating sequence to improve plant performance, but the physical layout was such that the two new gas preheaters which were added had to be placed farther away from the reactors than desirable. In contrast, the Puebla plant uses a single gas reformer, which is more thermally efficient than the five reformers at Monterrey, and the individual preheaters are closely coupled to the reactors. The inside diameter of the reactor vessels at Puebla is 3.76 m. compared with 3.35 m. at Monterrey - an area increase of 25 percent.

The HyL plants at the Monterrey steelworks have been operating consistently for many years at an on-stream efficiency of 95 percent. The Puebla steelworks has equalled this performance since 1970. The use of four reactors as the basic HyL concept contributes greatly to this reliability because at any time one or more of the reactors can be removed from service for maintenance, while the others remain in full operation. If an operational emergency occurs, such as gas supply failure or earthquake, as occurred in Vera Cruz, requiring a complete shutdown of the plant, it can be returned to full operation in a period of 12 hours.

A 600 tonne per day HyL plant is under construction in Bahia, Brazil, for the Usina Siderurgica da Bahia, S.A. (Usiba). This plant is scheduled for commissioning in March 1973, and will process Vale do Rio Doce iron oxide pellets. The HyL facility is in almost every respect identical to the Puebla plant. Full-scale tests have demonstrated that the reducibility of the Vale do Rio Doce pellets is equal to the Alzada pellets. It is anticipated, therefore, that the operation of the HyL plant at the U steelworks will equal or better the results at Puebla.

Engineering of a third HyL plant for HYLSA at Monterrey, Mexico, began in October 1971. This plant is rated at 1130 tonnes per day of reduced pellets, and is scheduled to start operations in September 1973. It incorporates several important technical improvements, among which are larger diameter reactors, higher exit gas temperature from the preheaters, lower gas consumption, and better control of carbon content. Production can be increased 25 percent by installing a fifth reactor at a later date.

A comprehensive testing programme was completed in 1971 to verify that process performance and rated plant capacity could be guaranteed with larger individual reactors. To avoid scale-up error it was necessary to devise a way to measure and establish the temperature profile across the reactor beds during commercial operation at several levels. The mechanical problems were difficult, but the means for comparative measurement were readily available. The reactors in the first HyL unit have an inside diameter of 2.6 m., in the second unit 3.35 m., and in the third unit 3.76 m. The tests showed conclusively that the temperature profile extends uniformly across the bed to a point approximately 15 to 20 cm. from the reactor lining, irrespective of diameter. Having verified under full-scale operating conditions that gas distribution and temperature

* "The HyL Direct Reduction Process - Past, Present and Future" submitted by the USA (prepared by R. Lawrence, Jr.) to the Seminar on Direct Reduction of Iron Ore, ECE, Bucharest, September 1972.

across the bed are uniform, the inside diameter of the reactors for the new plant was increased to 4.37 m. to achieve the 1130 tonnes per day rating. Even larger individual reactor sizes are now claimed to be feasible.

In addition to those installations which have been described, HyL plants are said to be under consideration in Algeria, Australia, Canada, Argentina, Bolivia, Venezuela, Colombia, France, Greece, Iran, Kuwait, Morocco, Iraq, Netherlands, Puerto Rico, Philippines, Singapore, South Korea, Thailand, Trinidad, USSR and South Africa, with a total annual rated production of 10.4 million tonnes of reduced pellets. Of this number, seven locations will use naphtha as the source of reductant and fuel. The smallest installation is rated at 200,000 annual tonnes, the largest at 1.65 million annual tonnes.

Costs of producing sponge iron by the HyL process are given in Table 11.3. These costs apply to an installation with a design output of 0.5 million tonnes per year and located at a site having natural gas readily available.

TABLE 11.3 - IRONMAKING COSTS OF HyL PROCESS

	Unit Cost $/t
Iron oxide pellets ($20/t)	27
Natural gas (14 ¢ per GJ)	3
Other conversion costs	5
Capital charge	8
	43
Allocation for general works services and working capital	7
TOTAL	50

The capital costs of this process can be seen to be very similar to those of the Elkem process (Chapter 10, Table 10.6), but whereas the iron from the Elkem smelter can be refined in a basic oxygen furnace, the HyL sponge iron must be melted and refined in an electric arc furnace.

The cost of natural gas is important in this process, the rate quoted above of 14 cents per giga joule (1.5 cents per therm) being very favourable. Rates of 50 cents per giga joule are more commonplace and would raise the total cost of the sponge iron to nearly $60 per tonne. Part of the gas may be replaced with oil since reduction only accounts for around 60 percent of the gas requirements of the plant; heat requirements use the remainder. Natural gas can also be replaced by naphtha if this is cheaply available, but it is important to note that naphtha reforming requires a more complex plant than that for natural gas. A recent development announced by Koppers Co. enables coal to be converted into carbon monoxide and hydrogen, and is said by the company to be suitable for direct reduction processes.

Using lump ore increases the cycle time and reduces the output, and it also has a tendency to 'arch' in the reactors during discharge. The use of oxide pellets obviates this tendency but results in a more expensive feedstock; it should be noted that it is necessary to use hardened pellets due to the method of charging to the reactors.

The Midrex process

This process was developed by the Midland Ross Corporation of the USA. It is continuous in operation, reducing oxide pellets to over 92 percent metallisation as they pass down a shaft furnace in a counter current flow of heated reducing gas. This gas is produced from natural gas in a gas-reforming plant.

At present there is a plant operating in Hamburg, West Germany, and there are two plants in the USA at Portland, Oregon, and Georgetown, Carolina. Each of these plants has an annual capacity of 400,000 tonnes of reduced product. Another plant of similar capacity is now under construction in Canada. Two further plants - one in the USA and the other in Japan - are planned, each with an annual capacity of 800,000 tonnes of reduced product.

The plant at Hamburg has recently been described as converting 67 percent Fe ore to sponge iron assaying 95 percent Fe without changing its outward shape.* The plant uses natural gas from the Gröningen field in the Netherlands which is fed from the reformer to the shaft furnace at about 800°C. Gas consumption is claimed to be about 425 cubic metres per tonne of sponge iron (about 13 giga joules per tonne).

No details of the costs of the Midrex process have been published. There have been suggestions that both the capital and operating costs are lower than for the HyL process, but in the absence of reliable cost data it must be assumed that there has, as yet, been insufficient experience with the process to establish its techno-economic success and commercial profitability, in the way that the HyL process has been proven over a decade of commercial operation.

The Orinoco HIB process (cf. Chapter 10, Article 10.7)

The HIB (high-iron briquette) process is based on the Nu-Iron direct reduction process originally developed by the United States Steel Corporation. It is the only fluidised-bed process which has been developed for large scale commercial operation.

The process is continuous and employs fluidised-bed reactors to reduce iron ore fines of particle sizes less than 0.6 mm. The reducing gas is preheated and pressurised prior to introducing into these reactors. The fine reduced products are briquetted while still hot and then cooled in an inert atmosphere. The process is capable of producing briquettes containing up to 92 percent Fe.

* Metal Bulletin Monthly, June 1972.

Natural gas requirements are reported to be of the order of 600 cubic metres per tonne of product, which is equivalent to 18 giga joules.

A plant using the process has been under construction in Venezuela for the past four years. It was reported recently that plant commissioning began in 1971, but full scale production is not expected before late 1972. The plant, which has an annual capacity of one million tonnes of 75 percent reduced briquetted product, has been described in Chapter 10, Article 10.7.

Several other processes have been proposed using fluidised-bed techniques, but none appear to have been developed beyond pilot or small scale operation. For example the Fior process was developed on a pilot scale by the Esso Company in 1962. Since then plans for a commercial Fior plant to produce reduced briquettes for general sale have been announced several times, but there are no reports of a project having been started. A French process, the Novalfa -Onia process, was intended specifically for the reduction of Algerian iron ores; the reducing gas was a mixture of carbon monoxide and hydrogen at a temperature of between 600°C and 800°C. There is no plant in commercial operation, and an HyL plant is now reported to be under consideration in Algeria.

The Armco process

The process was developed by the Armco Steel Corporation of the USA. Although it is a batch process, in many respects the metallurgical operation of this process is similar to that described for the Midrex process. Lump ore or oxide pellets are charged into a vertical shaft furnace in which they react with a counter current stream of heated reformed natural gas at 900°C to 1000°C. The top gas is cooled, has the water removed, and is then mixed with more natural gas and recycled.

The process is claimed to be capable of producing up to 95 percent metallised product. To produce a tonne of such product from an iron ore containing 60 percent Fe, the process is reported to require a supply of about 550 cubic metres of natural gas, which is equivalent to 17 giga joules.

According to recent information, a plant with a capacity of 1000 tonnes per day is now being built in the USA. The plant was scheduled to start production in mid-1972.

There is insufficient published data to enable an opinion to be passed on the status of this process. However, it is possible to observe that, as it is a newly developed batch process, it possesses neither the potential, but as yet unproved, economic advantage of the Midrex as a continuous process, nor the advantage of having been well tried and proven like the HyL.

The Purofer process

In this process also, lump ore or pellets are reduced to sponge iron in a shaft furnace using reformed natural gas. The reforming and pre-heating are done in two alternately operating catalytic reactors, with heating of the catalyst followed by reforming natural gas with air, oxygen and/or steam to produce a mixture of hydrogen and carbon monoxide at about 1000°C.

A 500 tonnes per day plant is under construction at Oberhausen in Germany.

11.3 Solid fuel reduction processes

The most important process in this category is the Stelco-Lurgi/RN, or SL/RN, process. A competitor to the SL/RN process is the Krupp direct reduction process which, apart from the detail of plant design and being manufactured by a different company, does not appear to differ in any important respect from the SL/RN process. Recently it has been reported that a Krupp direct reduction plant will be built in South Africa. This plant will have an annual capacity of 100,000 tonnes of reduced products.

The Stelco-Lurgi/RN process

The SL/RN reduction process was developed by the Steel Company of Canada in collaboration with Lurgi-Gesellschaft fur Chemie and Huttenwesen of the German Federal Republic, and from the end of 1964 in association with the RN Corporation of the USA. The process employs a rotating kiln in which sized lump ore or oxide pellets are reduced. The plant usually incorporates a pre-heating grate, a rotary kiln, a cooler and a char separation plant.

A feature of this process is its use of non-coking coal in place of coke. A part of the heat is provided by oil or natural gas unless high volatile coal is used. When reducing an ore containing about 60 percent Fe, it requires about 800 kgs of high volatile coal, equivalent to 18.5 giga joules, per tonne of reduced product. In order to prevent sulphur transfer from solid fuel to reduced products, a small amount of limestone or dolomite is added in the feed. The gangue constituents such as silica, alumina and phosphorus are retained in the products. The process is capable of effecting up to 97 percent metallisation in high grade ores.

SL/RN plants have been built in New Zealand, Canada and Korea, and are under construction in South Africa and Brazil. The New Zealand plant was designed to reduce titaniferous ironsands, while the plant in South Africa is intended to recover vanadium.

The three plants which have already been built are the focus of considerable interest because none of them has been successfully commissioned and brought up to design capacity.

As a result of difficulties with the SL/RN plant, pellet plant and ancillaries, New Zealand Steel Ltd. were reported* to have made a loss approaching $NZ 6 million in the fiscal year 1970-71. The failure of the plants to meet their output capacity and raw material consumption guarantees made it necessary for the company to import Australian oxide pellets and steel scrap.

* Metal Bulletin, 8 April 1971, page 31.

The nature of the difficulties was reported by New Zealand Steel Ltd. as follows: **

> "The most severe operating problem has been the formation of accretions which result from inaccurate control of temperature profiles within the kiln. This in turn has led to a series of blockages in the kiln to cooler transfer chute. On shut down of the rotary kiln, accretion was discovered. It was, therefore, decided to carry out extensive research into the factors affecting pellet strength, viz. its degradation within the rotary kiln."

A report of New Zealand Steel's operation during September 1971 indicated the following serious draw-backs:

i) The major problem in the SL/RN kiln unit is the build up of accretions in the kiln; because of this the continuous operation of the kiln is restricted to 8 to 12 weeks at a stretch. For each shut down, a period of about two weeks is required for the removal of the accretion and putting the kiln back into operation.

ii) With the use of green pellets, directly fed into the kiln, the loss of concentrate in the dust is quite high and because of this the waste gas cleaning and the dust disposal systems put a limitation on the operation of the plant.

iii) Even when heat-hardened pellets from Whyalla were used for the production of sponge iron in the kiln, though the dust losses were less, the accretion formation was of about the same order as in the case of using green pellets.

iv) The lignite used is very reactive and this results in increased carbon consumption.

v) With the use of only one type of coal it becomes difficult to balance carbon requirement and heat requirement.

vi) The thermo-couples installed on the kiln indicate the correct temperatures during the start-up period and for some time after start-up. Thereafter because of a coating of dusty raw materials on the thermocouple tips, the temperature indications become unreliable with resultant difficulties in controlling the kiln operation.

vii) Because of lower metallisation and the high gangue content of the sponge, the power consumption at the electric steel-making furnace is 835 kWh per tonne when using 75 percent sponge in the charge. The tap-to-tap time of the heat generally varies between 190 to 210 minutes.

viii) If there is a 10 percent drop in the metallisation of the product, that is from 90 percent to 80 percent, the power requirement increases by 100 kWh per tonne at the electric arc furnace.

** "Alternative Routes to Steel" Code No. P.137. The Iron and Steel Institute, 39 Victoria Street, London, S.W.1. (May 1971)

An attempt is being made to control the temperature profiles by reducing the carbon input at the sponge discharge end and adding lignite char at the charging end for the reductant. Additional shell burners are also distributed along the length of the kiln with heat-resistant tubes projected into the centre of the kiln to spread the temperature zone to about 25 m.

Because of the drawbacks referred to above, sponge production is less than one-third of the plant's rated capacity. In two years, only 50,000 tonnes of acceptable sponge have been supplied to the melting shop, and about 20,000 tonnes of partially reduced sponge have been stockpiled for reprocessing.

International Nickel Co. are reported to have experienced similar problems with their Falconbridge plant at Sudbury, Ontario, and it is understood that they share with New Zealand Steel Ltd. the view that the SL/RN process requires further development before it can be regarded as commercially acceptable.

The SL/RN plant at Inchon, South Korea, has been closed down since November 1970 because of an explosion the previous month in the electric smelting furnace, which was fed with the SL/RN sponge.*

It is understood that the original proposal to instal a large SL/RN plant at Hamersley, W. Australia, for the production of HIMET briquettes has been abandoned, and that consideration is now being given to the possibility of installing an HyL plant for this purpose, which would use the natural gas recently found on the continental shelf.

Notional costs for a 0.5 million tonne per year SL/RN plant are given in Table 11.4. In this example, it is assumed that the plant is located near a source of non-coking coal, and that it is operating at its design capacity.

TABLE 11.4 - IRONMAKING COSTS OF SL-RN PROCESS

	Unit cost $/t
Iron oxide pellets ($20/t)	27
Coal ($10/tonne)	7
Other conversion costs	5
Capital charge	6
	45
Allocation for general works services and working capital	6
TOTAL	51

The largest kiln installed to date has a design capacity of 150,000 tonnes per year. It has been suggested that it is feasible to develop the design to double this

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* Metal Bulletin, 5 October 1971, p.29.

capacity, although until the existing plants achieve their rated output, this must be in doubt. With kilns of 300,000 tonnes per year, economies of scale may be realised for installations in excess of one million tonnes per year. It is estimated that total costs will range from \$55 per tonne at 250,000 tonnes per year to \$49 per tonne at 1 million tonnes and \$47 per tonne at 2 million tonnes. Thereafter the rate of decline in cost is small. The capital cost is lower than for most other direct reduction processes, but not as low as was predicted by designers several years ago. Based on current output levels the capital charge of the plant given in Table 11.4 is too low. It is anticipated that the cost will eventually fall to the level in the table when the operating difficulties have been surmounted.

11.4 Electric pre-reduction

The Elkem process

The Elkem process, which has been described in Chapter 10, Article 10.11, as an electric smelting process, is really a two-stage process, of which the first pre-reduction stage is a rotary kiln direct reduction process.

At Skopje, Yugoslavia, where five Elkem rotary kilns are installed, all of them have been taken out of operation and electric smelting is now practised without pre-reduction.

Recent tests have been carried out in Norway, by Elkem, on high-grade iron ores from Orissa State (India) for direct reduction in rotary kilns using solid fuel. The tests were unsatisfactory and indicated that the process is inapplicable for these ores because of their adverse physical characteristics.

The D-LM process

A direct reduction process (named after Dwight-Lloyd McWane) which uses a sintering strand and electric smelting furnace has undergone extensive development. Green pellets of ore fines and coal fines are spread onto an enclosed down-draught sintering strand and ignited. About 60 percent reduction is achieved on the strand, and reduction is completed in the electric furnace.

The principal interest in this process arises from the fact that it does not require metallurgical coal.

11.5 Direct reduction iron-making using nuclear power

Mention has already been made (Chapter 10, Article 10.4) of the use of nuclear heat to provide reducing gases for injection to the blast furnace. Considerable interest also attaches to the possible use of nuclear energy to produce gases suitable for direct reduction processes.*

The development of high-temperature gas-cooled nuclear reactors has provided the potential for a technological and economic break-through in this field, since it is now possible to envisage reactors of 2 to 3 GW (thermal) providing helium gas at pressures up to 100 kg/cm^2 and temperatures of up to 1200°C.

* ECE Seminar on Direct Reduction of Iron Ores, Bucharest, September 1972.

Used in a suitable gas generator, this high temperature helium could convert fossil fuels, such as lignite, into hydrogen and carbon monoxide for use in direct reduction processes. The reducing gas generation is most likely to be carried out at the source of the solid fuel, and the gas piped to iron-making centres up to 100 km. distant. In this way full advantage can be taken of the economics of scale in the nuclear reactor. Further economic advantage will be gained by using the partially cooled helium leaving the gas generator to raise steam for electric power generation.

In the longer term, as direct reduction plants become larger, it will be necessary to incorporate several reactors, gas generators and direct reduction plants into a single system linked through gas distribution lines; in this way it will be possible to maintain flexible production schedules capable of coping with repairs and partial shut-downs.

If the relative movement of the price of fossil fuels and electricity generated by nuclear power continues to favour nuclear power, there may also come a point when electrolysis of water to yield hydrogen for reduction purposes, together with by-product oxygen, becomes an economic reality. This will require the development of a suitable electrolysis cell, however, and it appears more likely that the first applications of nuclear energy to direct reduction iron-making will be based on coal or lignite.

11.6 The future of direct reduction

Direct reduction processes will continue to attract attention and interest. The HyL process is already well-established as a commercially acceptable process in areas where gaseous reductants are available at an attractive price. Clearly, the success of the developments outlined in the previous article would be encouraging to further use of the HyL, and other gaseous reductant processes such as Midrex.

In commercial terms, none of the other processes currently in use has yet established itself as a competitor with HyL. The level of investment in Midrex plants and SL/RN plants, however, is such that eventual solution of the economic and technical problems appears likely.

All of the existing processes require further development and improvement, and there is no doubt that future processes will be introduced - a number of plants are already planned using processes which have yet to prove themselves. This is a field in iron and steel technology which is undoubtedly going to attract a major proportion of total research and development effort by the world industry over the next decade.

The extent, however, to which the application of direct reduction will replace other forms of iron-making is partly dependent on the total economics of steelmaking, and the place of direct reduction as a stage in the route to steel.

The alternative routes to steel are considered in Chapter 14, but an additional factor which is likely to assure a place for direct reduction in the iron and steel industry of the future is the progressively increasing demand for iron units. Miller* has suggested that the trend towards steel production by oxygen blowing and electric furnace melting will lead to scrap shortages which will need to be made good by metallised iron ore in the not too distant future; also that lower coke rates will be sought by adding prereduced ore to the blast furnace burden. The development of the mini-steelworks concept based on scrap and metallised iron ore, which is discussed in Chapter 22, will also influence the growth of direct reduction as a technique. These factors, taken together, lead to the conclusion that future developments in pre-reduction technology are inevitable.

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* **Jack Robert Miller** - "The Inevitable Magnitudes of Metallized Iron Ore" AISE Convention, Pittsburg, September 1972.

CHAPTER 12 - HOT METAL STEELMAKING

12.1 Recent process developments

The production of oxygen in tonnage quantities at a cost economic to steelmakers for bulk steel production became a reality after the Second World War, following rocket developments for aircraft and missile propulsion. At the time, it was found impractical to take advantage of this in existing processes, which were open hearth and Bessemer. A new process was evolved similar in concept to Bessemer, but using an overhead lance for jetting the oxygen into the liquid charge. This process, first named LD (Linz-Donawitz) after the original installations, is now commonly referred to as the basic oxygen furnace (BOF) process.

The economic advantages of the BOF process over existing processes for the majority of hot metal practices has led to a rapid decline in the proportion of steel produced by the open hearth and Bessemer processes. At the present time, around 30 percent of world steel is made in open-hearth furnaces, and about 5 percent using the Bessemer process. Much of this Bessemer steelmaking uses the Basic Bessemer or Thomas process, and is concentrated in a few countries which still have a high proportion of high phosphorus hot metal for steelmaking.

The decline continues and it is predicted that by 1980 open-hearth steel will account for less than 10 percent of world steel production, and that the Bessemer processes will no longer be used.

Recent developments in tuyere design have now made it practical to bottom blow a Bessemer type converter with undiluted oxygen. Development has been proceeding at several centres so that the process is variously termed OBM (by Maximilianshütte), Q-BOP (by US Steel) and LWS (by Société Creusot-Loire, Société Wendel-Sidelor and Etablissements Sprunck). This technological breakthrough has resulted in some Thomas converters being adapted to the new process instead of being closed down. The development is also seen as a means of prolonging the economic life of certain open hearth furnaces. Bottom blown processes are discussed in Article 12.3 below.

12.2 Top-blown converter processes

The LD or BOF is the main process under this heading. Several other processes based on the BOF have been developed to spread the advantages of tonnage oxygen injection over a wider band of hot metal practices. However, with development of the BOF process itself, and now the revival of bottom-blown converter processes, the future of these BOF variants is limited. In consequence, this Article deals principally with technological developments of the BOF; the other processes are reviewed briefly at the end of the Article.

Growth in furnace size

The size of BOF furnaces has grown progressively as the size of steelworks has increased. It is only now that furnace sizes are approaching those of the largest open hearth furnaces. The economic advantages of large furnaces are evident from Figure 12.1, which shows steelmaking comprehensive conversion costs compared with furnace size.

Table 12.1 shows the distribution of furnace capacity for the world in 1971. Furnaces in the 100 to 200 tonne capacity range are the largest group, and more than two-thirds of those under construction are over 150 tonnes capacity. This contrasts sharply with the size range of the earlier Bessemer converters which were less than 100 tonnes.

TABLE 12.1 - DISTRIBUTION OF BASIC OXYGEN FURNACE CAPACITY IN 1971 (Number of furnaces)

Country	Furnace Size (tonnes)				
	up to 100	101-150	151-200	201-300	over 300
Japan	40	8	21	17 (+2)*	
USA	8	17	22	33(+1)*	
All other countries	121(+6)*	86 (+9)*	20(+7)*	38(+2)*	10(+1)*
Total	175	120	70	93	17

* Furnaces under construction in 1971.

The largest furnace in operation to date is of 350 tonnes capacity, but a 400 tonne furnace shop is planned to go into service at August-Thyssen Hütte in West Germany in 1974. A trend toward still larger furnaces us unlikely, at least for some years, for three reasons. Firstly the trend in steadily reducing cycle times is making very large vessels unnecessary - for example, two 200-300 tonne furnaces can provide for the requirements of a steelworks having a capacity of 5 to 8 million tonnes per year. The second possible restraint is that of materials handling; this point has already been raised in Chapter 10 concerning the handling problems around the base of very large blast furnaces. Similar problems of congestion need careful evaluation and resolution if the benefits of increased furnace size are not to be offset by extended cycle times. Thirdly, the logistics of matching the furnace size to the casting facility,

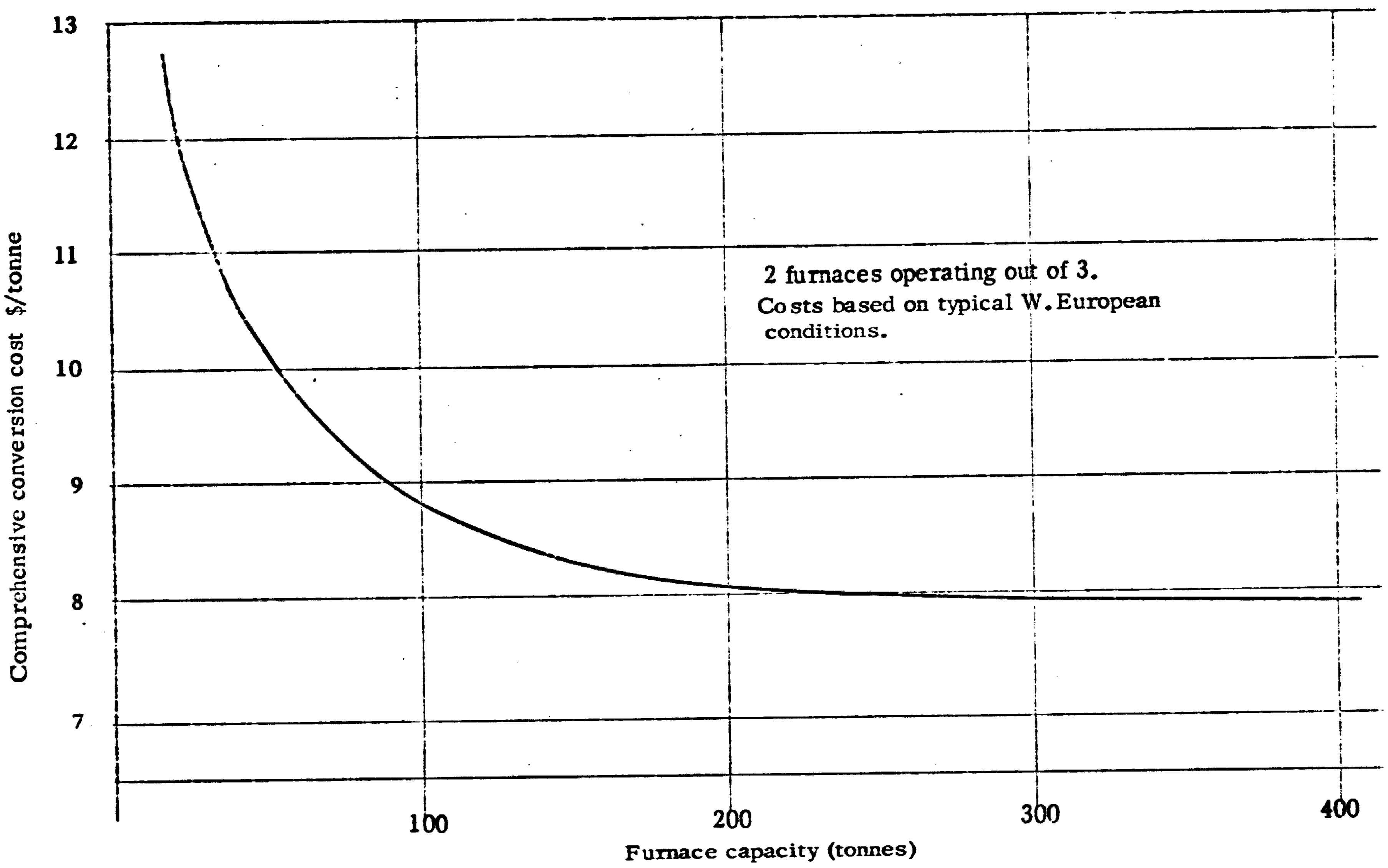

FIGURE 12.1 - ECONOMIES OF SCALE OF BOF STEELMAKING

especially if this is comprises a continuous casting machine, places a further restraint on the growth of furnace size.

Plant configuration

The short cycle time of the BOF process makes it desirable to have a constant number of furnaces in operation to ensure a smooth demand for hot metal and a smooth supply of liquid steel. Thus, it has been common practice to build one more furnace than the number to be operated, so that one furnace is relined while the others are producing steel. Initially lining lives and relining times were such that a two-furnace shop with one operating was the only practical layout. With longer lives and shorter relining times, three-furnace shops and in some cases four-furnace shops became practicable. Table 12.2 shows the current distribution of arrangements throughout the world.

TABLE 12.2 - BOF PLANT CONFIGURATION IN 1971

Operational configuration	Number of cases in world
1 furnace out of 2	48
2 furnaces out of 3	116
3 furnaces out of 4	59
4 furnaces operating	2

Most cases of one furnace operating out of two are now in works with a second BOF shop, the first shop being an early installation of small furnaces; when the time came to expand it was found necessary to build a second shop with larger furnaces and not add the third furnace to the first shop.

The use of three furnaces out of four requires either long campaigns on the operating furnaces, or very short relining time on the one furnace out of service. Long campaign lives can be achieved by 'gunning' the lining after each heat, but this increases the cycle time. This, coupled with the complex sequence of materials handling movements that arise when three or more furnaces are in use, reduces the utilisation of the furnaces, so that the increase in capacity of the shop is less than the increase in number of furnaces.

The most common configuration is two furnaces operating out of three. This provides the most effective compromise between flexibility and economies in capital and operating costs. In planning a works on a green field site, the 'two out of three' arrangement can be considered in two stages provided the second stage of development raising it from a two to three-furnace shop is programmed to take place within a few years of the first stage.

BOF cycle time

The most significant development in BOF practice has been the reduction in tap-to-tap time. During the last ten years the design cycle time for a medium size BOF furnace of, say, 120 tonnes has been cut from 1 hour to around 40 minutes*. This improvement has been achieved by design improvements that have enabled the oxygen to be blown faster and the incoming and outgoing materials to be handled more speedily.

Blowing time in best practice is about 20 minutes, but there is no technical reason why this should not be greatly reduced, perhaps halved. There is little scope for further substantial reductions in charging, sampling and pouring times, so further reductions in cycle time must be achieved by reducing blowing time. Shortening the blowing time in this way places stringent limits on the control of the process. To cope with this, on-line control by computer has been introduced (cf Chapter 24 Article 24.2) but this in turn has made it necessary to standardise the process as much as possible. Thus for bulk steel production the furnace will be programmed to produce a basic steel to a single specification continuously. The specification is then adjusted to suit individual casts by further treatment in the ladle. The key to success in reduction of blowing time lies in controlling the formation of and reactions in the slag metal emulsion. A problem with very short blowing times is the generation of a foaming slag. Effective monitoring devices for linking to the on-line control system to sense when this is happening are currently under development in several countries.

Cycle times vary from one plant to another, principally due to furnace size, amount of scrap charged and iron analysis, although plant characteristics such as the size of the oxygen plant also affect them. Current good BOF practice in Japan averages cycle times of about 35 minutes for furnaces over 100 tonnes capacity, with some furnaces operating a 30 minute cycle. Cycle times for furnaces of this capacity are forecast to drop to around 25 minutes with the full development of on-line control and improved materials handling. World average figures for good practice are likely to lie around 30 minutes by 1980*.

The use of scrap in the BOF

The amount of scrap melted in general BOF practice varies over quite a wide range, as is evident from Table 12.3.

TABLE 12.3 - SCRAP PERCENTAGE OF BOF STEELMAKING CHARGES IN VARIOUS COUNTRIES (1969)

Country	Average percentage scrap in charge (remainder is hot metal)
USA	29.3
Japan	19.7
W. Germany	17.1
UK	25.6
France	27.0
Italy	21.7
Netherlands	22.9

To some extent these figures reflect the availability of scrap in the countries concerned, that is to say, the reasons are economic rather than technical.

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* See Appendix 1

Among the objectives of technological trends in casting and rolling, and in the manufacturing industries, is the improvement in yields with consequent reductions in recirculating scrap. The change from ingot to continuous casting is perhaps the most important factor affecting yield. It is estimated that by 1980, steelworks yields in leading steelmaking countries will have improved by 8 to 10 percent, compared with today. At the same time, the trends towards larger BOF furnaces and shorter cycle times combine to improve the thermal efficiency of the process so that more scrap will be required for cooling. The net effect of these trends is that the BOF steelmaker will be forced to buy in scrap to supplement recirculating scrap supplies; this will reduce the proportion of scrap for cold metal steelmaking processes (cf Chapter 13). The price of scrap is discussed in Chapter 14 Article 14.2.

A problem associated with BOF furnaces which is receiving increasing attention is the pollution caused by the discharge of large quantities of 'brown fume'. The measures which have been developed to combat this nuisance are described in Chapter 23, Article 23.3.

Other basic oxygen processes

Several basic oxygen processes, other than the BOF itself, have been developed. They were designed primarily to increase the range of hot metals which the top blown converter could handle, particularly those with a high phosphorus content. Three processes reached commercial application - LD/AC, Kaldo and Rotor.

LD/AC process

This process was developed in France, and most of the plants using it are located there. The essential difference between the LD/AC and BOF processes is that powdered lime is injected as well as oxygen in the LD/AC furnace. Better understanding of the sequence of reactions in the converter, coupled with a general trend in ironmaking policy to lower the phosphorus level in the hot metal by ore blending, has enabled steelmakers to revert to the BOF process. LD/AC furnaces would be converted for OBM operation (Article 12.3) by installing removable bottoms.

Kaldo

The Kaldo process (developed by Stora Kopparbergs Bergslags AB) makes use of a rotating converter as a heat exchanger. Developed originally for converting high phosphorus irons into a wide range of steels, the rotation of the furnace and the facility for slag adjustment provided a high degree of flexibility and control. It also proved possible to melt more scrap - up to 40 percent of the charge - in the Kaldo than in the BOF. However, the higher cost of a rotating furnace together with the higher operating costs, due chiefly to high refractory wear, has made the process uneconomic compared with BOF steelmaking.

Rotor

The Rotor process (developed by Hüttenwerk Oberhausen AG) is similar in principle to the Kaldo but the configuration of the converter is different. The process has similar costs to the Kaldo.

The method of producing a range of steels by using the BOF to make a 'standard' steel which is then further processed to the desired specification in the ladle is currently gaining favour (cf. Article 12.5). This, coupled with the trend toward lower phosphorus irons mentioned above, makes these processes of little significance in the overall pattern of future hot metal steelmaking.

12.3 Bottom-blown converter processes

Bessemer and Thomas processes

Bessemer steelmaking today, as the basic Bessemer or Thomas process, is important only in France, Belgium, West Germany and Luxembourg for processing high phosphorus irons into cheap common steel. The continued use of this process in France and neighbouring countries is economically justified because the steel is used in an application where its nitrogen content is not a problem, namely ordinary structural steelwork. Nevertheless, no Bessemer plants have been built in those countries since 1955, and in consequence furnace sizes are relatively small compared with modern trends for bulk steel production.

OBM, Q - BOP and LWS processes

The development of a tuyere for oxygen injection through the base of the converter has now been successfully demonstrated. This has been achieved by shrouding the oxygen gas stream in a liquid or gaseous envelope to isolate it and the reaction with the steel from the refractories of the converter bottom. Possible isolating fluids quoted are water, carbon dioxide, propane and fuel oil. Fuel oil appears to be favoured.

Advantages over the BOF claimed for the processes include:

Shorter cycle times (15 percent gain)
Higher scrap usage (up to 36 percent of the metallic charge)
Lower FeO losses in slag and fume
Less bath turbulence, permitting a 25 percent increase in the charge for a given furnace size.
Absence of lance gear and the associated high structure over the furnaces, making it practicable to install such furnaces in existing Bessemer or open hearth shops.

Steelmakers at present associated with the processes are operators either of Thomas converters or, in the case of US Steel, of large modern open-hearth installations. Both processes are threatened by the BOF either on quality or economic grounds, which in part explains these companies' interest.

For all practical purposes OBM and Q-BOP are identical; the process was developed by Maximilianshütte for use with high-phosphorus metal originally, and was subsequently (April 1971) adapted, by changing the blowing to use low-phosphorus hot metal.

In July 1971, US Steel Corporation became interested and a joint development programme was set up with Maximilianshütte to run a series of experiments at US Steel's South Works, Chicago, Ill. The trials were designed to develop the OBM process further for use in furnaces of 150 to 300 tonnes, and were very successful. The US Steel version of the process is known as Q-BOP.

CRM (Centre de Recherche Metallurgique, Belgium) has also carried out trials with the OBM process, and has reported blowing several hundred heats with one single tuyere in the furnace. Premature disintegration of the tuyere has to be prevented by blowing a protective shield with the blast oxygen; both liquid and gaseous protective shields have been used, but CRM appears to favour fuel oil rather than propane or natural gas. The use of a single tuyere greatly simplifies the injection of powdered lime into the converter. The CRM group have also reported on the nitrogen content of OBM steel; using propane as liquid fuel the nitrogen content at blast shut down was 0.002 percent and 0.0025 percent at tap. Using natural gas from Gröningen (Netherlands) containing 14 percent nitrogen the nitrogen content of the steel rose to 0.0035 percent and 0.004 percent. The blowing time in the CRM trials has been 12 to 14 minutes. According to CRM, conversion of top blown converters to bottom blowing permits increases of up to 40 percent in the charge weight, primarily because of the excellent slag formation control associated with the process.

Following the successful trials at South Works, US Steel announced in December 1971, that the open hearth shop at Fairfield, Alabama was to be converted to a Q-BOP shop with two 180 tonne furnaces; early in 1972 the conversion of the No. 2 BOF shop (which was then still under construction) at Gary, Indiana to Q-BOP was announced. The Gary plant is due to come into operation at the end of 1972 and that at Fairfield towards the end of 1973. The pilot plant at South Works Chicago has now been shut down.

Undoubtedly, one of the aspects which has influenced the management of US Steel in pioneering this scale-up of the Q-BOP is capital cost, since it is reported * that there is a substantial saving in area when the process is compared with BOF.

There is a substantial difference between European and US raw materials and practices, as well as in heat size in major steelworks. The OBM process already produces some 3.5 million annual ingot tonnes in Europe, and the development of the Q-BOP installations in the USA will be watched with interest. A list of OBM / Q-BOP installations is given in Table 12.4.

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* "Industrial Heating" 39, 900, (May 1972)

TABLE 12.4 WORLD-WIDE LIST OF OBM/Q-BOP INSTALLATIONS

Country and company	Plant location	Start-up date	Converters		Crude steel capacity	Remarks
			No.	Heat size		
				tonnes	tonnes	
Germany						
Eisenwerk-Gesselshaft Maximilianshutte GmbH	Sulzbach-Rossenberg	1967	6	32	1,000,000	First commercial user
Rochling'sche Eisenund Stahlwerk GmbH	Volklingen	1969	2	40	500,000	Thomas to Q-BOP
Metallhuttenwerk Lubeck GmbH	Lubeck/Herrenwyk	1970	1	5	36,000	Experimental and production unit
France						
Societe des Acieries et Trefileries de Neuves Maison	Chatillon	1969	4	32	540,000	
Union Siderurgique du Nord et de L'est de la France (USINOR)	Valenciennes	1970	3	72	810,000	All commissioned in 1970. Largest vessels presently operating.
-	Longwy	1970	2	40	360,000	
Belgium						
Cockerin-Ougres-Providence	Marchiennes	1971	2	32	400,000	
Forges de Thy-Marcinelle et Monceau	Monceau	1971	4	32	600,000	
Luxembourg						
Miniere & Metallurgique de Rodange	Rodange	1971	2	32	270,000	Thomas to Q-BOP
South Africa						
South African Iron & Steel Industrial Corp. Ltd.	Pretoria	1971	1	46	(270,000)	This plant operates three 25 ton Thomas Converters. One is now converted to Q-BOP
United States						
U.S. Steel Corporation	Gary, Indiana	1973	2	180	3,200,000)	Largest units in the world. First planned to use low-phosphorus pig iron commercially.
U.S. Steel Corporation	Fairfield (Fairfield Works)	1974	2	180	3,200,000)	
Canada						
Sidney Steel Corporation	Sidney	1973	2	110	1,150,000	Replacing existing open hearth. Third vessel to be added after new blast furnace is built. First Q-BOP planned for greenfield site.
Total existing and scheduled capacity		"	"		12,336,000 tonnes	

The LWS process, developed in France, has recently been licensed to Koppers Co., of Pittsburg for exploitation in the USA and Canada, and on a non-exclusive basis in Latin America. Only two furnaces are operating in Europe - a 30-tonne converter at the Rombao plant of Wendel, and a 20-tonne unit at Longwry for Hauts-Fourneaux de la Chiers. A third installation is under construction in the Saar.

The Status of the companies involved in these bottom-blown processes implies validity of the claims made for OBM and Q-BOP; it is still too early to judge whether they will take the lead from BOF for future bulk steelmaking but the available data suggests that developments in these processes will have a marked influence on process selection over the next decade or so. It must be regarded as significant that US Steel has chosen to convert a proposed second BOF shop to Q-BOP at Gary, Indiana, before the BOF furnaces has been installed. In other words this must be seen as a deliberate choice between BOF and Q-BOP, and not a conversion of an open hearth shop as at Fairfield, Alabama.

12.4 Open-hearth steelmaking

The open-hearth is technically a most flexible steelmaking process, being capable of handling hot or cold charges with almost any mix of hot metal, pig iron and scrap, and of producing a very wide range of steels. The reason for steady decline of open-hearth capacity throughout the world lies in the high comprehensive conversion costs of open-hearth steelmaking compared with those of the BOF (Fig. 12.2) From the curves in the figures, it is evident that in an expanding industry existing open-hearth capacity is of value in delaying the date when new BOF capacity has to be built. On the other hand, where adequate capacity exists to satisfy the market demand, the open-hearth plants are at a considerable economic disadvantage compared with the BOF plants. This is undoubtedly one of the factors governing the US Steel Corporation's interest in Q-BOP. Another example of reaction to these economic pressures occurred in the UK recently, where an open-hearth shop only ten years old was scrapped to make way for a 240 tonne BOF shop.

The notable exception to the rapid decline of open-hearth capacity is the USSR, where capacity only fell from 84 percent of crude steel manufacture in 1965 to 73 percent in 1970. The rate of change is beginning to speed up now, but it is difficult to see how, on strict economic grounds, its operation has continued in the USSR on such a large scale. Factors that may have contributed to the situation are the development of large furnaces (up to 900 tonnes capacity), the widespread availability and use of natural gas for heating the furnaces, and oxygen lancing.

Modifications to improve open-hearth performance

Recent attempts to improve open-hearth performance have been chiefly in the area of productivity. The two most important developments have been the use of oxygen to speed refining and the concept of twin-hearth production - called the Tandem furnace.

Charge: 70% hot metal
30% scrap

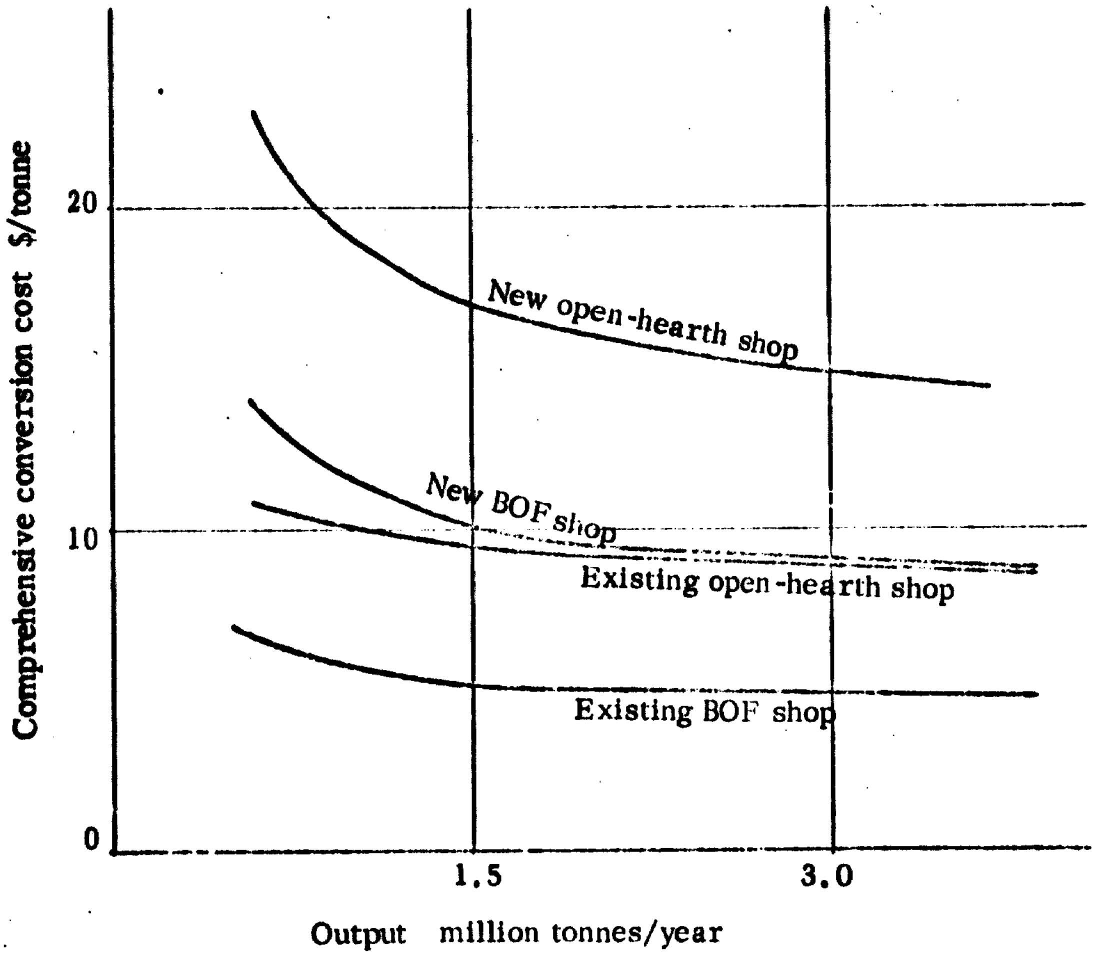

FIGURE 12.2 - COMPARATIVE BOF AND OPEN-HEARTH STEELMAKING COMPREHENSIVE CONVERSION COSTS

Oxygen lancing and injection

Once the technique of using tonnage oxygen for refining had been achieved in the BOF process, it was logical to extend the principle to the open-hearth furnace in order to accelerate the process. However, oxygen lancing or injection can only be applied to a limited extent without extensive modification to the furnace flues and checkers due to the increased rate of generation of reaction gases.

Oxygen lancing has become common practice, and in the USSR over 60 percent of furnaces used oxygen lancing in 1970. It is claimed that use of natural gas and oxygen on furnaces in the USSR has allowed productivity to be increased 15-25 percent, and fuel costs to be decreased by 15-20 percent. An example of a furnace installation that was modified to take further advantage of oxygen lancing was the Ajax development at Scunthorpe in the UK.

The development of the submersible tuyere for oxygen injection in Bessemer type converters is now being applied to the open-hearth furnace. Referred to as SIP (the submerged injection process), the technique has been pioneered by the Sydney Steel Corporation of Canada. Initially tuyeres were mounted in the bottom of the furnace, but it was subsequently established that horizontal blowing below the slag line from the sides was equally effective. This makes it applicable to fixed as well as tilting furnaces. Improvements in performance similar in character to those claimed for the OBM process are reported.

Tandem furnace

The Tandem furnace represents a very basic change in open-hearth steelmaking. The idea was developed to convert existing cold or mixed charge open-hearth furnaces to a faster process able to utilise the refining gases by burning them in a separate bath, where a second charge was undergoing preheating and melting. The furnace has two independent baths each with its own charging and tapping holes. The baths are interconnected at the top, so that gases have free access. Each half operates on a separate charge. Cycle time is greatly reduced. In the USSR, two tandem furnace installations, each of 250 tonnes total capacity, are in operation. Cycle time is about 6 hours per bath, which means that one bath is tapped every 3 hours. Total costs are claimed to be about $1.15 less than for conventional open-hearth practice. It is claimed that the tandem furnace installed in South Africa has an even faster cycle time, with operating costs (not including capital charges) reduced by around 30 percent, the bulk of which is from savings in fuel and oxygen. Tandem furnaces of up to 400 tonnes total capacity are in operation in Czechoslovakia.

12.5 Addition of alloying elements

Alloying elements are added to the steel to confer particular properties, usually by adding them to the ladle, through a chute, during tapping of the steelmaking furnace. (For a discussion of the manufacture of special steels see Chapter 21).

The practice of making additions in the ladle lends itself particularly well to a fully automated steelmaking sequence (cf. Chapter 24). A 'standard' specification of steel is made in the steelmaking furnace, and analysed by vacuum spectrometer just prior to tapping. Ladle additions can then be made on the basis of the analysis of the steel in the furnace and the final specification desired; the operation can be computer-controlled, the input data being the analysis of the steel in the furnace.

Ladle additions enable the steelmaking plant to be operated on a standard cycle to produce a consistent output from the furnace, and this also simplifies computer control; no limitations are placed, however, on the flexibility with which a range of common steel specifications can be produced.

12.6 Continuous steelmaking

Continuous steelmaking has at once its advantages and disadvantages. On the one hand it is easier from a control point of view to maintain a constant performance of the plant, but on the other hand it makes the process less flexible in terms of changing the characteristics of the product. Continuous processes will therefore have their main application in common steels for such products as reinforcing bar.

In twenty to thirty years time we expect the role of continuous steelmaking to be established in world steelmaking practice. By the end of the decade a small number of plants may be in commercial operation. However, the most promising processes so far developed do not appear to offer significant advantages over BOF steelmaking, and cannot therefore be expected to have much impact on steelmaking practice as a whole. The capital costs of the processes may be less than those of the BOF, but the operating costs can hardly be any different, although there may be some saving of flux and 'lost' steel in a WORCRA type process. The likely benefits will come from their continuous nature, permitting the creation of a process chain consisting of a continuously tapped blast furnace, the steelmaking plant and a continuous casting machine. The handling of the blast furnace iron and of the outflowing steel in a truly continuous manner are the keys to the success of these processes. We consider it unlikely that the problems involved will be solved within ten years.

By 1980, the BOF process, probably supported by the new bottom-blown processes, will be used to produce 70 to 75 percent of the world's steel. Against such a background, decisions to install a newly developed continuous process will only be made on the basis of an intimate knowledge of the progress of its development, and of the potential advantages over alternative processes that it holds for the future.

Three continuous steelmaking processes have aroused serious interest. These are the IRSID process (developed in France), the WORCRA process (developed in Australia), and the spray refining process (developed by BISRA in the UK). Of these, the IRSID process is perhaps the most promising at present.

The IRSID process

Refining takes place in a vertical chamber blown with an oxygen lance equipped with a lime blower. Metal is continuously introduced at the bottom. The slag-metal emulsion foams up the reactor chamber and flows through an opening in the side from which it runs into a decanting chamber, where slag and metal separate and are tapped off. This process has been operating on a pilot plant scale in France for several years, and there is now a small plant in operation at a steelworks for commercial evaluation.

The WORCRA process

This process involves counter flowing metal and slag. The slag is generated by lime addition at the metal outflow end. The central bowl-shaped section of the plant contains electrodes projecting from the roof to provide heat. The steel flows out of the bowl and into an elongated section where it is jetted with oxygen to refine it. At the end of the section it passes out of the process. The slag flowing in the opposite direction passes back through the bowl and into a quiescent section of the opposite side of the bowl, where the remaining metal droplets separate from the slag. A 5 tonnes per hour plant has been operating in Australia.

The spray refining process

In the spray refining process, the molten iron is poured through a ring, the periphery of which is provided with oxygen and flux jets. The iron is atomised and refined as it falls to the bath. The reaction thus takes place in a short time, and in consequence is very difficult to control. A pilot plant was built at Millom in the UK, but has now been closed down.

12.7 Future of hot metal steelmaking

Hot metal steelmaking is currently divided between two main processes with only a very small percentage of liquid iron being refined by other methods. Figure 12.3 shows the percentage distribution of crude steel by process on a world-wide basis. The open-hearth can be seen to be of declining importance with its share of steelmaking being taken up by the BOF. Bessemer steelmaking has already declined to a low level. When the basic Bessemer or Thomas plants in Western Europe are finally replaced by or converted to basic oxygen plants, (BOF, Q-BOP, OBM or LWS) then the Bessemer processes will be virtually extinct.

It is clear that by the end of the decade, the BOF will be the principal hot metal process. The development of the submersible tuyere for oxygen injection may extend the useful life of some open-hearth shops, but nevertheless by 1980 only a small percentage of steel will be made by this process. The extent to which the new bottom-blown converter processes will vie with the BOF for a share of the hot metal steelmaking will probably depend crucially on the degree of commercial success that the US Steel Corporation have with their developments. Certainly for new installations BOF plants are likely to be the choice for decisions made during the next three to four years, while bottom-blown process economics

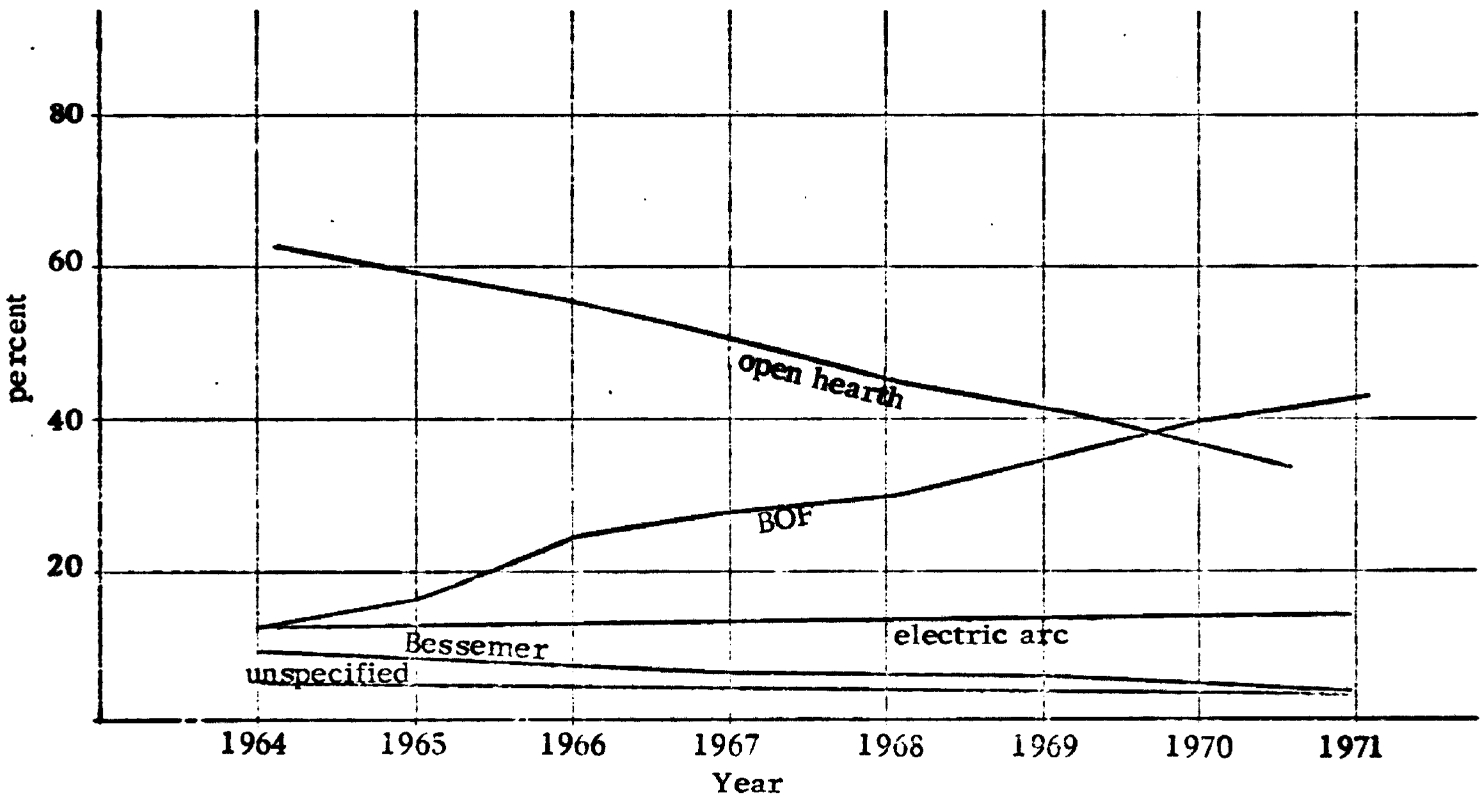

FIGURE 12.3 - PERCENTAGE WORLD PRODUCTION OF CRUDE STEEL BY DIFFERENT PROCESSES

are being fully evaluated. Continuous steelmaking processes are unlikely to be developed sufficiently to be considered in process selections for at least a decade. Also during the next decade the application of computer control to hot metal steelmaking will be extended and refined (cf. Chapter 24).

CHAPTER 13 - COLD METAL STEELMAKING

13.1 Trends in process selection

Most cold charge steelmaking is undertaken in electric arc furnaces with only a small proportion now processed in the open-hearth furnace. Initially developed for special steel manufacture, electric arc steelmaking has been so much affected by technological improvements that costs have dropped to the point where the process is cheapest for cold charge production, even of bulk common steel. This chapter deals only with bulk steel production; special steel production is discussed in Chapter 21.

Technological development of the electric arc process continues with the incentive now of competing with the BOF as the prime steelmaking process - which is discussed in Chapter 14. Trends in development are thus mainly directed toward increased unit output and reduced electricity consumption. As with burden preparation for the blast furnace, so scrap preparation has become a more precise process, with the consequent demands on technology.

It is, however, conceivable that a new process will be developed over the next decade which will replace or supplement both the open hearth and electric arc furnaces operating on cold charges. Such a process is likely to be based on new methods of melting and may involve applications of nuclear energy, or developments based on the principle applied in OBM, Q-BOP and SIP (Chapter 12, Articles 12.3 and 12.4) in which the submerged burner both melts and refines.

Costs of scrap based steelmaking (see also Chapter 14, Article 14.2)

The comprehensive conversion costs (including capital charges) of electric arc steelmaking are still higher than the operating (or conversion) costs alone of the open hearth on cold practice, so that many existing open-hearth furnaces are still able to remain in economic operation. Many have been changed from hot metal practice where competition from the BOF process has rendered them uneconomic. Even so, the number of open-hearth furnaces is steadily decreasing, due partly to increasing costs of maintenance and rebuilding, partly to improved performance of the electric arc furnaces.

The comprehensive conversion costs of modern high power electric arc steelmaking are illustrated in Figure 13.1. The economies of scale can be seen

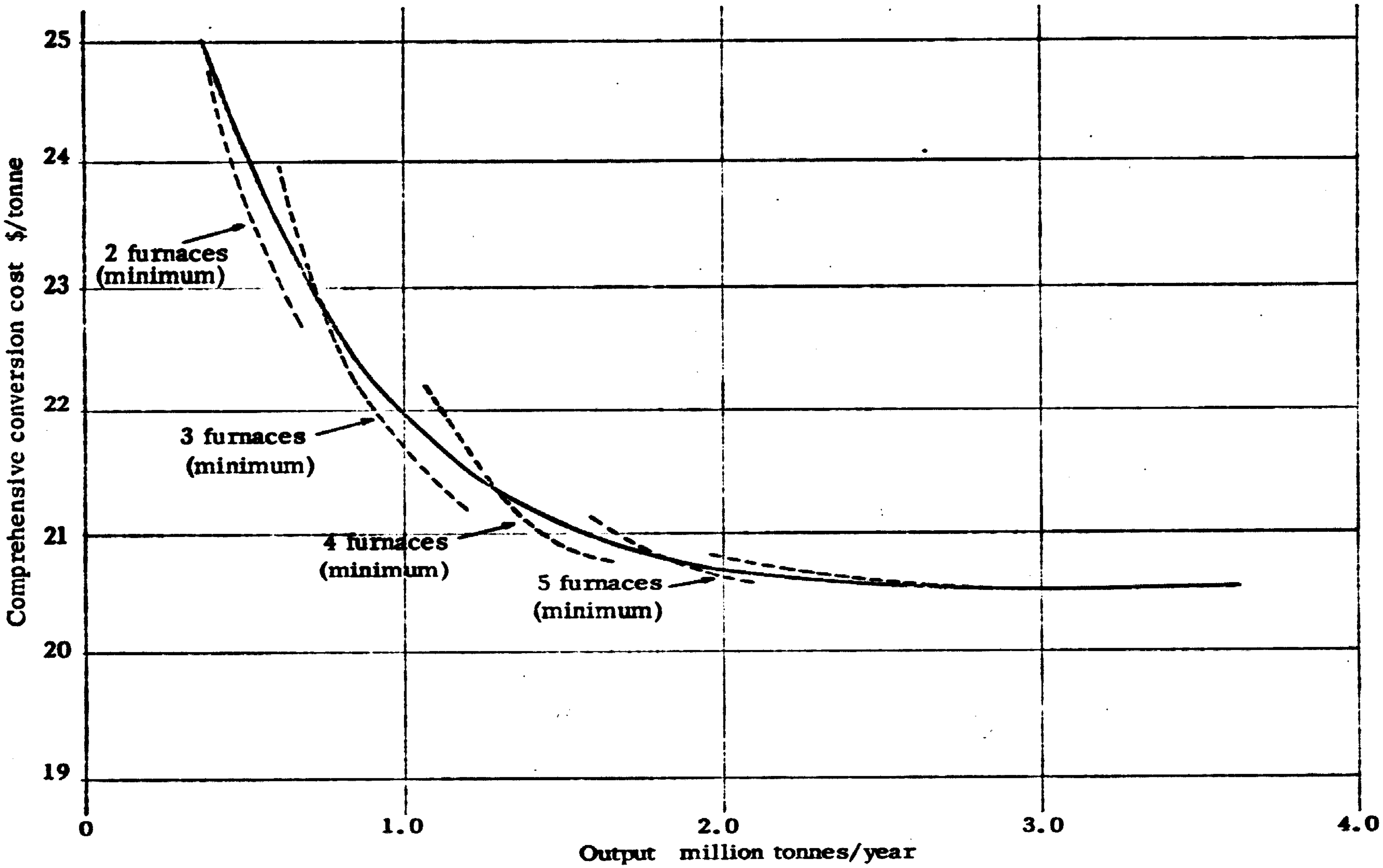

FIGURE 13.1 - ECONOMIES OF SCALE OF SCRAP BASED ELECTRIC ARC STEELMAKING (COSTS OF MODERN HIGH POWER PLANT IN W. EUROPE)

to be fully realised at capacities around 2 million tonnes per year. The marked difference in comprehensive conversion costs between scrap-based electric arc steelmaking and scrap-based open-hearth steelmaking is shown in Figure 13.2. The costs are based on installing new plant in both cases leading to a difference in cost of over $4 per tonne.

The capital charges for the open-hearth furnace lie in the range $4 to $6 per tonne of steel produced, so that in a comparison between an existing open-hearth furnace and a proposed new electric arc furnace, the open-hearth costs may fall below those of the electric arc furnace, particularly at the higher capacities. Thus, in cases where an efficient open-hearth plant still has useful life, there is usually a case for its retention for a further period.

Fuel-oxygen steelmaking

The lower energy cost of fuel oil compared with electricity has led to attempts to melt cold charges with a fuel-oxygen burner having a high intensity heat input. Trials have taken place in the USA and the UK.

The process referred to as FOS (fuel-oxygen scrap), makes use of a furnace chamber similar in shape to the electric arc furnace with the burner projecting through the roof. The capital costs of the plant are much lower than those of the arc furnace, because of the absence of heavy electrical gear. Also, the use of fuel oil instead of electricity gives a lower operating cost. On the basis of these favourable costs and promising pilot plant experiments, a 100 tonne furnace in the UK was converted to FOS steelmaking and the process tested on a large scale. It soon became apparent that, due to the highly oxidising conditions, the process had a lower yield than either the arc furnace or open hearth. This was coupled with a very high rate of refractory wear giving high refractory costs and resulting in a short campaign life. Further work on the process was abandoned in the UK, and it now appears to be discarded as a steelmaking method.

The development of submersible oxygen injectors for the OBM process may well lead to a reappraisal of the FOS process using submersible burners.

13.2 Developments in electric arc furnaces

Furnace size

The average capacity of electric arc furnaces is between 50 and 60 tonnes. In the USA some very large furnaces have been constructed, and capacities of 150 - 200 tonnes are not unusual. The largest furnace constructed to date is of 400 tonnes capacity at Sterling, Illinois. Outside the USA furnaces have not approached such size. There are, in fact, only a few furnaces of over 150 tonnes capacity, including installations in Japan, the USSR, Italy, South Africa and Belgium. Both Japan and Belgium have furnaces capable of producing over 200 tonnes.

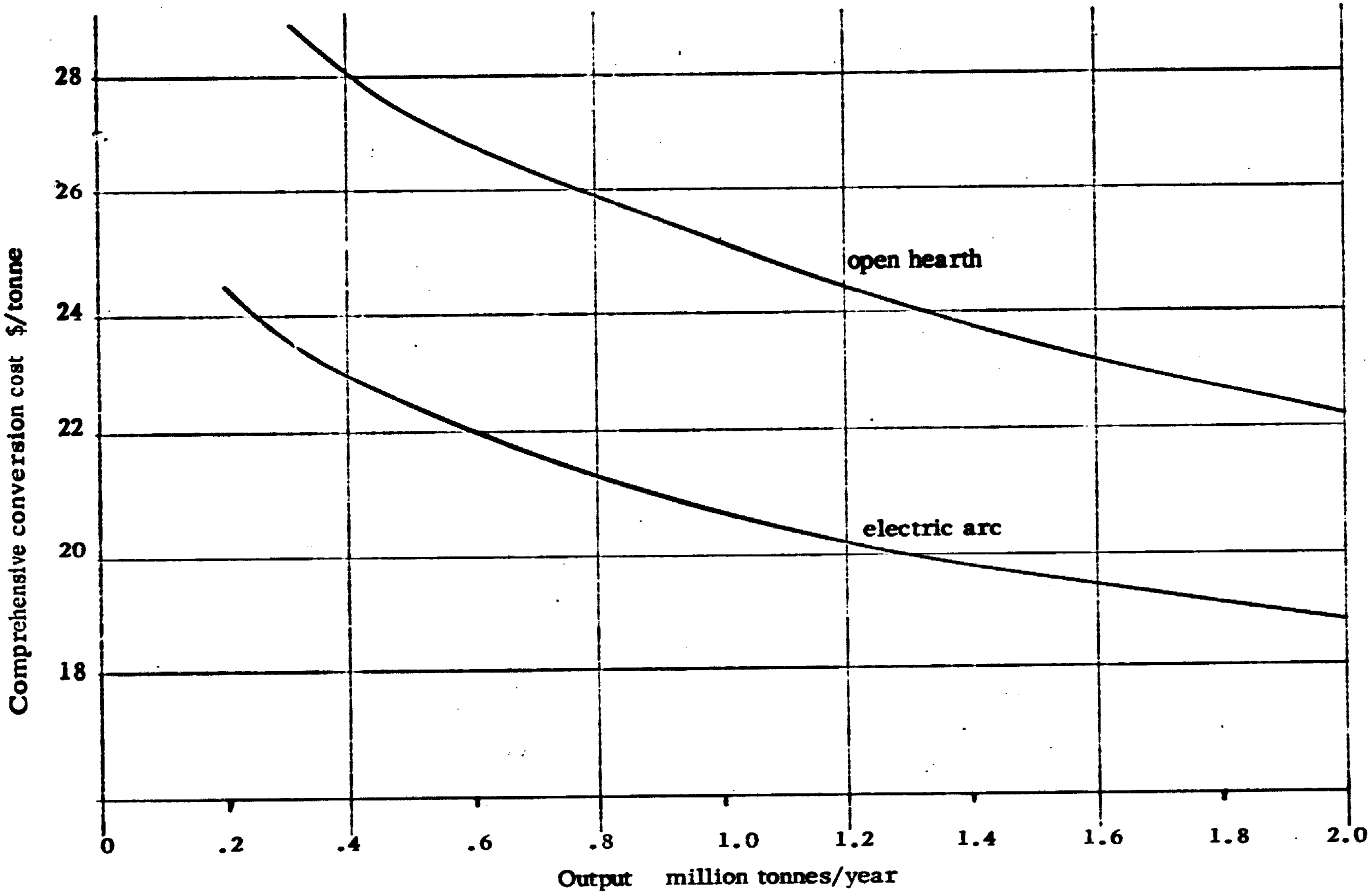

FIGURE 13.2 - COMPARISON OF COSTS BETWEEN COLD METAL ELECTRIC ARC AND OPEN-HEARTH STEELMAKING (COSTS BASED ON WESTERN EUROPEAN PRACTICE)

Furnace transformer ratings

A very important development in the technology of electric furnaces is their greatly increased power ratings. During the early 1950's it was unusual for furnaces to exceed 30 MVA. By 1970 there were a number of furnaces of over 65 MVA, and in the USA there is a furnace of 140 MVA. The advent of ultra high power furnaces has resulted in some medium and large installations having power ratings of 250 - 400 kVA per tonne and with the smallest sizes ratings rise up to 500 kVA per tonne at present. One works in Japan is now considering modifying an existing 10 tonne furnace to operate with a transformer rating of 7.5 MVA, or 750 kVA per tonne. In the USSR furnaces with transformers of 500 - 600 kVA per tonne are planned.

The inverse relationship between furnace size and maximum power rating is due to the conventional three electrode configuration which places limitations on electrode diameter. Without developing 6-electrode furnaces it is unlikely that the large furnaces will achieve the power input rates per tonne currently possible with small ultra high power (UHP) furnaces.

The very high power ratings at present in service allow tap-to-tap times of 2½ hours to be achieved when making common steels from scrap with single slag practice and oxygen lancing.

An important aspect of the move towards ultra high power (UHP) furnaces is the ease with which existing electric furnace shops can be modified to operate at higher powers. A good example of this is the Templeborough arc furnace shop in the UK where the six furnaces, originally of 135 tonne capacity and now at 180 tonnes, were first rated at 40 MVA then uprated to 55 MVA, and now two 80 MVA transformers are to be installed.

A Japanese UHP installation recently reported* has a capacity of 70 tonnes with a transformer rating of 45/54 MVA.

Electric arc furnaces impose heavy loads on the power system, especially during the melt-down phase. The 'spikey' current wave form during melting results in voltage fluctuations on the supply grid. These fluctuations are liable to cause serious inconvenience to other users unless the grid network has adequate capacity or 'stiffness'. The trend toward higher power ratings of individual furnaces especially existing ones may be halted by such limitations of the supply. Voltage smoothing equipment has been developed, but this is costly and so reduces the economic gain of raising the furnace power rating.

Power substitution

In these and other circumstances of power limitation, substitution of electricity by other sources for part of the heat input may be an economic solution. A furnace design applying this technique (the SKF/MR process**) has been recently reported from Sweden. The purpose is to optimise electricty utilisation, particularly since the works are in an area of Sweden where maximum electricity demand is severely limited.

* "Experiences of UHP arc furnace operations", E.C.E. Seminar on Direct Reduction of Iron Ore, Bucharest, September 1972.

** M. Tiberg and Y. Sundberg, I.A.M.I., April 1972. Iron and Steel, April 1972.

Two furnace shells are mounted side by side so that a single roof fitted with electrodes can be fitted to either of them. A second roof fitted with gas burners can be alternatively fitted to either furnace. By using two shells but only one electrode roof it is possible to continue drawing maximum permissible power for longer than with conventional arc furnace practice. During melting the electrode roof is used, and then during phosphorus refining and carbon content adjustment a second roof is used and the metal temperature is maintained by three gas burners. Final refining takes place in a ladle equipped with inductive stirring. The operational sequence of the SKF double furnace is shown in Figure 13.3.

The technique allows the furnace to draw power for around 5000 hours per year, as opposed to 3000 hours for conventional UHP arc furnaces. The double furnace of 60 tonnes total capacity, with a cycle time of 2 - 2½ hours, produces steel at up to 30 tonnes per hour. An interesting feature of the furnace is that one shell can be used as a conventional arc furnace, while the other is being changed or repaired. The use of gas burners and the very short cycle time allows electricity consumption to be reduced to only 330kWh per tonne. Liquified petroleum gas consumption is 22 kg per tonne, which, taking into account the lower efficiency of heating, is roughly equal to an electricity input of 240 kWh per tonne. The cost of the twin shell furnace and associated equipment is lower than that of a conventional electric arc furnace of equivalent capacity, due to reduced cost of shells, lighter handling equipment and greatly reduced electrical installation costs. The capital cost claimed for a 70 tonne unit is about $3.8 million including ancillary equipment. We estimate that the final capital cost of the melting shop would probably be 10 - 15 percent less than a conventional installation. The development merits consideration in situations where arc furnace operation adversely affects the local electricity network, or where prices for liquified natural or petroleum gas are less than $120 per tonne (28 cents per therm), when compared with electricity tariffs of 1.1 cents per unit.

Electrodes

A recent development in prolonging the life of graphite electrodes is the newly patented Bulgarian process of graphite electrode surface treatment which cuts down the electrode consumption per ton of steel to half the current figures; the British Steel Corporation in the UK has obtained these Bulgarian patent rights for commercial operations in the UK. Hungary is also working along these lines.

The following are extracts from a booklet published by "TECHNOIMPEX", State Commercial Enterprise, Sofia, Bulgaria:

> "A new modern installation for laying protective coating was commissioned in Bulgaria in 1970 which has an annual output of 2000 tons of protected electrodes. Protected electrodes are now beginning to be applied in other plants as well.
>
> The coating is prepared by laying aluminium and the additional substances on the electrode surface by familiar methods, followed by electric-arc treatment. The electric-arc burns continuously between

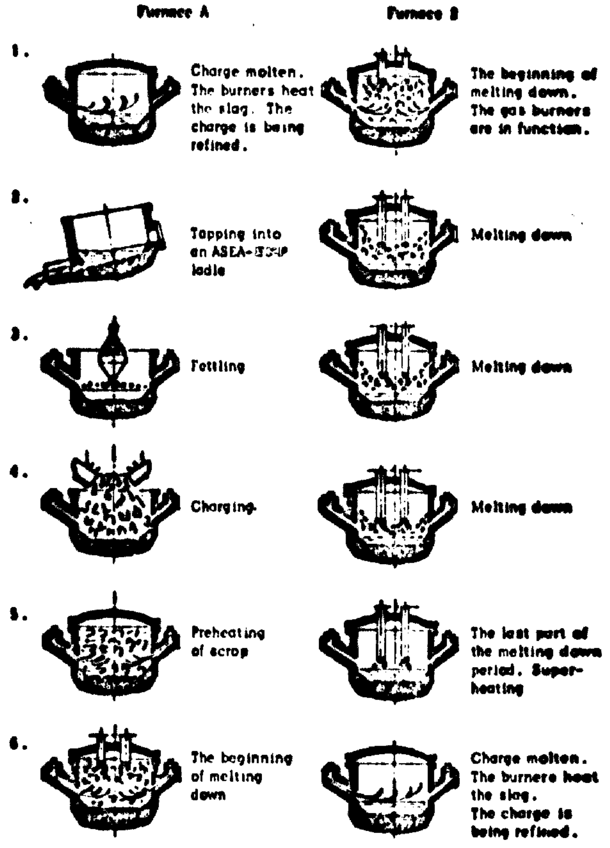

FIGURE 13.3 - OPERATIONAL SEQUENCE OF THE SKF DOUBLE FURNACE

the surface of the electrode and a small lateral electrode, while the surface is moving at an appropriate speed to the arc. The relative movement of the surface in relation to the arc proceeds along a thread-like line and this provides for the consecutive turning of the entire protected surface. The heating of the coating materials in the electric arc does not last very long, and this makes it possible for the process to be carried out in open-type installations and in normal atmosphere."

The use of charge preheating

Preheating of the charge prior to meltdown in electric steelmaking can reduce electric power consumption and increase productivity. There are three ways in which preheating can be achieved: (a) duplex practice with linked furnaces, (b) in furnace heating, (c) the use of a separate scrap preheating unit. Duplex-furnace systems were shown in the 1950's to be uneconomic. In-vessel preheating or assisted melting can be achieved by inserting burners below the scrap level, but the only advantage which can be claimed for this method is an increase in productivity, no savings in fuel costs being apparent in most of the trials. Productivity improvements for five different furnace installations are given in Table 13.1. The high cost of the process is due in part to the cost of providing oxygen for the burners on the relatively small scale required.

TABLE 13.1 - PRODUCTIVITY IMPROVEMENTS DUE TO IN-FURNACE PREHEATING

Size of furnace tonnes	Number of furnaces	Percentage savings		Fuel cost saving per tonne	Test period
		melt power kW %	melt time %		
130	2	5.1	12	0	1967
30	2	15.4	18.5	0	1968
30	1	0	15	15c	1968
25	1	10.9	22	0	1966/67
15	1	8.3	8.3	62 cents including time saving	1969

During the 1960's interest was shown in separate scrap preheating and over 30 such plants were installed during that period. Preheating outside the steelmaking furnace allows more time to be spent on heating and higher mean temperatures can be achieved. Preheating can be carried out in a special refractory lined unit or by using a charging basket with air cooled walls and a refractory lined removable roof which contains the burner. While existing charging baskets can be used, it is probably advisable to use alloy steel buckets. Commonly, separate vessel preheating is practised up to 550°C, but there are reports of temperatures up to 800°C being used. These high temperatures produce a compacted charge, so that the number of charging operations can be reduced.

A detailed economic evaluation of the effects of preheating in a separate refractory lined chamber was undertaken by an Austrian works in 1969, and the results are given in Table 13.2. The results relate to a long period of operation, and may be considered representative of the benefits which can be expected in typical practice.

If it is required to increase the output of the arc furnace only to meet temporary increases in market demands, then in-furnace preheating represents a cheap method of achieving this aim. If it is required permanently to increase the output by up to 20 percent, then separate scrap preheating is the best solution. Preheating can only be justified if the spare capacity can be utilised. The development of refractory lined preheating units makes it practical to carry out the preheating adjacent to the scrap preparation facilities and away from the arc furnace, thus offering flexibility in works planning or modification.

13.3 Steelmaking from sponge iron

Sponge iron or directly reduced solid product requires a cold charge steelmaking process for its conversion to steel. The electric arc process is by far the most suitable at the present time, and there are no firm indications that alternative processes will challenge its position in the foreseeable future.

The electric arc furnace can be operated on any percentage of reduced pellet charge, provided the sponge iron is not less than about 85 percent metallised. However, it is unusual to operate with more than an 80:20 ratio of pellets to scrap.

The principal effects of reduced pellet charging are threefold:

(i) Continuous charging becomes possible
(ii) The furnace power input can be increased
(iii) The electricity consumption increases.

The uniform and very manageable size of reduced pellets makes it possible to feed the charge continuously into the furnace.* It has been reported, however, that if feeding of pellets to the furnace is started before all the scrap has melted, some of the scrap still remains unmelted at the completion of sponge iron feeding, making subsequent operations difficult. In particular, the unmelted scrap makes it difficult to control the chemistry of the steel and tends to make the ladle temperatures rather unpredictable. During the first part of the melting cycle a mound of pellets surrounding the electrode tips produces dispersed arc formation and shields the walls of the furnace. During the final part of the melting cycle the pellets submerge forming a flat bath that allows higher power inputs than is usual with scrap. Both these aspects would serve to increase the utilisation of the plant and to help offset the increased cost of power required.

* "Electric Arc Steelmaking with Continuously Charged Reduced Pellets", J. Sibakin, P. Hookings, G. Roeder Industrial Heating, 36 (July 1969)

TABLE 13.2 -ECONOMIC ADVANTAGES OF SEPARATE SCRAP PREHEATING

Furnace (nominal capacity)	15 tonnes
Charge	17 tonnes
Bucket No. 1	10/12 tonnes
Bucket No. 2	7/5 tonnes
Buckets vol.	14 cubic metres
Preheating Bucket 1	90 minutes
Bucket 2	45 minutes
Natural gas	16 cubic metres/tonne
Scrap temperature	650 - 700°C
Reduction in meltdown time	25/30 minutes
Increase in output	15/18 %
Power savings	85 kWh/tonne
Electrode saving	0.8 kg/tonne

SAVINGS ACCOUNT:

		$/tonne
Meltdown power saving (electricity at 1.37 ¢/kWh)		1.16
Electrode savings		0.44
	subtotal	1.60
Savings due to utilising increased productivity		1.54
	subtotal	3.14
Cost of preheating (includes plant depreciation, natural gas, refractories at 1.76 kg/tonne, all operating costs.)	less	0.59
	Total net saving	2.55

In practice, however, extensive damage to the refractories can occur when pre-reduced iron is used in the charge, and it has been found necessary, in some cases, to operate at lower power inputs with a short arc and a large slag volume to shield the refractories from the arc.

When reduced pellets are charged to a furnace which has not had the transformer uprated, then improvements in productivity result only from the continuous charging. For example, using an 80 percent pellet : 20 percent scrap charge, the furnace productivity can be increased by around 12 percent. This arises partly due to smoother and faster melting and partly due to decreased charging time, because the furnace top does not have to be removed to allow buckets of scrap to be charged. When UHP furnaces are combined with continuous pellet charging, it is estimated that the cycle time on large furnaces might be reduced to well under 2 hours, although at present there are no installations effectively combining these two practices. Figure 13.4 illustrates the potential increase in power rating possible. The figure also shows the effect of pellet charging on electricity consumption. The curves are based on trials carried out in a typical modern electric arc furnace.

The following figures, based on actual trials*, indicate that the percentage of sponge iron in the charge has little effect on furnace productivity:

Sponge iron in charge (%)	Average tap weight (tonnes)	Charge to tap time (hrs.)	Tonnes/ hour	kWh/tonne tapped
0	247	4.38	56.4	494
40	231	4.70	48.9	592
50	194■	4.62	43.6	628
60	232	4.43	53.6	615
68	240	4.71	51.0	611

■ Low productivity is due to lower tap weight.

In these trials charging of the pellets was continuous, but the electrodes were removed for the addition of lime through the furnace top and, in consequence, the benefits of continuous charging were not realised.

The use of reduced pellets produces other benefits in operating costs. Firstly, electrode consumption is reduced, by over 25 percent in some cases, provided that proper control of the power input is exercised; secondly, the quantity of oxygen required during refining can be reduced, as the following figures, based on actual practice, show:

Pellets in charge (percent)	0	28	41	48
Oxygen consumed (cubic metres per tonne)	4.9	4.2	2.8	2.0

When the furnace is operated on reduced pellets rather than pig iron or scrap, then the impurity level of the charge is generally much lower; in particular, sulphur and phosphorous are much lower than in pig iron. This

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* Industrial Heating 39, 481 (March 1972)

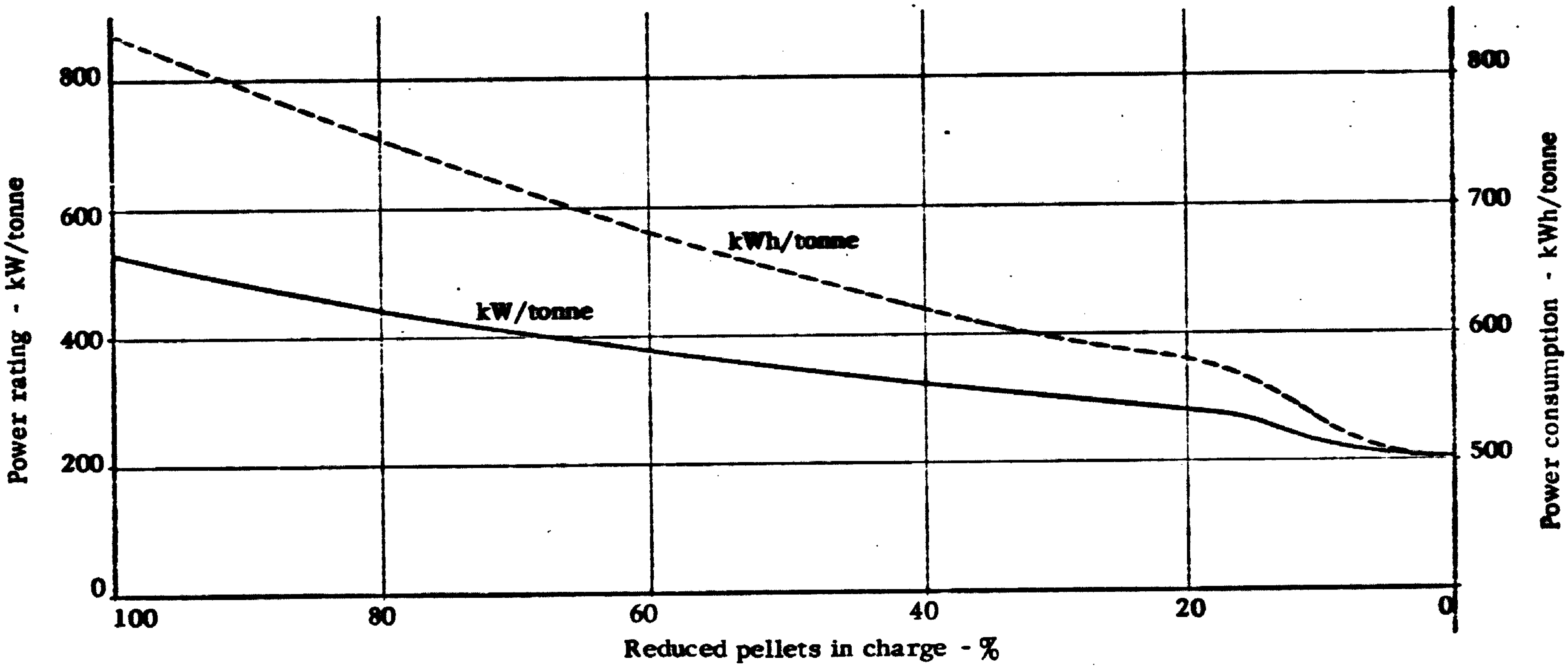

FIGURE 13.4 - EFFECTS OF REDUCED PELLET CHARGING ON POSSIBLE TRANSFORMER RATING AND ELECTRICITY CONSUMPTION

allows a shorter refining time and can produce a cleaner steel, which has advantages for special steelmaking. **

13.4 Scrap preparation and handling

The introduction in the late 1950's of hydraulically-powered shearing and baling machines and specialised fragmenting plant, such as Proler, heralded a new era in scrap processing. The availability of this equipment greatly increased the scrap processer's capability and also abruptly changed scrap processing from labour-intensive to a comparatively capital-intensive industry. Despite the major advances, the economies still to be achieved from more sophisticated scrap processing are leading to an intensification of the search for new methods, to which plantmakers, processers and government bodies are all contributing. Governments are taking an overall and radical look at the scrap industry, the best example of which is the $250,000 grant by the US Government to the Battelle Institute for a two year study of the US scrap industry.

Methods of scrap preparation

Scrap is available to the steelmaking industry in a variety of forms. These may be classified under five main headings - heavy scrap, light scrap, fragmented scrap, turnings and castings.

Heavy scrap is the easiest to prepare, requiring only cutting to a suitable size for charging. This is normally done by hydraulic shear or thermal lance. It has been common practice for heavy shears to have a squeeze box to compress scrap so that it will pass through the shear throat, but recently it has been claimed that shearing costs can be reduced by up to 50 percent by dispensing with the squeeze box and using large shears with blades of 4 metres, and a small shear for secondary cross cutting.

Light scrap is normally baled and the trend in baler development is towards greater capacity with bale weights now going up to 7 tonnes. There are also reports of light plate being baled. An extreme example of the trend towards larger bales is a special press for making 60 tonne bales for electric arc furnaces. Originally installed in Japan, such presses are now being introduced into the USA. The bales are made to conform to the furnace shape and are gently lowered in. The claimed saving of $10 per tonne appears rather high, but advantages are gained in most areas of capital and operating costs. Another new baling method involves press forming into a log and shearing the log. The throughput is said to be 20 percent greater than existing methods and may offer cost advantages.

Fragmented scrap covers car hulks and domestic appliances which are fragmented by various processes. The form of this scrap makes it difficult to process effectively, because of its awkward physical shape and contamination by non-ferrous metals. The Proler fragmentising plant is well proven, but such plants give acceptable operating costs only when there is a large source of scrap.

** "The use of sponge iron in an electric steelplant", G. Morelli and G. Urgnani, E.C.E. Seminar on Direct Reduction of Iron Ore, Bucharest, Sept. 1972.

There is a need for techniques viable at lower outputs, and for development of economic processes that will reduce contamination to an acceptable level. The latter point is of great importance and most current effort is devoted to this. The most troublesome contaminant is copper, although freedom from tin, zinc and aluminium is also important. Straightforward fragmentation followed by magnetic separation is not always sufficient to reduce car bodies to an acceptable residual copper level of 0.2 percent, but the ripper-shredder technique in which car bodies are torn into about ten pieces prior to feeding to small shredders gives better results. Work at General Motors has shown that the technique is capable of producing consistently, on a commercial basis, scrap of 0.12 percent copper. Incineration, which is a very costly process, can be used to remove non metallic contaminants.

One of Europe's biggest scrap processers has announced a cryogenic process in which baled scrap is tunnel-frozen in nitrogen vapour, after which it is shattered in a conventional hammer mill, shaken and screened. Freezing is said to increase hammer mill throughputs by up to 250 percent. All items in the cryogenic plant system are standard items except the cooling tunnel, which is still at a pilot plant stage. The operating costs are said to be high, due mainly to the cost of liquid nitrogen.

Turnings, including swarf and borings, are regarded by steelmakers as the least useful because of oil and non-ferrous metal contamination. In addition to this, it is difficult to handle and its high surface area renders it very susceptible to oxidation during heating. The only effective way to deal with turnings is to briquette them. The throughput of existing machines is low due to their reciprocating action, but continuous roll forming processes are under development.

Oil can be removed by drying or centrifuging. The latter process is up to 95 percent effective. A recent novel approach involves naphtha rinsing and naphtha recycling. Detailed design studies suggest a cost of $0.75 per tonne.

Steel castings are treated like heavy scrap but iron castings are normally fragmented by impact. Explosives appear to be the ideal solution for breaking rejected ingot moulds. The cost is in the region of $0.5 per tonne.

Future developments in scrap use

Continuous charging of steelmaking scrap to the electric arc furnace allows the melting and refining periods to be overlapped, as with reduced pellet charging, and large reductions in cycle time become possible. Similar benefits can be achieved by feeding shredded scrap to the BOF in a semi-continuous manner. Better process control is achieved particularly of steel temperature and cycle time.

Particular grades of scrap may be used in special ways. For example, high grade light scrap can be reconstituted direct to a usable steel product by chipping it and then heating the chips in a reducing atmosphere while the tray is vibrated. In this way a clean oxide-free partially formed slab is produced which can be rolled to a finished product. The process is successfully used by General Motors in the USA. Tests of using turnings in sinter burdens and for ore beneficiation have been made but the economic justification of such practices has not as yet been proved.

The continuing trend toward more uniform feed stock applies to scrap just as much as to blast furnace burdens. More precise classification of scrap is being called for by steelmakers, and this will lead to more processing particularly of consumer scrap to reduce contamination. Also the need to maximise recovery of non-ferrous metals will result in an increasing sophistication of recovery processes. A number of methods are currently under investigation. These include sink-float methods and the use of linear motors, but it will be some years before such processes can achieve commercial viability.

CHAPTER 14 - PROCESS ROUTES TO STEEL

14.1 Process selection trends for common steels

From the preceding chapters in this Section, it is evident that several well defined trends are taking place in the selection of processes for converting iron ore into common steels.

The main hot metal process chain is changing from that of the blast furnace and open hearth to the blast furnace and BOF processes. Electric arc steelmaking is supplanting the open hearth for cold practice. With the successful development of a number of direct reduction processes, about 1 percent (5 million tonnes per year) of world steel production is now made from iron ore by these processes. It is however noted that the conditions pertaining at the locations where these processes are used are particularly favourable to the process selected compared with the blast furnace.

New technological advances will determine the future direction of these trends but the advances themselves are to some extent determined by the economic advantages inherent in the trends. The likely direction of future trends is thus dependent on the present position of each process relative to the others in terms of cost.

14.2 Costs of different steelmaking routes

Note on calculation of the cost of scrap

In the comparative steelmaking cost calculations derived in this report, a long-term price of scrap has been used. This price was generated from a comparison of the costs of steelmaking by hot metal and cold metal routes, on the assumption that the cost of scrap is defined as that value which equates the costs of liquid steel from an electric arc at 0.5 million tonnes level of output with the costs from a blast furnace/BOF works at 3.0 to 5.0 million tonnes capacity. Details of the calculations are shown in Table 14.1. Two sets of calculations have been carried out; one using a capital recovery factor of 16.0 percent and the other using 19.2 percent, the latter being the value currently applicable to average international loan to equity ratios.

TABLE 14.1 - COMPUTATION OF COSTS OF SCRAP

Process Route	Blast Furnace/BOF				Electric Arc	
Annual level of output - million tonnes	3.0		5.0		0.5	
Capital recovery factors %	16.0	19.2	16.0	19.2	16.0	19.2
Capital cost - $ millions	245.8	245.8	373.0	373.0	19.3	19.3
Annual capital charge - $ millions	39.3	47.2	59.7	71.6	3.1	3.7
* Capital charge per tonne liquid steel - $	15.2	18.2	13.3	15.9	6.9	8.2
** Operating costs per tonne " " - $	39.5	39.5	38.8	38.8	23.6	28.6
** Total per tonne " " - $	54.7	57.7	52.1	54.7	35.5	36.8
*** Cost of scrap per tonne " " - $	.283x	.283x	.283x	.283x	.929x	.929x
Calculation of cost of scrap : $ per tonne	54.7+.283x = 35.5+.929x x = 29.7	57.7+.283x = 36.8+.929x x = 32.3	52.1+.283x = 35.5+.929x x = 25.7	54.7+.283x = 36.8+.929x x 27.7		

* Assuming 90 percent plant utilisation

** Excluding cost of scrap

*** Factors used represent the proportion of scrap used in the charge, adjusted for yield.
Blast furnace/BOF route based on 25 percent scrap in the charge, electric arc based on 90 percent scrap in the charge.

From an examination of the results of calculations shown in Table 14.1 a long-term price of $29 per tonne of scrap has been adopted. This is comparable with the average price paid for scrap in Europe and USA during the years 1966 to 1971, as shown in the Table 14.2.

TABLE 14.2- SCRAP PRICES (DELIVERED) FOR SELECTED COUNTRIES
($ per tonne)

Country	1966	1967	1968	1969	1970	1971
W. Germany	31	29	31	31	38	30
France	26	23	25	23	..	..
Holland	30	28	32	29	35	32
Denmark	26	27	26	26	27	30
Spain	36	33	32	35	43	53
Norway	27	34	29	30	44	34
USA	33	28	31	28	40	40
Italy	..	..	..	..	..	..

Source: "The Iron & Steel Industry in 1970 and Trends in 1971" - OECD

Process routes based on iron ore

A comparison of the costs of direct reduction processes with the costs of the blast furnace process has little meaning, since the processes do not produce the same products. Blast furnaces and electric smelters produce liquid iron that can be converted to steel in a BOF steelmaking shop. The remaining processes produce a sponge iron which must be refined by electric arc steelmaking. Cost comparisons between all the processes are therefore valid only at the liquid steel stage. Furthermore they can only be attempted using data relevant to a specific location, and such comparisons of process costs therefore have limited application since slight alterations in basic costs of such items as coking coal, non-coking coal, gas and electricity, have a major effect on the overall comparison.

Figure 14.1 illustrates the total costs of producing steel at different levels of output for four process routes. The three routes using direct reduction processes are assumed to be located at sites that have a cheap source of reductant or energy which benefits that process. Thus the SL/RN process is costed on the basis of cheap coal ($10 per tonne), the HyL on the basis of cheap natural gas (14 cents per gigajoule) and the Elkem on the basis of cheap electricity (0.25 cents per unit). All other costs and those of the blast furnace and steelmaking processes are costed on the basis set down in Appendix 3 for international steelworks sites. Tables 14.3 and 14.4 give examples of the build up of costs for the blast furnace/BOF and HyL/electric arc routes respectively.

TABLE 14.3 - HOT METAL STEELMAKING COSTS

Item	$/t (liquid steel)
Hot metal ($58/t)	46
Scrap ($29/t)	9
Other materials and all conversion costs	5
Capital charge	2
	62
Allocation of general works services and working capital	3
TOTAL	65

Table 14.3 shows the total costs of BOF steelmaking in a 4 million tonnes per year works, using hot metal costed on the basis of Table 10.1 in Chapter 10.

TABLE 14.4 - COLD METAL STEELMAKING COSTS

Item	$/t (liquid steel)
Reduced pellets ($50/t)	46
Scrap ($29/t)	7
Electricity	8
Other materials and all conversion costs	12
Capital charge	5
	78
Allocation of general works services and working capital	6
TOTAL	84

Table 14.4 shows the total costs of electric arc steelmaking in a 0.5 million tonnes per year works, using sponge iron made in an HyL plant and costed on the basis of Table 11.3 in Chapter 11.

Figure 14.1 shows that the routes intermediately producing sponge iron are still at a considerable economic disadvantage, even with favourable costs of reductants. Although the diseconomics of scale of a small blast furnace/BOF works might make the other processes the economic alternatives for a works of, say 200,000 tonnes per year, in the examples illustrated there is a potential difference of over $20 per tonne available to cover the cost of transporting billets from a large blast furnace/BOF works elsewhere to the location where such a works based on direct reduction and electric arc steelmaking might be built. With fuels at the rates generally encountered, this difference would be even greater.

Scrap based steelmaking

The comprehensive conversion costs of producing steel from scrap are around $34 per tonne. However, for common steels this must normally be considered as a subsidiary process to the ore-based routes because scrap is a derivative of steel production. It is the cost of steelmaking by the cheapest ore based route that determines the value of scrap to the steelmaker, as was discussed at the beginning of this article: Thus in Table 14.5 the cost of scrap taken results in the cost of steel made in an electric arc steelworks of 0.5 million tonnes annual capacity being equal to the larger capacity blast furnace/BOF works cost set out in Table 14.3.

TABLE 14.5 - SCRAP BASED STEELMAKING COSTS

Item	\$/t (liquid steel)
Scrap (\$29/t)	31
Electricity	7
Other materials and all conversion costs	11
Capital charge	6
	55
Allocation of general works service and working capital	10
TOTAL	65

The limited availability of scrap by virtue of its derivative nature makes it essential for steelmakers operating a scrap based practice to limit their capacity to a level that maintains a buyers' market in scrap. Once demand exceeds the scrap arising, a sellers' market develops and the cost of scrap to

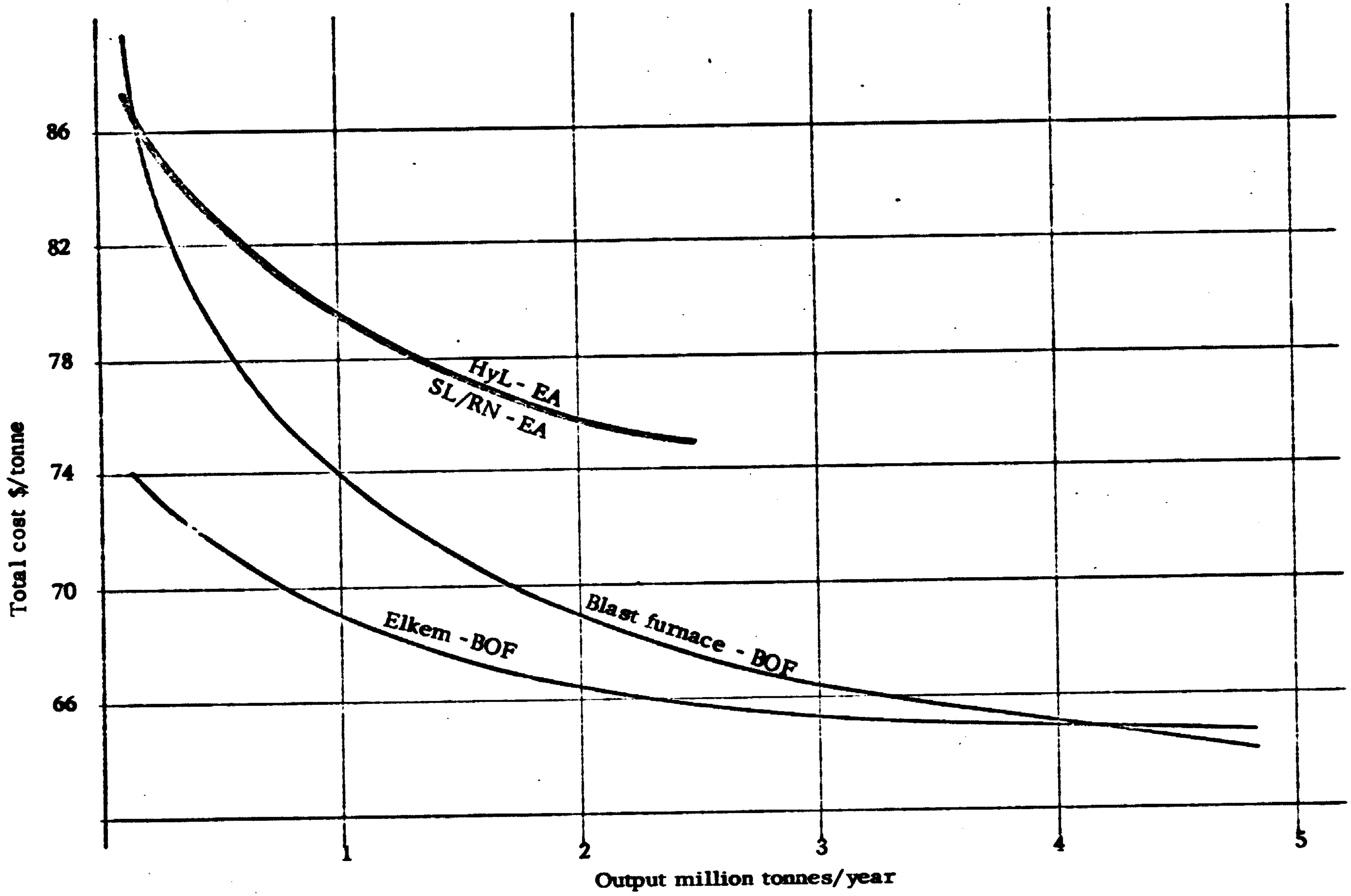

FIGURE 14.1 - ECONOMIES OF SCALE OF VARIOUS PROCESS ROUTES TO LIQUID STEEL

the steelmakers will rise above that determined by the balance of steel costs described above.

14.3 Future trends in process selection

Blast furnace/BOF route

The keys to future selection of processes lie in the development potential of the blast furnace and the inherent simplicity of converter steelmaking. The discovery and development of large reserves of high quality iron ore and the bulk shipment of these materials across the world is bringing about a standardisation of iron and steelmaking practice. In consequence, research and development effort generally need no longer be diverted onto problems peculiar to unusual combinations of raw materials.

Paramount among present problems, however, is the consumption of metallurgical coke. As discussed in Chapter 9, coke substitutes, particularly formed coke, are being successfully developed to meet this situation. In parallel, continued efforts are being made to modify blast furnace practice to reduce the actual coke rate. Longer term development currently under study include the CRM proposal to inject reducing gases into the stack above the reaction zone, and a Japanese proposal to use circulating gases from a nuclear reactor in the furnace, which were discussed in Chapter 10, Article 10. Blast furnace process thinking is clearly being liberated from the classic concepts of the the past and we expect the process to be continually adapted to remain competitive.

The blast furnace will undoubtedly continue to be the large scale iron producer. Oxygen blown convertor processes, of which BOF and OBM are the present principal examples, will be selected for hot metal steelmaking practice. The present trend indicated in Figure 12.3 (Chapter 12) will continue, so that by 1980 over 70 percent of world steel production is likely to be using this route.

Electric arc steelmaking

Although the electric arc furnace is replacing the open hearth for cold metal practice, the amount of electric arc steelmaking does not appear to be related solely to its function as a scrap melter. Its function in special steels manufacture is perhaps more important. In Figure 12.3 electric arc steelmaking is seen to have remained a constant percentage of world output for the past 7 or 8 years. In Japan, where scrap is now in short supply, electric arc production represents a higher percentage than the world average but, as may be seen in Figure 14.2, this is declining slowly towards the world average. The long term trend indications are that electric arc steelmaking will continue at the present world level.

Direct reduction processes

Seen against this background, the use of direct reduction processes is limited. Clearly, there are technological reasons for using them, as for example in New Zealand (high titanic ore) and in South Africa (vanadium extraction), but in economic competition with the blast furnace/BOF route, the

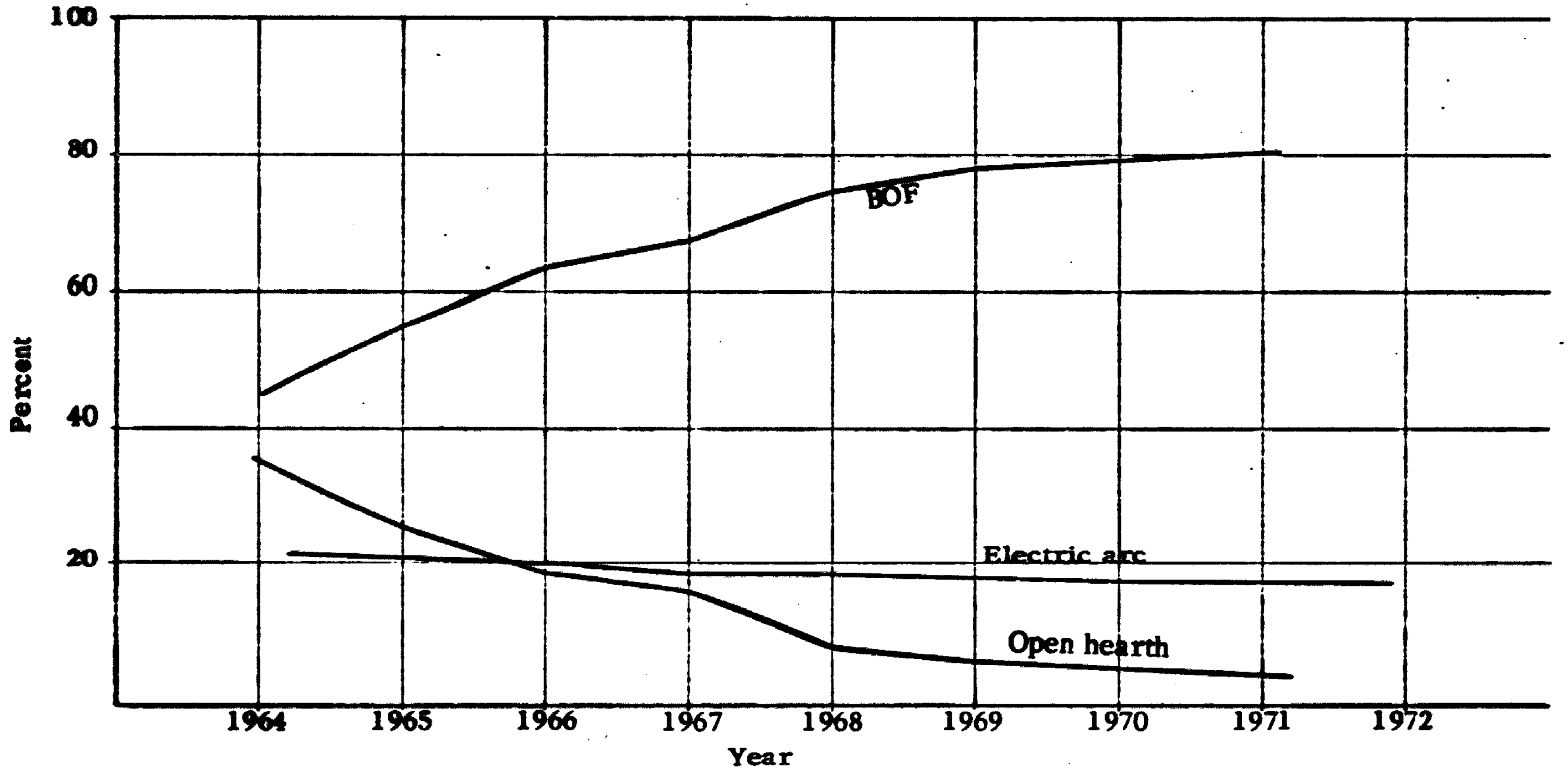

FIGURE 14.2 - PERCENTAGE JAPANESE CRUDE STEEL PRODUCTION BY VARIOUS PROCESSES

determining factor is going to be the cost of delivering the equivalent product from the large blast furnace/BOF works located at some vantage point such as the mine or a deep water port. Some plants are being built in conjunction with miniworks that have economic advantages over large scale works in certain locations (see Chapter 22).

The production of sponge iron as a control for scrap prices has been suggested but with indicated economic price levels for sponge iron itself of $50 per tonne under favourable conditions, this does not seem practical. Certainly, as a short term venture, in conditions of demand exceeding the scrap likely to be coming available, a sponge iron plant might be considered. Similarly, the addition of partially reduced pellets to the blast furnace burden may be justified as a short term expedient in order to delay expenditure on a new furnace. However, the operator of the direct reduction plant must be assured of continuing demands of this type if the plant is to be profitable.

We believe that direct reduction will play an increasing role in the totality of world iron and steel production, as was indicated in Chapter 11, but we see no immediate likelihood of the sponge iron route to steel becoming the leader, since it would require halving of present costs to justify massive investment in it.

CHAPTER 15 - CASTING

15.1 Ingot casting

The casting of steel into sizes suitable for further hot working has been practised since the middle of the 18th century. The sizes of the ingots originally cast were quite small and remained so for about a century because the end products were mainly small items such as knives and springs; and the machinery available for forging and rolling the ingots was limited in size.

Since the advent of bulk steelmaking at the end of the last century, using Bessemer converters and Siemens open hearth furnaces, there has been an economic drive to design larger machinery and use larger ingots which has resulted in steady progress in this direction up to the present day.

Many small steelworks in the world still produce small billet sized ingots of about 0.5 tonnes which are reheated and fed directly to small mills with little or no preparation. At the other end of the scale the largest mass-produced ingots are for slab rolling and have now reached 40 tonnes. For the production of blooms the ingot size is restricted to less than 20 tonnes by a combination of factors. These include a restriction in cross section area imposed by the design of the primary mills, a height limitation of about 2.5 m due to the need to avoid excessive lengths of blooms from an ingot prior to further rolling, together with practical teeming limitations. Specially designed ingots up to 250 tonnes in weight are individually cast for heavy forging operations and heavy slab and plate production.

There is still some incentive for an increase in average ingot sizes, but it is doubtful whether the maximum ingot sizes will increase much beyond those used at present. For this to happen, rolling mills capable of handling larger blooms and slabs would be required, and the alternative possibility of the intermediate products being continuously cast,as continuous casting machines are increased in size to meet the demand,must be considered.

In recent years there have been big changes in the layouts and operation of the ingot casting facility, brought about by the rapid increases in the outputs of steelplants. Early casting facilities were in many instances operated under the same roof as the steelmaking process, and thus all operations from teeming to ingot stripping were carried out in close proximity using multi-purpose equipment. Developments in materials handling led to the 'ingots cast on bogies' technique and in the modern casting facility ingots are cast in moulds travelling on bogey units which circulate continuously from the casting bay to the combined stripping and mould preparation bay, where the used moulds are replaced by cooled, cleaned and coated moulds before the bogey unit is returned to the casting station.

Cost of ingot casting

A build-up of typical operating costs for ingot casting is given in Table 15.1 below.

TABLE 15.1 - INGOT CASTING OPERATING COSTS

	$ per tonne of ingot
Moulds and bottoms	1.1
Refractories	0.4
Maintenance materials and spares	0.4
Fuel and energy	0.4
Labour	0.4
Others	0.1
TOTAL	2.8

These costs, which exclude capital charges and all overheads, apply to an installation producing ordinary quality balanced steels in excess of 1.0 million tonnes per year, with ingots in the 10-20 tonne range from heat sizes in excess of 100 tonnes.

While the relative costs of the items will vary from location to location, the cost of moulds will always account for nearly half the total operating cost. In addition to the operating costs, capital charges contribute a significant amount to the conversion cost of ingot casting and these charges can vary greatly with the size of the operation and the location.

The ingot yield from liquid steel in the ladle is a key factor in the total economics of casting. The actual contribution of ingot yield to the costs of casting is difficult to isolate as it can only be determined from cost evaluations through to the finished product. As in most steelworks there is a large variety of products, this makes the practical problem of cost distribution between departments somewhat complex. However, improved yields of ingots from liquid steel can in practically all cases be regarded as a cost saving.

A great deal of research has gone into the ingot casting field and much of this has been directed to reducing the cost of the finished product by improving the overall yield of liquid steel to finished product. The improvement in overall yield obtainable is a combination of the improvements in yields at the ingot, semi-finished product and finished product stages.

The yield from liquid steel to ingot depends to a great extent on avoiding the production of a short un-rollable ingot at the end of the cast. This is now possible with modern accurate weighing techniques, applied both to the charge in the furnace and the liquid steel in the ladle.

The yield on primary rolling has increased steadily, especially with regard to killed steels, where careful control of hot-topping has reduced primary piping and segregation to a great extent.

The improvement in ingot surfaces brought about mainly by better temperature and teeming control and careful mould preparation has been reflected in higher yields of finished products.

15.2 Continuous casting

In the continuous casting process, liquid steel is poured into a bottomless, watercooled, copper mould from which it is continuously withdrawn and then cut to the required lengths when solidification is complete. The technique has been used for casting non-ferrous metals for some time but has only been applied to casting steel for about twenty years. The delay in its introduction for steel casting was due to the problems which arise from the much higher melting point of steel and its very poor thermal conductivity. The latter property results in an extremely long liquid metal core as the product is cast, which meant that the original 'vertical' casting machines had to be of great height. Modern continuous casting plants have been reduced in height either by using curved moulds or by bending the strand through 90° to the horizontal.

An important feature of the process is that the yield from liquid steel to semi-finished product is normally considerably higher than for ingot casting and primary rolling; the yield, however, is strongly influenced by the efficiency of the casting shop.

Since their introduction for steel casting, the number of continuous casting installations has increased rapidly. The capacity of the machines has also been raised, largely by increasing the number of strands in the machines being built, and to some extent by increasing the strand speeds. It has thus been possible to use larger ladles and the average ladle size employed has increased steadily over the years and is still rising.

The capacity of a given machine is restricted by the maximum time allowable for pouring one ladle. This maximum period is generally taken as 70 minutes. Attempts have been made to increase this time by pre-heating ladles and particularly by heating the steel in the ladle during pouring by means of gas or oil burners. The results of attempting to increase the pouring time of a ladle have not been completely satisfactory and, while the pre-heating of ladles is now normal practice to avoid excessive superheating of steel, ladle heating during pouring is carried out only as an insurance measure rather than as a means to extend the normal pouring period. Temperature loss is not always the only factor to be considered, however; it has been reported* that in casting aluminium-killed steels, for example, aluminium losses during casting increase with time, and casting times should, in such cases, be limited to about 40 mins.

* R.Schoeffmann "Iron & Steel Engineer" 49, 25 (1972)

Growth of the process

Figure 15.1 shows the increase in the number of machines built per year; also shown is the increase in ladle size which the new machines can accommodate, which has been achieved both by increasing the cross sections cast and by increasing the number of strands. The maximum number of strands in use is now eight for billets and blooms, and four for slabs. As the ladle capacity of such machines for bloom and slab production is equivalent to that of the largest ladles and steelmaking furnace capacities now in use, there is at present little incentive further to increase the capacities of these machines.

Billet casting machines, however, are at present restricted to a maximum of eight strands, because with more than eight strands it becomes extremely difficult to keep all the strands operational. Consequently, billet casters and especially those machines casting the smaller billet sizes have relatively low outputs. The drive to increase the number of strands has resulted in a number of back to back machines being designed in an effort to circumvent the problem of a large number of strands in one machine. As yet, no really large billet installation has been built but this is partly a result of the large existing capacities of billet rolling mills, which are able to roll down the blooms produced by the large bloom casting machines.

The rapid growth of continuous casting over the last twenty years from practically zero to a present day potential capacity exceeding 50 million tonnes has occurred for a number of reasons. The ability to utilise this new method to gain a small but significant increase in the output of a works where the primary rolling capacity was saturated, without having to build expensive high output primary mills, was a great incentive to its introduction. Also, as the process became established, it became apparent that this was in many cases the most economical method for new, large-scale production capacity, particularly when the increased yield was taken into account. The range and variety of the products cast has also increased rapidly as the process has been more widely adopted.

Although there is probably no economic justification for the replacement of some existing ingot casting and large primary mills by continuous casting, the use of the latter process is justified in most new works. This will be demonstrated by the comparative cost evaluation of continuous casting versus ingot casting in Article 15.3.

Developments in machine design and operation

The future advancement of continuous casting will result in part from the recent development of 'non-stop' casting. In normal continuous casting each ladle of steel is poured within the pouring period limit of about 70 minutes. After this the machine is reset which normally takes up to 30 minutes for the replacement of the dummy bar, fitting of new nozzles and cleaning out or replacing the tundish. In non-stop casting, ladle after ladle is cast with only momentary stops, enabling a continuous product to be made. US Steel's South Works, Chicago, has recently cast 18 consecutive heats into more than 3,600 tons of blooms in a 15-hour period.

There is thus a large increase in machine output but also an increase in yield due to the reduction in the number of discards from the ends of the cast billets. It should be noted that the application of this technique is restricted to the production

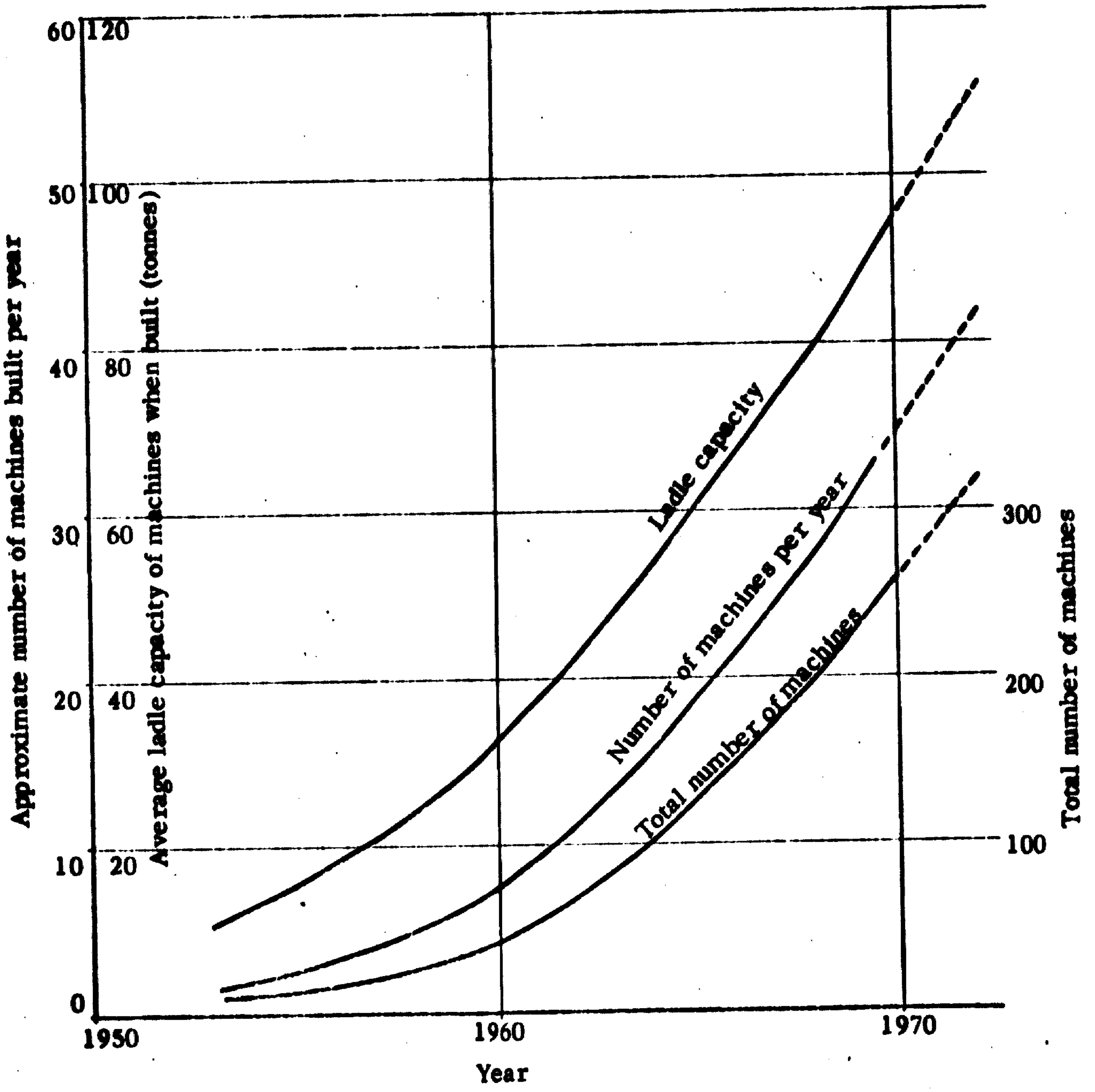

FIGURE 15.1 - INCREASE IN THE USE OF CONTINUOUS CASTING

of long runs of a specific size and quality of steel, and in practice proves extremely difficult to achieve. To do so the non-stop continuous casting machine has to be designed with high speed changing facilities for the tundish, nozzle and ladle, and to be of a sufficiently robust design to stand up to the intensive utilisation required. The outputs of such machines can easily exceed double that of many of the normal machines designed for single ladle casting, although if the normal pouring and resetting times are assumed it would appear that only a 40 percent increase could be obtained, i.e. the equivalent of the increase in the availability of the machine. The larger increases in output obtained in practice are usually a reflection of the normal under-utilisation of machines through the intermittent use which results from poor matching of the furnace tap times to the availability of the casting plant. Flying tundish systems with rotary-turret ladle handling suitable for continuous continuous casting have now been introduced in Austria, as well as Japan and the USA. *

Much of the improvement of machines over the last twenty years has been in the design of moulds. The most important aspect of this has probably been those developments aimed at increasing the rate of heat transfer and hence the casting speeds, which have risen steadily.

The original vertical casting machines, in addition to requiring tall structures and the hoisting of the steel ladle to considerable heights, also presented problems in handling the castings after cut-off, from the vertical to horizontal plane. The first development to overcome this was to bend the casting through an arc to the horizontal plane and then straighten it onto the run-out table before cutting to length. This 'vertical-plus-bending' casting did not significantly reduce the height of the machine, however, and this provided the incentive for the development of the curved-mould machine. In this with the use of an oscillating mould of special design and a curved cooling chamber, the height of the machine is reduced to about one third of the vertical types. The curved casting from these machines only has to be straightened, which results in lower costs for mechanical equipment than with the vertical-plus-bending machines.

The advantage of reduced capital cost for curved mould machines is to some extent offset by the increased operating costs which result mainly from the high costs of the specialised moulds. Moreover, the assymetry of the stream of steel within the mould can create problems of differential freezing in the billet, particularly in the production of special steels. These problems have led to the development of the straight bow-type caster. This type of plant has a straight mould with the strand bent into a bowed arc starting about 200cm below the mould while its core is still liquid.* As with the true curved mould machines the mould is oscillated and the overall machine height is similar. The use of the straight mould, however, gives improved heat transfer, better skin growth and eliminates accumulation of impurities on the inner casting radius.

* R. Schoeffmann Iron and Steel Engineer, 49, 25 (1972)

Casting machines are now manufactured to produce the complete range of billets, blooms and slabs required, but the production of dog bones and also shapes such as hollow rounds have not been adopted on a commercial scale, although great initial promise was claimed.

Single machines that are required to produce a range of sizes need a complete range of moulds for this purpose which, as well as being expensive, will give reduced output due to the changeover time. Variable geometry moulds have been designed to cater for this problem in the case of slabs. The simplest form is the fixed thickness slab mould with movable ends which can then produce the full range of widths required. The success of variable geometry moulds is not proven and it is understood that the problems of mould design to maintain the required corner radius are proving difficult to solve.

The need to produce a complete range of slab widths is particularly applicable to strip rolling where the mills can only marginally reduce the width of the slab. It is thus necessary to produce a range of slabs with about 50 mm increments in width. Although there is a trend towards continuous slab casting, only one producer in the USA - McLouth Steel Co. - has adopted continuous casting as their only means for producing slabs. The experience at McLouth has been very unsatisfactory and the difficulties are only gradually being overcome. Most producers are installing slab casters as adjuncts to their conventional facilities to obtain additional capacity and, at the same time, to gain experience and know-how.

From the discussion above it will be seen that any future changes taking place in the technology of continuous casting are likely to be aimed at improving what is already a very sophisticated process. The major advances which can be predicted for the next decade are the more widespread adoption of non-stop casting and increased strand speeds, but these demand much from both plant and personnel.

Quality aspects

The continuously cast product is more homogeneous than the normal ingot. This is particularly so in the longitudinal direction where the normal vertical segregation, due to the solidification of a static ingot, is absent. Segregation across the width of the section is in many cases equivalent to that occurring in the better parts of ingots.

Due to the high solidification rates and small cross sections, compared with those of ingot casting, the continuous casting of steels other than the fully killed varieties is difficult. These other steels produce large quantities of carbon monoxide on solidification and it is the effervescent action in the ingot mould which gives rimming steels their characteristic inclusion-free surface layer of pure iron, which is necessary to obtain a good surface finish in sheet rolling, etc. In continuous casting only limited effervescence is possible and this limits the formation of the pure iron rim.

Attempts to continuously cast rimming steels have, at best, resulted in a product with a visible rim devoid of blow-holes, but which does not have the same rim composition as that of a rimmed ingot. The difference in composition between the two products is mainly in carbon content which, while approaching zero in the heavy rim of the slowly solidifying ingot, approaches the average steel carbon content in rims of the rapidly cooled continuous-cast product.

Substitute, killed steels have now taken the place of rimming steels for many applications and this has extended the use of continuous casting. Rimming steel is still required for a number of purposes, such as sheet for enamelling, and this has at present still to be rolled from ingots. Considerable advances have been reported by the Russians, however, in the continuous casting of low carbon rimming steels for the production of cold-rolled sheets.*

Normal, low carbon killed steels have proved to be ideal for continuous casting. Higher grade billets of all types have been successfully cast including free cutting grades, cold heading qualities and stainless steel. However, the difficulty of producing these qualities is reflected in increased overall costs, and the effect of this on the cost of the finished product needs to be carefully assessed. This is discussed further in Chapter 21 Article 21.9, on special steel casting.

Casting speeds

Casting speeds for specific cross sections are usually defined in terms of the linear speed in millimetres per minute or the output in tonnes per hour. In general the speed of casting decreases rapidly with increasing cross sectional areas, but the output actually increases with increasing cross sections. This is illustrated in Figure 15.2 which shows the average outputs obtainable for billets and blooms on present day machines.

Specially designed machines have reached much higher strand speeds such as 10,000 mm per minute achieved on 50 x 50 mm billets in the UK. A four-strand machine at South Works, Chicago, designed for a strand speed of 4,500mm per minute, is regularly casting 7½ inch (190mm) blooms at over 4,000 per minute, and has reached speeds of around 4800 mm per minute.

The smallest size of billet cast commercially is 50 x 50 mm, but demand for this size is small and the usual small billet size is 80 x 80 mm. Many machines have been built with this as the minimum size in a range up to 145 x 145 mm which is classified as a small bloom size. Large, eight-strand bloom machines are now being built which incorporate sizes from 250 x 250 mm to 480 x 300 mm.

The casting speed for slabs is usually slower than for billets of the same dimension as the slab thickness, but the outputs are generally much higher because of the extra width. Slab machines are now being designed with speeds in excess of 2,500 mm per minute for 125 mm thickness slabs, but the normal speed range is 1000 - 1500 mm per minute as shown in Figure 15.2. For double this thickness the normal speeds are down to less than 750 mm per minute and eventually level off at about 600 mm per minute for the thicker slabs.

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* UNIDO workshop on Creation and Transfer of Metallurgical Know-how. Jamshedpur December, 1971 (ID/WG.110/13)

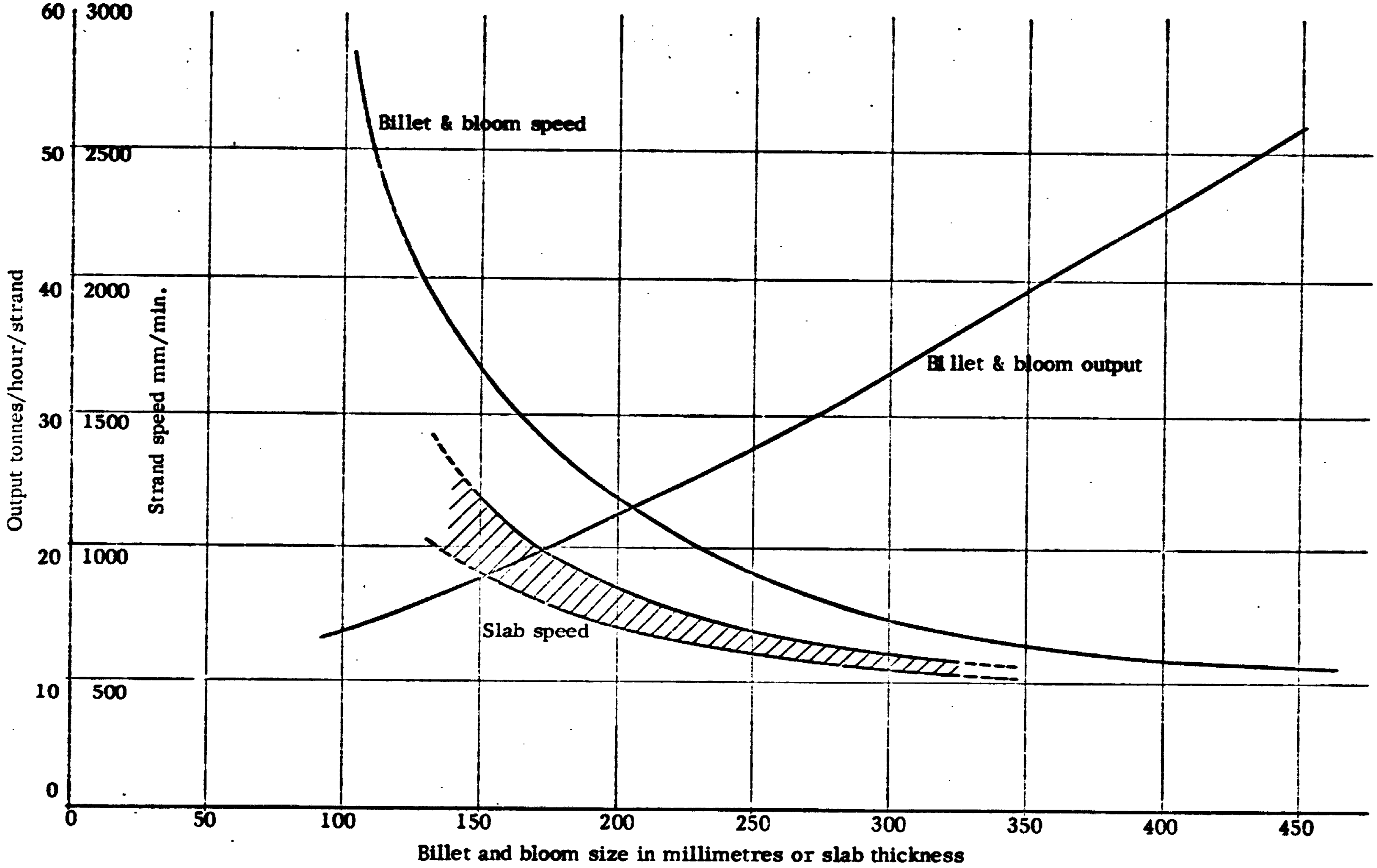

FIGURE 15.2 - VARIATION IN CONTINUOUS CASTING SPEED AND OUTPUT WITH PRODUCT SIZE

The largest slabs currently being produced are 300 x 2,200 mm and are cast in a two-strand machine using a 250 tonn ladle. Four-strand machines have been built with slightly smaller slab sizes using 300-350 tonne ladles.

Efficiency

The efficiency of a continuous casting machine does not depend entirely on the casting speed; even more significant is the synchronisation of the casting cycle with the steel production cycle. Figure 15.3 shows theoretical casting capacities as a function of casting speed. A 225 tonne BOF furnace with a heat cycle of 40 minutes has been assumed in preparing this curve, and the cast slab size has been taken as 250 x 1500 mm. A further assumption is that the casting machine has been cleaved after one heat and that, subsequently, the dummy bar is entered and sealed, an operation requiring 15 minutes; solidification requires an additional 20 minutes. This shows the influence of the casting speed on the incremental steps of plant output; the peaks indicate the points where the casting and heat-cycle times of the steel plant coincide, in other words where "back-to-back" casting is possible. The highest peak indicates the take-over of each heat, while the smallest represents the take-over of only one heat in three.

Another possibility for increasing plant output is to reduce the time of interruptions between casting heats. If reductions in idle time from 35 minutes to 15 minutes were achieved the effect on plant capacity would be as shown by the shaded areas.

Figure 15.3 indicates that a specified output may be achieved by providing a small caster with facilities for back-to-back casting, instead of a large, high-speed caster. Capital and, usually, operating costs are lower for the smaller machines, but the latter may have limitations as far as quality is concerned. Figure 15.4 shows the maximum casting time as a function of ladle size and quality classification. The maximum casting times are based on the formula:

$$t = f \quad \frac{\log G - 0.2}{0.3}$$

where t = casting time (minutes
G = ladle contents (tonnes)
f = 10 for highest quality
f = 16 for lower quality
the factor f depends on the allowable temperature loss in the ladle.

Cost of continuous casting

Table 15.2 illustrates the operating cost of continuous casting, and is based on a similar output to that for the ingot casting costs given in Table 15.1. Thus the costs apply to the casting of common steel billets in works with outputs in excess of 1.0 million tonnes per year.

NB: Slab 250 x 1500 mm
Ladle 225 tonnes
Cycletime 40 minutes
Solidification time 15 + 20 minutes

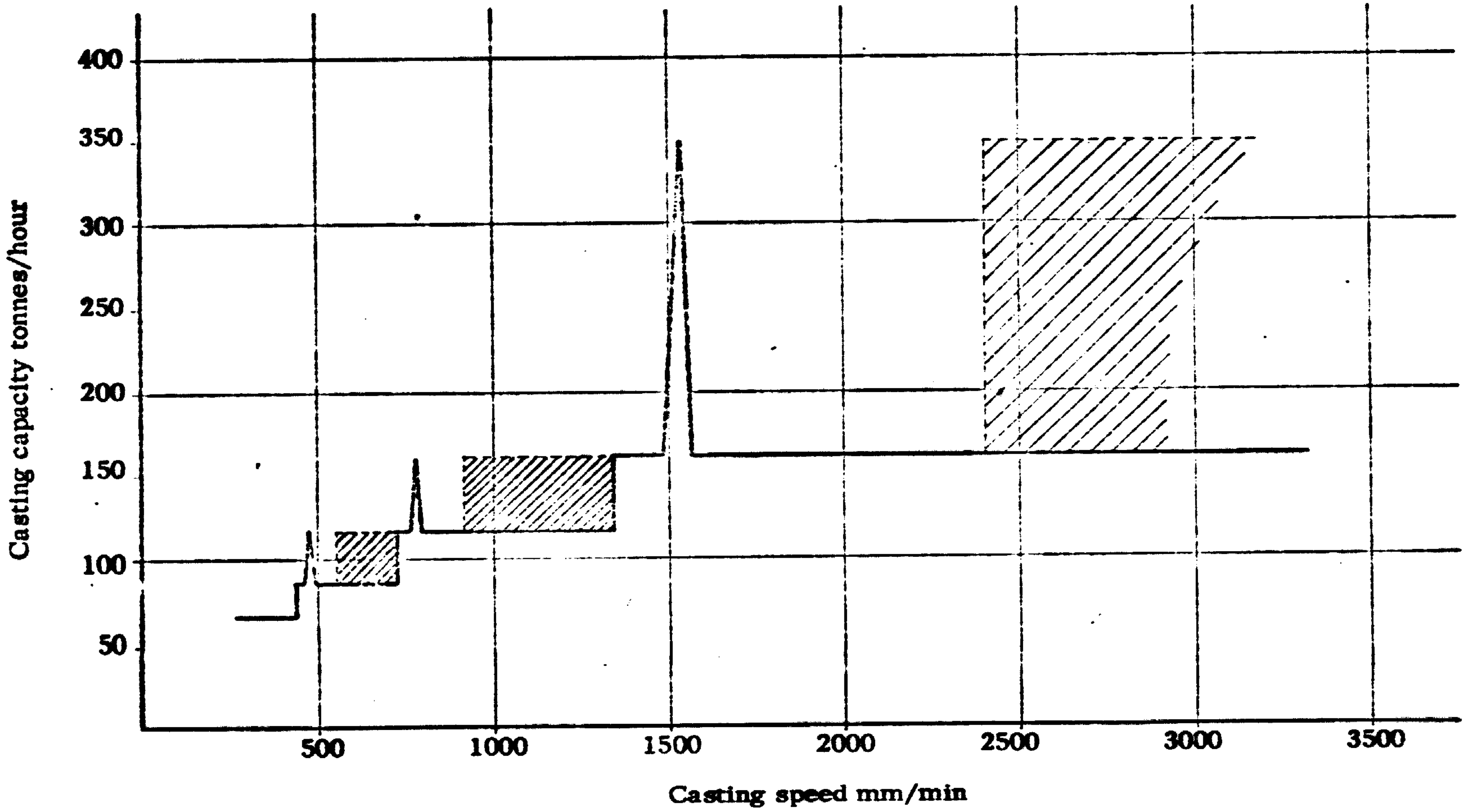

FIGURE 15.3 - THEORETICAL CASTING CAPACITY/CASTING SPEED

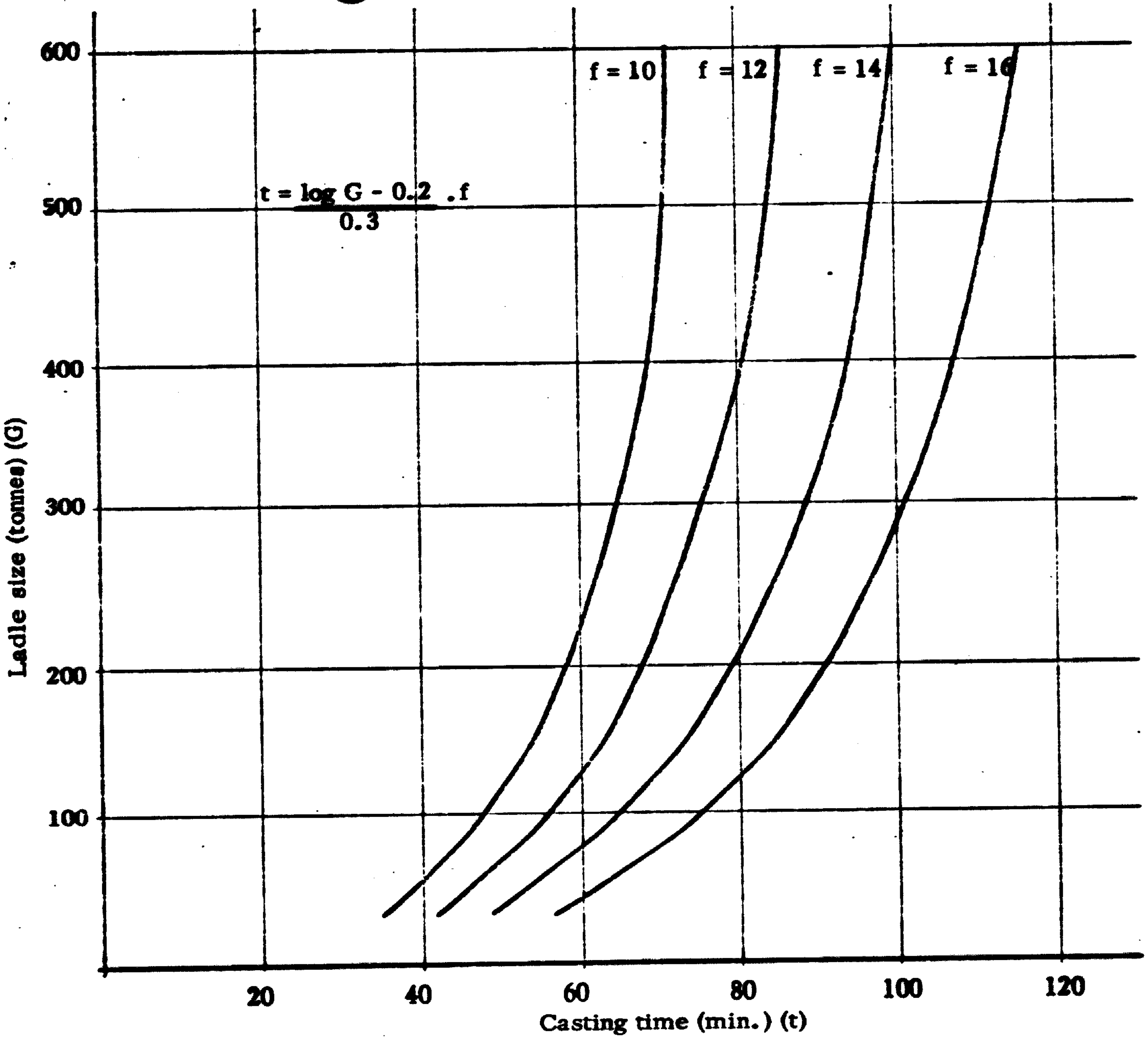

FIGURE 15.4 - LADLE SIZE/CASTING TIME

TABLE 15.2 - CONTINUOUS CASTING OPERATING COSTS

	$ per tonne of product
Moulds	0.4
Refractories	1.0
Others	0.5
Maintenance materials and spares	0.4
Fuel and energy	0.5
Labour	1.5
TOTAL	4.3

These costs exclude capital charges and all overheads.

15.3 Comparison of ingot and continuous casting.

The position of continuous casting as an alternative to ingot casting in any existing or potential situation needs to be considered in some detail both from technical and economic standpoints. For the production of killed and semi-killed steels for strip and plate production generally and for common bar production up to one or two million tonnes per year, continuous casting can usually be demonstrated to be the economic solution in new works. Ingot casting and primary rolling installations, built recently in existing works and some large new works, demonstrate that ingot casting may still be the preferred process in certain circumstances.

The total costs of steel casting will be considered on the basis that the two processes are completely interchangeable with regard to the product output and mix required in a new works, which will permit a fair comparison to be made of the two processes, and the main differences in costs highlighted.

Continuous casting installations cost substantially more than ingot casting installations for outputs in excess of one million tonnes per year. However, the total capital expenditure on the plant required to produce blooms and billets from liquid steel is lower for continuous casting plants, due to the elimination of soaking pits and primary rolling mills. The saving can be up to 30 percent in such cases, and for small outputs the capital cost of continuous casting plants is considerably less than the equivalent ingot casting and rolling facilities. Indeed the overall saving on both capital and operating costs can be sufficient to make the total cost per finished product tonne of a small plant, based on electric arc steelmaking and continuous casting, comparable with that of a large integrated works as demonstrated in Chapter 22 on mini-works.

Comparative costs of ingot casting and continuous casting

The total costs of ingot casting and primary rolling to billets are compared with the costs of continuous billet casting in Table 15.3.

The capital and operating costs of the continuous casting operation are assessed on the basis of the plant boundaries being liquid steel in the ladle and billets in stock immediately after the hot bank. The operating costs in Table 15.1 for ingot casting and in Table 15.2 for continuous billet casting are used in the comparative cost evaluation of the two processes.

In order to evaluate the comparative costs of the two processes it has been assumed that the unit cost of liquid steel is the same for the two routes. The ingots are assumed to be heated in soaking pits, primary rolled to blooms which are then immediately rolled to billets in a continuous billet mill. The recoverable steel scrap is credited at $30 per tonne.

The capital charges are assumed to be 20 percent of the capital costs of the process plants involved and do not include a works services element. Similarly, operating costs do not include overheads of any description. The comparison, therefore, assumes that works have identical outputs and that different processing routes carry the same overheads.

TABLE 15.3 - COMPARATIVE COSTS OF BILLET PRODUCTION BY THE INGOT CASTING AND CONTINUOUS CASTING ROUTES

	Cost per tonne of billets $		
	Continuous casting route	Ingot casting route	Difference
Liquid steel cost at $80 per tonne	84.2	94.8	+ 10.6
Casting operation costs	4.3	2.8	- 1.5
Bloom rolling operating cost	-	2.7	+ 2.7
Billet rolling operating cost	-	3.1	+ 3.1
Capital charges	5.2	7.1	+ 1.9
Sub-totals	93.7	110.5	+ 16.8
Credits for scrap	- 1.3	- 3.8	- 2.5
TOTAL COSTS	92.4	106.7	+ 14.3

From Table 15.3 it is seen that the continuously cast billets are about $14 per tonne cheaper than the rolled billets. The difference is due largely to the difference in yields coupled with the difference between the assumed cost of liquid steel and that of credited scrap. The cost advantage to continuous casting is sufficiently large to make the estimating insensitive to major variations in individual items. The costs in the table are based on interrupted continuous casting; continuous continuous casting would result in somewhat lower costs.

The figures thus highlight the main technological advantage of continuous casting, that is the reduced liquid steel demand, due to the much higher yield of finished steel. In Table 15.3 the yields used are 95 percent for continuous casting and 85 percent for ingot casting, neither of which can be considered best yields but both are representative of casting a range of ordinary quality steels.

The economics of replacing existing ingot casting capacity with continuous casting

When comparing a new facility with an existing facility any capital charges on existing plant can be taken as remaining the same for the two alternatives and can therefore be ignored. In Table 15.3 the total cost of continuously casting billets on new plant is approximately $7 per tonne less than the comprehensive conversion cost of billet production from ingots on existing plant, that is to say excluding the capital charges on the ingot casting and primary rolling plant on the assumption that the plant is fully written down. In this case it would, therefore, be economic to replace the existing facilities with continuous casting if other factors such as the yield from ingots remained constant.

When slab rolling is compared with continuous casting the same argument applies, but to a lesser extent, as in this case the ingot casting route only has to bear the cost of rolling slabs, whereas production of billets involves two processes, bloom and billet rolling. Consequently the operating cost advantage to the continuous casting route is reduced. The difference between the two greenfield site alternatives is $8.7 per tonne, and the capital charges involved in slab production via the ingot route are some $4.7, leaving an advantage to continuous casting of $4.0. As before, the main difference in the total costs results from the difference in the cost of liquid steel and scrap and this is totally dependent on the yields assumed in the calculations.

If the finished product from the slab route is plate, or the product mix contains a substantial proportion of plates, the overall costs of the continuous casting route for slabs will be reduced. This is because slab casting for plate production is cheaper than for strip rolling as the range of widths required for strip rolling is not required.

The figures above apply to a works with an output of approximately one million tonnes per year and 10-20 tonne ingots. If outputs are increased and ingot sizes increased, the differences in yield will decrease and at the same time the economies of scale of the large ingot casting shop will be greater than those for continuous casting.

In certain circumstances multi-million tonne greenfield works producing slabs from ingots can be competitive with similar sized continuous casting installations and hence it is clear that many existing slab producing plants must be capable of producing slabs cheaper than brand new continuous casting installations with their heavy capital charges; thus the $4 per tonne advantage of continuous casting disappears due to the increased efficiency and flexibility of the large ingot casting and primary rolling units.

Similarly, with large greenfield works producing billets, ingot casting and primary rolling has been estimated in specific circumstances to be cheaper than continuous casting. This may occur when the mix of steel types contains some which are unsuitable for continuous casting, thus dictating the use of some ingot casting.

Where there is a borderline case with the steel plant heat size approaching or exceeding the present day billet casting machine limit of 120 tonnes, the comparison should be made between bloom casting and ingot casting routes. With case bloom sizes approaching ingots in cross section and in weight, it is to be expected that the future will show bloom casting to be the preferred route for high outputs.

15.4 Technical innovations in casting

Novel ideas may find a place in the casting field in the future, but it should be emphasised that the bulk of the technology upon which the ideas will be based has already been developed.

Horizontal continuous casting

The design of a machine which could operate with a horizontal mould has been the aim of numerous workers in the last twenty years. Recent efforts have produced such a machine in which a horizontal billet mould is fed from a right-angled tundish which is sealed on to the vertical face of the water cooled mould. A 1 million tonne per year plant is reported to be operating in Russia; the throughput is claimed to be twice that of conventional continuous casters, while capital costs are reduced by one third. Krupp are reported to be interested in co-operating with the USSR in continuous casting development.

Pressure Pouring

This advanced process is also used for casting semi-finished products, in particular slabs, and has been in operation for a number of years in the USA notably at Oregon Steel Mills' Rivergate Plant in Portland.

The process was developed for the production of cast steel railroad car wheels. The ladle containing the liquid steel is pressurised and the steel is thus forced up a refractory lined tube into the mould. The rate of flow of the metal is carefully controlled, by adjusting the pressure to prevent turbulence in the mould. The moulds, which are made of graphite, are gas purged before casting. The dimensions of the product are accurately maintained and the surface finish is good. The main development has been in the casting of stainless steel slabs which are cast in individual vertical graphite moulds. Here the process has many of the advantages of continuous casting, and in addition produces a better surface finish. However, yields are generally less than those in ingot or continuous casting due to liquid steel remaining in the ladle, and the process is not a continuous one.

CHAPTER 16 - PRIMARY ROLLING

16.1 The development of rolling

The rolling of steel products has been a continuously developing art and science since the earliest designs of rolling mills in the fifteenth century. However, since the rolling process is intimately bound up with the metallurgical characteristics of the steel itself, the scope for development of the process lies mainly in more consistent and controlled operation. This is manifest in the changes and improvements in the design of plant used in the process. The speed with which the process can be carried out is mainly a function of the rate at which the rolling force can be applied. Here again the design of the plant has been the determining factor in the advance of the process.

In consequence, throughout the history of rolling the latest innovations in other technologies have been harnessed, as in the progression in the source of power from hand through water and steam to the electrical power which drives the rolling mills of today. Many improvements have also resulted from changes in the design of bearings, new casting and fabricating techniques, and so on, but, while all these changes have been going on, the basic principles of the rolling process have remained constant.

This and the next two chapters are presented in a different style from preceding chapters, in that the plant, as distinct from the process, is the centre of our interest. Technological development and trends in the design of rolling mills can best be discussed by reference to mills of different types. These chapters on rolling mills are set out accordingly. The subject is so large and so many books and papers have been published within this highly specialised field of engineering that it is hardly possible to cover the entire subject comprehensively; we have, therefore, approached it with the developing country in mind and with the object of provoking thought on a number of development aspects which we believe to be relevant thereto.

The modern rolling mill is an extremely sophisticated piece of equipment. The degree of sophistication is justified by the improvements in output and resultant economies of scale which have accrued, together with the improved yields and closer tolerances on the rolled products. However, not all advantages to be gained by improved design are additive. Very often, conflicting requirements need satisfying so that a compromise may be necessary, and a solution evolved that is unique to the situation under consideration.

Sometimes this leads to a choice between different mills. At other times it may be a choice between processes. For example, this has already occurred in the use of continuous casting machines to produce billets, doing away with the need for primary rolling. A second example is the development of swing and continuous forging of billets from blooms which, while not able to compete with high capacity billet mills can replace the small billet mill which might otherwise be required in a miniworks or in small works in a developing area.

The three main factors that have to be taken into account in each mill project are product range, dimensional accuracy and capacity required. The relative importance of these for each type of mill is discussed in this and the following chapters. Mill capacity and the range of products rolled compete for priority in mill design. The modern trend is generally toward specialisation of mills for limited ranges of products, as more and more products rise in demand to the point of justifying the specialist mill. The multiproduct mill is left with a very varied selection of products to roll. In some cases this has led to changes in process such as fabrication by welding, or extrusion.

The largest single element of cost in the rolling process is the feedstock, as is evident from the breakdown of costs for different rolled products set out in Table 16,1. In consequence demands by the steel user for closer dimensional tolerances have to be met with improved capability to produce accurate products if yields are not to drop. This leads to developments in instrumentation and control and in some cases automation of the mill, as discussed in Chapter 24.

TABLE 16,1 COSTS OF ROLLING FOR DIFFERENT MILLS

($ per tonne of rolled product)

	Slabbing Mills	Blooming Mills	Billet Mills	Section Mills	Merchant Mills	Strip* Mills
Capital charges	2.2	3.2	3.1	16.3	8.2	5.4
Feedstock	78.0	78.0	78.0	83.8	84.1	82.8
Consumables and Maintenance materials	0.7	0.8	0.9	2.3	1.8	1.9
Fuel & energy	1.5	1.4	1.4	1.7	1.6	1.8
Manpower	0.4	0.4	0.7	2.3	2.3	0.3
TOTAL	82.8	83.8	84.1	106.4	98.0	92.2

* Plate mill costs are similar.

Any improvement in the yield of the process will obviously show savings in feedstock costs. When new plant is to be installed a cost benefit analysis should be undertaken to determine the economic advantage if any, of incorporating automatic process and gauge control. It can be seen also that the capital charges per tonne of product vary considerably between different types of mill. In general it is most advantageous to increase the unit size and speed of those mills that carry a high capital charge per tonne, provided that economies of scale are still present. In contrast, the manning element is low so that the effect on this cost of automating a mill would be negligible. It is to be expected that the development of rolling mills will take different forms for different types of mill.

The rolling of special steels is dealt with separately in Chapter 21, Article 21.10.

16.2 Slabbing mills

It is likely that any slabbing mill built today, at least for substantial outputs, would be a universal mill with driven vertical rolls in close proximity to the horizontal rolls. For example, in the last five years or so, six new slabbing mills have been built in Japan, of which four are universal mills and two are high lift mills, each with a capcity of over 2 million tonnes per year. The provision of vertical rolls in a universal slabbing mill does not necessarily eliminate the desirability of a high lift top horizontal roll. Normal practice is to deliver the ingot to the receiving roller table on edge and to take the first passes with the horizontal rolls, doing the work necessary to bring the ingot width down to within about 50 millimetres of the slab width. If a slabbing mill is required to deliver slabs in a width range from 2000 millimetres down to 600 millimetres with, say, only 4 ingot sizes to span the range, this means that the total amount of edge reduction will vary from 550 millimetres maximum down to 150 millimetres minimum on each ingot. To do this on the flat using only the vertical rolls of the universal slabbing mill would be virtually impossible since the maximum reduction achievable with the latter is only about 50 millimetres per pass, whereas the horizontal rolls can make pass reductions as high as 150 millimetres. It is thus normal to take two or three passes through the horizontal rolls with the ingot on edge and then roll it on the flat for the remainder of the work. A major advantage of bringing in the ingot on edge is that the scale on the sides of the ingot which will form the top and bottom of the strip, falls away rapidly when the first heavy passes are taken by the horizontal rolls.

On a universal mill, tilting facilities are only required on one side of the mill and for some of the really high output installations where tandem rolling from heavy ingots is obligatory, a separate tilting station has been installed where the ingot is tilted on a static grid in order to avoid the impact loads on the main roller tables. A further advantage of the universal mill is that it produces slabs with good square edges. This is important because the slabs butt against each other properly and more predictably in the pusher slab reheating furnaces ahead of the hot strip mill.

To match up with the largest continuous strip mills, modern slabbing mills are being designed with very high outputs. A recent feasibility study has shown that a universal slabbing mill can be designed to roll 6 million tonnes of ingots per year, using 40 tonnes ingots and rolling two at a time, in tandem. It is claimed that at this output the cost of slabs is less than the continuously cast product.

Much work has been done in arranging automatic positioning of ingot buggies to feed ingots from soaking pits to mill; tandem rolling techniques are now generally practised and various slab cooling systems, such as the Siemag wheel (a rotating table), or the Yawata roller table with top and bottom sprays have cut down on scale losses and reduced the amount of slab yard space necessary for slab cooling.

16.3 Blooming mills

On blooming mills there have been no dramatic design changes in recent years, except detail improvements which aim at greater reliability. Like slabbing mills, any modern high output mill has twin motor drive with separate motors driving the top and bottom rolls, with electrical synchronisation. A producer installing a new blooming mill should examine the respective advantages and limitations of thyristors and motor-generator sets for controlling the main mill motors.

A substantial improvement in the operation of both slabbing and blooming mills has been the development of automatic preset programme control. This is achieved by using punched cards or similar devices encoded with the rolling schedule required , the mill and manipulators then follow the sequences dictated by the control devices. Similarly, photo-cell devices are used for mill reversal. If these devices save one or two men in the mill pulpit, they possibly add them again in the programming and maintenance staff, but the system has the advantage of most automated processes that it does not get tired and makes fewer mistakes than human operators.

16.4 Billet mills

Billets and slabs (of relatively small cross section) are the standard semi-finished products for the bulk of the non-flat steel trade and the availability of the right quality and quantity at the right price is of great importance. In most of the developed countries, there is a considerable trade in these "semis", which are sold to the non-integrated re-rolling concerns, most of which have their own specialised trades which they have studied and developed. It is customary for these re-rolling concerns to make long term contracts with large billet producers. In some cases these have been bought out by the big steelmaking companies in the pursuit of vertical integration. In Europe particularly and in most industrialised countries elsewhere, however, there are many independent re-rollers. This situation in the industry is likely to remain so for some years to come.

Billets should not be thought of only in terms of common low carbon steel. The billet (or slab) is the basis of many items of hardware used in everyday life that rest on quite exacting specifications e.g. for spring steel, drawing qualities, free-cutting steels and many degrees of hardness, softness, ductility, surface finish, and so on. It is perhaps true to say that little money is to be made in world markets for soft basic billets of common mild steel. The return on investment follows the skill in producing the special qualities required to match the hundreds of industrial requirements.

Any modern high production mill will have alternate vertical and horizontal roll stands and may have 10 stands, probably arranged in two groups, of six and four respectively. There would be a lateral take-off between the groups for the larger sections and these would be cut up by hot saws. The smaller sections will go through the 4-stand finishing group and be cut up on the flying shear. On the new Scunthorpe plant of the British Steel Corporation, the shear will cut up to 125 millimetres square.

However, the number of stands and the mill configuration generally will depend greatly on the issues discussed earlier - the cross-section to be cast (either in continuous casting machines or in ingots) and the sizes to be delivered to the market, and also on the tonnage to be rolled both at a single rolling and annually. There are numerous configurations to produce smaller tonnages at capital costs lower than those incurred for a continuous mill and each case requires a close engineering study to produce the best economic solution.

There is another important trend. Since a re-rolling customer is not pleased if defective billets are delivered to him, especially if he sells his own products in quality markets, new billet mills are fitted with extensive finishing departments equipped with facilities for sophisticated techniques of automatic inspection and non-destructive testing, stacking and binding. This is a new field of technology which should be fully studied. These finishing departments are extensive and they can also be expensive. In the Scunthorpe plant mentioned above, the capital cost of the mechanical part of the billet facility divides approximately as: one third primary rolling: one third billet rolling: one third billet finishing department.

Swing forging machines

'Swing forging' describes the relatively recent developments in "continuous" forging of billets where relatively low outputs are involved. The two most prominent are the GFM continuous forging machine and the Kocks swing forge. These work on different principles. Both processes use two pairs of forging heads which operate alternately on the bar at right angles to each other. In the Kocks machine the heads are pivoted so that they preform with a special rolling action on the billet, whereas the GFM machine uses the simple forging action of a forging press.

Trials with these machines indicate that certain processing problems have yet to be resolved. In particular it appears that both machines tend to produce, on certain steel qualities, an internal cruciform crack which does not weld up during subsequent re-rolling. However, these and other problems may be overcome in due course.

CHAPTER 17 - ROLLING OF FLAT PRODUCTS

17.1 Plate mills

There has been a steady process of evolution in the detailed design of the 4-high plate mill. Shipbuilders, who are among the largest consumers of plates, have demanded wider plates for economy in hull construction. Mill designers have responded to this demand and plate mills up to 4 metres in width are now available. Such mills are being installed where a high proportion of ship building plates are to be produced. It is now generally agreed that mills of this width or greater should be equipped with back-up roll bending devices for the control of lateral gauge, shape and crown.

There has also been some growth in recent years in the production of universal plate. This plate is rolled in a mill having driven vertical edging rolls, arranged in close proximity to the horizontal roll stack, and on both sides of it. The purpose is to produce plate of accurately controlled width, for welding together to form structural sections larger than those that are economic to roll on universal beam or structural mills. A good example of a universal plate mill is at the Lackenby plant of the British Steel Corporation. This started in the mid 1960's as a single stand reversing 4-high universal mill, but a further 5 stands were subsequently added so as to convert it into a semi-continuous plate mill of 80 inches (2 metres) width. The plates produced can either be coiled or taken to flat cooling banks which have sophisticated handling equipment designed to maintain straight edges suitable for welding without further edge preparation. The latter feature, is of course, essential to the success of a universal plate mill, because its justification is its ability to deliver plates with straight edges and accurately controlled width. This is not only important to the fabricator but also to the steelmaker, because a better yield results than from the alternative method of shearing and edge trimming wider plate, the improvement being at least 4 to 5 percent and sometimes more.

Experience with the Lackenby mill shows that although the establishment of such a mill for the purposes described has been highly successful, it is important to be sure of the market requirements before embarking on such a project. For example the main demand for universal plate in the U.K. is for material less than one metre wide. Such plate can be satisfactorily rolled on a 2-high mill, at lower capital costs. The BSC is understood to be actively considering acquiring such a mill at the present time. This situation is a good example of the conflicting requirements referred to in Chapter 16, Article 16.1, in this case between the range of products and the economics of production. This is perhaps most common where product demand is spread unevenly over the spectrum of product size.

Detailed development has taken place in plate cut-up, levelling, shearing and inspection lines and some of these are very extensive in modern installations.

17.2 Hot strip mills

It is not possible in this article to cover the entire field of strip mill engineering or the whole process of evolution which is still continuing and has been covered in detail in "The Hot Strip Mill - Generation II"*. Here we pick out what we regard as the technologically salient points.

Improvements in hot strip mill design continue to be based on the same premises as always, namely the demand for:

(a) better product quality,
(b) better yield of prime quality saleable product from the slab, and
(c) better utilisation or productivity from what is always an extremely expensive investment.

Better quality in this context means more accurate and uniform gauge, both laterally and longitudinally (i.e. from edge to edge and from one end of the coil to the other), better surface finish and metallurgical properties.

Improvements in these quality standards are in general being obtained by more roughing stands in the hot mill, by additional finishing stands and by the application of growing technology in automatic gauge control and in the use of on-line computers.

Mill layout

The strip mill operators, in what might be termed the "big league" of auto-body sheet and tinplate, do not believe they can remain competitive on the basis of using a semi-continuous mill with a reversing rougher. Modern mills are now built with continuous roughing trains with 5 or more stands. This change in layout not only improves the quality of the rolled product, it also results in a three or four-fold increase in the capacity of the mill.

Hot strip mills used to have six finishing stands but more often nowadays have seven. The reasons for this are manifold. For example, thinner gauges can be hot rolled and such products can replace cold rolled material for certain uses in autobody manufacture where the material is not normally seen. Also a thicker

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* Published in 1970 by the Association of Iron and Steel Engineers, 1010 Empire Building, Pittsburgh, Pennsylvania, USA.

breakdown can be employed, resulting in a shorter delay table between the last rougher and the first finisher for a given coil weight. Alternative advantages are the capability to handle heavier slabs and to achieve higher finishing speeds. Both of these factors contribute to a higher annual capacity. An example typifying these trends in design is the mill built at the Kimitsu plant of Nippon Steel Corporation; this, one of the most recent hot strip mills with a width of 90 inches (2.3 metres) has 7 roughers and 7 finishers.

A number of mills in the USA have 5 or 6 roughing stands and 7-stand finishing trains. The demand for larger coils entails heavier slabs and these slabs tend to be a cause of longitudinal gauge variation, owing to heat losses at the tail end of the slab caused by delay whilst the leading end of the slab is passing through the tandem finishing stands.

Gauge control

Automatic gauge control (AGC) and on-line computer systems have now reached an advanced stage of development. AGC will only ensure that the whole strip length is rolled to the gauge at the head, or front end. On-line computer control will enable the initial settings to be made so that the head end will be rolled sufficiently close to the desired gauge to be within the commercial tolerance. The computer control will also select the acceleration rate such that even temperature rolling can be obtained, which is an important factor in achieving uniform metallurgical properties and uniform gauge down the length of the coil. The operators of older hot strip mills usually become very skilled in setting the stands of a continuous mill manually. Nevertheless, there is generally some trial and error before the mill consistently rolls coils to the required gauge and this results in some off-gauge coil being rolled, which has to be used for other purposes or sold at a second quality price. All this represents loss of prime quality yield. It is an objective of computer control and of AGC to reduce this loss by pre-setting the mill stands and adjusting for causes of gauge variation automatically during rolling. A considerable degree of success has been achieved and it is greatest when the mill, computer control and AGC are designed as a total system. There have been some disappointments where a degree of automatic control has been added subsequently to mills originally designed for manual operation. For example, the screw down drives must be powerful enough to screw down accurately under load and the mill bearings must also be adequate in capacity to carry the greater loads thus imposed. Similarly the loopers, which control inter-stand tension in the finishing stands, must have much faster speed of response; but above all the speed of response of the main drive motors must be such as to carry out the dictates of the automatic equipment with extreme rapidity. A change in the roll gap setting of one stand during rolling will immediately call for adjustment in the speed of the following stand in order that the same mass of material per second may pass through it - and, while the speed of response of loopers has also been improved, the storage provided by any form of inter-stand looper is very limited.

It will be appreciated that any system of automatic control consists broadly of two elements. The first is the equipment which senses variations, processes the signals and dictates changes in mill settings: the second is the mechanical and electrical equipment which receives the signals and alters, for example, the roll gap of the appropriate stands. Conventionally, roll gap changes have hitherto been performed by electrically driven screw down gear which raises or lowers the top roll assembly, but the speed of response is inherently slow in relative terms. One solution to the problem of response is the "Wheeler nut". In essence this device provides a micro-adjustment on an otherwise conventional screwdown system by rotating the nut in which the mill screws normally turn. This rotation, which can be in infinitely small increments, is actuated by a hydraulic cylinder through a rack and pinion. The system is installed in two fairly recent hot strip mills in the USA with a fair degree of success, but the range of correction of the Wheeler nut is relatively small, owing to the short stroke of the hydraulic actuating cylinder and this in turn necessitates a relatively coarse pitch of screw. These screws tend to back off under load unless powerful brakes are fitted, but these add inertia problems to a system required to have an inherently rapid speed of response.

Later in this chapter, in connection with cold mills and with stainless steel, reference is made to hydraulic gap control and gauge systems. In this design, electric screwdown is dispensed with altogether, the roll gap being maintained and controlled by hydraulic cylinders acting directly on the roll assembly. There is no doubt that this is the system of the future for cold rolling applications. As described later, it has already proved its worth on single stand hot strip mills of the Steckel type. It is now being fitted on a narrow (24 inches/ 600 mm wide) continuous hot mill at the Providence-Réhon plant in France. We predict that it will become the roll gap control system on the wide tandem hot strip mills of the future; and certainly no mill manager should order a hot strip mill without considering its merits most carefully.

As regards lateral gauge variation and shape control, the technique of back-up roll bending has been applied on some wide mills, having the control of roll crown on the final stand as the objective. For instance, the final finishing (F7) stand of the very recent 88 inches (2.25 metres) wide hot strip mill at Hoogovens in Holland is fitted with back-up roll bending and we understand the operators are pleased with it. There is, however, a school of thought which believes that similar results can be achieved at lower cost by the simpler technique of work-roll bending for the control of crown .

It should be said, however, that back-up roll bending can be installed on the last stand of a continuous finishing train without great extra cost, because the percentage gauge reduction on this stand is normally so low that the rolling loads are much less than on the earlier stands. Thus, if the Morgoil bearings and screw-downs are standardised throughout the mill, (as they normally would be), the final stand can accommodate the higher bearing and screwdown loads caused by back-up roll bending without the higher cost of larger bearings.

Technology in all the subjects discussed above is advancing rapidly and some of it, for example, computerisation and gauge control, is complex. The leading rolling mill engineering companies and the experienced electrical equipment suppliers are, for the most part, the repositories of this technology. Any strip mill project, either for a new plant or the improvement of an old one would normally call for an extensive study of all aspects - product mix and quality engineering and production. Such a study should include consultations with these companies, some of which have well developed computer programmes designed especially for such feasibility studies.

Roll changing

A modern hot strip mill will also be equipped with automatic, or mechanical work roll changing equipment, whereby the down-time for changing work rolls can be drastically reduced and the availability and output of the mill be correspondingly improved.

Power input

There are, of course, many other features of hot strip mill design which have evolved over recent years. One is the increase in power employed. Roughing stand drives have commonly reached 12,000 hp, with 16,000 hp reported for a mill just recently built. Several mills have reached the maximum total of 54,000 hp for the roughing train. Finishing mills have reached 12,000 hp per stand, or a total of 84,000 hp for the train, whilst the use of multiple armature drives on finishing mills has increased, so as to reduce inertia problems and improve the speed response factors necessary for computer control. Double, triple and even quadruple armature motors are now in use on some stands. There has in fact been a considerable evolution in the electrical engineering of a hot strip mill, all of which is a field of study on its own.

Reheat furnaces

There have been important changes in slab reheating furnaces. These are an increase in the number of heating zones, the development of walking beam traversing gear and discharge extractors. In modern plants, furnaces now have a 5 zone heating layout to maintain more precise thermal conditions. Walking beam mechanisms are replacing simple skid bars in order to reduce the damage to the slabs and slab extractors at the discharge end are now almost universal. These dispense with the need for expensive bumpers to arrest the slab when falling under gravity from the furnace outlet on to the receiving table. With the ever growing size of slabs, these extractors are becoming essential because a large slab of say 45 tonnes will virtually destroy any bumper or its foundations after only a few months of operation, giving rise to a constant source of maintenance trouble.

Cooling and coiling

There have been developments at the exit end of the mill also. Laminar flow water cooling between the last finishing stand and the coiler has been found more efficient than turbulent jets. This development has led in some instances, to the possibility of shortening the run-out table and saving building cost. The laminar flow can also be computer controlled so as to give uniform coiling temperature.

It is becoming normal for high capacity mills to have three coilers so that maximum production can be maintained even if one coiler is out of action.

Another major development being pioneered is to have the normal coilers some 150 metres away from the last finisher for the medium and heavy gauges but have one or two additional coilers only 30 to 45 metres away from the mill for the very thin gauges. The reason for this is that the thinner gauges require less distance to cool the strip in the first instance and secondly, it gives a considerable boost to mill output because it is normal practice to accelerate the mill with thin strip only when the coilers have been threaded and if another 100 metres of strip has to be rolled before acceleration can begin, quite a few seconds are added to the cycle time per slab. With coilers close to the mill there is less chance of cobbles and a greater proportion of the strip is rolled under tension between the coiler and the mill, leading to improved quality.

Speed control

A further improvement concerns the pacing of the mill and the automatic slowdown equipment which reduces the speed of the finishing stand rolls from the high speed at the tail end of one coil down to the relatively slow speed for threading the next bar. Mills built only a year or so ago operate on the basis of starting to thread the first finishing stand with the new bar only when the tail end of the old bar has left the final stand. This results in something like a 20 second gap between one bar and the next. If computer control is applied so that the mill can be decelerated rapidly, and the controlling factor on time is the traverse time of the new bar from the rotary crop shear to the first stand, the gap time can be reduced to about 8 seconds. On the average product mix, this development plus the addition of coilers close to the mill can add up to 10 percent to the potential capacity of the mill.

Smaller hot strip mills

Before leaving the subject of hot strip mills, some reference must be made to mill size and output capacities, because to a major extent this dictates the size and capacity of the total flat products steel complex in which a mill is installed. The total investment in a steel works becomes ever larger as hot mill capacity increases, so in many developing countries the question is not so much "How much will the mill produce?" as "What is the smallest economic capacity of hot strip mill we can have?".

It probably remains true that the smallest hot strip mill of, say, 66 inches (1.7 metres) width comprising a reversing rougher and 4 or 5 finishers, will have a capacity of at least 500/600 thousand tonnes per year on an average product mix having a mean thickness of 2.5 millimetres. Moreover, as noted above, the quality of common steel strip obtainable from these mills does not compare well with the high qualities obtainable from modern fully continuous installations. Also, a mill with only four finishers has too few stands to allow an adequate automatic gauge control system to be incorporated and the coil weight is limited because of the heat loss on the delay table of a slab reduced by the reversing rougher to only 10 millimetres thick for most finished gauges of the strip mill. With 5 finishers the reduction can be to 15 millimetres which allows a rather longer bar length and delay table. With 6 finishers, the normal reduction thickness is to 25 millimetres and with 7 finishers, to 35 millimetres.

Although, as we have said earlier in this chapter, the production of most sheet and tinplate is now on continuous mills, it remains a fact that a reversing rougher, even with a minimum installation, makes possible rather better temperature control than a continuous mill. The semi-continuous mill still has a place, therefore, when the production programme contains a high proportion of steels such as the stainless qualities where temperature control is important and where many more passes are necessary to reduce the slab to the much thinner entry gauge required to feed the finishers.

So the problem of the "mini" strip mill for low carbon quality strip remains and a good deal of time and money have therefore been spent in various parts of the world at various times in seeking a low-cost small output mill design, suitable for the needs of smaller developing countries. One of the earliest attempts was the Steckel mill, which is a 4-high single stand reversing mill with coiler drums of heat resisting steel revolving inside gas or oil fired furnaces, or "hot boxes", of special design. Suffice it to say that Steckel mills have been steadily phased out for quality low carbon strip applications and we see no likelihood of their being reintroduced, although they are used for small scale tinplate and galvanising operations where the problems of surface finish are not quite so acute as on sheet products.

The Sendzimir planetary mill is also designed to produce hot rolled strip on a small scale. The top and bottom rolls are surrounded by a cage of smaller diameter work rolls, revolving around the main roll in a planetary manner. Passing a slab between these two sets of revolving planetary rolls can achieve a very substantial reduction in thickness in a single pass. In relatively narrow widths, this mill has achieved moderate success, but as the width increases so do the design problems arising from the increased bending moment on the planetary roll system and the high stresses imposed on the bearings which contain it. Thus the maintenance costs can be high. We do not think mills of this type are suitable for producing low carbon steel strip which is comparable in quality with that produced by the high production hot strip mills. For some limited applications they may have a place, but not for the demanding specifications imposed by, say, auto-body sheet.

One or two companies are rolling stainless strip on planetary mills and some success has been achieved in rolling high nickel austenitic grades (A151 300 series). We understand, however, that production of low nickel ferritic stainless (A151 400 series) has not proved practicable, although it can be successfully rolled on a Steckel type mill.

17.3 Cold strip mills

The considerations which have led to change in the design of cold strip mills in recent years are much the same as those applicable to hot mills. There is a constant call for improved accuracy and consistency of gauge and temper and for excellence of surface finish. Similarly, as investment in these mills

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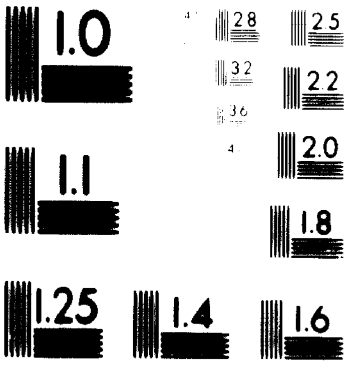

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increases, so does the demand for better yield and productivity. Some of the solutions to these problems have a similarity with hot mills. The number of stands in a tandem sheet mill has grown over the years from 3 to 4 and now to 5. What used to be a 5-stand tandem mill for tinplate is now, frequently, a 6-stand mill. Similarly, much progress has been made in the application of on-line computer control.

The requirements of improved accuracy and consistency of gauge have led to heavy mill stands of ever increasing stiffness. This has led in turn to the development of pre-stressed designs which had some vogue for a time, but they, in turn, are now giving way to hydraulic roll gap control. As a result, it is now possible for a hydraulic system to make the adjustments dictated by an automatic gauge control device with an accuracy and speed of response unattainable with conventional electric screw down systems operating through mechanical gearing. This is an example of the transfer of technology from one industry to another. The hydraulic systems and controls embodied in these designs owe much to developments in the aerospace industry.

It is thought that the limiting factor in the control of gauge in a cold strip mill is now no longer the mechanical operation of the roll gap; rather is it a function of speed and speed response time in the main drives of the mill stands and of the tension reel; and it is also a function of roll eccentricity. It must be appreciated that perfect concentricity in mill rolls is not achievable. In operating practice any or all of the 4 rolls of a 4-high mill may have eccentricities of the order of 0.01 millimetres and these may produce any number of out-of-balance permutations and combinations of patterns which are difficult to control. However, the various devices developed in recent years have greatly improved gauge accuracy in comparision with what was thought to be possible a few years ago. It is interesting also to note that hydraulic gap control in a cold mill is appreciably cheaper in capital cost than it's electro-mechanical predecessors.

As regards availability and productivity, automatic work roll changing equipment is now available for cold mills, whilst the mechanical arrangements for the feeding of hot rolled coils at the entry side of a tandem mill have been greatly improved so as to reduce the time delay between coils. Just recently a 5-stand "continuous" cold mill has gone into operation in Japan.* In this design overhead looping arrangements are provided and disposed in a manner whereby the tail of the coil in the mill may be welded to the head of the coil following without stopping the mill. At the outgoing end of the mill, there is a crop shear and 2 tension reels, deflector rolls feeding the sheared ends to the two reels alternatively. It is claimed that the mill can roll three coils in the time that conventional mills require for two. The system is under extensive computer control (see Chapter 24, Article 24.2), the elaboration is considerable and it is probably most suitable for tinplate where width and quality remain fairly constant. In sheet rolling, orders of a given specification are often much too small for such a system to be practicable At the Nippon Kokan Fukuyama works the cold rolled sheet coils are continuously annealed (thereby reducing by 90 percent the time required in batch annealing). The continuously annealed sheets are said to possess excellent deep drawing quality and formability.

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* No. 2 Mill at Fukuyama Works of Nippon Kokan.

Nevertheless, this development will be watched with interest. It is of importance, because the gauge of cold rolled strip passing through a tandem mill is dependent not only upon the setting of the roll gap or gaps and on the tension between stands and between the final stand and the reel, but also upon the acceleration rate of the mill. Thus, in the conventional method of cold rolling there is an appreciable length of off-gauge strip at both ends of the coil, reflecting the acceleration of the mill whilst the strip is being threaded and its deceleration as the tail of the coil passes through. This is the phenomenon (which arises from changes in the oil film thickness in the back-up roll bearings during acceleration) which has dictated steadily increasing coil weights, so that the off-gauge length of the coil is reduced as a proportion of the whole. Thus, on the new 88 inch (225 metres) 5-stand tandem mill at Hoogovens, the coil weight is as much as 45 tonnes, and over 2.5 metres in diameter.

As in the case of hot strip mills, there has been a demand for cold rolling mills of smaller types suitable for operation in small scale plants. The cold rolling of strip in a single stand reversing mill presents no problem and such mills are in successful operation in many countries. There is certainly some loss of yield of on-gauge strip at both ends of the coil, but by good management and the application of automatic gauge control this loss can be contained within manageable proportions.

The Sendzimir cold strip mill is worthy of special mention, as it is particularly successful in certain circumstances. This design is characterised by the small diameter of the work rolls mounted in a back-up or support system of "cluster" configuration, the whole system being made to a high degree of precision. The small work roll is particularly suitable for the cold rolling of stainless steel and of other special quality steels which work harden, the effect being to render possible relatively large reduction in gauge in each pass, thereby reducing the number of annealing operations. The Sendzimir cold mill has earned for itself an established place in the cold rolling to thin gauges of special quality sheets and of stainless steels in particular.

17.4 Narrow strip mills

Under this heading, we have in mind 2-high mills hot rolling strip up to about 300 millimeters width and 4-high mills rolling strip, both hot and cold, up to about 600 millimeters in width. A variant of the first group of mills has vertical edging stands to produce strip of controlled width and with edges of controlled shape. This, in English, is commonly called "skelp. It is used for the production of welded pipe, made by hot fusion welding in mills corresponding to the Fretz-Moon process, for such applications as household water and gas pipe, electrical conduits and tubular scaffolding.

Narrow strip produced on such mills is also cold rolled for numerous applications, of which probably the most exacting specification is for razor blade strip. Box strapping is another example of a product cold rolled (and slit) from a narrow hot band.

Four-high mills are particularly suitable for hot and cold strip rolling facilities for the special quality steels that are uneconomic or impractical to make and slit on wider mills, because the metallurgical qualities required would disrupt the even flow of their production. A special example is the type of installation required for the production of cold rolled grain oriented electric sheet. Such mills today are of the four-high type and have an advanced degree of automatic gauge control incorporated in the design, so as to achieve the maximum yield of prime quality product from relatively expensive materials.

These narrow strip mills are normally fed with slabs from a billet plant.

CHAPTER 18 - ROLLING OF NON-FLAT PRODUCTS

18.1 Structural mills

It is probable that any heavy structural mill built today will be a universal beam mill for rolling universal columns and parallel flange beams and channels. The better section moduli offered by these shapes in comparison with that of earlier standard shapes are widely preferred by structural engineers for many applications. The same mills can usually be equipped with conventional 2-high roll stands which can be substituted for the universal stands, utilising the same drives. The conventional stands will roll shapes to the earlier standards, as some operators have felt that they cannot safely commit themselves to a total change over to universal shapes in one operation. Universal beam mills can also be designed to roll rails and sheet piling sections. Many of them are also capable of rolling universal flats or plates of limited width. For example a beam mill capable of rolling a 600 millimetre beam could also probably produce a 750 millimetre wide flat. Similarly a beam mill designed to roll a 1000 millimetre wide beam could produce a flat 1250 millimetres wide. It is usually economic to roll universal sections up to 600 millimetres but above this size it is often cheaper to fabricate from plates owing to the relatively small quantities of the larger sections required. Universal beam mills are established in Europe, (the first "Grey" mill was built in Luxembourg many years ago to a British design and within the last 5 or 6 years has been completely modernised). They are also in use in the USA, Japan and Australia. Another is currently under construction in Mexico for sections up to 21 inches by 16 inches (530 millimetres x 400 millimetres). A smaller universal beam mill recently installed in South Africa at Highveld has a product range including beams 450 millmetres by 200 millimetres, columns 300 millimetres by 300 millimetres, channels 350 millimetres by 100 millimetres, angles 200 millimetres by 200 millimetres and flats up to 550 millimetres wide. It is also designed to produce rail sections up to 60 kilogrammes per metre.

An interesting development now taking place is the construction of a continuous medium section and light beam mill for the British Steel Corporation. This has two 2-high reversing roughing stands, an intermediate train with some stands capable of rotation for horizontal or vertical rollings and a continuous finishing train. The very last pass can be through a universal roll stand for rolling junior beams. Typical products from this mill are flats up to 200 millimetres wide, angles up to 250 millimetres x 250 millimetres, channels up to 300 millimetres, joists up to 200 millimetres x 150 millimetres and beams up to 500 millimetres. It can also roll a number of very small sections, such as pit arch joists 90 millimetres x 90 millimetres.

The predicted annual output of this mill is of the order of 500,000 tonnes per year, but continuous medium section mills up to 750,000 tonnes per year are already being discussed.

In mills for heavy or medium shapes, the finishing end is of equal importance to that of the mill itself and it is a mistake to treat it as a place for economy in capital expenditure. There are many structural mills around the world where cooling beds are inadequate and where the space necessary for cutting up, straightening and collection of orders for shipment has been undesirably restricted. Therefore, on recent structural mill installations, considerable attention has been paid to the finishing department. For example modern cooling beds are designed to reduce the amount of distortion caused by differential cooling to the practical minimum. In one modern installation an electronically controlled device is used to locate rolled sections on the cooling bank so that they are precisely spaced. Sections advance down the cooling bed by means of a walking beam system, so that the interspaces remain constant. In this way, the loss of heat throughout the length of the sections is reasonably uniform and this, in turn, greatly reduces the amount of distortion arising from uneven cooling. This system however, has not yet been widely accepted.

The fact that it is possible to buy a continuous medium structural mill capable of rolling 500,000 tonnes per year does not, however, necessarily mean that this is the most efficient solution. Where the market served by the mill is such that long rollings of particular sections are economic, then continuous or near-continuous rolling is probably right. Where production rollings need to be short, the time taken to change rolls in a multistand mill may offset, in whole or in part, the advantages to be gained by continuous rolling. The mill may and probably will, be designed so that duplicate stands are available within which rolls for the next programme may be mounted; and in this way the net down time for roll changing will, of course, be greatly reduced. On the other hand, it is obvious that the capital cost, by reason of the duplicate stands, with or without automatic stand change, is substantially increased. The fact is that any structural mill is designed as a solution for a particular set of conditions. There are situations where a breakdown mill, followed by two or three 2-high reversing stands in train may be the best solution. There are other situations where a breakdown mill followed by 3-high non-reversing stands with tilting tables, may be the best answer; and there are situations where a continuous or semi-continuous mill will give the best economic return. When contemplating the construction of a new mill of this kind, it is always prudent to obtain proposed solutions, from two or three of the rolling mill engineering companies which specialise in this field.

18.2 Rail mills

There have been no dramatic changes or improvements in rail mills as such during recent years, if only for the reason that the demand for rails has been falling due to the less important place occupied by railways in the transport systems of the developed countries. On the other hand, increasing train speeds demand heavier section rails.

Reference should be made to the system devised and patented by the French steel company de Wendel et Cie. In this system, rails are rolled in a universal beam mill. It is claimed that the relatively large amount of mechanical work done on the head of the rail gives very good physical properties. A blank is first produced in a structural roughing stand. The shape of this blank is similar to a conventional rail blank but has an excessively proportioned head. It is then passed to the universal roughing mill. During the roughing operation, the head of the rail is brought into proportion and the heavy reduction work taken on this part of the section is the basis of the de Wendel claim for a rail having a head with very good properties. The horizontal rolls work the head of the rail, the underside of the head and the top side of the flange, whilst one vertical roll having a parallel face rolls the bottom of the flange. The other vertical roll has a curved face and works the head of the rail.

A feature of the process is the need to make two horizontal edging passes, the horizontal edging rolls having to work on both the side of the head and the edge of the flange. Normally this would require two edging stands, one on either side of the universal roughing mill, but we believe that the de Wendel plant has a horizontal edging mill with two sets of pass grooves that are slid in sideways between passes. The rail is finally finished in a universal stand with no edging pass.

As experience is still limited, it is hard to say to what extent this system of rolling rails may gain acceptance. Iscor, in South Africa, took out a licence to operate the de Wendel patent but have not yet put it into operation. At the Highveld plant, also in South Africa and referred to above, rails are being rolled using five passes in the structural roughing mill, followed by three passes in the combination finishing mill equipped with 2-high structural rolls. In this way, a perfectly acceptable rail is produced and it seems to be a simpler method than the de Wendel process.

It must be borne in mind that the rolling of rails in a mill otherwise intended for universal sections requires suitable provision in the finishing department. The cooling banks must be wide enough to take the rail lengths required by the railways to be served and in Europe these lengths have grown considerably. Also, railways require rails in accurate lengths, so provision has to be made for "ending" to requirements and this may also involve drilling where fishplates are still used; there may also be special heat treatment plant. On the whole, therefore, it is better to separate the rolling of rails from other structural sections, except where the quantities required do not justify a mill mainly engaged on rails.

18.3 Merchant mills

Under this description, we refer especially to bar mills, and/or mills for the production of what are frequently termed "merchant products". These consist of bars which may be round, hexagonal, square, or of other regular cross section, as well as flats, small sections, and reinforcing bars of various kind. A high production facility for this purpose would today be a fully continuous mill and its capacity could be of the order of 500,000 tonnes per year depending upon the product mix. Mills of this type and capacity have been considerably developed in recent years. Stiffer stands and better bearings give a product of greater dimensional accuracy, rolling speeds have increased and various devices have been designed either to reduce roll changing time or to change whole stands automatically. Such a mill will have an alternative vertical and horizontal stand configuration at least on the roughing stands, probably arranged for cartridge roll changing, whereby complete roll assemblies may be mounted in the mill housings.

In other configurations, there may be automatic stand changing. In this system, spare roll stands are situated alongside the mill. While one section is being rolled, rolls and guides are being mounted in the spare stands for the next section to be rolled. When the change over is to take place, the new stands are placed on traversing platforms to replace the stands in the mill line. The entire change operation is fully automatic and takes about 5 minutes. The down time between rolling the last bar of the previous batch and the first bar of the new lot can be as short as 15 to 20 minutes. This saving of changeover time makes major production increases possible, compared with rolling mills without facilities for automatic stand change. The economics, however, must take into account the appreciable extra capital cost of the equipment; and in any circumstance, calculations have to be made which take into account roll groove life and the expected average production runs for given sections.

Cooling beds for straight lengths have not altered greatly in recent years, and most high output mills now have automatic bar bundling equipment whereby the bars are automatically counted and tied in bundles with wire. Makers of rivets, nuts and bolts nowadays generally order bar stock in coil form and a modern mill would probably be equipped to coil bars up to about 25 millimetre diameter.

The foregoing paragraphs relate to merchant mills having a capacity of about 500,000 tonnes per year, but there are, of course good merchant mills in operation in many parts of the world having an annual capacity of 100,000 tonnes or so.

The trend in developed countries and in countries like Australia where the market is relatively concentrated, is to install the higher capacity mills. The right solution will always depend upon the circumstances of a particular case and generalisation is impossible. The characteristics of the market will normally be the governing factor.

18.4 Wire rod mills

This is a very specialised field of rolling mill technology, the development of which has taken place over many years. Today the linear delivery speed of 5.5 millimetre rod out of a modern mill may be between 50 and 60 metres per second. Speeds of 80 metres per second have been achieved experimentally. It is thus obvious that the design of the mill and the means of controlling its throughput have reached a very high order of sophisticated engineering. There are perhaps only three or four companies in the world today who specialise in this field and no enterprise contemplating entry into the large scale production of wire rods should think of proceeding without consulting at least two of them.

The availability of higher finishing speeds (and therefore greater output) coupled with high accuracy, has come about through the development of the "no-twist" finishing block, in which the last ten or so reductions are achieved by pairs of rolls mounted at right angles to each other, (or trios at 120° in one version) with a controlled speed relationship between them. The machinery in these blocks is built to very fine precision limits and the single groove rolls are usually made of tungsten carbide. Similarly, highly developed speed control is employed in the earlier reduction stands.

In addition, wire drawers, the main customers for wire rods, have called for greater consistency of physical properties in certain qualities of carbon steel rod. This had led to the "Stelmor" system of controlled cooling, developed jointly by the Steel Company of Canada and the Morgan Construction Company. This system of cooling rods was originally developed to replace subsequent "patenting". However, whilst it was possible to roll rods on a conventional finishing mill at speeds higher than 30 metres per second, it was found that it was impossible at these speeds to form a coil. A "basketweave" effect resulted in a coil which could not be unwound at the subsequent wire drawing processes. The application of the Stelmor process to this problem allowed laps, or convolutions of rod to be laid on a moving table, with provision for blowing more cooling air at the edges where the concentration of steel is greatest. The laps are subsequently put together to form orderly coils. It was then found that at speeds of about 35 metres per second trouble occurred with the twist guides in the finishing mill and this gave rise to the "no-twist" concept. So it is the combination of "no-twist" finishing and the Stelmor cooling process which has enabled speeds up to 60 metres per second to be achieved.

Two other significant developments should be mentioned. The first is the demand by wire drawers for heavier coils of wire rod (which improve the economy of wire drawing.) This, of course, calls for heavier billets at the entry to the rod mill, so whereas 5.5 millimtre rod (the smallest diameter sold commercially) used to be rolled from billets as small as 48 millimetres square, today it is more commonly rolled from 80 mm to 90 mm billets. This calls for more rolling stands in the rod mill. Secondly, whereas billets used to be 9 metres in length, re-heating furnaces are now designed for 12 metres. Indeed the latest thinking is to use billets 115 millimetres square and 15 metres long. It will be appreciated that the heavier the billet, the faster must be the delivery speed at the finishing end: otherwise the exit speed of the billet from the reheating furnace becomes too slow and the rolls in the early roughing stands of the mill become damaged. Thus a 115 mm billet requires a delivery speed of the finished rod up to 60 metres per second.

CHAPTER 19 - TUBE AND PIPE MAKING

19.1 Production trends in tube and pipe making

In recent years there has been a growing acceptance of the use of welded tubes and pipes. This has been strongly influenced by the development of specifications and test methods to permit these tubes to be used for the conveyance of high pressure gases and fluids, and as structural members.

The discoveries of oil and natural gas in many parts of the world have led to a demand for large diameter pipes, required for the transmission of vast quantities of oil and gas over long distances. These requirements have been met by the use of welded high tensile steel tubes, whereas the production of seamless tubes in these sizes would be very costly.

In a developing economy the production of welded tubes for general use has definite advantages over the seamless tube. In the former case, the plant unit is of a small size, producing between 2,000 and 20,000 tonnes per year, whereas an economically-sized seamless tube plant will produce at least 100,000 tonnes per year. It is therefore possible to install a series of welding plants to match an increasing demand for tubes and so ensure that an over capacity situation, with the heavy financial commitment that this implies, does not arise.

It is considered that in the future there will continue to be an increasingly large proportion of welded tubes produced by those countries who are developing natural gas and oil fields, and using steel tubes as structural members in light and medium construction works. New processes such as extrusion and powder metallurgy are not expected to influence this trend but will be confined to the production of highly specialised smaller sized tubes in special steels and of complex shape or properties.

Before considering the methods of manufacture in detail, it is illuminating to look at the relative proportions of seamless and welded tube manufactured. In both Japan and the USA the proportion of welded tubes rose to a peak in the mid 1960's and subsequently fell. In 1970, 75 percent of Japanese production and 60 percent of USA production was welded.

In the USSR and in the EEC, there has been a steady increase in the proportion of welded tube, rising from approximately 40 percent in 1960 to 60 percent in 1970. These trends are considered to reflect to some extent the expansion which has been made in the use of natural gas pipelines in those countries.

Available tube making processes

In the existing commercial technology there are a multitude of processes available for producing both welded and seamless tubes, as shown in Figures 19.1 and 19.2, which also relate the manufacturing processes to the end use.

Welded tubes may be produced by longitudinal or spiral welding and seamless tubes may be produced on two or three roll mills. Within each of these broad classifications there exists a multitude of processes differing in detail to produce the final product. Following the basic process of making the pipe or tube there are a number of finishing processes, the choice of which again depends largely upon the end use of the pipe or tube. Although each process will not be considered in detail but the general principles of the major types of processes will be described below.

19.2 Welded tubes

Spiral welded tube mills

Spiral tube mills are in use for the production of large diameter tubes with high diameter to wall thickness ratios. Tubes can be produced from about 300mm up to 2500mm in diameter, and each spiral tube mill is capable of producing a large range of sizes; however, for small diameter tubes below 600mm, the continuous longitudinal welding process may have economic advantages.

The feedstock for spirally welded tube is hot rolled coil, which has the edges prepared for welding. The coil is formed into a helix, the helix angle and strip width defining the diameter of the finished tube. After forming into the tube shape, the strip is welded on both the inside and outside using submerged arc welding. After welding, the tube is cut to length using a travelling gas-cutting machine.

Longitudinal welded tube mills

This process differs basically from the spiral tube mill inasmuch as the strip is progressively formed into a tube shape through a series of rolls. The final diameters most commonly produced on these types of mills are between 12.5 and 100mm. There are a number of different welding processes which may be used for the production of the tube. One of the earliest methods, and still widely employed, is the Fretz-Moon process in which the edges of narrow strip of rimming quality (skelp) are heated to welding temperature in a long tunnel type furnace. The skelp is then formed into a tube shape prior to welding. During the welding stage the skelp edges are air blasted to clean the surface edges prior to final forming and welding. The formed skelp then passes through a welding horn and into the welding stand where the edges are butt welded together under pressure.

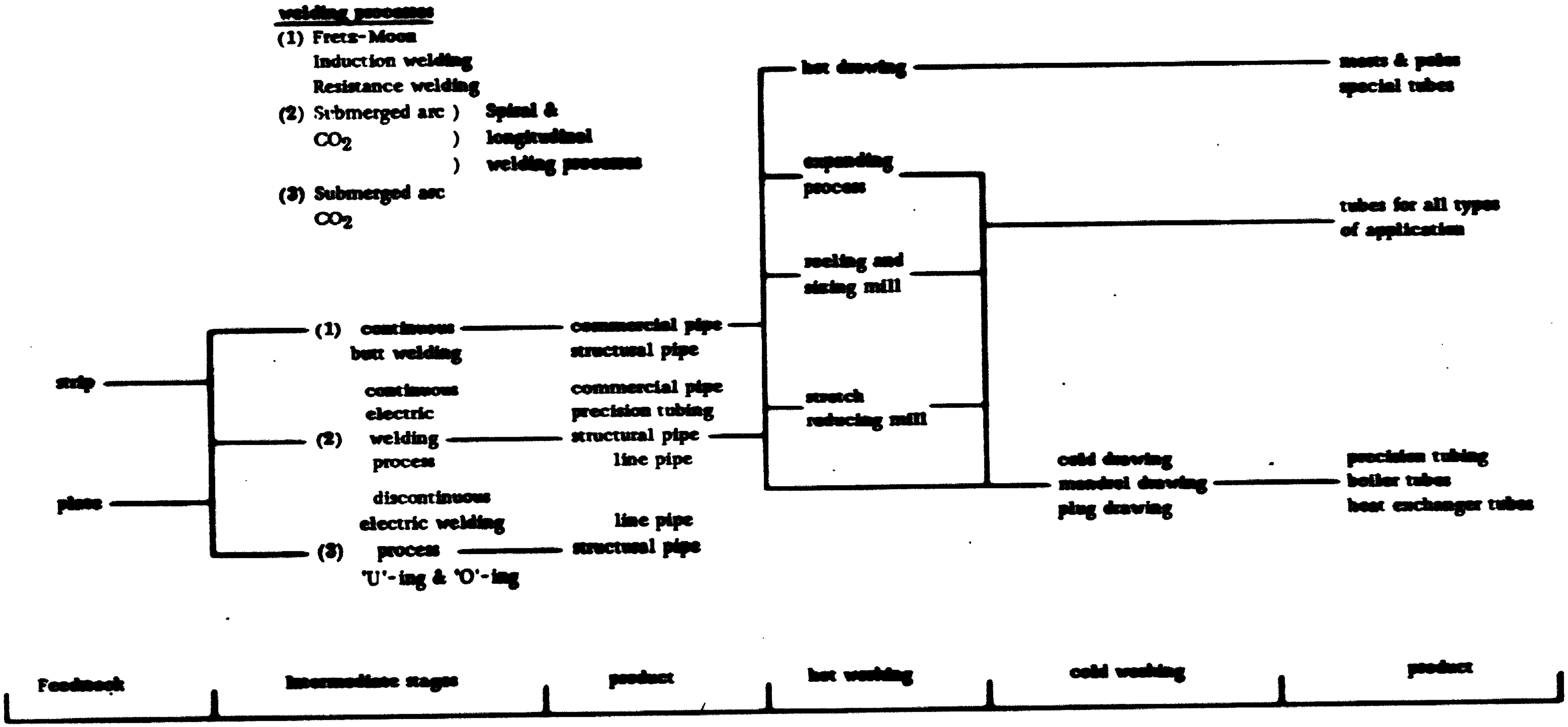

Figure 19.1 - Process routes for Welded Tube manufacture.

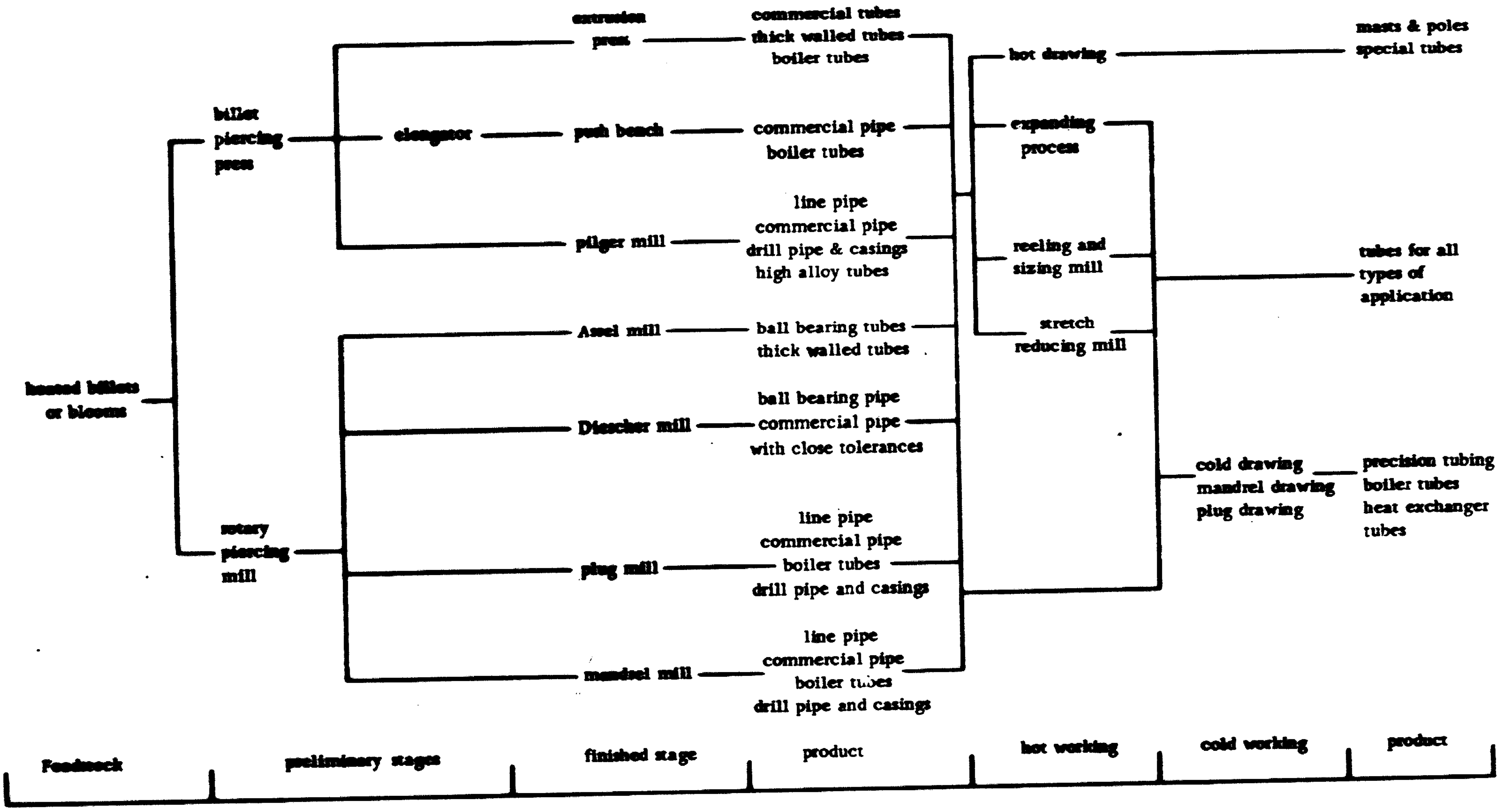

Figure 19.2 - Process routes for Seamless Tube manufacture.

Alternatively, the heat source for the welding may be induction heating. In this process an electr, ' coil surrounds the tube prior to the strip being formed into the final tube pe. The high frequency current locally heats the strip edges and they are then brought into contact under pressure by a pair of rolls where they are forged together. The heat to the weld zone may alternatively be put in by resistance heating just before the final tube shape is formed. These mills are capable of producing tubes at 50 to 375 metres per minute. In order to make the process fully continuous, successive coils are joined together using a strip butt welder and looping device.

Larger diameter tube can be produced by a discontinuous 'U'-ing and 'O'-ing process. In this method, lengths of plate are formed progressively into a tube shape by dies in a long press of at least 20,000 kN capacity. Before pressing, the correct edge preparation for welding is made by an edge-planing machine.. After edge preparation, the edges are bent slightly to ensure that after final forming the tube is perfectly circular. After this process, the plate is formed into a 'U' shape between a pair of dies. The dies run the whole length of the plate. After 'U'-ing the semi-formed plate is transferred to another press which has two semi-circular dies. The capacity of the press required for this operation may be 200,000 kN or more. The final tube shape is an almost enclosed circle which is then welded. Welding may be performed by a number of methods, the most common being submerged-arc. During welding the pipe is held in a completely circular shape by a series of rollers bearing on the outside of the tube. Normally the internal and external welds are made separately. To make the internal weld, the welding head is mounted on a long cantilevered arm and the tube is drawn over the welding head.

19.3 Seamless tubes

The first stage in the production of seamless tubes is the piercing of the heated billet or bloom. This process may take many forms but is common to all the subsequent tube making processes.

The feedstock may be either continuously cast billets or rolled ingots. These are firsted heated to a uniform predetermined rolling temperature before piercing.

When hot, the billet (or bloom) may be pierced by rolling it over a plug in such a way as to pierce and simultaneously rotate it. The rotary piercer may be of two or three roll design. Each has inclined barrel-shaped rolls with a tapered plug located between them. As the rolls rotate the billet, it advances over the plug and a hollow bloom is formed. Although the accuracy of the bloom dimensions is not critical, the concentricity of the pierced hole is important as it is upon this that the concentricity of the final tube depends.

Alternatively, if the tube is to be made by extrusion or on an elongator or pilger mill, the heated billet or bloom may be pierced by using a hydraulic ram to pierce the feedstock which is constrained by a cylindrical die to limit the barrelling effect which would otherwise occur.

After piercing the partially formed tube may be further processed in a variety of ways. The choice of the process depends to a large extent upon the end use of the tube as shown in Figure 19.2. However, the alternative processes may be broadly classified into two and three roll mills.

The mandrel, plug, pilger, Diescher mills and push bench use two roll configurations whilst the Assel mill and its derivatives use a three roll set up. The number of stands, the inclination of the rolls, and the type of mandrel or plug differ between each process. For example, the mandrel mill has 8 - 12 two-high stands, and the pierced bloom has a mandrel inserted into it to control the internal diameter. The mandrel travels through the mill and is extracted after the tube is formed. The plug mill uses a single stand two-high mill with grooved rolls. The plug is held stationary between the roll gap, and usually the tube is passed twice through a single gap, with the tube rotated through 90^{o} between passes. The pilger mill also uses shaped rolls which reduce, stretch and size the tube over a travelling mandrel. The tube is continuously rotated as it passes through the mill. The Diescher mill is used for the production of close tolerance tubes; the main work rolls are supplemented by two large diameter sizing disc rolls with hollow faces which bear upon the tube being formed. The disc rolls form an almost closed pass effect, producing excellent external and thickness tolerances. The push bench is similar in operation to the mandrel mill except that the hollow billet or bloom is closed at one end and an internal mandrel pushes the feedstock through a series of disc rolls.

The three roll Assel mill reduces the diameter and wall thickness of the pierced feedstock by cross rolling onto a mandrel. The wall thickness of the tube produced corresponds closely to that of the finished product, and by selection of mandrel diameter and radial adjustment of the three elongator rolls, any thickness and diameter can be accurately produced.

19.4 Other developments in tube production

Extrusion

Extrusion has been in use since the middle of the nineteenth centry for the production of non-ferrous tubes. The problems of very high die-wear due to inadequate lubricants was not overcome until the advent of graphite lubricants. It then became viable to extrude high value products such as high-alloy and stainless steels but the process still suffered from low productivity compared with other tube mills.

The introduction of the Ugine-Sejournet process of glass lubrication of the workpiece has made it possible to consider the large-scale production of extruded tubes. The process normally uses a heated pierced billet which is inserted into the extrusion press together with the glass. During extrusion the glass in contact with the die is almost solid whilst at the billet it is viscous. During extrusion, most of the shear strain occurs in the glass and not at the surface of the billet, unlike lubricated extrusion.

A new plant has been in operation for about 2 years at Tubacox, Llodio, Spain, where 180 mm square continuous cast blooms are pierced and extruded into pipe and tubing from 25 to 250 mm diameter, currently at a rate of 5,000 tonnes per month; however, with additional heating capacity this could be raised to about 8,000 to 10,000 tonnes per month. A second and larger unit has been installed in Japan by Kobe Steel at Nadahama for a range of 25 to 300 mm outside diameter.

This process has hitherto found particular application in the production of high alloy and stainless steel tubes in the size range 50 to 150 mm diameter, with diameter to thickness ratios up to 30:1. Larger diameter tubes, up to 250 mm can be produced by extrusion, but at these sizes the process becomes less attractive because of high tool wear and excessive tube faults.

The recent developments referred to above permit competitive costs for carbon steel and allow a wide range of product size from a single operation, whereas other types of equipment restrict the range of product from a single unit. As the process permits production of both light and heavy walled tubing, the product can be used for a wide range of applications, such as line pipe, drill pipe, petrochemical tubing, machinery and various other industrial applications.

Such extrusions can also be used for production of special shapes that cannot be produced in rolling mills.

Hydrostatic extrusion has recently been the subject of much research and development work. Use of hydrostatic pressure in the extruding process produces triaxial compressive stresses, whereas with conventional extrusion there are biaxial tensile stress components. Hydrostatic extrusion therefore eliminates the possibility of the normal surface defects becoming enlarged during the extrusion process.

This process is still in its early stages of development, but it appears assured that in the future the existing problems will be overcome to make this a common process for the production of complex shapes in high alloy steels.

Other processes

Other processes are being developed for the production of tubes and tubular products, such as powder metallurgical processes. In this process, the tube is formed from steel powder, compacted and then sintered. This process is currently being used for forming special products, such as filters and lubricant retaining parts, and has been applied to tubes up to about 50 mm diameter. It is considered that whilst this is an important and fast-growing technique, it is likely to develop its own markets rather than to substitute for any of the existing major production processes.

Attempts are being made to produce continuously cast hollow blooms. This would obviously reduce the total capital cost and the operating costs by saving the initial piercing operations in seamless tube manufacture. However, the metallurgical and mechanical problems of such a process are yet to be overcome and it will probably be at the least some years before the technique is sufficiently well developed to enable it to be widely applied.

19.5 Finishing processes

The basic methods of producing tubes, described above, produce tubes which are suitable for certain specific applications, as detailed in Figures 19.1 and 19.2. However, due to the limited size range that each of the mills can produce, the tubes may be further processed to change their final dimensions or impart specific surface properties. A seamless tube mill is often installed to produce a very limited range of sizes, and the size range is extended by further working, using one of the following processes.

Stretch reducing

After the seamless tube is formed it is reheated and then passed to the stretch reducing mill, which is similar in construction to the mandrel mill. It usually consists of a twelve stand two-high mill with adjacent stands positioned at 90° to each other. Each stand is individually motored using variable-speed motors. The individual stands are driven at speeds which progressively increase down the line from the entry stand. Thus by rolling under the tension imparted by the increasing roll speeds, this decreases both the diameter and wall thickness without using a mandrel.

Reeling and sizing mills

The reeling mill imparts a burnish to the inside and outside surfaces of the tube and accurately sizes the tube. The operation of the mill is similar to the rotary piercing process except that cylindrical rolls up to 1 metre in diameter are used. The rolls are inclined at a slight angle to the tube axis and reeling takes place over a torpedo shaped cylindrical mandrel. The roll gap is set at a little less than the diameter of the mandrel, and the rolls are geared together and rotate at a surface speed of approximately 5 metres per second.

If, following the reeling process, tube sizing is necessary, it is effected by the use of two or three two roll stands. The rolling may be performed either hot or cold, and ensures uniform size and roundness throughout the length of the tube whilst reducing the tube diameter slightly.

Expanding

Pressure expanding has for some time been used to correct both the shape and size of tubes. In this process both ends of the tube are sealed and the tube is filled with a fluid, normally water, which is pressurised. The tube is allowed to free form into the correct shape and size.

The expansion of seamless tubes by the use of a plug on a hydraulic ram is a comparatively new process, and is used to increase the yield strength of the formed tube. One end of the tube is machined prior to having a plug inserted. The expander plug is then forced through the tube using a high pressure hydraulic ram. The expander plugs are commonly of the same diameter as the outside diameter of the tube, and the tube is therefore expanded by approximately the same amount as the wall thickness.

Hot and cold drawing

These two processes are considered together as the basic principles are similar, apart from the temperature of the operation. Prior to drawing, the end of the tube is pointed, to allow it to pass through the die or rolls. The draw bench process consists of a heavy frame with a die rigidly mounted on it. The pointed tube is inserted into the die and the reduced end picked up on clamps. The tube is drawn through the die by an endless linked chain. The internal diameter of the tube is controlled by a fixed mandrel. The effect of the process is to reduce both the diameter and the thickness of the tube.

Cold reducing

The cold roll reducing of tubes is normally used when a high diameter reduction is required on small diameter tube. The process accomplishes a simultaneous reduction of tube diameter and wall thickness by a cold-swaging action. The process takes place under compression rather than tension in the conventional drawing process and hence the tensile strength is not a limitation upon the amount of reduction that may be imparted.

The rotating dies used in the process are discs of complex shape, with matching semi-circular grooves machined into their curved faces. In operation, one die is located above the other so that the matching semi-circular grooves make a circular pass. The dies are geared to each other so that as they are rotated a converging circular pass is traced by the die grooves. When a tube is held stationary on the centre line of the pass, the converging path of the die grooves reduces its diameter. A tapered stationary mandrel is held at the centre line of the pass which controls the internal diameter. The tube is progressively reduced and is fed into the work rolls during the idle stroke.

19.6 Testing of tubes

After final sizing of the tube it is visually inspected for surface defects and flaws before hydraulic testing, if necessary. Hydraulic testing is used when the tube is going to be used for high pressure tubing. Both ends are plugged and the tube filled with water and a hydraulic pressure applied. The applied pressure may be as low as 30 kg/cm^2 up to 1050 kg/cm^2, depending upon the type of tube, the size, and the service for which it is to be used. The testing machines are highly automated and are capable of testing about 20 tubes per hour.

19.7 Protective coatings

Galvanising

The hot dip galvanising process is widely used for applying zinc coating to small diameter steel pipes for protection against corrosion. Before hot dipping, the pipe is thoroughly cleaned to remove oils and grease. It is then pickled in hot dilute mineral acid to remove rust and mill scale after which it is washed. The surface is then fluxed by dipping in a hot solution of zinc ammonium chloride, and bringing the tube up to the bath temperature. It is then immersed in the zinc bath which is held at a temperature of 550°C. The tube is slowly removed in an inclined position to permit the excess zinc to drain off. Further surface treatment is applied to preserve the bright metallic surface coating.

Developments have been made to this process to speed it up by making it continuous. The tubes are continuously dipped and removed from the baths using a series of inclined spiral-grooved rolls. This development can handle tubes between 12.5 and 50mm in diameter, larger tubes continuing to be processed by the bath method.

Bituminous coatings

These coatings, based upon coal tars, asphalts and their derivatives, are applied to tubes as protective coatings against corrosion. They are particularly used for underground applications, as they do not have good weathering characteristics when exposed to sunlight. The coatings can be applied as a thick mastic or built up in thin layers, sometimes in a water based emulsion.

19.8 Production costs

The costs of tube manufacture within the broad classification of seamless and welded tubes, is highly dependent upon the size being produced, and on the process route chosen from amongst the alternatives which are technically capable of producing a particular type and size of tube.

Typical production costs for welded and seamless tube plants are shown in Figure 19.3. These costs include capital charges, but do not include a general works services element. It will be seen that when the full economies of scale for each of the plants are reached, then the conversion cost of producing welded tubes is approximately the same as that for seamless tubes. However, when the cost of feedstock is taken into account, production of seamless tubes of this size is more economical than welded tubes at high outputs.

In general, as the size of the tube is decreased the production cost advantage moves from welded to seamless tubes.

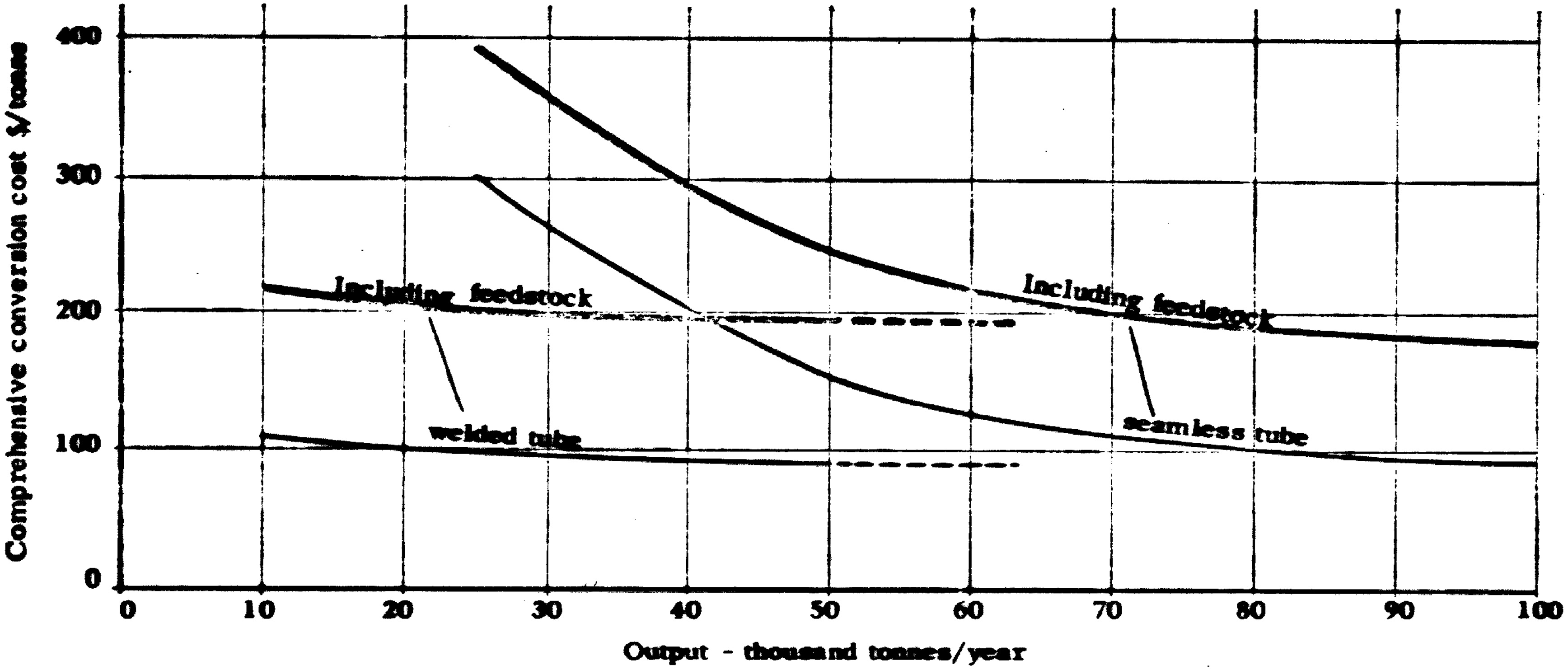

FIGURE 19.3 - COMPREHENSIVE CONVERSION COSTS OF SEAMLESS AND WELDED TUBE PRODUCTION
(150 - 200 mm DIAMETER)

CHAPTER 20 - COATINGS

20.1 Coated products

The coating of thin flat products for protective or decorative purposes has always been of great importance to the steel industry. Traditional coatings based upon tin and zinc are still being improved, whilst newer coatings such as aluminium and plastics are gaining in importance. The present state of the major alternatives is outlined below:-

Tinplate

The production of tinplate has reached a stage of sophisticated engineering development in which the speed of operation, productivity and yields have been highly developed, and the existing demands of the tinplate user for a cheap and acceptable product have largely been met. The production rate of the fastest tinning lines is now some three times as fast as lines ten to fifteen years old, and the current limitations on the maximum speeds result from the problems of supplying the line with coils, removing them from the finishing end, and the process limitations of dragging out the tinning solution at high line speeds.

Tinfree steel

Tinfree steel (TFS) is becoming a contender to tinplate, due to its comparative cheapness. TFS coatings use ultra thin layers of chromium and chromium oxide, and are completely interchangeable with tinplate for almost all applications. The use of these coatings has advantages over a tin coating inasmuch as the price of chromium has been much more stable than that of tin. This has led the can producers in the USA, who are the largest users of tinplate, increasingly to demand TFS; this has forced many of the tinplate producers to install TFS lines. TFS lines are very similar to the modern tinning lines, and most tinning lines currently being installed are capable of producing both tinplate and TFS.

Galvanised sheet

Galvanising of flat products has traditionally been carried out in large quantities for general purpose sheeting and roofing. The most common method of production is by hot dipping; however, electrogalvanised sheet is being produced in small quantities. This latter method produces a very thin coating which is not generally acceptable to most users of galvanised sheet, but it may find application in markets which are currently using uncoated sheet, for example for certain parts produced in the automobile industry.

Organic coatings

Organic coatings on a galvanised strip base are finding an increasingly large market particularly for such items as decorative side wall cladding. They have the advantage of a long life without maintenance - up to 15 years in some cases.

20.2 Tinplate

Feedstock preparation

Hot strip for tinplate is frequently made approximately 1000 mm wide. To obtain a good profile it is best rolled on a 1500 mm mill with a roll crown of approximately 0.075 mm.

The hot strip, usually 0.175 - 2.5 mm thick, is then descaled by pickling either in hydrochloric or sulphuric acid, although hydrochloric acid may give a cleaner material. There is a trend towards the use of hydrochloric acid in pickling lines partly because of the high line speeds it makes possible, and partly because of the high cost ($0.24 - 0.36 per tonne of pickled strip) of recovering the sulphuric acid.

Shot blasting has been examined as a descaling process, but abrasive systems are very costly. Acid processes will certainly remain the standard for the next five to ten years. Rolling in controlled atmospheres may become more important in the long term and this could make pickling unnecessary.

After pickling the hot rolled strip is cold rolled. Most cold reduction, to 0.0175 - 0.0190 mm, is undertaken on 5 or 6 stand four-high mills with work rolls of 450 - 625 mm diameter and back up rolls of approximately 1250 mm diameter. Single stand reversing Sendzimir mills are in use for small outputs.

After cold reduction the tinplate is de-oiled by passing through an alkali cleaner, and annealed.

Many tinplate lines still operate with batch annealing plants, but these are quickly giving way to continuous annealing. In the USA 50 to 60 percent of tinned strip is continuously annealed, and whilst in the UK the figure is only 30 percent, it is acknowledged that annealing capacity represents a production bottleneck.

Continuous annealing carries several production advantages over batch annealing. It is possible to use a coil of any size and the batch annealing problems of sticking and of damaged strip edges are absent.

Drawing quality steels which are required to be fully soft are still usually batch annealed. There is a move away from multiple stack batch annealers towards the single stack; this has been prompted by the requirement for larger coils which simplify the fully continuous operations that follow.

Although continuous annealing is clearly more economical, there is sometimes a conflict with the requirements of the canmakers, as some canmakers prefer the very soft tinplate produced by batch annealing because it simplifies the canning works machine requirements.

Before passing to the tinning line, the strip is temper rolled in a 1 or 2-stand four-high mill very similar in construction to the cold reduction mills.

Tinning

Before tinning the coils are welded together since electrolytic tinning is a fully continuous process. There are two main forms of electrolytic tinning. The "Ferrostan" process uses vertical tanks in which the strip descends into the tank between electrodes, loops around a bottom roller and rises again between electrodes. A pheno-sulphonic acid electrolyte is used.

The second, more modern method, known as the "Halogen" process, employs horizontal tanks in which the strip runs across the tank above the electrodes and is plated on one side only. A fluoride/chloride electrolyte is used. In both processes, the strip passes through a number of tanks in sequence - up to eight in some plants, and in the Halogen process the two sides are coated by turning the strip over part way along the line. Different thicknesses of plating and differential plating, where the coating on one side is thicker than on the other, are no problem on modern Halogen lines; they are simply 'dialled' up.

At present approximately 70 percent of world electrolytic tinning is carried out in Ferrostan plants, but there seems to be a trend towards the more costly, but faster, Halogen plants. The fastest Halogen plants operate at approximately 11 metres per second and Ferrostan plants at 8 - 9 metres per second.

The tinning is followed by washing and a flow-heating operation in which the matt white electroplated tin is melted by induction or resistance heating to a temperature just above the melting point of tin. Resistance heating plant is more common, being considerably cheaper than induction heating.

The plating operation is concluded by passivation in tanks of chromic acid and then electrostatic oiling. The thin chromium oxide film gives added protection and assists painting. The finished strip may be sheared or coiled according to the needs of the customer.

Tinning rates have progressively increased over the last few years as engineering refinements have been introduced into new plants. Ferrostan plants are now capable of depositing coatings at approximately 250×10^4 m^2 per week compared with approximately 150×10^4 m^2 per week a few years ago. The recently installed Halogen plants are slightly faster than the most modern Ferrostan plants, operating at approximately 300×10^4 m^2 per week. Line speed is limited by the problem of drag-out of electrolyte which appears to increase as the square of the line speed. At present the techniques are not developed to the point where faster line speeds are possible, and it is unlikely that the speeds of the most modern lines will change much during the next five years.

When installing an electrolytic tinning line it is common practice to leave gaps in the line so that additional stages may be added at a later date. In this way it is possible gradually to expand the capacity of the plant over a wide range of outputs and so avoid the problem encountered in iron and steelmaking, with large unit sizes.

Double reduced tinplate

Double reduced tinplate (DRTP) was developed to meet the need for a high strength sheet, but with a low thickness, and consequently at low cost. The main difference between DRTP and conventional tinplate is that instead of being temper rolled prior to tinning the double reduced strip is given a cold reduction of one third to bring the maximum yield strength up to about 7 kg per cm^2 at a thickness of approximately 0.150 mm. The strip has a markedly lower formability, but is still suitable for canmaking. Double reduced tinplate is growing rapidly in importance.

20 .3 Tinfree steel

The processing of tinfree steel is basically the same as tin coating. However, because the coating is much thinner (1/20 - 1/40 micron) it makes greater demands on the surface finish of the strip. There are several methods of producing the film, which all involve the electrolytic disposition of chromium metal or chromium oxide or both, the oxide coating method being the simplest.

Most tinfree lines are in fact dual purpose tinplate and TFS lines. Some make provision for using the same tanks for both solutions and have separate piping systems. This is an inferior and, in the long run, more costly method than employing separate tanks and running the strip above the tanks not in use. A change from tinplate to TFS takes about 8 hours with a separate tank system, but 24 - 30 hours with a common tank system.

When installing a tin coating line, consideration should be given to leaving sufficient gaps to enable the requisite parts of a TFS line to be installed later if required. Tin is a scarce product, and is largely irrecoverable from scrap products. Eventually the price may increase to the point where TFS is likely to take over in most parts of the world, but this will not happen within the next decade. It is thought that one reason why TFS grew rapidly in the USA was because the tin producers had allowed the price of tin to fluctuate widely. Certainly TFS has had the effect of stabilising tin prices.

There might also be advantages in installing a cold reduction mill instead of a temper mill where double reduced tinplate is likely to be required at a later date.

A list of tin free steel plants in the USA and Canada is given in Table 20.1.

20.4 Galvanised strip

Galvanised strip manufacture is relatively insensitive to surface condition

TABLE 20.1 - TIN FREE INSTALLATIONS - US AND CANADA

Company and plant	Line	Number of plating passes	Amp per side per pass	Total plating, amp/v	Chemical treatment, amp/v	Nominal line speed, mpm	Single purpose	Dual purpose
Bethlehem Steel Corp. Burns Harbor Plant Chesterton, Ind.	No. 1 ETL	7	6000	84,000/40	24,000/50	500 (2200 overvoltage)		X
Sparrows Point Plant Sparrows Point, Md.	No. 4 ETL	5	3000	30,000/30	12,000/30	250 (1000 overvoltage)	X	
Sparrows Point Plant Sparrows Point, Md.	No. 8 ETL	8	3750	52,500/30	15,000/30	460 (1800 overvoltage)	X	
Dominion Foundries and Steel Ltd. Hamilton, Ontario	No. 3 ETL	4	8000	64,000/36	16,000/36	400 (1700 overvoltage)		X
Kaiser Steel Corp. Fontana, Calif.	No. 2 ETL	5	4500	45,000/40	9,000/40	300 (1250 overvoltage)		X
National Steel Corp. Midwest Steel Div. Portage, Ind.	No. 1 TFS	7	4000	56,000/36	8,000/36	360 (1550 overvoltage)	X	
Weirton Steel Div. Steubenville, Ohio	No. 1 ETL	8	3750	60,000/40	20,000/40	460 (1700 overvoltage)		X
Weirton Steel Div. Weirton W. Va.	No. 2 ETL	4	7500	60,000/40	15,000/40	420 (1800 overvoltage)		X
United States Steel Corp. Fairless Works Fairless Hills, Pa.	No. 1 TFS	8	4500	72,000/36	18,000/36	500 (2000 overvoltage)	X	
Gary Works Gary, Ind.	No. 1 TFS	3	3200	19,200/30	6,400/30	250 (1150 maximum)	X	
Wheeling-Pittsburgh Steel Corp. Yorkville, Ohio	No. 1 ETL	3	4500	36,000/39	9,000/39	220 (250 to 300 overvoltage)		X
Youngstown Sheet & Tube Co. Indiana Harbor Works East Chicago, Ind.	No. 1 TFS	9	2000 first 4000 balance	68,000/30	10,000/25	225 (1000 overvoltage)	X	

ETL = electrolytic tinning line TFS = tin free steel Source: Iron and Steel Engineer, September 1972 and departures from steel specification. Much steel is rejected because the alloying elements are not within the required limits, but usually this does not matter for the applications requiring galvanised strip, and galvanising plants often make use of rejected black strip.

Most galvanising is done by hot dipping, and there seems no likelihood of a change in the process during the foreseeable future. The strip, usually thicker (0.40 - 0.625 mm) than for tinplate, is annealed and then cooled to the point where it is in equilibrium with the hot zinc bath. Immersion time is short, 2 - 4 seconds, and the coating thickness is controlled on emergence by contact rolls, or in more modern lines by air or steam jets. On modern lines the heat treatment atmosphere is adjusted so that the lubricating oil is removed, but the strip surface is not oxidised. Stretch levellers are now used at the end of the line to control distortion.

Sheet distortion, lack of zinc adhesion and edge build up cause difficulties at hot dip galvanising plants, but in general a high level of skill is not necessary to achieve satisfactory results.

Whilst old lines may work at 0.5 metres per second, recently installed lines operate at around 1.6 metres per second. The effect of all the current developments may be to increase line speed eventually to 3 - 4 metres per second, but few such plants are likely to be installed within the next few years. Simple, low speed plants are, however, available at low cost.

Output of electrogalvanised sheet is growing, but not as fast as for hot dipped. Electrogalvanising is a costly process and requires a lot of electricity. The process results in a deposit about .0075 mm thick - only one third that of hot dipped galvanising. There is a possibility of electrogalvanised steel replacing uncoated steel in some applications, possibly in parts for the automobile industry.

Galvanising of pipes and tubes has been discussed in Chapter 19, Article 19.7.

20.5 Organic coatings

Organic coatings are laid on a hot dip galvanised base. They combine the attraction of a coloured finish with the corrosion resistance of galvanising. In moderate atmospheric conditions they will last 15 years before repainting is necessary, and provided they are painted every five years they should last indefinitely. Most of the output goes into external building construction - at least 60 percent in the UK, 75 percent in the USA, and 85 percent in Japan. There has been a particularly rapid growth of organic coating in Japan where 26 lines are now in operation producing about 1 mtpy of products.

The process commences with a severe brushing of the galvanised sheet by plastic thread reinforced with nylon or stainless steel to remove some of the zinc coating. This is followed by a chromic rinse to passivate the exposed zinc. Next the first coat of paint is roller-coated on and partially stoved at 200-220°C for 10 - 15 seconds. Then the top coat is rolled on and the whole is cured at 200-220°C for 35 seconds. The finish is then cooled and perhaps embossed.

In the UK, PVC-plasticols about 0.25 mm thick are usually used for the coating, but in the USA the greater exposure to sunshine has led to the use of acrylic coatings about 0.025 - 0.050 mm thick.

Many existing lines run at about 0.5 metres per second, but the most modern lines run at 1 - 3 metres per second. There is no technological reason why the lines should not run at much faster speeds, and it is anticipated that new lines will run at 4 - 5 metres per second during the next few years. The organic coating market naturally demands a multiplicity of colours. Changing the colours on the line is a very time consuming operation, as it is essential to clean all the parts of the line thoroughly. This fact causes considerable lost production and great variability in the daily output.

Successful operation of these liquid-based lines requires great skill on the part of the operators. As in parts of the paint industry. colour matching is best achieved by the eye of a skilled man; with experience, such a man can even produce a new finish which will exactly match a service-faded earlier product.

About 80-90 percent of the organic coated steel is made using liquid-based processes. The remainder is made by rolling a preformed strip onto an adhesive base on the steel. The latter method, of which 'Stelvetite' is an example, is more expensive because of the cost of the preformed strip, but it allows a wider range of patterns on the finished product, and it is easy to change colour. The liquid-based processes are likely to grow more rapidly than those based on preformed sheet.

Organic coatings for pipes and tubes have been discussed in Chapter 19, Article 19.7.

20.6 Other coatings

Lead

Lead coating, known as 'Terne' in the UK, finds its chief application in automobile petrol tanks. The technology is basically the same as for zinc coating, and it is not likely to change much in the foreseeable future.

Aluminium

Aluminised and aluminium clad steel sheet has good corrosion resistance at high temperatures in atmospheric and sulphurous environments. It has found extensive application in radiators for central heating systems, vehicle exhaust systems and high temperature furnace components. Aluminium coatings are also finding an increasing use in general outdoor applications such as decorative cladding, where they have a life 3-4 times longer than the equivalent galvanised coating under the same corrosion conditions.

The continuous hot dip process is most commonly used despite much effort to develop alternative production methods. The major problem encountered in hot dipping is the formation of a brittle Fe-Al compound at the interface with the substrate, and this can cause problems during subsequent forming. Armco have developed a process which overcomes many of the problems of hot dipping. In this process the strip is first heated to about 450°C in an oxidising atmosphere to burn off grease and other contaminants, and at the same time to form a thin oxide layer. The strip then passes to a reduction furnace at about 800°C, using dry cracked ammonia as the reductant. This converts the oxide layer into a highly reactive iron layer. Whilst still being maintained in a reducing atmosphere the strip is cooled and passed through the aluminium bath. The strip leaves the bath moving vertically and passes through a pair of rollers, air jets, or gas wiping, to control the coating thickness.

The technique used in the latest BSC line at Shotton is based upon research undertaken by BISRA into the dry deposition of aluminium powder followed by sintering. This process allows a greater flexibility such as differential coatings in the product produced, and at the same time overcomes the problems of the Fe-Al brittle interface.

A number of producers operate dual purpose aluminising/galvanising lines, but such installations are far from ideal due to the need to change the molten metal bath, line speeds, and other process parameters.

There are between ten and fifteen world producers of continuous aluminised and aluminium clad steel strip. Most of these are located in the major steelmaking countries - France (Ziegler), Japan (Nippon, Nisshin and probably NKK), UK (BSC and Coated Metals), USA (Armco, Inland and USS) and West Germany (ATH, Hoesch and Wickeder). There is one plant in Latin America - Armco Argentina, Saic. The total installed capacity of aluminising lines is nearly one million tonnes per year*. Whilst this capacity is small compared with that of the more traditional surface coatings, it indicates the importance that has been attached to this product in the relatively short time it has been commercially available, and it is known that a number of other steel companies are investigating the possibilities of aluminising installations.

20.7 Long term future

Tinplate and tinfree steel are technologically the most advanced of the coating processes, and the manufacturing procedures are very similar. It is necessary today to link the planning of tinplate and tinfree steel production, and even where there are no immediate plans to manufacture tinfree steel, possible future requirements should be taken into account when installing the tinplate line.

Where markets are not ready to accept tinfree steel, or there are other reasons why tinplate is preferred, the similarities between the production of TFS and tinplate make it possible to invest heavily in tinplate production, safe in the knowledge that the plant can readily be used for TFS when the time comes.

The most critical factor in manufacture of both tinplate and TFS steel is the surface condition of the steel strip supplied for coating. The development of improved techniques for surface preparation is therefore likely.

In the long term it is likely that ultrathin coated steels will be developed and the possibility of markets for 0.025 mm sheets is being explored. Such a material will probably be heat treated to produce very high strength. This development is not expected to have any significant impact within the next ten years.

* Metal Bulletin Monthly, July 1972

CHAPTER 21 - THE PRODUCTION OF SPECIAL STEELS

21.1 Production of liquid steel

The major processes for the production of common steels were discussed in detail in Chapters 12 and 13. All these processes with the exception of the basic Bessemer or Thomas process, can also be used to produce special steels. One further process which is particularly appropriate to very small lot sizes is the electric induction furnace.

The bulk of the special steels produced come under the category of austenitic stainless steel (covered by the AISI 300 series) which contain an appreciable quantity of nickel. These steels have for many years been manufactured in electric arc furnaces and this process is particularly suitable for stainless steel manufacture. Growth in demand led to investigations into alternative processes for bulk production, and the BOF process has been utilised to produce certain qualities of austenitic stainless steel and some of the high chrome AISI 400 series steels,* whilst some of the high nickel cryogenic steels have been produced in open hearth furnaces. However the recent growth in size of electric arc furnaces together with greatly increased power inputs has reduced the capital costs of electric arc bulk steelmaking. These developments were originally related to the production of ordinary quality steels where large batches and large outputs were commonplace, and a number of electric arc shops exceeding one million tonnes per annum capacity have been built. Similarly some large shops specially designed for the bulk production of stainless steels have been erected in countries where demand for stainless steel has shown strong growth, for example, in Europe.

The use of BOF and electric arc steel plants together as a duplex process finds some application for special steelmaking. The processing of special steels in the BOF requires a long operating cycle to achieve the necessary control of metal composition. An advantage of duplexing is that there is no need for delays in BOF processing. The BOF acts as a pre-refiner and the liquid steel is then charged to an arc furnace for final refining. Small quantities of special steels can be made in a large works producing ordinary steels at lower costs using this technique than in a normal arc furnace installation. Electrical power consumption is low, for example in the 60 tonne duplex plant at Lorraine, France, it is 120 kWh per tonne of steel.

* R.F. Carlson and R.B.Shaw, Iron and Steel Engineer 49, 53 (1972)

The most important factor influencing the choice of steelmaking method is usually the lot size, but whereas variation in conversion costs is central to the selection of steelmaking processes for common steels, it is less important in the case of many special steels due to the high cost of the materials. Moreover, in the manufacture of special steels refining takes on an enhanced importance, due to the close specifications demanded. Thus the choice of an appropriate refining process for special steels is influenced less by the plant operating costs than by the technical requirements. These in turn are dictated mainly by market considerations through the quality and quantity requirements, but also partly by the plant available for steelmaking and casting.

The discussion below will cover aspects of refining which are applicable to common steels and to the more common special steels as well as techniques which are only applicable to the highly specialised steels.

21.2 Steel refining

The quantities of dissolved alloying elements, dissolved gases and inclusions, and the form which they take in the final product, are the factors which determine the properties of a steel. These will be influenced by the entire process route, but are largely controlled when the liquid steel is refined. Refining usually takes place in the ladle but can be carried out whilst the steel is in the furnace as in the case of special steels made in an induction furnace, or even in the mould as for ingot mould degassed steel.

Two distinct, but often overlapping, operations are involved in refining steel to ensure that the final product has the desired composition. The first is the reduction to the desired level of those elements which are present in excess, and the second is the addition of those elements of which there is a shortage.

These operations may involve the following treatments:

Addition of alloying elements

Addition of deoxidisers

Physical gas extraction

Removal of non-metallic inclusions

Removal of metallic and non-metallic elements.

These treatments have been considered in turn below.

21.3 Addition of alloying elements

The material containing the elements to be added may be charged to the furnace bath or added to the steel in the ladle, or both, depending on which elements are to be added and which steelmaking process is involved.

For ordinary quality and low alloy steels, relatively small quantities of carbon, manganese, silicon and chromium are added to the steel in the ladle in the form of carbon ferro alloys. Some of the manganese requirement may be added to the bath during steelmaking in the form of low grade ferro manganese, the balance being added to the steel in the ladle. The stirring action obtained by pouring the superheated steel into the ladle, together with convection, is usually sufficient to mix and dissolve the additions thoroughly.

When the larger quantities of alloying elements are required, it is necessary to charge them into the furnace to ensure complete melting and mixing before tapping. Some elements such as copper and nickel are invariably charged into the furnace as there is little or no loss to the slag. Others such as chromium involve a high loss to the slag, even though care is taken to minimise this loss.

The cost of furnace additions can be greatly reduced by selecting the cheapest source of the element to be charged, even though it may be contaminated with elements which then have to be removed. Examples of this are the addition of high carbon ferro chrome and raw chrome ore to make high chromium steel, and recently the use of nickel oxide and nickel sinter to charge to the furnace rather than metallic nickel, although the process then involves the reduction of the oxides to the metallic element.

The yield of alloying elements, that is, the percentage of the element added which finishes up in the liquid steel, is largely affected by the degree of oxidisation of the steel when tapped and the amount of slag remaining on the steel in the ladle, together with the time in the process at which the additions are made.

21.4 Addition of deoxidisers

Deoxidisers are primarily added to combine with the oxygen in order to prevent or reduce the release of carbon monoxide during solidification of the steel. The commonest deoxidisers are silicon and aluminium which react with the oxygen and other elements to form complex silicates and aluminates which, because they are insoluble in the steel, form non-metallic inclusions and so whilst removing oxygen also reduce the 'cleanliness' of the steel. A number of alloying elements are also good deoxidisers and also form insoluble compounds, thus reducing the yield of alloying elements. Careful control of oxidation prior to alloying or deoxidising is therefore of paramount importance in the production of special steels, particularly where a high degree of cleanliness is specified.

21.5 Physical gas extraction

The combination of dissolved oxygen with deoxidisers may be regarded as a chemical method of oxygen removal. Physical methods of removing oxygen and other gases have been developed and are now finding increasing application in particular for special steels, as they produce a 'clean' product. These methods are vacuum degassing, of which there are a number of variations, and gas flushing.

Vacuum degassing

Vacuum degassing was developed for degassing large quantities of steel after the change from acid to basic open hearth steelmaking practice resulted in the production of steel containing increased quantities of hydrogen, which was particularly detrimental to the production of large forgings. Vacuum degassing proved invaluable in the treatment of such steels and the technique simultaneously demonstrated the ability to remove oxygen, to reduce the number of inclusions present and to save on solid deoxidants and alloy additions.

Once the potential of vacuum degassing was realised, a range of plants was evolved with facilities for heating, stirring and alloying steel whilst undergoing vacuum treatment. The rapid improvements in the technology of pumping permitted the process to be applied on a commercial scale around 1955, and in the following ten years some two hundred degassing plants were built. Growth in the use of vacuum degassing is continuing, and while there are now more than a dozen different types of plant, these may be classified into the four process groups - ladle degassing, stream degassing, circulation degassing and ingot degassing.

Ladle degassing:

In this process, the ladle of steel is placed in a vacuum chamber which has provision for making ladle additions, and the steel is heated and stirred by the use of induction coils. Alternatively, the steel may be stirred by a stream of inert gas, usually argon. Adequate stirring is important to ensure thorough mixing and solution of alloying elements, and to obtain uniform temperature in the steel to prevent stratification. The agitation also ensures that fresh steel is continuously brought to the surface and subjected to the vacuum.

An example is the ASEA-SKF process which was developed to produce bearing steels having qualities equivalent to those produced by the acid open hearth process. The system has been widely adopted in the USA, Sweden, Brazil and Italy; further plants are scheduled for Britain and Spain. The ASEA-SKF process has been used in conjunction with the SKF-MR double furnace (Chapter 13, Article 13.2) in the SKF plant at Hallefors in Sweden since 1971.*

Stream degassing:

In this process group the steel is poured in a stream under vacuum. The stream of steel breaks up into small droplets in the vacuum which increases the rate of degassing by exposing a large surface area. The most recent stream degassing processes involve tapping the steel from the furnace directly into an evacuated casting ladle and so dispensing with the normal vacuum chamber. The steel from the furnace is poured at a controlled rate into a tundish situated on top of the sealing lid of the ladle. It then passes through a stopper and nozzle assembly directly into the evacuated ladle, from which it is teemed into ingots in the normal manner. Alternatively, the steel may be stream degassed directly into ingot moulds which are in a vacuum chamber.

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* **Iron and Steel, April 1972**

Circulation degassing:

The two main processes used are the Dortmund Hörder or DH process and the Rheinstahl Hüttenwerke or RH process. In the DH process a vacuum chamber fitted with one vertical barometric leg is used. When the leg is lowered into the steel in the ladle, the steel rises up the leg and flows into the chamber, where it is degassed. By raising and lowering the chamber this process is repeated with about 25 percent of the steel entering the chamber in each cycle. Good mixing is obtained with the steel repeatedly flowing back into the ladle. In the RH process the steel circulates back into the ladle on a continuous basis. The apparatus uses two barometric legs connected to the vacuum chamber. The steel is induced to flow up one leg into the chamber, where it breaks into droplets, and back down the other leg into the ladle. Argon is introduced into the rising leg to assist the flow of the steel by lowering the density in this leg. The flow rate can reach 20 tonnes per minute. Both processes can degas a heat of steel in about 20 minutes and both have the facilities to make alloying additions, and to heat the steel during processing. In another circulating process, termed 'continuous degassing', the steel flows through the vacuum chamber via two barometric legs and then directly into the ingot mould or continuous casting machine. The time taken to cast incorporates the time to degas and is the same as for casting ordinary heats.

Ingot mould degassing:

This process has found only limited application but can be particularly useful for the production of small quantities of vacuum degassed steel, since the capital cost of the equipment is low for small outputs. In this process individual moulds are fitted with a vacuum lid which is sealed on after teeming the ingot. The lid is then connected to the vacuum pumping system, which maintains a reduced pressure over the ingot during solidification.

Costs of vacuum degassing:

For circulation degassing plants the capital costs vary from about $5, 000 per tonne of ladle capacity for 100 tonne ladle plants, to $3, 000 per tonne of ladle capacity for 400 tonne ladle plants. The capital costs of ladle degassing plants vary widely according to type and size of unit. The minimum cost for a unit to process bulk steels is of the order of $0. 25 million rising to about $1. 25 million for a large unit.

Operating costs also vary widely because of the variation in utilisation and different manning requirements. For circulation units with outputs of 500, 000 tonnes per year and upwards, the operating cost is in the range $1 to $3 per tonne in excess of that for normally tapped and cast steel. This figure takes account of the reduced yield and the benefit gained from the reduced need for ladle additions. A typical operating cost for a 100 tonne ladle plant would be $2 per tonne for outputs of more than 100, 000 tonnes per year. The capital cost of such a plant would be of the order of $0. 6 million, and hence the comprehensive cost of treatment including capital charges would be in the region of $3 per tonne.

Gas flushing

In addition to using vacuum techniques to extract gases physically, a much cheaper method, gas flushing, has been developed in which argon is bubbled up through the steel in the ladle. A refinement of this process specifically developed for processing stainless steels is the argon/oxygen decarburising method in which an argon/oxygen mixture, which can be continuously varied, is used to decarburise stainless steel in the ladle, with very little chromium loss.

Argon/oxygen decarburising was developed in the USA by the Union Carbide Corporation in 1969. When the melt leaves the arc furnace it is analysed and the slag is removed before it passes to the decarburising plant. In this unit the mixture of argon and oxygen is blown into the melt from low down at the sides. Initially the mixture is 75 percent oxygen, but when enough carbon has oxidised for the chrome also to start to oxidise, the mixture of gases changes first to half and half, and then to two-thirds argon. The final carbon content is less than 0.05 percent. Additional processes remove any remaining oxygen and chrome is reclaimed from the slag. The British Steel Corporation has converted its electric arc furnace at Panteg, S.Wales, to argon/oxygen decarburisation. *

The Alleghany Vacuum Refining (AVR) process of vacuum decarburisation consists in oxygen flushing below the surface while the melt is held under reduced pressure in an atmosphere of carbon monoxide. **

21.6 The removal of non-metallic inclusions

The physical properties of steel are affected by the number and size of the non-metallic inclusions present, that is the cleanliness, and also the shape of these inclusions. The inclusion count is only specified for certain special steels, but this does not mean that the cleanliness of ordinary quality steels is unimportant. As all steel freezes inwards from the sides, segregation of some elements and compounds occurs in the centre of the cast product and the resultant concentration of non-metallic inclusions may produce unacceptable ingots.

The origins of inclusions in the cast product vary according to the steelmaking, refining and casting processes used, and it is as important to prevent inclusions from being formed in the steel as it is to remove the inclusions once they are present. As all non-metallic inclusions are lower in density than liquid steel, given sufficient time they will float to the surface, and so the time allowed for refining in the furnace or ladle has an important effect on the inclusion content.

Large inclusions, which are usually considered more detrimental than small ones, float to the surface more readily and therefore tend to be less common than small ones, especially when the standing time of the liquid steel is considerable. Most small inclusions are the product of deoxidisation, and are thus greatly affected by the oxygen level of the steel prior to additions being made. Careful refining in the steelmaking furnace and vacuum degassing to lower the oxygen content are two ways to reduce inclusion contents. Furthermore the extended refining time in the degassing process also helps to remove inclusions.

Circulation in the ladle, resulting from either natural or induced convection, can significantly reduce inclusions as long as a liquid slag layer is present to trap the small non-metallic particles. Slag washing, (the Perrin process) in which a prepared slag is poured into the ladle either before or with the steel, is basically used for the removal of sulphur and phosphorus and for deoxidising, but a large reduction of the inclusion level can be obtained with this process.

* New Scientist, 23 March 1972.

** V.P.Ardito and R.B.Shaw. Iron and Steel Engineer 49, 58 (1972).

21.7 Removal of undesirable metallic and non-metallic elements

Liquid steel in the steelmaking furnace will have various tramp elements dissolved in it, the particular elements and their concentration depending on the source of the charge and the steelmaking practice. The difficulty of removing these elements when introduced into the charge via contaminated scrap or pig iron is such that in many cases the most economic solution is the careful purchase of materials and sorting of scrap in order to limit the level of tramp elements charged to the furnace.

The liquid steel can be processed in the ladle in order to reduce substantially the unwanted elements dissolved in the steel. Reactions with solid ladle additions, or with molten slag such as in the Perrin process mentioned above, will form compounds which then come out of solution, float to the surface and are trapped in the slag during mixing.

21.8 Special techniques

To make steels with very high performance figures for creep, tensile strength, fatigue resistance, strength impact etc. it is necessary to refine the steel to a much higher degree of purity than can be achieved by any of the methods described above. A number of techniques have been developed to meet these requirements. They are all expensive to operate and, in general, as the degree of purity of the steel increases so does the cost of producing it. Four of the techniques are described below; the first two, vacuum melting and remelting, and electroslag refining are in relatively common use whilst the other two, plasma arc melting and electron beam melting are recently developed processes.

Vacuum melting and vacuum remelting

In vacuum melting a high frequency induction melting furnace is contained in a vacuum chamber which is equipped to enable ladle additions to be made and samples and temperatures to be taken. The steel produced is cast into an ingot mould which is also situated in the vacuum chamber. By careful selection of the charge constitutents and by the extraction of gases, very pure alloy steels can be produced. The main drawbacks to the process are that while plant capacities in Britain for example, are at present limited to 10 tonnes, with correspondingly small outputs, conventional ingots are produced with all the disadvantages associated with segregation in complex alloys.

A large proportion of the output of this process is re-melted, either in vacuum induction furnaces for the production of ingots and castings, or in the consumable electrode vacuum arc melting process (CEVAM). The latter process, in which a DC arc is produced between the consumable ingot electrode and the steel in the water cooled copper mould under vacuum, was originally developed for remelting titanium alloys and was adopted for the production of special steel ingots in the late 1950's. Ingots up to 1500 mm diameter and 3000 mm in length can be produced but the process is slow, up to 12 hours being required for the larger ingots, and hence outputs are also limited.

Vacuum arc remelted ingots have a homogeneous structure and are completely free from segregation. The oxygen content can be reduced by more than 50 percent during remelting and inclusions above 10 microns diameter can be more or less completely removed from most steels. Smaller inclusions can be reduced by more than 50 percent. Whilst the resulting steel shows improvements in all the normal measured physical properties, the most important benefit is the consistency and reproducibility of batches of special steels.

Electroslag refining

The electroslag refining process (ESR) was developed in the USA about 30 years ago but it has only recently been utilised to any great extent. The steel to be refined, in the form of a consumable electrode, is melted in a pool of calcium fluoride-based slag by a current which passes from the electrode through the slag and the refined steel to a copper mould. The steel is melted by the heat from the slag pool and forms droplets which sink through the slag. Refining takes place in the slag, and the droplets solidify in a water cooled, copper mould. The manner in which the ingot is formed - continuous solidification at the curved liquid-solid interface between the steel and slag - produces a steel which, unlike others, is isotropic in its physical properties.

In general the level of oxygen, sulphur and non metallic inclusions are all reduced, while those inclusions remaining are consistently small and evenly distributed. The process has recently been improved by the use of movable moulds, which travel up the ingot as it is cast. This is a development of the Russian electroslag welding process in which the molten weld metal is contained between two water cooled travelling copper shoes. Ingots up to 24 tonnes and 1100mm diameter can be produced.

Up to 1970 about three quarters of the world's ESR capacity was in the USSR but recently western countries have adopted the process to replace some refining and vacuum refining operations. The product is not deoxidised as completely as in vacuum arc refining, but similar inclusion counts can be obtained.

Plasma arc melting

Plasma jets, produced by heating gases such as argon to extremely high temperatures by means of electric arcs can be used to conduct high currents into a furnace charge. The charge can thus be melted in an inert atmosphere. When this method is coupled with induction melting in a plasma arc induction furnace, it is claimed to be able to produce steels to vacuum induction process standards. The process has been developed in USSR for the production of super performance alloys.*

Electron beam melting

This is another specialized technique applicable to melting and refining of steels which depends on the melting and superheating of the steel in a vacuum. The most recent commercial version melts the steel in an induction furnace which taps it into a holding furnace. The holding furnace then pours the steel at a controlled rate down a cascade of hearths into a tundish feeding the ingot mould. The whole of the operation is carried out under high vacuum and electron beams are used to raise to a high temperature the surface of the steel in the hearths as well as to keep the top of the ingot molten whilst it is continuously cast.

* Metal Bulletin, 5750, 36, 14 Nov. 1972

Focusing electron beams on the surface of the steel is stated to facilitate the volatilisation of unwanted metallic elements, in particular, lead and tin. The process is also said to reduce the inclusion count to an extremely low level, and at present can produce ingots of up to 10 tonnes.

Costs and choice of process

The comprehensive cost of remelting ingots by vacuum arc is very similar to the ESR process cost; both are approximately $360 per tonne of product. This figure includes capital charges and other overheads. The choice between these two processes, therefore, depends on the quality of the alternative products and the use to which they are to be put. The electroslag process is probably the best for larger forging ingots and it is likely that the capital costs per annual tonne of output of the new moving mould installations will decrease as larger sizes are built. A further advantage of the ESR process is that for some qualities of steel, ingots cast from the electric arc furnace but not under vacuum can be used as the electrodes, and this is considerably cheaper than using vacuum induction melted ingot stock.

Costs are not available for plasma arc and electron beam melting. Electron beam melting appears to be even more expensive than electroslag refining, and hence this process is only likely to be used for producing the limited number of steels which cannot be made by other methods.

21.9 Trends in stainless steel refining processes

Over the period from 1955 to 1971 most stainless steel was produced in the electric furnace by the oxidation-reduction process. Total free-world annual ingot production of stainless steel reached 4.96 million tonnes in 1970, declining to 4.35 million tonnes in 1971.

The successful development of pneumatic processes for stainless steelmaking is rapidly altering the role of the electric furnace; it is now becoming an integral part of duplex practices for producing molten alloy charges for refining, using the argon-oxygen and vacuum recarburisation reaction processes and the BOF. In some cases, electric furnace smelting of ores and the blast furnace or cupola are used to produce the molten charge. The coreless induction furnace is an alternative method of producing the molten alloy charge but, as yet, no large induction furnace has been installed for steelmaking purposes.

A survey in 1971 (reported in 1151/E/602/4) indicated the following trends in pneumatic stainless steel production:

Process	Yearly ingot production (tonnes)	
	1970	1975 (estimated)
1. Electric furnace* - BOF (oxidation-reduction)	220,000	320,000
2. Cupola - BOF (oxidation-reduction)	3,700	90,000
3. Cupola - BOF - vacuum decarburisation	20,000	45,000
4. Blast furnace - BOF - vacuum decarburisation	45,000	435,000
5. Electric furnace - vacuum decarburisation	6,800	1,110,000
6. Electric furnace - Ar/O_2 decarburisation	63,000	1,635,000
7. Induction melting, refining or vacuum decarburisation	40,000	75,000

* Electric furnace smelting and melting.

From the forecasts for 1975 it can be seen that electric furnace-vacuum decarburisation and electric furnace-argon/oxygen decarburisation are expected to gain the most ground by the middle of this decade.

21.10 Casting special steels

The casting of special steel ingots in vacuum chambers has already been mentioned. An alternative method of preventing oxygen pickup is to shroud the metal stream with an inert or reducing gas on its passage to the ingot mould. A number of special steels, however, will tolerate the normal degree of oxygen pickup, and these may be cast in moulds in air in the normal manner. As practically all special steels are killed and are more valuable than ordinary steels, they are usually cast in hot topped moulds and can be covered with exothermic compounds to reduce the yield loss to a minimum.

Virtually all special steels are suitable for continuous casting, and the improved yield obtained is particularly worthwhile due to the value of the products.

Irrespective of whether or not the steel has been degassed, protection from the atmosphere during continuous casting is of particular importance. The methods used to ensure this are a combination of submerged refractory shrouds acting, in effect, as extensions of nozzles, slag coverings in tundishes and moulds, and argon gas shrouding of the tundishes and moulds. It is important to keep the temperature of the steel being cast as constant as possible, and resistance heating of the tundish has proved to be an efficient and practical method of achieving this.

Straight moulds are generally preferred to curved moulds for special steels, particularly since the latter result in a higher inclusion content in silicon killed steels. Large nozzle and stopper assemblies and argon flushing of nozzles are used to control the pouring of aluminium killed steels, and slag covering of the liquid steel in the moulds is used to trap inclusions. An alternative, for the production of large size slabs and forging blooms, is pressure pouring (discussed in Chapter 15) in which precision graphite moulds are used.

21.11 Rolling special steels

The mechanical working of special steel after casting in general follows the pattern followed for ordinary qualities, but wherever differences occur they result in a lower production rate for specials than for ordinary steels. Since these lower rates are cumulative, the final outputs may be very small. The main differences between the methods adopted for the two broad groups are related to the outputs required and produced, and the power required. Most special steels are produced in very small lots compared with the batch size of ordinary quality steels, and therefore do not warrant the use of semi-continuous and continuous mills. The power requirement is on average higher for special steel because many are appreciably harder even at the high rolling temperatures. This leads to smaller draughts when rolling special steels on mills designed for the production of ordinary quality steels with correspondingly lower outputs.

In addition to lower output due to reduced draught and rolling speeds, the shorter lengths produced result in lower yields with a corresponding reduction in output. The greatest effect on output, however, is the small batch sizes required and the corresponding reduced availability of the mill due to repeated roll changing. A typical example is the regular production in one mill of over 2,000 batches per year with an average batch size of less than 2 tonnes.

The actual operating costs per tonne in these mills cover an extremely wide band largely because the high percentages of fixed costs strongly influence comprehensive costs when the wide range of outputs obtained for different products is considered.

Stainless steel flat products

The rolling of stainless steel strip and light plate is ideally undertaken on a semi-continuous hot strip mill. The high output of such a mill relative to the demand in most countries means that the mill cannot normally be filled only with stainless and other special steels. Nevertheless, an increasingly large proportion of the world's stainless steel strip is being hot rolled in semi-continuous mills, usually by hire rolling contracts or the equivalent. Being a high value material, the cost of transporting stainless steel over appreciable distances can represent a relatively small proportion of the total cost, and this provides some flexibility with respect to the manufacture of slabs in one location, hot rolling in another, and even cold rolling and heat treatment in a third.

However there are a number of hot strip mills which are suitable for small outputs, and are therefore relevant to stainless steel. These have been discussed in Chapter 17.

Although opinions may differ, it is considered that whilst the Sendzimir planetary hot mill may have a place for narrow widths, it is less suitable for the widths in which stainless steel is commonly rolled. Moreover, it appears to be limited in respect to the metallurgical specifications that it can successfully roll.

The Steckel single stand reversing hot strip mill has for many years been used to hot roll much of the world's stainless strip. As the market increased in the USA and Germany, there has been a trend towards hire rolling on continuous or semi-continuous mills. However, in the UK, in Sweden, in Canada, and to some extent in Japan, Steckel hot rolling continues. In fact the Steckel hot mill has recently taken on a new lease of life as regards its capability. Its shortcoming previously was that, due to its method of re-heating the coil in 'hot boxes' on either side of the mill, the ends of the coil received less reduction due to temperature variation, which in spite of the use of automatic gap control, led to 'heavy ends' and gauge variation in the hot band beyond the compensation of the subsequent cold rolling. This situation now appears to have been radically changed by the application of modern hydraulic precision gap control to a mill of this kind, coupled with the latest automatic gauge control equipment. For example, Dosco in Canada recently converted a Steckel mill to hydraulic gap control with modern gauge control. They claim that all of their stainless hot band production is now within plus or minus 0.13 mm of the nominal gauge, which is entirely within the correction capacity of cold mills.

The demand for flat stainless steel in plate thicknesses is increasing steadily for the fabrication of vessels for the chemical, gas and food industries, and the mills discussed above can produce a proportion of this in the width range of the available strip mills. Wide plate, however, needs to be rolled on plate mills and is normally hire rolled from ingots or slabs supplied by the producer.

For cold rolling stainless steel strip, the Sendzimir cluster mill, with its very small work rolls, is probably unequalled.

Transformer sheets

What has been said about rolling stainless steel strip is also generally applicable to grain oriented silicon steel strip for the manufacture of low watt-loss transformer sheets. Although silicon steel sheets of this type are commonly made under a process patent owned and licensed by Armco, we believe the hot rolling mill equipment and the initial annealing and pickling lines can be the same as for stainless steels, and that the two products can form part of a single operation up to this point. However, it is not considered good practice to cold roll stainless and silicon steel on the same mill, and it is certainly not good practice to use the same cut-up and slitting facilities for the two types, owing to scale and dust contamination.

Non flat products

A large proportion of special steel production is cast in ingots, and the rolling of these down to the appropriate semi-finished product is often performed by ordinary steel rollers on a hire basis, especially for the larger sized ingots.

Alloy steel rods and bars are commonly produced on mills with looping configurations. However, there is a special need for precision rolling in alloy steel rods, not only because the customer usually demands precision for his own purposes, but also the producer himself is anxious to control his yield with precision, because of the high value of the material. To achieve this, alloy steel rod mills with pre-stressed roll stands and precision bearings have increasingly found favour as they produce rods and bars to high degrees of accuracy. Swedish companies, in particular, have designed highly sophisticated looping mills with repeater designs and control techniques far in advance of those available elsewhere. However, to justify this type of new investment it may be necessary to rationalise the production of existing smaller mills. Such a rationalisation took place in recent years amongst some of the alloy rod rollers in the UK.

CHAPTER 22 - MINIWORKS

22.1 Definition

A mini-steelworks is a works of limited capacity (normally between 70,000 and 300,000 annual tonnes) which markets a strictly limited range of products under certain specialised environmental conditions. The products, which are mainly bars, are invariably hot rolled from billets, and the process route is scrap melting in electric arc furnaces usually followed by continuous casting.

The commercial aspect of the miniworks is central to the concept. The miniworks achieves a competitive commercial position by employing a number of second order advantages to offset the disadvantages of a higher equivalent comprehensive conversion cost than in a large integrated or semi-integrated works. These advantages are:

i) utilisation of local or other cheap scrap sources

ii) minimising transport and selling costs by serving a localised market - typically within 150 kilometres of the mill

iii) achievement of high operational efficiency and minimal overheads (administration, development and marketing) by producing only a limited range of simple products in ordinary steels, e.g. reinforcing bars

iv) using relatively simple plant of low capital cost - but carefully matched to the product range, and to each other.

The principal weakness of the miniworks is its sensitivity to scrap prices, and the need for low-cost electric power. In many developing countries the market conditions are appropriate for miniworks and there is the potential for low-cost power from hydroelectric sources, but scrap is in short supply. This has led to the interest in sponge iron (cf Chapter 11) as a scrap substitute.

It should be emphasised that not all small works fall within the concept of miniworks as discussed herein. Rerollers, works making a wide product range or producing only billets, and the majority of works with similar capacities but process routes other than those indicated above, would not be classified as true miniworks.

22.2 Survey of existing miniworks

The development of miniworks can be illustrated by reference to their position in Italy and the USA.

Italy

In Italy the major part of the national crude steel productive capacity of 23 million tpy is provided by small units.Of the 124 steelmaking plants operating in 1969, 116 were under 0.5 million tpy. However, 22 Italian works representing 2.6 million tpy (average 115,000 annual tonnes) were classified as miniworks in 1970, representing a relatively high proportion of 11 percent of total crude steel capacity. All these miniworks employ electric arc melting and continuous casting; all make reinforcing bar, some make light 'structural' sections, but only three make other products (narrow strip and wire).

Examination of the industrial uses of Italy's steel provides a clue to the success of Italian miniworks. For the past decade the Italian construction industry has been exceptionally buoyant, and of 14.8 million tonnes of finished steel products delivered in 1969, 2.6 million tonnes were used in building, civil and structural engineering. Compare this to the position in Germany (which has a similar population), where out of a total of 35.2 million tonnes of finished steel products, only 1.3 million tonnes were delivered for use in the construction industry, and where there are only six known miniworks.

The growth of miniworks has probably been encouraged by Italy's geography; constructional activities are relatively widely dispersed and this permits many of the works to serve local markets without competition from nearby larger works. On the other hand, the extensive use of scrap for steelmaking has led to heavy imports of scrap - 5.1 million tonnes in 1969 - which must mean that some of the miniworks are unable to obtain the benefits of cheap local scrap.

USA

There are also numerous small steelworks in the USA. Over 40 'minimills' with individual capacities up to 300,000 tonnes and a total capacity of some 6 million tpy (average size 140,000 tonnes), have been reported. However, these represent less than 4 percent of total US crude steel capacity. The current total number of plants operating in the USA is not known, but in 1967 there were 90. US plants with a capacity of less than 200,000 tonnes per year are listed in Table 22.1.

Examination of the specifications of these works shows that they are playing a slightly different role to those in Italy, and indeed that some may not really fit into the miniworks concept. Whilst almost all the works make reinforcing bars and many make other hot rolled bars, the total product range of the works is far wider than that of the Italian miniworks. About 75 percent of these works have continuous casting.

The difference between the miniworks in Italy and in the USA probably arises from the pattern and timing of development. The USA is a net exporter of scrap, and local scrap availability creates a favourable environment for a miniworks. The impetus which led to the development of the US miniworks was the federal highways building programme of the late fifties and early sixties, and at this

TABLE 22.1 - STEEL PLANTS IN USA WITH LESS THAN 200,000 TONNES ANNUAL CAPACITY

Company & Location	Hot Metal	Approx. Raw Steel-Annual Capacity tonnes	Date in-stalled	Product Hot Rolled & Rebars	Company & Location	Hot Metal	Approx. Raw Steel-Annual Capacity tonnes	Date in-stalled	Product Hot Rolled & Rebars
Allison Steel Mfg. Co. Temple, Arizona	3-20 t EF	135,000	-	Reinforcing bars	LeTourneau, Inc. Longview, Texas	3-27 t EF	180,000	-	Slabs & Plate
Armco Steel Corp. Sand Springs Works Tulsa, Okla.	1-70 t EF*	125,000	1965	Hot rolled & rebars	Mississippi Steel Corp. Jackson, Mississippi	2-10 t EF	70,000	-	Hot rolled and rebars
Border Steel Rolling Mills. El Paso, Texas	2-25 t EF	125,000	-	Hot rolled & rebars	North Star Steel Co. St. Paul, Minnesota	1-50 t EF*	90,000	1967	Hot rolled and rebars
Calumet Steel Div. Borg-Warner Chicago Heights, Ill.	2-30 t EF*	160,000	1967	Hot rolled bars, structural and special shapes	Northwest Steel Rolling Mills, Inc. Seattle, Washington	1-30 t EF	90,000	-	Hot rolled and rebars
Connors Steel Div. H.K.Porter BirminghamAlabama	3-20 t EF	180,000	1954	Structural & Merchant bars	Oregon Steel Mills, Portland, Oregon	3-20 t EF+	180,000	1970	Hot rolled bars, plate
Huntington, W.Va.	2-30 t EF	135,000	-		Owen Electric Steel Co. Cayce, S.C.	NA	NA	-	Hot rolled and rebars
Edwanda Steel Producers Edwanda, California	2-10 t EF*	80,000	1967	Hot rolled bars & rods and rebars	Pollak Steel Co. Marion, Ohio	1-30 t EF*	90,000	1963	Hot rolled and rebars
Florida Steel Corp. Tampa, Florida	1-25 t EF* 2-15 t EF	180,000	1965	Hot rolled bars and structurals	Roanoke Electric Steel Roanoke, Va.	1-12 t EF* 2-25 t	90,000	1962	Hot rolled and rebars
Croft N.C.	1-25 t 1-15 t	90,000	-		Roblin Steel Corp. North Tenawanda.NY.	2-25 t EF*	125,000	1964	Hot rolled and wire rods
Georgetown Steel Corp. Georgetown, S.C.	2-55 t EF*	180,000	1969	Wire rods' and hot rolled	Soule Steel Company San Francisco, Calif.	1-15 t EF*	59,000	1965	Hot rolled and rebars
Harrisburg Steel Co. Harrisburg, Pa.	3-50 t OH	70,000	-	Forging Blooms	Southern Electrical Steel Birmingham, Alabama	2-14 t EF	108,000	-	Hot rolled and rebars
Hawaiian Western Steel Ltd. Ewa, Hawaii	1-15 t EF	45,000	-	Hot rolled & rebars	Southwest Steel Rolling Mills, Inc., L.A., Cal.	2-13 t EF 1-15 t	135,000	-	Hot rolled and rebars
Intercoastal Steel Corp. Norfolk, Virginia	1-20 t EF	45,000	-	Hot rolled and Reinforcing bars	Structural Metals, Inc. Sequin, Texas	2-25 t EF	45,000	-	Hot rolled and rebars
Judson Steel Corp. Emeryville, California	3-50 t OH	70,000	-	Hot rolled & rebars	Tennessee Forging Steel Harriman, Tennessee	1-20 t EF*	63,000	1967	Hot rolled and rebars
Kankakee Electric Steel Kankakee, Illinois	1-15 t EF	63,000	-	Hot rolled & rebars	Texas Steel Co. Forth Worth, Texas	1-25 t EF 1-12t 1-4t 1-3t	90,000	-	Hot rolled rebars and alloy steels
Kentucky Electrical Steel Coalton, Kentucky	2-15 t EF	125,000	-	Structurals and merchant bars	Washburn Wire Co. Phillipsdale, R.1	2-35 t EF	109,000	-	Hot rolled bars and rods & strip & wire
Knoxville Iron Co. Knoxville, Tennessee	2-10 t EF 1-25 t	90,000	-	Hot rolled & rebars	Total Capacity		3,406,000	-	

* Continuous casting

+ Pressure casting

time virtually all the miniworks served the reinforced concrete industry. Continuous casting had not been developed at the time when these works were built. With the highways programme now largely completed, the miniworks are being forced to seek additional market areas, and leading authorities in the USA have stated that they do not expect any further growth in the number of miniworks.

22.3 Miniworks costs and location

Capital cost

The miniworks has a lower capital cost per annual product tonne than the cost attributed to an equivalent product manufactured in a large integrated works, and a capital cost comparable with or possibly lower than that of a large scrap melting works. For example, a miniworks can be built for between $120 and $180 per annual product tonne, and some works have been built for under $100 per tonne. The capital cost of an ore based integrated works could be between $180 and $300 per tonne, whilst the capital cost attributable to the production of bars is likely to be 20 or 30 percent higher than in the equivalent miniworks.

The miniworks achieves its relatively low cost by a careful choice of plant. The rolling mill is normally the most expensive item, but sophisticated plant items are kept to a minimum, and because of the limited product range and generally wide tolerances, downtime can be minimised and consequently output is high. To minimise capital outlay, some miniworks have been built using secondhand mills.

For efficient operation, it is important to match the furnace and casting plant capacities to the mill capacity. Continuous billet casting is almost invariably specified for new miniworks, but unlike larger works standby casting facilities are not normally provided. Larger miniworks frequently use two identical electric arc furnaces, but some of the smaller works use a single furnace, although this does not match the continuous casting plant so well.

The miniworks can make a major saving on the cost of 'works services' by minimising the provision of workshops, stores, laboratories and offices, and by its careful layout and compact size, on services, distribution and transport facilities.

Another important difference between large works and miniworks lies in the time taken to build, commission and bring the plant up to full output. Instead of 3 - 4 years to build and commission, plus 2 years of 'learning' for a large integrated works, a miniworks can be built and operating at full output in half the time. The difference stems from the inherent simplicity of the miniworks and the fact that its plant is normally proven standard equipment, rather than the more sophisticated plant of the large integrated works. This difference is important to the success of miniworks, as reaching early profitability improves the profile of the cash flow which justifies a lower capital recovery factor, and hence lower capital charges.

Because the plant is standard and simple, holdings of spares, especially in developed countries, can be minimised and this can assist in holding down the working capital requirements.

Location of miniworks

The lower capital charges for miniworks compared to integrated works are generally offset by higher operating costs, but these are strongly influenced by commercial operation of the miniworks. A miniworks can only compete with larger integrated and semi-integrated works under favourable conditions, and its location is of paramount importance, as both income and operating costs are strongly influenced by the location of the works. The locational factors which must be considered are:-

i) Proximity to markets.
ii) Location of competition.
iii) Proximity to reliable inexpensive sources of scrap.
iv) Availability and cost of electricity.
v) Availability and cost of labour.
vi) Fiscal environment.

The miniworks must plan to serve a suitable market, and it is important that the product range is limited and that generally the products themselves are simple. This reduces both direct production and overhead (technical and marketing) costs. Most miniworks aim to sell the major part of their output within 150 km. of the plant and often serve a far more localised market. Nor would they expect to supply the whole of their local market - they prefer to limit the market share in order to hold down marketing costs and to assist in keeping plant utilisation high. An unstable or rapidly changing market would not be attractive, as a miniworks has only limited ability to change its product range.

The most important consideration about scrap is to keep the delivered price low. Depending on the product pricing system in use and nature and location of the competition for both the market and the scrap, local scrap sources may be more important than local markets. It is also in the miniworks' interest to ensure that it does not use all the locally arising scrap; this will tend to force up prices and restrict choice of quality. Given a local market and scrap, it is generally advantageous for a miniworks to be located well away from all competing works, using the effect of transport costs to assist it to obtain a commercial advantage.

Operating costs

Table 22.2 shows a breakdown of costs for a hypothetical international miniworks producing reinforcing bars The finished product price is comparable with that from a large integrated works; under less favourable conditions the finished product cost could be as high as $250 per tonne. Even at these levels of cost, miniworks may be appropriate in developing countries if they can eliminate the need for importing certain types of steel product. The effect on the finished product cost of changes in the major individual costs is illustrated in Table 22.3.

TABLE 22.2 - MINIWORKS COMPREHENSIVE COSTS

Cost	$ per product-tonne
Bought in scrap	29
Pig iron	7
Electrodes, lime, additions	9
Electricity *	8
All labour *	7
Consumables, other conversion costs *	15
Capital charges *	22
Working capital charge	4
Total product cost	100
* Includes all works services. Based on a capital cost of $140 per product tonne	

It will be seen that the product price is very sensitive to scrap price, and some of the factors which influence scrap price are discussed in Article 22.4. The product price is also sensitive to capital charges, and hence to the capital cost of plant, its utilisation and the cost of capital. However, the product cost is not as sensitive to plant utilisation as in a large integrated works, and the miniworks has some ability to diminish the adverse effects of a low level of output through its scrap purchasing policy.

Annual output can be as high as 1,000 tonnes per man in a miniworks, although figures around 500 tonnes are at present more common. Consequently, the product cost is not particularly sensitive to labour rates or productivity. A high proportion of the men are employed on direct production rather than as support staff, and availability of suitable labour may be more important than the hourly rates. A new miniworks will often train up local operatives, rather than attempt to attract experienced steelworkers from other locations.

Table 22.3 also shows that normal variations in electricity costs do not have a very strong influence on the product cost, although it must be remembered that in special circumstances there can be large variations between the charges in different locations. It is also possible that the magnitude of the maximum demand - typically 25 MVA - may affect the sites which can be considered.

TABLE 22.3 - SENSITIVITY OF MINIWORKS COMPREHENSIVE COSTS

A. Percentage change in cost required to change product cost by one percent, assuming all other costs remain constant.

Item	Percentage change
Scrap cost	3
Capital charge	5
Electricity charge	11
Labour cost	13

B. Change in parameters to change product cost by $3 per tonne, assuming all other parameters remain constant.

Parameter and unit	Parameter level for product costs of:- $97/tonne	$103/tonne
Scrap price $ per tonne	$26	$32
Electricity $ per kW-h	$0.007	$0.015
Average labour cost $ per man p.a.	$2500	$5700
Plant capital cost $ per product tonne	$123	$157
Average plant utilisation percentage of capacity	100%	80%

22.4 Scrap availability and price

The price of scrap is strongly influenced by demand, and in a free market local differentials merely reflect transport cost differences. The miniworks must compete with other steelmakers for the available scrap, and experience shows that unless some form of price agreement is employed, the short term price of scrap is highly volatile, as the supply is limited. This is particularly true of process scrap which could be the major source of non-circulating scrap in a developing country. The desirability of scrap for steelmaking, and hence its price, is strongly dependent on its chemical composition, and is also influenced by its physical form. Process scrap commands a premium because its composition is known, and for this reason much process scrap is returned to its originating works. Because it usually makes only ordinary steels, a miniworks can accept a higher level of tramp elements than many large integrated works, particularly those making flat products. This permits the miniworks to utilise the cheaper grades of scrap for which there is less demand. This is particularly true in times of slack demand, as more time is available for refining the steel, and under these circumstances iron scrap can be used as a source of carbon instead of pig iron.

Transport costs for scrap are similar to those for finished products, and might be say 1.0¢ per tonne kilometre. Thus delivery over 400 kilometres could add $4/tonne to the scrap cost, increasing the product cost by a similar sum. This illustrates the importance of local scrap availability. For this reason miniworks will normally avoid a location where there is strong competition for scrap, as this will push up prices. The effect can be greater than might be expected at first sight. For example, consider a small isolated source of scrap, situated 400 km. from a large established scrap market in which the price is $29 per tonne. A small works adjacent to the isolated source should be able to buy scrap at $25 per tonne, i.e. $29 per tonne less the transport differential. On the other hand, if there is strong competition for scrap in the vicinity of the isolated source the price will tend to rise to $33 per tonne (i.e. $29 per tonne plus the transport cost from the scrap market) - an increase of $8 per tonne.

Modern scrap processing is becoming relatively capital intensive, and this will tend to concentrate scrap processing in the areas where there are high arisings. These are frequently areas where there are other steelworks, but of course a miniworks located close to an integrated works need not be in competition for scrap provided the miniworks can use grades which are not of interest to the integrated works.

22.5 Future developments in miniworks

Because the miniworks use standard plant they will not be at the forefront of technological development. On the other hand, they will closely monitor technological developments, partly to be ready to adopt any proven innovations, and partly because developments will affect the position of the miniworks' competitors.

The most important development which is of direct interest to the miniworks is the possibility of substituting pre-reduced products for scrap, provided these products are available at a competitive price.

There are several advantages to using sponge iron in the electric furnaces. The pre-reduced material can be charged continuously, and presents less problems of tramp elements than does scrap. However, mixtures of sponge iron and scrap offer the most promise at present. A mixed charge will give a faster cycle time and lower power and electrode consumption than either 100 percent scrap or 100 percent sponge iron. These advantages will offset some of the additional cost of pre-reduced material, and one authority calculates that pre-reduced material can become competitive when the price per tonne of material containing 90 percent metallic iron is about $5 higher than that of scrap.

One long term trend which will have an influence on the role of miniworks is the relative increase in the cost of coke compared with electricity. This will tend to encourage electric arc steelmaking routes relative to the blast furnace/BOF route. On the other hand, relative reductions in transport costs resulting from containerisation and improved handling facilities will reduce the extent to which miniworks can be insulated from their competitors by distance.

There is a long term trend towards an increasing proportion of flat products and towards more sophisticated products; even the reinforcing bar markets are being affected by increasing demands for high tensile steel. These trends may limit the development of the type of miniworks described in this article, but could in turn encourage the development of small market oriented works making specialised products in small volumes.

CHAPTER 23 - POLLUTION

23.1 The need for pollution control

An environmental pollutant is any substance or combination of substances whose presence detracts from the health or social quality of the environment. The control of pollution may in any instance need to be local, national or world-wide depending on the type of pollutant and where its effects will be felt. The legislative consequences of pollution control will, to a large extent, depend upon the degree to which people will accept the reduction in the quality of their living and working environment resulting from uncontrolled pollution.

When considering pollution control in an iron and steel industry, account should be taken of the pollution level produced by other industries in close proximity. It would certainly be unacceptable to allow high levels of pollution from a steel plant in an area where neighbouring industries are maintaining a pollution free environment. Similarly, it is not reasonable to expect better pollution control than the country's planned best standards.

This chapter discusses the various forms of pollution control used in the iron and steel industry and relates the quality of control to the costs.

23.2 Current pollution legislation

Legislation to control the emission of pollutants was initiated originally only to alleviate the acute local effects of industrial effluents of a positively dangerous or aggresive nature. However, with the growth of industry, other less obvious pollutants became apparent. The combination of fog, sulphur dioxide and high atmospheric dust content has been encountered in many countries, and the harmful effects that this has upon human lives is now well known.

Pollution control is invariably a non-profit making activity, requiring considerable capital expenditure and, as such, is often implemented with reluctance. This is particularly so in a highly competitive situation where profit margins may be narrow. Where pollution legislation exists it is crucial that industry should have confidence in the fair and consistent implementation of the law by the controlling authority. In this respect, it is important that legislation be enacted on a national, or even international basis in order to prevent the emergence of "pollution holiday" areas where low standards of pollution control are exercised in order to attract industrial investment.

It is not possible to present quantitative standards in a concise manner since, under the operating licence method widely employed, discharge limits are often assessed for individual cases on the basis of discharge volume, pollutant concentration, background concentration, discharge temperature and discharge methods.

The degree of pollutant control depends upon:

(a) The governmental authority involved

(b) Who or what will be protected by the control

(c) Where the effluent is to be discharged

Governments have in a number of industrialised countries laid down acceptable standards for the level of common pollutants, such as toxic metals, cyanides, oils, suspended solids, etc. These levels may be varied depending upon the discharge point of the effluent.

There is a growing worldwide concern over environmental pollution, and in consequence, public pressure upon governments to introduce effective pollution legislation. A trend is now emerging in European countries for the formation of a legislative framework to encompass all aspects of pollution based on scientifically assessed needs related to technical viablity, and national and local conditions. It would be relevant for countries of presently low industrial activity, possibly with few or no restrictions on the discharge of effluents, to take notice of the trends in pollution control of heavily industrialised nations. Despite the seemingly vast capability of the environment to absorb pollutants, the development of large scale industrial complexes will inevitably cause a serious deterioration in the local working and living conditions unless preventive action is taken from the outset.

23.3 Review of iron and steelworks pollution control methods

Coke Ovens

Carbonisation of coal results in the generation of large volumes of tars and dust which potentially constitute a considerable pollution problem and coke ovens have been large scale polluters of the atmosphere. In the past pollution products were ducted into an adjacent oven; today, however, it is common practice to equip the coal charging car with mechanical or venturi wet scrubbers. A more refined pollution control system employs pipeline charging of ovens utilising a central wet scrubbing system. This system also deals with the fine coal dust escaping from the coal preparation and pre-heating section. After carbonising, the coke is quenched with water sprays resulting in the production of large quantities of steam and odorous components. These can best be prevented from polluting the atmosphere by fitting the quenching tower with simple irrigated baffles to trap steam droplets and dust.

An alternative which would appear to offer greater reductions in air pollution resulting from pushing and quenching operations is the rotating bed continuous quencher. In this process the coke is discharged onto a rotating table where it is quenched as a shallow bed before discharge from the quencher. The complete unit is sealed to the oven door during pushing. In the control of pollution from coke ovens using wet scrubbing processes there is the problem of disposal of the substances removed from the previously polluted gases. The scrubbing water may be heavily contaminated with ammonia, cyanide, thiocyanate, sulphides, etc. Modern practice for the purification of aqueous effluents involves biological treatment using specific groups of bacteria to oxidise the contaminants.

The costs of effluent treatment from coke ovens will obviously vary depending upon the degree of treatment undertaken. As an example the cost of gas cleaning is of the order of 25 ¢ per tonne of coke product plus an additional 4 ¢ per tonne if a biological water treatment plant is included.

Burden preparation

The handling and treatment of dry raw materials produces large quantities of dust. The dust produced from the crushing and screening of iron ore and coke may be supressed using methods as simple as the water fog technique, or as sohpisticated as enclosing the entire dust producing area, and providing air exhausters and dust arresters. The choice is entirely dependent upon what the operator is prepared to pay or what he is prepared to accept in terms of cleanliness.

In wet grinding and concentration the tailings may contain, for example, high proportions of harmful compounds. Such solids are commonly removed by settling. The tailings are normally lagooned and the water allowed to evaporate leaving the solids in a cake form. Under certain circumstances such as acute water shortage, a water recirculation system may be used.

In pelletising and sintering plants the dust generated may be collected by a variety of methods such as cyclones, wet washers, electrostatic precipitators and fabric filters the characteristics of which are shown in Figure 23.1. The choice may be made on cost grounds or the operators preference. In the sintering process, developments have taken place in strand cooling enabling simpler dust collection techniques to be employed.

The costs of pollution control depend upon the degree of reduction of pollutants that is to be obtained from the available processes and the scale of operation. For dust control in raw materials preparation areas, the total costs can be as low as 15¢ per tonne for bag filters and up to 25¢ per tonne for low energy wet scrubbers for plant producing 6000 tonnes per day. For a similar sized sinter plant the costs for the same treatment plant vary between 23¢ per tonne and 37¢ per tonne.

Blast furnace operation

It is in the treatment of blast furnace gas before it is burnt that the major pollution problem in blast furnace operation arises. Wet washing is a popular method of treating this gas but the resulting highly contaminated water has then to be purified. Simple settling ponds have in the past been used for this purpose but owing to the space required mechanical clarifiers and filters are now increasingly used.

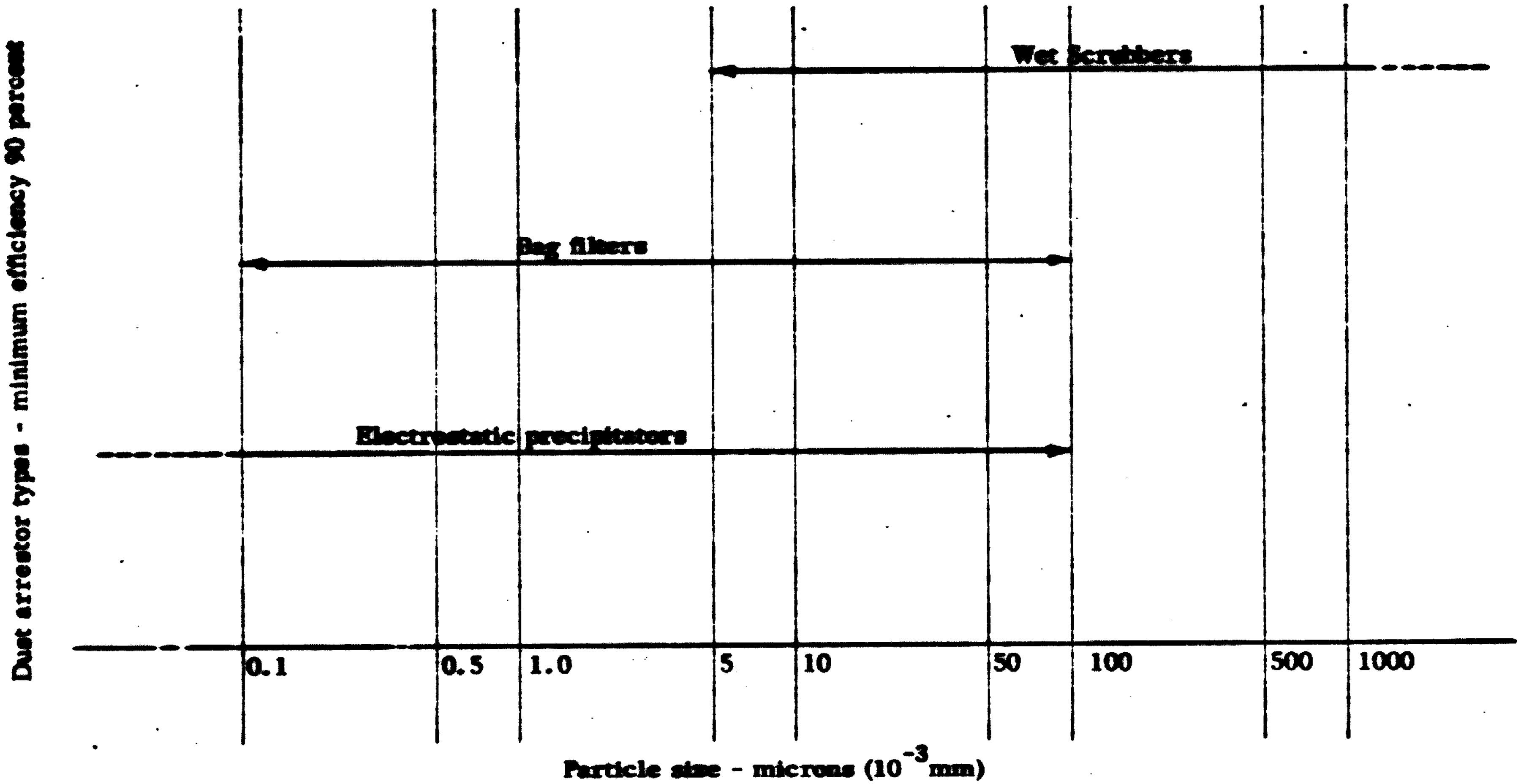

FIGURE 23.1 - SUITABILITY OF DIFFERENT TYPES OF DUST ARRESTORS IN RELATION TO PARTICLE SIZE

The handling of raw materials to the blast furnace generates dust in a similar manner to that previously described in the burden preparation section and similar anti-pollution processes may be used.

Steelmaking

Steelmaking emits large quantities of fine iron oxide fume and dust. Open hearth and electric steelmaking produced dust which was once considered to be an industrial inevitability. However, with the advent of oxygen blown steelmaking, the dust emission increased to unacceptable levels, approximately to 1.5 percent of the total charge weight. The plants, therefore, had to be constructed with pollution control devices which would be effective in reducing this percentage. One of the major problems of dust control from the BOF plants is the high temperature of the gas, which is in the range 1,400°C to 2,000°C; this hot gas contains combustible gases which may be utilised for steam raising.

There are in general three basic methods of cleaning waste gases from BOF plants:-

(i) By using an electrostatic precipitator equipped with a pressurized hood system.

(ii) By using a variable throat wet scrubber plant equipped with a pressurised hood system.

(iii) The Yawata Oxygen Gas (OG) Recovery Process.

Whereas the first two systems burn the waste gases with a plentiful supply of air, and clean them either in an electrostatic precipitator or a wet scrubbing plant, the third system treats the gases in the unburnt state. There are two types of electrostatic precipitator - wet plate and dry plate. Compared with the dry plate system, the wet plate precipitator is operated at lower inlet gas temperatures (about 80°C), resulting in a reduced volume of gas to be cleaned; the wet plate system is also more eifficient, per unit of collecting area, than the dry plate system. The cumulative effect of these two factors is that wet plate precipitator plants can be smaller than their dry plate equivalents.

A wet plate system would, therefore, appear to be the more economical installation until the disposal problem of the iron oxide slurry is considered and the capital cost of the necessary water clarification and dust recovery plant included. However, for a gas cleaning plant being installed in an integrated works where there is existing capacity for handling the wet slurry, a wet plate precipitator is an attractive proposition. It should be noted that where the BOF plant incorporates a full waste heat boiler system, wet plate precipitators are not appropriate. The auxiliary oil-firing used in such boiler systems to supplement the process waste gases gives rise to considerable corrosion problems when the fumes are cooled to dewpoint conditions.

The dry plate precipitator is designed for an inlet waste gas temperature of 260°C to 300°C. Both wet and dry systems require a cooling section to cool the gases leaving the hood from approximately 1000°C to the treatment temperature.

The wet scrubbing process comprises a venturi quencher and a variable throat venturi scrubber, in which the dirty gases are cleaned to an outlet dust burden not exceeding 1g. per 50m^3 of dry gas.

The gases leaving the hood cooling section pass into the venturi quencher where they are cooled to approximately 80^{o}C. The quenched gases then immediately enter a separating elbow where most of the liquid is separated from the gas stream. One quencher with its associated elbow is provided for each furnace. Two separate refractory lined ducts lead the gases from the elbows into the venturi scrubbers, which remove the remaining fume.

An example of the variable throat wet scrubber process is the IRSID-CAFL, system as installed at the South Teeside Works of the British Steel Corporation. The system was developed in France by the French Research Institute (IRSID) and the Compagnie des Ateliers et Forges de la Loire (CAFL) in the late 1950's. The first commercial installation was at the Dunkirk plant of Usinor in 1963.

The OG gas recovery process was established in Japan in 1961. The first commercial OG plant began operating in 1962 at the Tobata No. 2 works of Yawata Iron and Steel Co. Ltd. In 1969 the first European plant was commissioned at the Abbey works of the Steel Company of Wales Division of the British Steel Corporation. The process requires a separate gas cleaning plant for each basic oxygen furnace installed.

In order to collect the waste gases in an unburnt condition the gap between the furnace mouth and the waste gas hood is minimised by a movable skirt. In the original OG installation any space remaining between the skirt and the mouth was sealed off by a nitrogen curtain. In the present installations, no nitrogen curtain seal is used, but the space between the skirt and the mouth is closed as much as possible by lowering the skirt directly onto the furnace nose section. During the oxygen blowing period a slightly negative pressure is maintained inside the hood.

The waste gases collected by the movable skirt pass into the hood section which subsequently leads the waste gases into the gas cooler. The hood is in two sections with the movable skirt attached to the lower section. The upper section, which is equipped with the flux chute hole and the oxygen lance entry hole, is mounted on a carriage and may be moved away from its operating position to facilitate entry of the brick relining elevator. The necessary process fluxes are added to the BOF during the oxygen blowing period through a system of gas seals.

The waste gases pass from the upper section of the hood at a temperature of 1260^{o}C and are cooled to approximately 1000^{o}C in the gas cooler before entering the gas cleaning plant. The gas cooling section has been designed as a radiation section only, and consists of a series of nested tubes supported in a mild steel circular outer jacket. The top of the radiation section incorporates a self closing water cooled pressure relief door.

The waste gas cleaning plant for the OG system is similar to that described earlier for the wet scrubber plant, with the feature that the equipment is considerably reduced in size, and can be more readily accommodated within the steelplant building. The waste gases leaving the radiation section of the hood pass into a venturi quencher where the gases are cooled to an outlet temperature of approximately 80°C and at the same time some 85 percent of the dust entrained in the gases is removed. The cooled gases leaving the venturi quencher pass through an elbow separator into a variable throat venturi scrubber. The adjustable venturi throat acts both as a highly efficient dust collecting unit and also as the means of controlling the pressure in the waste gas hood. This system maintains, as effectively as possible, a constant hood pressure during the oxygen blow by opening and closing the movable throat inside the venturi. The dust particles remaining in the waste gases after the quencher are removed in the venturi scrubber.

The cleaned gases then pass through a second elbow separator into a simple mist eliminator, before finally being passed into a combustion chamber and burnt before discharge to atmosphere.

The secondary ventilation system, designed mainly to collect the dirty fumes emitted during hot metal charging also performs the useful function of removing the minor quantities of fume and gas that escape from the collection skirt and hood during the blowing period. The quantity of dust to be collected here is small and most types of dust collection methods are suitable.

The capital costs of the three gas cleaning processes, for a typical 2-vessel shop, are within 10 percent of each other. One would expect that with the substantial reduction in the waste gas volume treated in the OG system a capital cost advantage would result. However, due to the unburnt condition of the collected gases a separate gas cleaning plant is required for each furnace, and this eliminates the advantage of the smaller equipment.

The wet scrubber system has the lowest capital cost, which could be reduced by a further 10 percent if the thickener underflow is pumped to waste.

In a three-vessel shop, in both the precipitator and scrubber systems, the gas cleaning section is duplicated and this is proportionally reflected in the capital cost. However, in the case of the OG system, the number of gas cleaning units is only increased from two to three, and hence becomes a more attractive proposition.

The precipitator system has substantially lower operating costs than the alternative systems. This is due to the low electrical power requirements of the induced draft fan. The OG system has a similar power cost to the precipitator system because of the reduced gas volume, but this advantage is offset by the cost of nitrogen gas.

Recent developments in OG technology indicate that nitrogen is no longer required and may be replaced by approximately 0.5 m^3 of steam per tonne of steel. The cost of operating the OG and the precipitator would, in this event, be similar.

The high operating costs of the scrubber system result from the induced draft fan power requirements.

The most significant distinction between collected gas and burnt gas systems is the claim that operating the basic oxygen furnace with a closed hood system results in a substantial increase in ingot yield. Results from the Tobata Steelworks suggest that a 1 percent improvement is obtainable, although the comparison is being made between furnaces of different sizes.

The closed hood system would appear to be the most advantageous at plants having a supply of low phosphorous hot metal, and engaged in the production of low-carbon steels. This is because high phosphorous hot metal results in foaming slag steelmaking techniques, and bringing the hood adjacent to the furnace mouth during the blowing period is a hazardous operation.

A recent development has been the use of dust trapped in the gas cleaning plant for the manufacture of pellets. Kawasaki Steel Co. has had a plant at its Cuiba works since 1968, capable of processing 6000 tonnes of dust per month. A new plant in the course of construction at Kawasaki's Mizushima works will produce 600 tonnes daily of green balls with an Fe content in excess of 75 percent; it is claimed by Kawasaki that zinc and lead content will be reduced to 0.02 percent and 0.01 percent respectively.

Rolling

Large quantities of water are used in the rolling of steel, for both cooling and scale removal. The scale together with oil are the major contaminants. The water is normally cleaned in a series of systems, the first being scale pits, where some 75 percent of the scale may be removed. Further treatment may consist of clarification and flocculation or pressure filtration depending upon the purity required for the recyled water. The systems employed are simple and effective.

It is in strip processing, however, that the major pollution problem occurs. Sulphuric or hydrochloric acid may be used for pickling, and it is in the treatment of these spent liquors that the major pollution control effort is applied. The simplest form of treatment may be by very high dilution to reduce the acid content to acceptable levels. Simple neutralisation by lime or other alkalis results in the formation of large volumes of hydroxide sludge which are difficult to separate and dewater, although the availability of land for lagooning and drying may favour the adoption of this process.

Considerable effort has been put into the development of processes for the recovery of sulphuric acid and solid ferrous sulphate from pickle liquors, and several processes involving the recovery of the salts are in use. These methods are suitable for the treatment of effluent from large scale pickling installations although the economics depend to a large extent on the market for recovered ferrous sulphate.

The growing problem of the treatment of sulphuric acid pickle wastes has spurred the development of hydrochloric acid pickling technology despite the relatively high cost of this material. Processes for the complete regeneration of the acid from spent liquors now renders its use economic. Spent liquor is subjected to concentration by evaporation and is then spray roasted to dissociate the ferric chloride to obtain ferric oxide and hydrogen chloride. The latter is absorbed in water or dilute acid rinse water to yield hydrochloric acid for recycling.

Complex waste liquors from other pickling processes, such as are used for stainless steel containing nickel and chromium, require very stringent treatment. These are normally treated with lime and the large volumes of sludge are tolerated because of the high toxicity of the untreated liquor.

Works utilities and drainage

Recirculated water may require cooling before re-use and sedimentation of contained solids is often achieved at the same time. Cooling towers are most commonly used for this purpose together with lime-soda water softening for critical cooling waters. When water is discharged into rivers or streams the temperature is again critical as this can seriously affect the marine and fresh water life.

To provide potable water it may be necessary to treat the water which is available. Various processes may be employed for clarification, softening and desalination, all yield essentially harmless sludges which may be safely disposed of.

Domestic sewage must be treated before disposal. Biological treatment produces a treated sludge suitable for dumping or incineration, or a liquid effluent of a quality suitable for discharge to water courses. In areas of water shortage treatment may be economically extended by fine filtration and chlorination to yield an effluent acceptable for recycling to the cooling water circuits.

23.4 Total costs of pollution control

It has been shown in the preceding sections that pollution control is available at a price. It is the responsibility of the plant operator to match his pollution control methods with the national pollution standards. While these standards must be met it is in his interests to achieve them at the minimum cost. Where pollution regulations do not exist it is left to the plant operator to decide what level of pollution from his plant he will permit.

Whatever the regulations may be, pollution control costs money and the cost of the control is proportional to its effectiveness. The total cost of acceptable to excellent pollution control in an iron and steel works is in the range $1.30 to $2.00 per tonne of product in a new works and up to twice this figure in an existing works.

23.5 Trends in recovery and recycling techniques

Solid waste from pollution control plant may contain substantial quantities of valuable materials, for example mill scale, hydrochloric acid, etc. Most recovered solids contain iron oxides and/or coke which may be recycled to the sinter plant. Similarly coarse mill scale may be charged to the sinter plant or to the steelmaking furnace. Blast furnace slag, whilst not by definition a pollutant, is often treated to produce roadstone or railway ballast, or it may be granulated, foamed or made into slag wool for use in the building trade.

The recycling of water obviously depends to a large extent upon the availability of water on a local and national scale. Where water is scarce, and at a high price, every endeavour will be made to treat and recycle all the process water used. In the iron and steel industry a vast quantity of water is needed, approximately $65m^3$ per tonne of finished product. It has been shown that it is possible to reduce the amount of make-up water from the typical value of $15m^3$ per tonne, to about $5m^3$ per tonne by proper water management.

The cost of recycling process water should be compared to the costs of buying process water irrespective of its availability. The economic incentive to try and achieve total recycling will obviously increase as the cost of make-up water increases.

CHAPTER 24 - AUTOMATION

24.1 Aspects of automation

A feature of the past twenty years has been the adoption by organisations, both large and small, of automation in the fullest meaning of the word. One definition of automation frequently used is : 'the replacement and extension by means of a machine of the human effort, both physical and mental, required in analysing, organising and controlling operations'. The breakthrough that has hastened the implementation of automation schemes has been the development of reliable and powerful digital computers, following the improvement of electronic devices and advancements in analytical instrumentation.

The computer first obtained a foothold in the field of process automation in the late 1950's, when several companies installed digital computers to control their plants directly, in place of the conventional control systems. Prior to this period the digital computer was used as a supervisory aid to management performing stock control, production planning and costing operations. These roles for digital computers still exist independently of process automation schemes but now integrated schemes are being designed and built to enable control of all operations of an organisation to be exercised under an umbrella of hierarchical computer systems.

The electronics industry has developed rapidly and many of the advances made are now incorporated in automation systems. The use of electronically activated controllers to replace pneumatic ones has increased steadily over the past twenty years. This has in turn, meant that digital computers can be more easily connected to the controllers, an arrangement particularly useful on supervisory computer control systems.

The advances made in measurement devices and analytical instruments have also contributed to the speed with which automation has spread. The use of radio-active sources to provide measurements of level and thickness has meant that some hitherto immeasurable quantities can be held under a much tighter control. Thus coatings of one metal on another can be measured using gamma ray sources and the deposition of metal in, say, a tinning line, controlled.

The chemical analysis of process streams on-line to the actual process have also received much attention. The use of gas chromatographs, spectrographic analysis, X-ray spectrometry and X-ray fluorescence to perform analysis of products, in a short timescale and with minimum operator intervention, has encouraged the movement towards fully automated industrial process units.

The communications industry has also played a large part in the rapid development of automation. The ability to transmit data over long or short distances, rapidly and with great accuracy and reliability, has provided a tremendous impetus. Large organisations are now able to control the day to day scheduling of operations of many products with rapid decision making on stock levels, product ranges and product quality.

The main benefits of automation are improved product quality, increased process yield and better plant utilisation. Automation also has an effect on the manpower requirements. Usually the introduction of automation reduces the number of operating personnel required. However, the automated plant will require personnel, at all levels, of a higher technical calibre. This improved technical competence will have to be introduced through educational and training programmes. All levels of personnel required, from process operators through maintenance engineers to process management, will need this technical education and appreciation before the full potential of an automated process is realised. The net result is that, including the effort involved in training, the overall manpower costs of operation are not very different whether a process is automated or not.

24.2 Automation in the iron and steel industry

During the last decade considerable progress has been made in applying on-line computer control to the various manufacturing areas of the steel industry. Most of these areas - from raw material preparation and handling to finished product production - are at least partially automated somewhere in the world. Each of these areas where automation has been successfully applied are described below:

Raw material preparation

It is upon the quality and uniformity of the raw materials in an iron and steel works that the quality of the products from subsequent processes depend. Great attention has been given to this area, particularly in burden preparation for the blast furnace. A uniform burden makes it easier to operate the blast furnace smoothly with consequent improvements in furnace performance and hot metal consistency.

The automation process may start at the initial weighing and batching of raw materials and, by using this information, ensure that correct blending is achieved. Sintering has also been successfully automated; iron ore, limestone, coke fines and recycled materials are blended prior to laying on the sinter strand and the sintering process may be automated to control grate speed, rate of suction, coke content, bed depth and permeability. The aim is to optimise the operation of the plant to ensure that good quality sinter is produced, while maintaining the highest possible level of plant productivity. Automation engineers are now turning their attention to pelletising but, until the mechanics of balling are better understood, manual supervision of the process will continue to be necessary.

Cokemaking

It has long been recognised that the ultimate aim in coke-oven practice should be the complete automation of all machines and processes to enable the use of minimum numbers of operating and supervisory personnel and to provide a regular and continuous operating schedule. Partial automation has already been achieved in most coke oven installations in industrialised countries. Coal charging cars are generally completely automatic, being operated by push button actuated electrical/hydraulic gear. Coke pushing machines have been developed along similar lines and most operational pushers are now semi-automatic.

Coke side door machines and guides are now available with sufficient automation to provide complete cleaning in one minute, and all operations can be controlled by electronic programming if coke side bench operators are required for other duties. Coke quenching cars have been controlled automatically without drivers in both the USA and W.Germany and it is anticipated that remote control from a central computer with fully integrated safety and alarm systems will be in widespread use throughout the industrialised world during the next decade.

Blast furnace ironmaking

The complex nature of the physical and chemical processes that occur in the blast furnace stack combined with the difficulties of monitoring these has precluded complete automation of the furnace so far. Systems have been successfully developed for the control of the hot stoves and of the blending and charging of a predetermined burden. Development of systems for the control of the furnace itself have centred round the evolution of mathematical models that represent the reactions thought to occur in the furnace, and that simulate observed performance. Once such a model is perfected, the furnace is controlled by measuring all inputs to it against set points that are adjusted by reference to the model in accordance with the observed furnace performance.

Automation of stoves involves controlling flows of combustion air, enriching gas and cold blast. The cyclic use of the stoves are sequenced by the computer and in addition the firing rates and the mixture are controlled to minimize the heating cycle times while maintaining fuel efficiency. The inputs to the computer for this purpose include dome temperatures, by-pass conditions, checker temperatures and gas conditions.

The charge preparation system involves the proportioning and accurate weighing of the feed materials. Linear programming is often used to maintain the required composition of output iron from a knowledge of the analysis of the feed materials. A feature of charging a blast furnace is sequence control to give different burden distributions, together with control of the feed bunkers to ensure smooth operations.

For the blast furnace itself, the control system would generate set points for burden weights and composition, blast volume and moisture, fuel oil flow and oxygen injection. Inputs to the computer from the blast furnace would include cold and hot blast conditions, bustle temperature, stack temperature, hearth temperature, top gas conditions and analysis, cooling water and spray water conditions, stock rod position, and iron temperatures. Spectrographic analysis of the burden materials and hot metal would also be inputs.

Most large steelworks with modern furnaces have at least one furnace fitted with the necessary instrumentation, computers and actuation equipment for fully automated control. The systems operating the burden blending and the hot stoves will be operational but the main furnace system is used only under manual supervision and is normally operated as an open loop with the computer used in a data logging function in order to generate a history of performance to assist in the refinement of the mathematical representation of the process.

Steelmaking

Automation in steelmaking is increasingly important with the advent of high speed steelmaking processes such as the BOF. In the more traditional steelmaking methods, such as the open hearth, the tap-to-tap time is long enough to allow sufficient time for manual control of the furnaces.

Automation of the BOF can be used to control oxygen volume for a given charge weight and steel quality and quantity. On-line analysis of the waste gases is used to regulate the oxygen flow, lance height and converter additions, to give the final required carbon content and steel temperature. Commonly, on-line metallurgical analysis of steel samples is employed, using spectrographic analysis feeding directly into the computer.

Control techniques for the BOF may also be applied to electric arc furnaces since similar metallurgical reactions occur so that the use of heat and mass balances for control is possible with the same basic aim of increasing productivity. Of particular importance in electric arc steelmaking is the control of maximum power demand. By continuous monitoring of consumption the control system is used to adjust the electrode positions so that power input is maintained steady at the level above which penalty payments arise. In addition the sequencing of electrode movements, roof control, door movements during the phases of scrap charging and melting can be incorporated in the computer control. Again on-line analysis of output product steel is used via a spectrometer to ensure close proximity to the required chemical analysis.

Casting and hot rolling

Automation has been used in the continuous casting shop to control the heat transfer requirements to ensure that the desired cooling rate is achieved as the strand is withdrawn. The objective is to produce the required steel with the correct grain structure and physical properties. The optimum casting rate is achieved by relating this to the mould oscillating frequency, and cooling water flow rates.

Automation of soaking pits is used to maximise the throughput and minimise the heat input. This is achieved by scheduling the ingots prior to placing in the soaking pits. Control is exercised from heat transfer calculations for each ingot after pouring, to determining the soaking time required. The control of the pits includes: heating time, temperatures, fuel/air ratios, fuel cut offs, recuperator temperatures, and switch-over valves. Control is also exercised over the rate of temperature rise, the differential heating of ingots in a pit, and pit atmosphere control.

Re-heat furnaces are now automated. This is particularly important when the subsequent rolling process is automated to achieve a "total" control system. Automation again takes the form of correcting furnace parameters against set points to provide feedstock at the required temperature. The set-points for furnace conditions depend upon the feedstock size, and the trend today is to programme the computer to calculate the heat input for individual feedstock sizes.

Automation is now being successfully applied at the hot rolling stage, particularly in hot strip mills; the aim is to produce the required gauge at the maximum production rate. The roll gap is controlled to obtain the correct draft against a production schedule and sequencing of the slab through the mill. Each slab to be rolled begins by having its temperature and physical dimensions measured, and the roll gap is then set for the required product. Depending upon the mill configuration, i.e. continuous, semi-continuous, or reversing, the roller tables and sequencing operations are set. For example, in a reversing mill the selection of backpassing is controlled for single or double reversals, based upon the required reduction and the capacity of drives and motors; this would include the necessary sequencing of lifting and lowering rolls and table reversals. When edging stands are used, the width setting would be set automatically to take account of the slab spread. Scale breaking roll gaps would also be set to remove the scale and size the slab.

All of these functions can, in their simplest form, be programmed by a set of stored data against the computer relating to slab and product size. Alternatively full automation using models of the mill operation can be used to control the mill functions, based upon the condition of each individual slab against the product required.

When slabs have been roughed down, the outgoing product size and temperature is measured and used to set the conditions for the following finishing mill. In this mill automatic control similar to that in the roughing stands is exercised, with control being extended to the coilers. Principal areas benefitting from automation are:

Optimal nose and tail cropping at the shear before the mill.
Primary set-up of the mill for conditions of incoming slab and scheduled finished coil dimensions.
Feedback control of mill settings as adaptive control of the finished gauge dimensions.

Automation outside the hot rolling of strip has been confined to mills which are predominantly producing a single product type - for example, rod and bar mills. Section mills have only been partially automated because of the problems in setting up the control functions for a multiplicity of products. In rod and bar mills the tendency has been to automate the corrective measures required for close tolerance products, for example the control of looping and inter-stand tension. As an illustration of a typical flow-sheet for computer control of operations in the iron and steel industry, Figure 24.1 shows a system for the complete control of a hot strip mill.

Cold rolling

Automation of the cold mills is very similar in form to automation of the hot mill, the aim being to produce close tolerance products at the highest production rate and productivity. Automation is used in calculating and setting up the initial mill conditions, roll gap, speed and tension. The product dimensions are highly dependent upon changes from the pre-set conditions and automatic gauge measurement is used, through feed back devices and control mechanisms, to correct the mill settings to bring the product back to the required gauge.

Coating

The design features of modern coating plants are such that the operation of these plants is generaly automatic. In recent years, however, a number of sophisticated control systems based on computers, have been incorporated, thus integrating the manufacturing and product quality control functions as a continuous operation.

Automation is now being successfully applied in several tinning plant installations. In this type of plant the main operating criterion is to manufacture products with uniform tin deposition at the desired thickness. This has been achieved by the application of automated control systems which have facilitated operation at optimum level.

Similar developments have also taken place in other types of coating plants; for example, automation of galvanizing lines has enabled the plant operators to control parameters such as zinc bath temperatures, to ensure good galvanising.

24.3 Future trend

Automation depends upon the methods of measuring change from pre-set values. It is in this area that perhaps the most rapid development is taking place to produce accurate, robust and reliable instrumentation. To a lesser extent the basic chemical and physical models of the behaviour of the process are being improved. However, the basis of establishing reliable mathematical and empirical relationships depends, in turn, upon accurate measurement.

The concept of total automation in the iron and steel industry is still a long way off. At the moment, automation has been applied in areas where the largest cost benefits can be found. However, there is a tendency to group processes together under a control automation system; for example, re-heat furnaces and rolling mills, and hot and cold stip mills. However, the total automation of

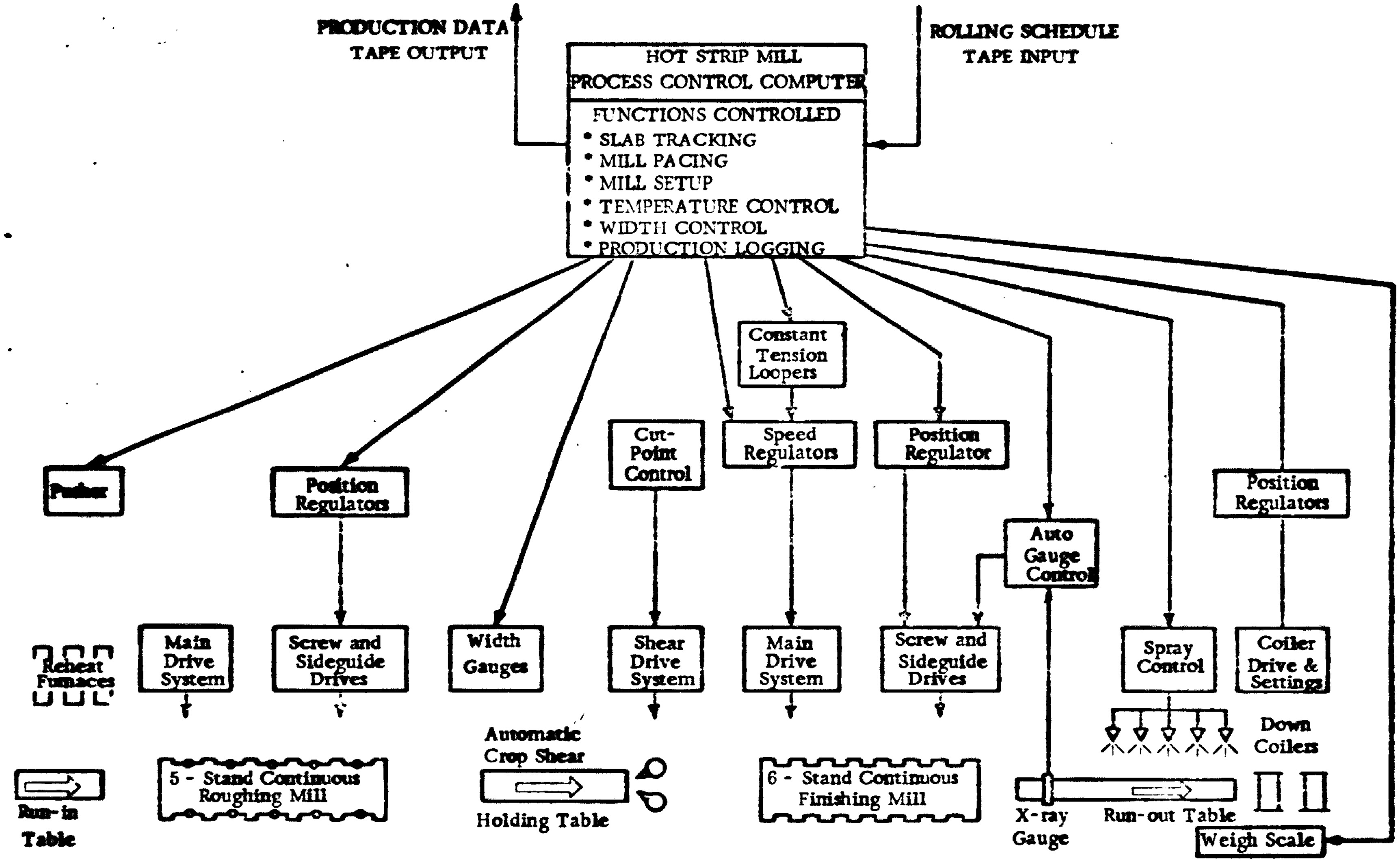

FIGURE 24.1 - A TYPICAL FLOW-SHEET FOR COMPUTER CONTROL OF A HOT STRIP MILL

processes from raw materials handling to finished product despatch would require a detailed knowledge of the flow of material through the works and an ability to identify individual pieces of products as they progress through the works.

It is unlikely at the present time that the costs of a fully automated system can be offset by the savings that accrue from such a system, but certainly within the total system, particular areas will be automated increasingly to reduce dependence upon human judgement and control.

For developing countries, it is important to distinguish between the judgemental and control functions of automation. Where automation is used for control, it is often because the control demands are beyond the capacity of human reactions. It is therefore necessary, regardless of the state of development the country has reached. If the control system is installed to take judgemental action then it is probably justified on the basis of the cost of skilled operators - a situation that may apply to a developed country but not to a developing one which may possess a tradition of crafts, and hence, craftsmen capable of training as skilled operators.

CHAPTER 25 - ENERGY REQUIREMENTS

25.1 Integrated works

The term "integrated works" was originally used to describe a works designed to achieve an energy balance internally, with coke as the only input, being regarded as a reductant rather than a fuel. Even though a complete energy balance may not be achieved, it is still true that the principal benefits of the integration of iron and steel works result from the use that can be made, within the works itself, of by-product fuels, and the energy savings that arise from the ability to pass hot intermediate products from one process to the next, so minimising the heat required to bring them to working temperature. The cost of fuel and power in an iron and steel works constitutes about one quarter of the total operating costs, and it is therefore essential to use the optimum fuels and to have the correct balance of fuels.

The normal process route for a modern integrated works involves the manufacture of iron by the blast furnace and its conversion to steel by basic oxygen furnaces. An alternative route for smaller works is direct reduction followed by electric arc steelmaking. The trends of energy usage in each of these works is discussed in the following articles.

25.2 The blast furnace - BOF route

In the blast furnace - BOF route, the bulk of the fuel is consumed in the form of metallurgical coke.

The price of metallurgical quality coal is now high relative to the cost of fuel oil and non-coking coal in terms of its ability to produce heat. In consequence, as discussed in Chapters 8 and 10, efforts have been made to reduce the coke rate of the blast furnace, and hence the requirements for metallurgical quality coal, chiefly through improvements in burden preparation and improved furnace practices such as the use of high blast temperatures and high top pressures. Further reduction has been achieved by the substitution of fuel oil injected into the blast furnace. These developments will continue and we foresee coke consumption in blast furnaces being reduced by a further 100 or 150 kg per tonne during the next decade.

These economies in coke are reducing the amount of gas evolving in the works so that the total thermal energy available in the coke oven gas and blast furnace gas are no longer sufficient for the requirements of the complete integrated works, and the remaining requirements, including the generation of electric power, must be met by use of other fuels. The particular fuel chosen will depend on its availability and on the relative cost of the useful quantity of heat produced by it.

Provided that the costs of transmission are not high, it is now normally more economic to buy electricity from the supply authority for the base load of the works than it is to generate it locally. Despite this, it must be possible to generate some electricity on site. The reason for this is that sufficient power must be available at all times in order to support essential loads in the event of a failure of the authority's supply. Essential loads are those which enable the plant to shut down in safety, but not to maintain production at even a greatly reduced level. If the external supply is not very secure, then there should be sufficient generation equipment to provide for continuous operation of the works, although at a reduced output, when the external supply fails.

An indication of the magnitude and effect of these trends in energy usage over the next ten years is given in Figure 25.1. This shows the changes in energy flow with the decreasing consumption of coke. The calculations are based on a large blast furnace/BOF works of 5 million tonnes annual capacity. A decrease of 125 kg of coke per tonne is assumed and increases in efficiency expected in mill furnaces are also incorporated. In calculating changes in the works thermal requirements it has been assumed that any additional energy required will be supplied by fuel oil. The nett annual saving in energy requirements are 6100 tera joules and at present day prices for fuel oil and metallurgical coke this corresponds to a nett saving in the energy cost of approximately $1.5 per product tonne. There are also other capital cost savings which accrue from using fuel oil as a replacement for coke, such as smaller coke ovens and blast furnaces.

25.3 The direct reduction - electric arc furnace routes

The direct reduction processes do not generate any valuable by-product gases of the kind that arise in coke making or blast furnace iron making. Any trends there may be in energy usage in this route, therefore, will affect each process separately without reacting on any of the other processes.

The choice of energy source for each direct reduction process is governed by the technological characteristics of the process, but it is the availability and price of fuels that largely determines what process is used. Generally, direct reduction processes produce iron in solid form with subsequent steelmaking usually in electric arc furnaces. If electricity is cheap, however, electric smelting followed by BOF steelmaking may be the chosen route.

Although the electrical energy consumed by electric arc furnaces decreases as the size of furnace increases, there is not likely to be any significant reduction in the consumption of a furnace of a particular size during the period up to 1980. The rolling mill furnaces will become more efficient, with a consequent annual saving in a 500,000 tonne a year works of about 85 TJ.

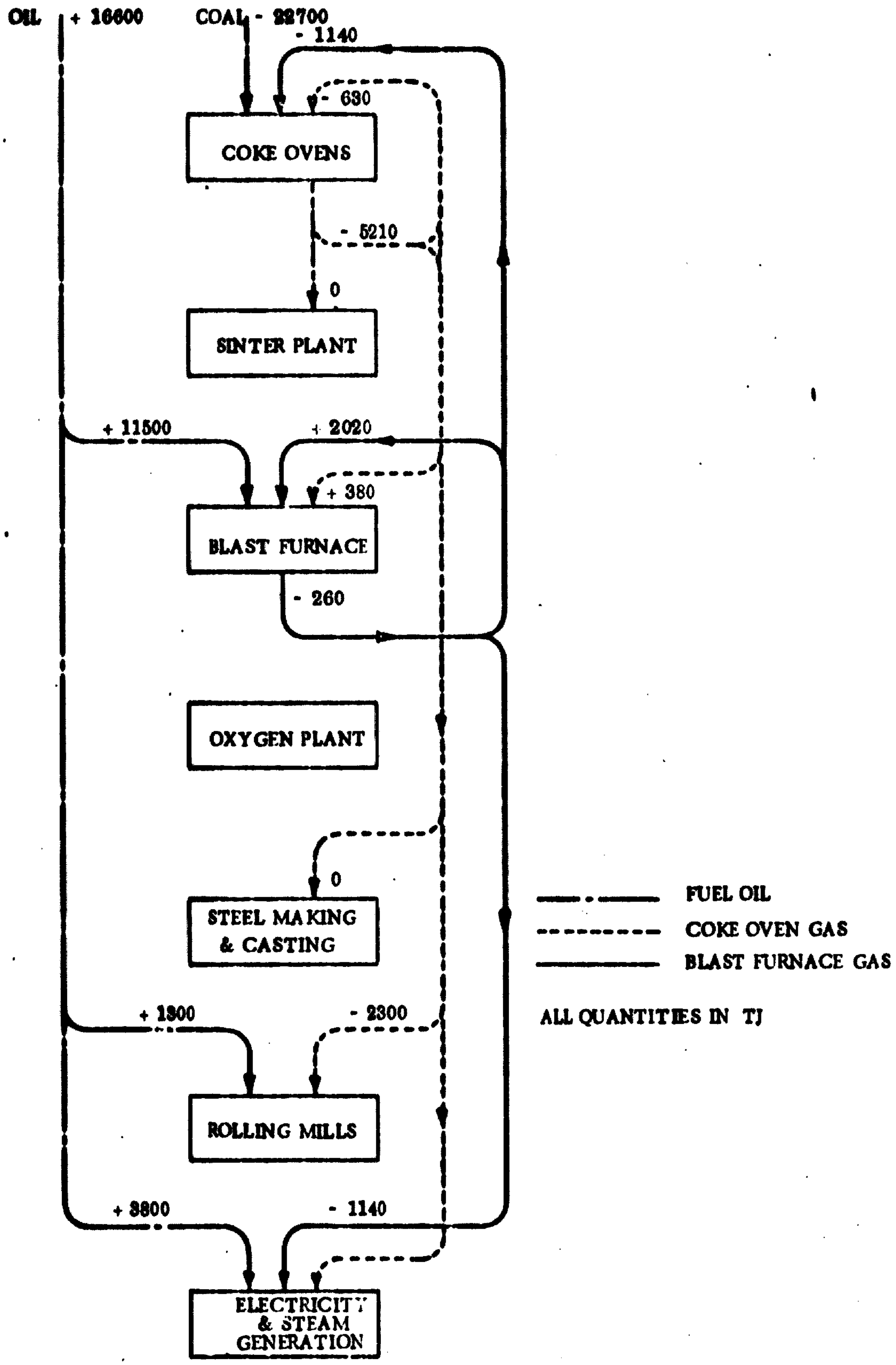

FIGURE 25.1 - DIFFERENCE IN THERMAL REQUIREMENTS FOR BLAST FURNACE/BOF WORKS

(ELECTRICAL REQUIREMENTS ARE ASSUMED IDENTICAL)

25.4 The scrap based electric arc furnace route

In a non-integrated works, based on scrap rather than iron ore as the principal raw material, the energy requirements of the electric arc furnaces are lower than those of furnaces charged with reduced products because less slag is made. In practice, the charge comprises both scrap and pig iron, and the minimum power consumption occurs when about 10 percent of the charge is pig iron.

There is scope for saving electrical energy in a scrap-based electric arc furnace by preheating the scrap, usually to a temperature of 500-700°C, in the scrap bucket, using either gas or oil. A typical saving, in a 500,000 tonne a year works, is about 145 TJ (80 kWh per tonne). To obtain this saving, 310 TJ of gas is used for preheating the scrap. At first sight it may appear that there is a net increase in energy use, but it must be remembered that the efficiency of generation of electrical energy is about 25 percent; and allowing for this gives a saving in the consumption of primary fuel, assumed to be natural gas, of about 270 TJ per year.

CHAPTER 26 - LOCATION OF IRON AND STEELWORKS

26.1 Factors affecting location

The location plan for a national steel industry depends on two main groups of factors; first are the technological factors affecting the type of works, costs of operation and transport economics, second are the politico-economic factors. The social costs and benefits of the latter are not quantifiable in general terms, these being factors which are the direct concern of the nation involved. The relevant technological factors are given below:

(i) The availability and location of raw materials and the location and size of markets.

(ii) The location of the existing steel industry.

(iii) The availability of various forms of energy.

(iv) The positioning of the existing transportation network.

(v) The availability and location of infrastructure capable of supporting a steelworks. This includes skilled management and operatives.

(vi) The processes available for selection.

In some cases,technological factors may effectively rule out location in certain areas, and these factors should in consequence be considered in this way before an economic evaluation of alternatives is made. In locations which are feasible, the decision as to which is the optimum choice depends upon the careful evaluation of the effect of all factors. There is no general answer, and each location must be considered separately on its merits.

26.2 Historical background to location

In the last century European steel industries grew up in areas where iron ores and coking and non-coking coals were available within the same region. Industry, the market for steel products, was also powered by coal and so grew up in the same areas. In these circumstances the location of an integrated iron and steelworks was not a problem.

Bythe middle of this century, however, depletion of traditional sources coupled with the demand for higher grade ore led to the development of remote ore fields. In the last two decades the development of bulk shipping has allowed these richer ores to be further exploited, with their attendant economies in ironmaking.

Partly because these deposits happen generally to be in unfavourable climatic zones and partly because the soils arising from such rocks are ecologically unsuitable for the majority of flora and fauna, modern iron ore mines are found in undeveloped areas. Moreover, these higher grade ores were formed in rocks far older than the coal measures in geological conditions which are such that they do not occur in the same geographical area as the coal. In consequence the traditional factor affecting the location of an iron and steelworks namely the juxtaposition of iron ore, coal and markets, has ceased to apply, and many steelworks are now located far from their iron ore or coal supplies or sometimes from their markets.

Although it is generally no longer possible for an iron and steelworks to be located adjacent to more than one of the three factors mentioned above, it is the transport economics which play the major role in determining the most economic location for the works.

26.3 Heritage

Much of the potential value of a location as a site for a steelworks depends on what is already there. Moreover in developed countries and in the socio-political context, the prior existence of heavy industry in an area means that there is possibly less likelihood of objections being raised to proposals to build a new works.

One of the principal advantages of a site with a history of steel or other heavy industry is the heritage of labour skills available. This has a major effect on the learning time and ultimate output performance attained at a new works - factors which make a very important contribution to the cost per tonne of product. The lack of it is particularly evident when starting up a new works in an otherwise non-industrial society, and is only partially to be remedied - at additional expense - by bringing in experienced labour from elsewhere.

The presence of adequate external services can be a major advantage to a new works. If access roads, railways, water and electricity supplies do not already exist in an area, the steelworks must bear the high cost of setting them up, in whole or in part. Sea links can be particularly costly in this respect, especially if the steel company has to provide its own dock facilities.

Of even greater cost can be the provision of the total infrastructure of housing, hospitals, schools - all the complex services that the labour force needs. In some areas a large proportion of the cost may have to be borne by the works, if a large influx of people is involved and no financial support is forthcoming from the Government or local authorities. The total cost of a fully developed township to support a 10 million tonne integrated steelworks, including a full transportation network, is more than the capital cost of the steelworks.

26.4 Operational performance

Two aspects to be taken into account when assessing suitable locations are the rate of growth of production attainable when starting up a new works or developing an existing one, and the maximum output to be achieved when the works is fully operational. Both of these will affect the cost of the finished product, and may in consequence determine the choice to be made between alternative locations.

Many factors influence operational performance, but ultimately it depends on the abilities of the labour available, coupled with those of management. Management has to organise the phasing of the work to be undertaken, and the recruitment, training and deployment of the men to make best use of the plant.

Recruiting good-quality operational management for a new steelworks is more difficult in a non-industrialised country than in an industrialised one. The fact that a lack of local managerial background in steel usually occurs in areas where capital cost is high due to lack of heritage, and where the workforce have no experience of heavy industry, serves to accentuate the penalties of inadequate management. Starting up a new works is a particular problem, as it imposes a heavy workload on all levels of the management structure and demands organisational skill often different from that required for running an established works; and it is here that consultants or temporarily engaged expatriate staff can play a useful part in reinforcing the local management team.

The importance of good management in this context is demonstrated in Figure 26.1. Case A is the 'learning curve' representing a rapid and efficient build-up of production in a well-managed plant. The other two curves illustrate what may

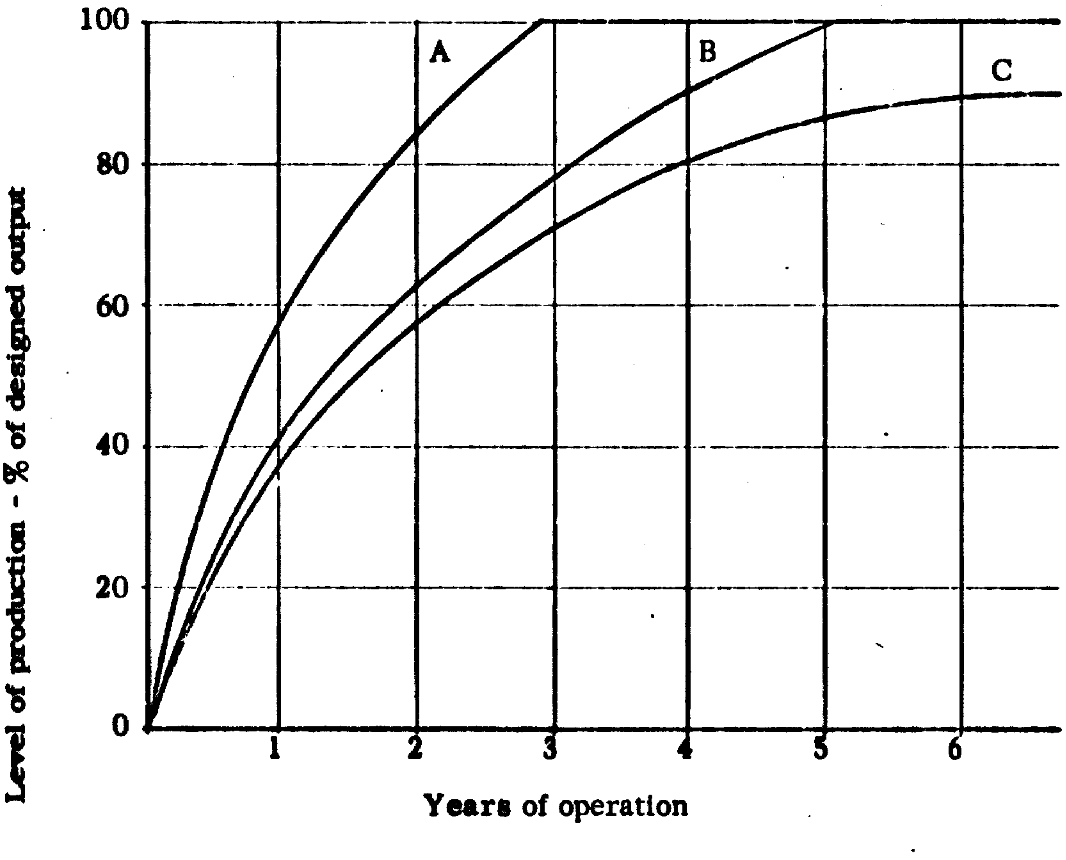

FIGURE 26.1 - EFFECT ON PRODUCTION OF DELAYED COMMISSIONING

happen if management is not of this quality. The rate of build-up may be slowed down, delaying the attainment of full output, as in Case B, in which an extra two years are taken to achieve this target. Or the designed output is never reached, and the work operates permanently at below its maximum potential throughput, as in Case C.

The penalties can be assessed by carrying out a discounted cash flow calculation over say fifteen years. The figures thus derived apply to every tonne so sold throughout the life of the project. Case A represents a 3 million tonnes per year works with finished product costs of $150 per tonne. The slower build-up in Case B raises the costs to $162 per tonne - a penalty of £12. The even more inefficient Case C adds a further $7 raising the product cost to $169 per tonne.

26.5 Transportation costs

Product and raw material transport

As stated in Article 26.2, it is now common for a steelmaking country to import either coal or iron ore; it may sometimes be necessary to import both. This involves the cost of transporting either 1.5 tonnes of iron ore or 0.7 tonnes of coal for every tonne of steel product which, in turn, has to be transported to the market. Since the density of coal is much less than that of iron ore, the actual transport costs per tonne/km are similar in either case assuming that the distance and transport mode are the same.

The costs of transporting one or other (or both) of the raw materials have to be weighed together with the costs of delivering the finished products to the markets, which may either be scattered at some distance from the steelworks or located close to it. The trend at present is to locate new integrated works on coastal sites since at least one major raw material generally has to be imported and can then be fed to the works at a point where transhipment has in any case to be effected. Moreover, an established port is often a market centre in itself, with the necessary infrastructure for a steelworks, as well as being a node in the national transportation network.

Scale of output and market location

Whether a large works can supply a given market more economically than a number of smaller works will depend very largely on the costs of transporting finished products. Where a number of large inland markets are separated by relatively short distances, provided that a good transport network exists, the economies of scale can justify the setting up of a large central works as opposed to smaller works at each market centre. Table 26.1 compares various ways of satisfying a hypothetical market, typical of the situation in developed countries. The larger works are seen to have definite advantages when the average transport distances over which products are transported is not more than 1500 kilometres.

Sea transport costs are normally less than those for inland transport; thus, if the market is represented by a series of small centres along a coastline, the economies of scale are likely to outweigh the costs of transport. Under such

TABLE 26.1 - EFFECT OF SIZE AND LOCATION OF STEELWORKS ON PRODUCT COSTS

Case	Mean product costs ($per tonne)	
1. 3 million tonnes per year steelworks located at market centre	150	
	Distances transported (km)	
	1500	2400
2. 6 million tonnes per year steelworks: 3 million tonnes per year sold locally; 3 million tonnes per year transported	150	154
3. 9 million tonnes per year steelworks: 3 million tonnes per year sold locally; 6 million tonnes per year divided equally between two equidistant market centres.	144	150

circumstances, a single, large, works can be the most economic solution, even though the individual tonnages transported to the market centres may be quite small.

CHAPTER 27 - TRENDS IN PRODUCTION OF STEEL

27.1 Factors causing changes in the production pattern

In the foregoing chapters the major changes which have been and are still taking place in the manufacture of steel products have been discussed. There are two main factors causing these changes in the pattern of world steel production - the increase in size of the production units and the pattern of supply and utilisation of raw materials. These factors have an influence not only on the works and its individual production departments but also on the structure of the whole industry within a country or even within an international region.

Although there is some indication that the rate of increase in the size of production units is now slowing down, and that in certain areas the capacities now available have developed beyond the requirements of the market, the pattern of supply and utilisation of raw materials still has potential for change, particularly in the siting of steelworks.

27.2. The trend towards large works and its implications

Iron and steelworks have steadily increased in size since the last century but more recently, since the second world war, there has been a dramatic increase in the maximum size. Whereas previously works of about one million tonnes per year capacity were considered large and highly economic, works of over ten million tonnes are now being built.

The rapid increase in scale of works has been brought about by the increase in size of individual production units as the economies resulting from larger unit size were proved and the facilities to produce these units were constructed. It is now possible to integrate the productive capacity of much larger units to take advantage of the economies of scale of a whole range of processes.

The key process in a steelworks is the steelmaking process itself. To produce outputs of up to one million tonnes a year the number and size of furnaces had increased during the 1950's, resulting in open hearth steelplants with up to ten units and in furnace sizes of several hundred tons capacity in open hearth shops and over fifty tonnes capacity in Thomas shops. The advent of the BOF with its basically simpler and faster operation meant that high output shops could be built with only two or three converters, and there has consequently been a dramatic increase in the maximum capacity of single steelplants to many millions of tonnes per year.

Simultaneously with the development of the large BOF plants, continuous casting was entering a phase where it proved reliable enough to compete with ingot casting. By removing the necessity for handling moulds, continuous casting is able to reduce the materials handling requirements in new integrated plants or increase production in existing works.

The big increase in capacity of steelplants has been matched by a similar increase in the outputs of rolling mills. The continuous mills that were being developed, particularly for strip rolling, had grown to a size capable of absorbing the output of a giant BOF steelplant by the time this process had attained commercial acceptance.

At the ironmaking stage, the sizes of blast furnaces are now such that the plant is capable of feeding even a large steelplant from a small number of units.

The growth in the potential output of the various production plants has now reached a stage where the maximum economies of scale have been approached. The present size of flat-product works with optimum sized units appears to be about six million tonnes a year, but a second steelplant can be added, with extended ironmaking capacity and additional rolling mills, to double this output. In such a case some savings can be made in service facilities, and with careful planning the difficulties arising from more complex materials handling and the overall management problems of running such a large works may be successfully overcome.

In the past, the development of small production units which supplied local markets could be planned on a piecemeal basis, because it was reasonably practical for the decision-maker to be aware of all the issues affecting his decisions.

Modern works, having very large units of production and requiring large amounts of capital to be invested, have to take account of the demand for steel products in a whole region. It is therefore imperative to give careful consideration to the phasing of production facilities to the development of the markets which they will serve, and national and regional planning have become necessary to balance the total development, whether the facilities are being installed to meet a growth of demand or to replace obsolete facilities. The fact that fewer units are required in each planning region has led to co-ordinated planning, in many countries by government agency, with a view to avoiding duplication of facilities. This, in addition to the influence which many governments seek to exert over the prices of steel products, has led to a position in which, either through nationalisation of the industry or by other measures, government plays a major part in the overall strategic planning of the steel industry in most countries.

Further, the problems of planning and financing are leading to the position in which the planning of steel works will be increasingly considered on a multinational company or an international basis. Such co-ordination has been taking place since 1954 within ECSC. The interdependence of EEC member countries, especially as regards steel products, demonstrates that national security is no longer considered a major criterion. Trade in raw materials and steel products, together with international investment in materials and their distribution, invalidate national boundaries as the natural areas in which to plan the development of steel.

However, the very large steelworks is not appropriate to every situation and side by side with this development there have been developments in the concept and designs of efficient "mini-works" supplying a limited range of products in a limited market area. This subject is fully discussed in Chapter 22.

It is sufficient to say here that because mini-works take advantage of favourable but not typical circumstances, they can never be a dominant part of the steel industry and will never produce more than a small proportion of the market demands. Indeed, in some countries the mini-works may only be a transient phase in the development of the steel industry. In particular, where an industry is developing rapidly from a relatively small amount of heritage (as in Brazil) it may well be that with a well-planned industry in which large electric arc works and large modern rolling mills are sited adjacent to the market, the operational advantages which mini-works are enjoying in other countries at the present time will not be apparent.

27.3 The effect of changes in iron ore usage

The pattern of steelmaking and distribution is undergoing a major change at the present time in many countries because of the change from the utilisation of home ores to imported foreign ores. The siting of works is a question of optimising for the lowest total cost of transport, and the typical solution for a large number of countries is now the establishment of large coastal works into which the iron ore is shipped direct. The speed of change, however, is heavily influenced by the heritage of both plant and management in the original geographical locations of steelworks.

The pattern of development of international trade in high grade ores is shown in Table 27.1. The iron ore traded constitutes over one-third of the total quantity of iron ore used, which is some 650 million tonnes. Importing countries have a choice of where they purchase their iron ore. In these circumstances, the pattern of trading can be regarded as being relatively stable. As the countries which supply the iron ore are spread throughout the world, the total supply can be viewed as being relatively insensitive to political issues arising in one part of the world. This pattern of trading represents a major divergence from the previously widely accepted requirements that steel in the industrialised countries should be produced from their own raw materials for national security both commercial and military.

The situation in 1980 is thus likely to be similar. The forecast world demand for steel is about 950 million tonnes which will lead to a consumption of at least 1,000 million tonnes of iron ore, and the proportion that is traded is likely to be the same as in 1970 i.e. approaching 400 million tonnes in 1980. Table 27.1 gives one forecast of the 1980 trade in iron ore, which totals 350 million tonnes; this forecast may well prove a conservative estimate.

A large number of the industrialised countries now rely on a major proportion of imported iron ore, the most significant example being Japan. The indication of this is that to be competitive, either in the home or export market, it is not necessary to have an indigenous source of iron ore. Clearly, however, the existence of a source of high quality iron ore in a country must constitute an advantage at least as regards its home markets, the position in the export markets depending on the relative costs of transportion of materials.

TABLE 27.1 - IRON ORE INTERNATIONAL TRADE

(Million of tonnes)

Year (19--)		58	59	60	61	62	63	64	65	66	67	68	69	70	Est. 1980
Liberia	Exports					3.7	6.4	12.2	15.3	16.5	17.4	19.2	20.6		57
USA	Imports	27.8	35.6	34.6	25.8	33.4	33.5	43.1	45.8	47.0	45.4	44.6	41.4	45.6	53
	Exports	3.4	3.0	5.2	5.0	5.9	6.8	7.0	7.0	7.8	5.9	-	5.3	5.5	8
Canada	Imports	3.0	2.5	4.5	4.1	4.6	5.3	5.2	4.8	4.3	2.4	2.8	2.3	2.2	3
	Exports	12.4	18.5	16.6	14.9	21.6	23.8	30.5	30.8	30.7	31.4	36.6	28.4	39.3	44
Brazil	Exports	2.8	4.0	5.2	6.8	7.6	8.2	9.7	12.7	12.9	14.3	15.0	21.5		+ 97
Chile	Exports	3.6	4.3	5.2	6.2	7.2	7.1	9.1	10.7	11.1	9.9	10.5	9.6		
Venezuela	Exports		17.4	19.3	14.6	13.3	12.3	14.9	17.0	17.0	16.5	15.1	19.0		
India	Exports		2.5	3.4	3.2	3.4	3.8	9.9	10.9	12.3	13.4	13.7	15.7	16.5	33
Japan	Imports	7.6	10.4	14.9	20.9	22.1	26.0	31.2	39.0	44.1	56.7	68.2	83.1	102.0	172
ECSC *	Imports	23.8	22.7	34.3	34.8	33.1	36.5	47.7	53.8	50.5	55.4	67.1	75.2	84.0	123 ++
	Exports	0.8	0.7	0.8	0.7	0.6	0.5	0.5	0.4	0.4	0.4	0.1	0.4	0.9	
Belgium-Luxembourg	Imports	16.9	18.3	20.8	20.7	21.2	19.8	23.0	23.7	21.4	21.9	26.3	27.6	29.2	
France	Imports	1.0	1.0	1.5	1.7	1.9	3.5	3.6	3.9	4.2	4.8	5.0	6.9	9.6	
	Exports	15.3	20.0	27.2	25.9	25.7	21.2	22.1	20.8	18.2	17.5	18.3	18.5	18.6	
W.Germany	Imports	17.0	20.0	33.7	32.7	29.1	27.1	35.1	35.6	31.3	31.9	39.6	43.4	47.8	
Italy	Imports	2.3	1.6	2.6	3.3	4.4	5.2	5.0	7.9	8.1	9.9	10.1	11.0	10.7	
Netherlands	Imports	1.8	1.9	2.3	2.3	2.3	2.5	3.1	3.6	3.5	3.6	4.4	5.0	5.4	
Sweden	Exports	14.8	15.5	19.7	20.3	19.4	20.3	24.3	24.5	22.3	23.1	28.8	31.7	28.0	26
UK	Imports	12.9	13.4	18.0	15.0	12.9	14.3	18.9	19.2	16.2	16.3	17.9	18.5	19.9	
USSR	Exports	11.9	13.4	15.2	16.3	18.9	20.8	22.6	24.1	26.1	28.7	32.2	33.1		64
Australia	Exports	-	-	-	-	-	-	-	0.1	0.3	5.5	12.5	20.4		57
World **	Imports	75.1	84.6	106.3	100.6	106.1	115.6	146.1	162.6	162.1	176.2	200.6	220.7	252.6	351

* Imports from and Exports to Third Countries.

** USA, Canada, ECSC, Japan, UK only.

\+ Includes Peru.

++ Includes UK.

Sources: BSC Statistical Handbooks.
The Changing World Market for Iron Ore 1950-1980. G. Manners.
John Hopkins Press, Baltimore and London (1971).

27.4 The effect of scrap supply

After iron ore in its various forms, scrap is the only other significant source of iron used at present in the production of steel. It arises in three ways: firstly, as works scrap arising in the steelworks; secondly, in the processing of steelworks products into engineered goods; and thirdly, through the obsolescence of capital goods.

The form and locations in which scrap in the steelworks and engineering works arises are such that in normal circumstances it is readily available in a reasonably usable form.

Capital scrap, however, arises in a large number of ways and ranges from scrap which can be readily collected and used by a steelworks to scrap for which the cost of reclamation would be obviously uneconomic. An example of scrap recovery which has recently become economic in countries with a large turnover of cars is the 'Prolerising' process. In most steelmaking countries, process and capital scrap is readily available to the steel maker at a price determined by the commercial arrangements for its procurement and transportation to the steelworks. So far as procurement is concerned, the quantities of scrap which could be made available are on the whole relatively insensitive to the price that is paid for the scrap, because much of the scrap originates in such a way that it would not be profitable to store it to await more favourable prices. There are certain exceptions to this statement, notably ship-breaking scrap, where the owner of the steel has some choice of when he sells for scrap and can afford to hold on for a good price without incurring heavy storage costs. From the point of view of transport economics, there is a natural tendency for scrap to be consumed by the steel maker in the region in which it arises.

Iron ore is traded internationally and the normal commercial relationships have determined its price on a supply and demand basis. The price of steel in any country or region is largely determined by the cost of making steel from this ore. Beyond a certain minimum requirement scrap is then in competition with iron ore and the price of scrap in the market adjusts itself to make the utilisation of scrap economically attractive to the steel maker.

The international trade in ores will lead to a position in which there is a greater parity in the cost of making bulk steel throughout the world. This is likely to influence the regions within which a balance of the utilisation of scrap will be established, further enlargement of the region carrying too high a transport cost penalty. Thus the aim will be to establish within such regions a pattern of steelmaking development, employing the blast furnace/BOF hot metal route and the electric arc scrap-based route which together create a balance in the utilisation of scrap arising within the region, together with imported or indigenous iron ore.

Table 27.2 demonstrates that the concept of scrap being used on a regional basis is valid. The world level of consumption of scrap for steelmaking in 1969 was about 200 million tonnes. The quantities of scrap traded by comparison are relatively insignificant and in the main represent tactical trading, which may appear from time to time in all aspects of international commerce. Although a

TABLE 27.2 - EXPORTS AND IMPORTS OF IRON AND STEEL SCRAP

(Millions of tonnes)

		1964	1965	1966	1967	1968	1969	1970
Australia	Exp.	0.4	0.4	0.3	0.5	0.4	0.5	
Canada	Imp.	0.8	0.9	0.7	0.5	0.6	0.6	0.8
	Exp.	0.6	0.2	0.3	0.4	0.4	0.7	0.6
ECSC	Imp.	2.1	1.5	0.8	1.2	2.1	2.2	1.9
	Exp.	0.2	-	-	-	-	0.1	0.1
Belgium/Luxembourg	Imp.	0.2	0.1	0.2	0.2	0.3	0.6	0.8
	Exp.	0.6	0.7	0.7	0.8	0.7	0.7	0.7
France	Imp.	0.6	0.5	0.5	0.5	0.4	0.5	0.4
	Exp.	1.5	1.8	1.8	2.2	2.2	2.2	2.6
W. Germany	Imp.	1.8	1.1	0.7	1.1	1.6	1.2	1.4
	Exp.	1.3	2.0	2.0	2.1	1.8	1.8	2.2
Italy	Imp.	3.2	4.6	4.1	5.0	5.1	5.1	5.1
Netherlands	Imp.	-	0.1	0.1	0.2	0.2	0.3	0.3
	Exp.	0.4	0.5	0.4	0.6	0.7	0.7	0.8
India	Exp.	0.5	0.4	0.5	0.5	0.5	0.5	0.4
Japan	Imp.	5.1	3.4	3.5	6.7	3.9	4.9	5.8
Poland	Exp.	-	-	-	-	0.2	0.2	
Spain	Imp.	0.3	0.4	0.4	0.4	0.6	1.2	1.4
Sweden	Imp.	0.2	0.2	0.2	0.1	0.2	0.4	0.5
UK	Imp.	-	-	-	-	-	0.3	0.3
	Exp.	-	-	-	-	0.9	0.6	0.4
USA	Imp.	0.3	0.2	0.4	0.2	0.3	0.3	0.3
	Exp.	7.1	5.6	5.2	6.8	6.0	8.3	9.4
USSR	Exp.	0.5	0.6	0.6	0.7	0.7	1.3	
Yugoslavia	Imp.	0.1	0.1	0.1	-	0.1	0.1	

Sources: BSC Statistical Handbooks
The Iron and Steel Industry in 70 (OECD)

significant tonnage is shipped by the USA to Japan and Italy, this represents less than 20 percent of the quantity of scrap consumed in the USA and in Japan. Only in the case of Italy does the tonnage traded represent a significant part of the total amount of scrap consumed in the country and, as would be expected, scrap prices in Italy tend to be nearer than Japanese prices to the price of scrap in the USA. In Japan, the dominance of the BOF route and the long term falling cost of iron ore, taken together with the relative place of imported scrap in the total steel make, have kept scrap prices much nearer the free market price of scrap in the EEC. However, scrap imports to Japan represent a decreasing proportion of the scrap being consumed and even in Italy the large tonnage of blast furnace/BOF steelmaking plants which are being installed in that country will decrease the relative reliance on scrap.

In examining the implications of the above concepts, relating to regional scrap balance, care should be taken not to place too much importance on transient conditions which may apply only at the present time. Although the general pattern of usage of scrap around the world could be in line with these concepts, the trading of scrap by the USA to Japan and Italy is an exceptional feature. It can be explained by the geographical pattern of development of industry in the United States which made it expensive for scrap to be transported from the areas in which it arises to the steelmaking areas. Merchants have found ready markets in Japan and Italy, in which the steel industry was expanding very rapidly, and in which it was possible to direct the pattern of developments to match the most economically available raw materials. It is probable that this pattern of trading will not continue in the long term, and indeed there are signs within both the Italian and Japanese industries that they are seeking to reduce their dependence upon trading of scrap by the construction of a number of large blast furnaces/BOF works.

In a slowly developing industry, it is difficult to alter the structure of the industry within a short period of time. Thus where historical evolution or technical changes have produced an out-of-balance situation, a so-called scrap shortage (or surplus) can arise. Scrap shortage is typically associated with a high price of scrap. Insofar as this problem cannot be solved in a very short period of time the question arises whether to base decisions on the prevailing price of scrap or to plan to establish a balance in raw materials. In commercial terms, it may be possible in the short term to justify certain decisions on the basis of the high price of scrap, but such a decision may not be in the best long term national interest. For example, some direct reduction plants have been justified on a commercial basis relative to a high price of scrap. If, however, a long term price of scrap comparable to that established in countries where there is a balance of raw materials (say $30 per tonne), had been used, then the installation of these plants could not have been justified on economic grounds. Direct reduction processes should thus be looked upon as consumers of iron ore, rather than as producers of a substitute for scrap, the real question being whether they can be economic relative to the blast furnace/BOF steelmaking route. The often expressed view that possession of a pre-reduced pellet plant can effectively control scrap prices is unsound,because once a plant is installed the pellets must be used even when scrap prices are low; either shutting down the plant or stocking pellets without deterioration would have the effect of increasing the average price of the pellets and hence the scrap price can only be controlled at a higher level than would normally obtain.

27.5 The effect of coal supplies

Apart from the iron bearing materials, ore and scrap, the only other internationally traded material that has a major influence on the world steel industry is coking coal, which combines the roles of fuel and reducing agent in the blast furnace process.

Although in the early 1960's it was thought that the availability of coking coals would be a major world problem, developments in the processing of coals now make it possible for the blast furnace to use qualities of which the world resources are much greater.

Although complete import and export figures for coking coal, as distinct from other types of coal, are not recorded, some indication of the level of trade in coking coal between major suppliers and consumers is given by the tonnages shipped in 1967. The figures refer to millions of tonnes.

Exporters		Importers	
Country	Tonnage	Country	Tonnage
USA	30.3	Japan	24.0
West Germany	9.5	Canada	5.6
Australia	9.0	Benelux	3.0
Poland	2.1	Italy	7.9
		France	4.8
		Netherlands	3.1

The annual international trade is thus in excess of 50 million tonnes, to which must be added a trade in prepared coke of about 20 million tonnes.

Although at the present time the sources of coking coal are more restricted in number than those of iron ore, it is not considered that potentially large consumers should have any major problems in negotiating contracts with the major suppliers. The present prices, however, are very high. Figure 27.1 shows how prices have risen very rapidly since 1969; in the first half of 1971, the FOB price of American coking coal for delivery to Europe had shown a further rise to $19-20 per tonne. In the future, however, with the developments in coking techniques, other sources of coal are likely to be developed on a commercial basis, and prices may then settle down at a more reasonable level.

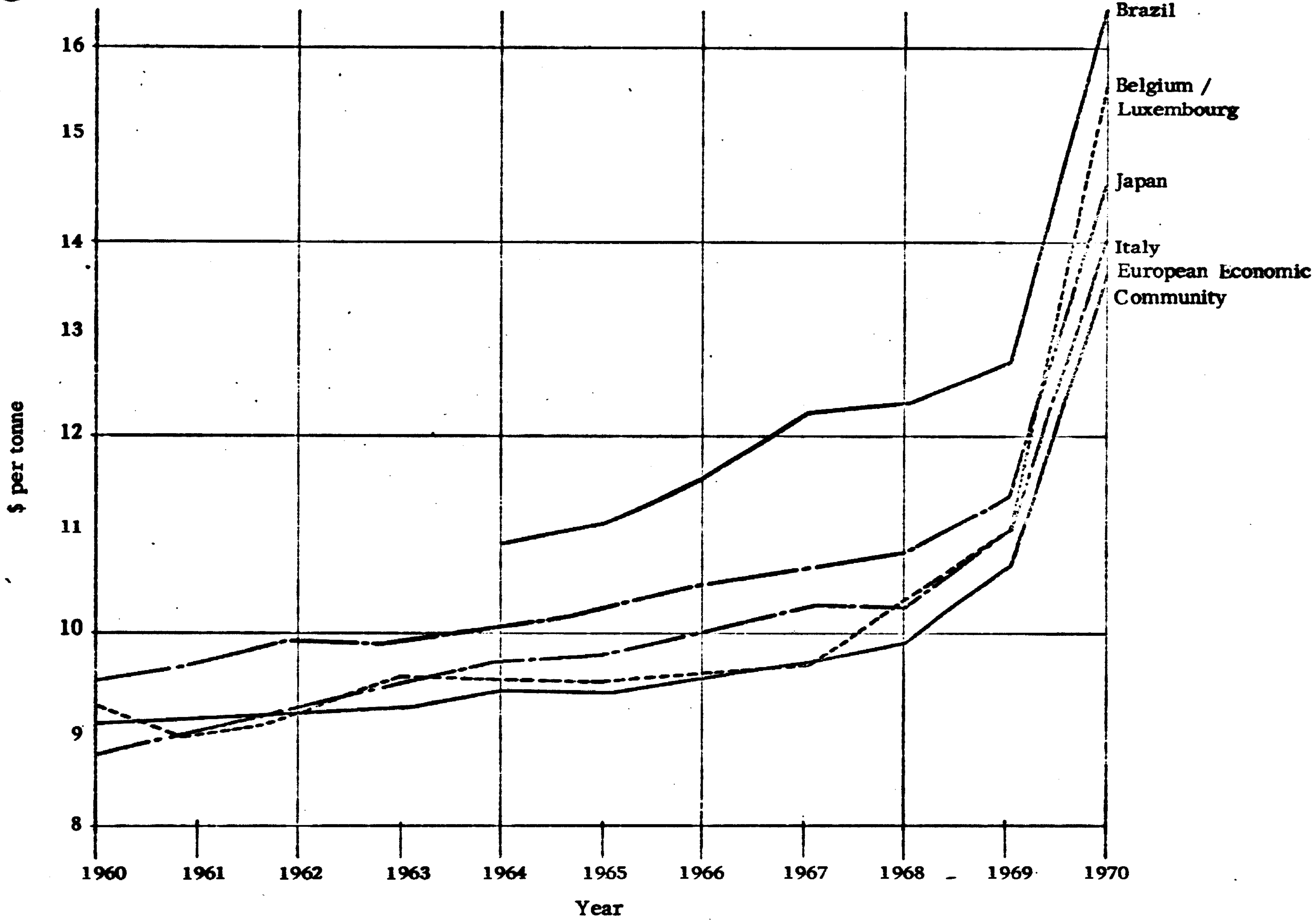

FIGURE 27.1 - AVERAGE VALUE OF AMERICAN EXPORTS OF METALLURGICAL COAL FOB AMERICAN PORTS

27.6 Factors affecting the shape of steel works

The steel industry in a region or a country is concerned with the utilisation of iron ore and scrap for the production of semi-finished steel products, through the various steelmaking routes, the subsequent rolling of these into finished products, and the marketing of these to stockholders and users. The ways in which this total activity are carried out are influenced by a number of technical, commercial and geographical factors which determine what may be called the 'shape' of the various works that are established, that is to say, the range of processes that are carried out in the works. For example, integrated works, semi-integrated works, re-rolling works, etc., are works having different 'shapes'. In the past, consuming industries and steelworks, with their common needs of energy and transport were typically concentrated in the same locations. Technical and economic factors then determined whether a particular works should produce pig iron, semi-finished products for feeding to re-rolling works or finished products. Factors which influenced the shape of the works included the utilisation of waste gases, the specialist service which the final re-roller was able to provide to the customer in the market place, and the degree of common ownership with steel-using enterprises.

The significance of these factors has changed with time and other factors have assumed increasing importance. Works are now much larger, and in particular the plant for producing a particular product may now be larger than is required to satisfy a single market region. Further, new industries are now located nearer to the major concentrations of population and services, while the location of works in many countries will be at deep water coastal sites, which may not be adjacent to the market. These changes lead to a review of the basic factors which determine the shape of works.

Firstly, up to the semi-finished product stage, the production units are concerned with the bulk manufacture of basic products. Even though a variety of semi-finished products may be produced, their numbers are small by comparison with the many specifications that exist for the finished products. It is possible, therefore, for the production of semis for re-rollers to proceed with only a broad knowledge of the end products which are required by the market; it is the business of the re-roller to order semis to specifications that suit his knowledge of end products.

The rolling of semis to finished products then requires a detailed knowledge of the specifications of the products required. In practice, the industry finds it difficult, at present, to manufacture in advance of orders, and to supply from stocks. Since the industry rolls to order, it needs to be in close touch with customers, and this may influence the location of the rolling mills near to the customers, even if the basic steel-making up to the semi-finished product stage is best carried out elsewhere. There are, in fact, differences between the service requirements of the flat and non-flat sectors of the industry; the former tend to have contract orders from single customers, for example the automobile manufacturers, whereas the latter tend to supply a larger range of products to a greater variety of smaller customers.

Another factor which has become increasingly important concerns the size of investment which is required and hence the way in which funds can be attracted to the industry. Large iron and steelmaking complexes, whether for the production of billets or slabs, require an investment of several hundred million dollars, and rolling mills for the production of flat products also tend to require similarly large investments. On the other hand, rolling mills for non-flat products only require an investment of several tens of millions of dollars, a sum more easily raised from private investment sources.

It may be seen, therefore, that the factors which determine the shape of works are changing. Before establishing new works, the technical, economic and geographical factors of the region in which the works is to be sited should be examined. Any commercial and technical links between steel producers and the consuming industries which they serve apply to the manufacture of finished products rather than to the production of bulk steel from iron ore; thus, where transport economics indicate there are savings to be made, the production of bulk steel could be carried out nearer to the iron ore mine, and semi-finished products such as billets, slabs or hot rolled coils transported to the market, where they would be rolled into the finished product. Such a prospect would have considerable interest for iron ore mining countries.

The practicality of moving the centre of steel production overseas has been under close study recently by a number of countries and several have already investigated the commercial and economic possibilities of investing abroad. For example, the British Steel Corporation has explored the possibility of making billets in either Australia or South Africa, but it is reported that such a procedure will not be adopted at the present moment. The Japanese steel industry also is known to be interested in the possibility of making semi-finished products in South America, though talks with various countries have not yet proceeded beyond the exploratory stage. On a small scale Australian semi-finished products have recently been imported by a German works.

This practice has certain potential advantages to both the maker and the purchaser of the semi-finished products, but there are also disadvantages of a commercial nature.

The advantages are:

The supplying country, by exporting a more valuable product, is acquiring more foreign currency for other developments, often much needed in developing countries.

The purchasing country is avoiding pollution problems associated with iron and steel making, of increasing concern in industrialised countries.

Shipping charges are paid on only about half the tonnage compared with shipping iron ore.

The disadvantages are:

If the two countries are widely separated, it would often be difficult to place orders for semis sufficiently in advance to allow for shipping time when a particular order for finished products has been accepted.

There would be additional working capital tied up in the form of valuable material in transit between countries.

Thus, although it is probable that at some future time the advantages will bring about such a development, it is difficult to foresee when changes in commercial and possibly shipping practices will sufficiently overcome the disadvantages.

27.7 The growth of production in different areas

The world production of steel in 1969, chosen as being a mid-cycle year, is summarised below:-

Region	Estimated percentage of world population	Steel Production: Million ingot tonnes per year	Steel Production: Percentage of total
Western Europe including UK	8	152	27
North America	6	137	24
USSR	7	110	19
Asia (excluding mainland China and North Korea)	31	89	15
Eastern Europe	3	40	7
Latin America (including Mexico)	8	11	2
Others	37	32	6
		571	

It is significant that Latin America, which has a large population and is rich in mineral resources and particularly iron ore, contributes only 2 percent to the world production of steel. It would seem that the potential for increasing production and trade in steel in this area is considerable.

The period 1958 to 1968 saw dramatic increases in steel production in a number of countries, with different environmental pressures, as shown in Figure 27.2. The paths along which individual steel industries have developed have been different, however, even though in the end they have led to a similar kind of development, for example in Japan and the EEC.

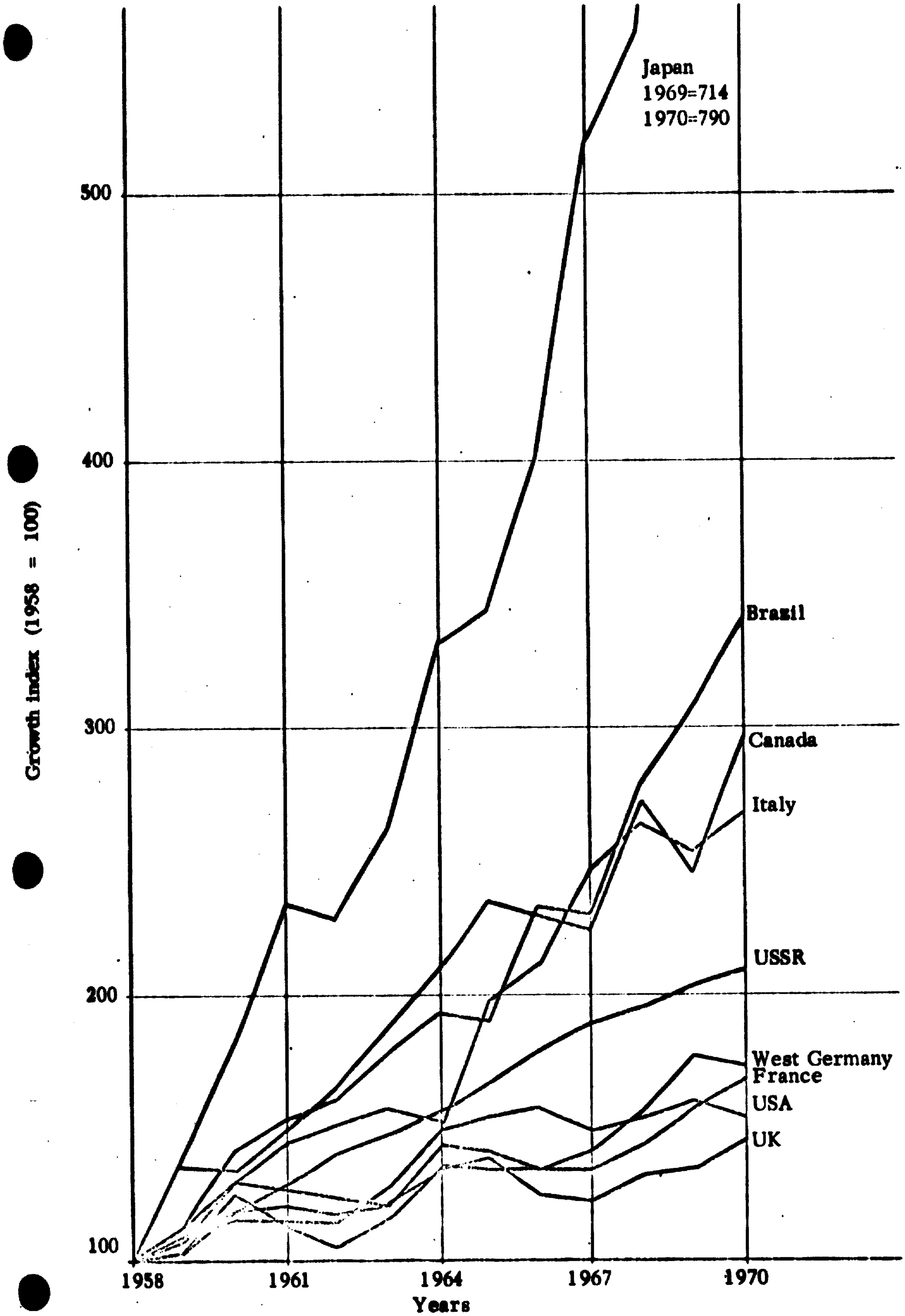

FIGURE 27. - GROWTH OF CRUDE STEEL PRODUCTION

Steel production in the USA increased by about 43 million tonnes from a baseline around 75 million tonnes per year. This development was based mainly on the fast development of her home market. The USA has raw materials of her own but imports a significant tonnage of iron ore. A similar increase has taken place in the USSR, in which from a baseline of about 50 million tonnes per year an expansion of about 50 million tonnes per year took place. This was also home market based, using all indigenous raw materials.

The pattern of development of the Japanese steel industry was different in almost every aspect. As with the industrial development of the 1930's, so again in the 1950's the steel industry had to export to contribute to foreign exchange earnings, for Japan imports almost all industrial raw materials. The striking feature of the decade 1958 to 1968 is the expansion of steel from a base of 11 million tonnes to 66 million tonnes. This involved organising the acquisition from overseas on a long-term contract basis of all the raw materials, and developing high throughput steelmaking technology to obtain low cost steel from these materials. The steel industry of the 1950's and early 1960's was given priority for the development resources of Governmental agencies, but in order to justify the largest and most economic facilities, it was necessary to base the development on both the Japanese and Asian markets for steel.

It is worthy of note that by comparison, an additional 12 million tonnes in a decade as a target for Brazil would be a similar step and would be only a slightly greater increase than that which was recently accomplished by another once predominantly agricultural country, Italy.

27.8 Financing of production growth

The levels of investment expenditure by a number of countries related to the levels of steel production to show the relative importance of the investment, are shown in Table 27.3. Although, as might be expected, Japan has one of the highest figures in the table, around $18 per tonnes, it is not as high as Spain ($40 per tonne for a number of years) or the Netherlands. A comparable figure for the likely levels of spending in Brazil over the next few years is about $50 per tonne of steel produced. Such rapid development programmes for the steel industry require the commitment of large sums for investment in new plant in both steel and user industries. Such large investments cannot be committed lightly. They may be a major proportion of indigenous funds, whose use will have a serious impact on the total development of the economy, or they may be obtained from sources outside the country for which a guarantee may be required.

Capital phasing risks for the steel industry are greater than for other industries associated with the rapid development of an economy, because the steel industry must develop ahead of its main customers, and the risks of not fulfilling forecast production plans become more serious in the light of commitments to long-term contracts for raw materials. One interpretation of the development of the Japanese steel industry is to view resources devoted to technological development and the increasing economies from large plant as being pre-emptive bids to secure increasing shares of home and export markets. These were needed by Japanese steel makers to give flexibility for the

TABLE 27.3 - INVESTMENT EXPENDITURE IN RELATION TO CRUDE STEEL PRODUCTION

($/tonne)

	1965	1966	1967	1968	1969	1970
Germany	8.5	8.3	6.1	5.5	6.8	13.9
Belgium	15.5	16.0	11.0	6.4	10.3	18.3
France (1)	8.6	7.5	9.1	12.4	12.1	15.5
Italy	19.4	12.2	8.0	6.6	8.7	17.2
Luxembourg	5.6	6.5	3.5	2.8	6.2	9.0
Netherlands	11.8	21.0	27.8	33.7	26.4	22.8
ECSC	10.8	10.0	8.3	8.1	9.5	15.5
Austria	9.0	14.6	13.8	8.9	7.8	15.2
Spain (1)	33.1	37.1	41.3	41.9	36.9	33.9
United Kingdom (1)	5.1	4.7	5.6 (2)	4.5 (2)	3.8 (2)	9.7
Sweden	19.7	21.6	19.7	18 1	18.8	21.8
Canada	16.6	21.5	13.0	5.9	10.1	15.7
United States	15.2	16.1	18.8	19.9	16.7	16.8
Japan	11.0	11.3	13.6	17.4	18.2	20.2

1. The exchange rates of the pound sterling and peseta in terms of the dollar were changed in November 1967 and those of the French franc and German mark in August and October 1969 respectively.
2. British Steel Corporation only.

Source: "The Iron and Steel Industry in 1970 and trends in 1971", OECD. Investment expenditure during the fiscal year has been related to production in the calendar year.

maintenance of production plans. These developments have also been accompanied by market protective measures. It is remarkable that a country that in 1958 had a relatively small proportion of the world's production has made such a major contribution to the world steel industry; its success is attributable to the marrying of marketing effort with a rapid increase in production, producing early high utilisation of the facilities. This is an example of a total corporate approach which has been lacking in the steel industry throughout the world until quite recently.

It is those countries with fast developing home markets and exports to natural trading areas that have had the greatest opportunity to take advantage of technological innovations. The penalties for delaying innovation can be great both for a bulk steel industry and for user industries. The 1960's saw 16 million tonnes of imports into the USA because US producers were not then cost competitive, and at the same time very high tariffs were needed to protect old technology industries, with the consequential high cost of steel to users. In the ECSC the incentives to embrace modern technology have been very clear, and imports from outside are negligible and exports to third parties are now as great as intra-EEC trade.

The development of the Community has demonstrated the practicality of co-ordinating investment of private and state-owned steel companies, and a substantial interdependence for the supply of steel products has evolved in these conditions. This specialisation and interdependence has resulted in the development of the modern steel facilities which are required if the steel and engineering industries are to remain competitive both at home and in their export markets.

Profit achievement through modern technology requires a greater degree of specialisation, and this has been possible within the larger regions. The large specialist production facilities which are being constructed today have high initial capital investments. Although there is no obvious evidence that the pattern of development has been inhibited by the size of the investment, clearly the forming of international consortia will make the fund-raising for these enterprises that much easier. The key features of the steel industry - the need for modern technology and skills, international trade in raw materials, and world markets - carry a potential for steel to develop as an international industry like its major customers. The incentive to mergers is reinforced by changes in product requirements (demand for bulk steel for consumer durables is rising faster than that for heavy engineering), highly competitive trading conditions, and the demand for low cost steel.

CHAPTER 28 - PRODUCT DEVELOPMENT

The range of finished products manufactured by a steelworks is very wide. Steels have been developed to match new and often extreme environmental conditions and new shapes have been introduced to improve final products. The range of steels will continue to increase under the impetus provided by changing markets and competing newly developed alternative materials. The field of product development is thus too large to deal with comprehensively and it is necessary to select examples of developments which are indicative of the overall trends.

The development of new steel compositions and shapes is also a large subject, and will vary considerably from country to country, depending on local factors such as the level of technical development and the nature of social demands and industrial structures. However, it is possible to review the recent changes that have in general occurred in the market demand for steel compositions and shapes. These changes have not always contributed to the enlargement of the market for steels, but they are and will continue to be necessary if steels are to compete with the increasing number of substitute materials available to the markets.

Developments in steels and steel products are dealt with separately in the two ensuing articles.

28.1 Steels of specified properties

Corrosion resistant common steels

There are two main markets where corrosion resistant common steels are particularly needed - where atmospheric corrosion has to be combated, and the newly expanding market created by ocean exploitation.

Sea water resistant steels are made in a wide range of composition and shapes for use in both sea transport facilities such as docks, wharves, dolphins, etc. and facilities for the exploration and subsequent exploitation of oil, gas and other mineral deposits at off-shore sites. Emphasis has been placed particularly on steels which combine corrosion resistance with other desired properties such as high strength and ductility. For example, low carbon steels with substantial additions of manganese have the desired mechanical properties and are partially resistant to marine corrosion. Since ocean development of all kinds is likely to be a high growth market, it may be assumed that there will be an increasing demand in this market for a wide variety of corrosion resistant steels which retain the low cost level of common steels. They will be required in large quantities for use in marine conditions where they will have a much greater life than the previously available products.

Steels with resistance to atmospheric corrosion are just beginning to achieve general acceptance on a worldwide basis for structures where a patina of permanent 'rust' is acceptable. The addition of around a half per cent of copper greatly enhances resistance to atmospheric corrosion. Early trial structures - bridges, pressure tanks and ship superstructures - have been found successful and their appearance can be pleasant where care has been taken in the design to accommodate the weathering effects caused by variations in the exposure of different surfaces of the structure. The absence of continuous corrosion enhances the life of any coating that is applied to these steels, so that paint life may be doubled where a coloured finish or special preservation is required.

Cheaper heat treatable steels

The market now appears ready for the introduction of a family of steels of medium strength, high notch toughness and good weldability. The plain carbon quenched (PCQ) and quenched and tempered (QT) steels possess these properties.

The PCQ steels are made by the addition of trace quantities of the elements niobium and vanadium to steel made under carefully controlled process conditions. The basic steels contain 0.1 percent C and 1.5 percent Mn. The effect of the trace element additions is to improve nucleation and hence reduce grain size, which improves resistance to crack propagation. They also produce intermetallic precipitation which further raises the yield point. The steels are quenched after hot working down to 950°C. Further toughness improvements can be obtained at the same strength levels by adding a trace of aluminium, and if this steel is rolled until its temperature has fallen to 750°C, the notch toughness is increased still further. Thus the combination of controlled rolling, controlled cooling and trace element additions results in commercial steels with yield strengths up to 770 mega-Newtons per square metre (80 kg/mm^2) and good impact strength (notch ductility) at temperatures down to -40°C.

There has also been a growth in high tensile quenched and tempered (QT) steels with alloy content of less than 5 percent, which can be easily welded and possess good low temperature impact strength. Whereas the PCQ steels need to be rolled at a prescribed temperature in order to attain their properties, the high tensile QT steels can be made at higher temperatures since their properties result entirely from the subsequent heat treatment processes.

Mills designed for rolling these steels need to be capable of sustaining high loads and torques, but most modern mills are capable of accommodating them. Quenching equipment for plates is needed at the exit from the mill and thicker plates may need to be platten quenched to keep the plates flat during quenching.

Another recent development has been the substitution for the expensive alloy steels previously used in engineering components, of common steels containing special additives which considerably enhance the qualities with which subsequent heat treatment will endow the product - for example the addition of a very small percentage of boron to a common manganese steel will permit its use for automobile gearbox components.

Stainless steels

Many new stainless steels with specific performance characteristics are being developed to meet the demands of particularly corrosive environments. Underwater technology has played a prominent part in this development, for example through the need for precision moving parts which can be exposed to sea water - a relatively new requirement which is likely to grow in the future. New techniques for producing very low carbon steels will make available a range of stainless steels of excellent weldability and workability, both of which properties are difficult to achieve at the moment. This should allow stainless steels to be more widely applied and their use extended much further into such fields as heating tubes and motor exhausts, where their penetration has, in the past, been held back by expense. In the USA 13 percent Cr steels are increasingly used in the motor industry. Stainless steels have been developed with high strength provided by precipitation hardening or heat treatment, a very good example being the copper bearing 17 percent Cr, 4 percent Ni, steel which provides the stainless qualities of higher alloy steels at lower alloying cost and with improved strength.

Steels for high temperature service

Developments in process plant for the chemical, petro-chemical, natural gas, power generation and metallurgical industries are demanding cheaper steels for use at higher temperatures. The considerable research undertaken in the recent past has resulted in the development of a wide range of special steels for these applications. The markets for these steels are growing and the expansion of nuclear applications and further space developments will demand even more specialised specifications in the future.

The creep resistant requirements for steels for power generation plant and the metallurgical industries has resulted in the increasing use of ferritic steels – 1 percent Cr, $\frac{1}{2}$ percent Mo steels for temperatures up to 500°C and $\frac{1}{2}$ percent Cr, $\frac{1}{2}$ percent Mo, $\frac{1}{3}$ percent V or $2\frac{1}{4}$ percent Cr, 1 percent Mo for 500-600°C. Above these temperatures high alloy Cr-Ni steels are used. In the petroleum and chemical industries large quantities of $\frac{1}{2}$ percent Mo and Cr-Mo steels are used to reduce corrosion by hydrogen and sulphur bearing hydrocarbons.

Steels for low temperature service

The development of steels for low temperature service (cryogenic steels) has resulted from the increasing requirement for transportation and storage of liquified gases, particularly liquified natural gas, which is transported at -190°C. There will continue to be a demand for these steels as further gaseous fuel sources.

remote from their markets, are tapped; it is also becoming environmentally unacceptable to flare off into the atmosphere refinery wastes, which must now be stored and used.

While the low temperature strength of some of the recently developed QT steels allows their use in extremely cold climatic conditions (down to -40 °C) they cannot be used for cryogenic purposes, which demand steels containing up to 9percent Ni.

Steels with specific electrical and magnetic properties

There have been recent developments in grain oriented sheets which can be used to improve the flux density of magnetic fields in the cores of transformers and other electrical machinery; alternatively, they can be made from thicker strip without reducing the flux density in such machinery. Highly grain oriented sheets should continue to have large markets as power consumption increases. The required orientation of the grains places greater demands on rolling and the annealing facilities need to be twice as great as for plain carbon steels.

Steels with special machining properties

A range of free-cutting steels containing sulphur, lead, or more recently, tellurium, has been developed for the manufacture of engineering parts for applications where rapid machining is of particular importance, such as nuts and bolts. Free cutting steels can retain the characteristics of strength and heat treatability possessed by the base steel. Better appreciation of the monetary savings possible when these steels are used will ensure a widening market in the future.

Steels with special cold working properties

Particular interest has recently been focused on low yield point and deep drawing steels mainly for autobody sheet. The very low nitrogen steel produced by the BOF has provided a stimulus to the makers of such steels to improve their deep drawing qualities. The trend is likely to be encouraged by the potential tool cost savings available from adopting the stretch draw forming process for autobody panels.

Ultra high strength steels are now available in a form which allows extensive cold working in a soft condition with the high strength developed by a low temperature (and so distortion free) final treatment. These 'maraging' steels contain around 18 percent Ni together with 5 to 10 percent of other alloying elements. At present the high cost of these steels limits the application mainly to aerospace or defence uses.

Steels with good welding properties

There is a marked trend to substitute fabricated products for castings and heavy sections, which is partly accounted for by the high cost of foundry moulding and of rolling heavy sections, but is also influenced by the advantages to be gained from choosing material to suit specific circumstances when components are to be fabricated. For example, different steels can be used for the flanges and web of

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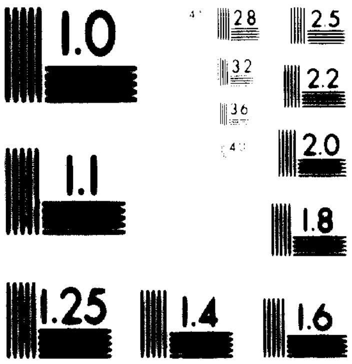

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STANDARD REFERENCE MATERIAL 1010a
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a beam according to the requirements imposed upon each part. In order to make best use of this method the new steels have been developed with improved weldability. There have also been developments in welding processes and welding rods or electrodes.

It appears likely that improved weldability will be required of an even greater proportion of steel in the future, so that the labour intensive methods of the past can be replaced by automatic welding processes (such as spiral welding for making transmission pipes).

Steels with hard wearing properties

Special development effort has recently gone into the production of steels which exhibit good wearing characteristics, for incorporation into such products as railway lines, crane rails, railway wheel tyres and a whole range of plates, castings and forgings used in the construction machinery and plant industry. The trend is to develop hard wearing characteristics by surface hardening treatments such as hard surfacing or flame hardening.

The use of bimetal - a material comprising steels of different qualities, including wear resistance, welded together - to achieve self sharpening tools is growing, particularly in the field of agricultural equipment such as ploughs.

28.2 Finished products

Heavy sections

Within this category, which includes structural shapes, rails and sheet piling for special applications, there have been few new developments. Universal structural sections have now superseded the rolled steel joists previously used, except for very small sizes. Very heavy H-sections with flange thicknesses up to 125 mm and widths up to 1200 mm have recently been produced for use as columns in high-rise buildings in the US and Japan, because they have an economic advantage over the alternatives, even when they have to be encased in concrete for fire protection purposes.

As a result of the increasing demand for waterside facilities, irrigation schemes and other civil engineering applications, more complex shapes of sheet piles have been evolved so that longer driven sections can be used. In other areas, the demand for heavy sections in the wide range of shapes and sizes now required is increasingly being met by the use of sections fabricated from plates - the choice between rolling or fabricating universal beams depends primarily on the quantity involved. This trend is taking place both in the shipbuilding and civil engineering industries. With the increasing size of ships, particularly bulk carriers and tankers, the ship profiles required exceed the dimensional capacity of existing mills to produce them. It has been found more economic to produce these by fabrication than to design specialist mills. Similarly, as noted in Chapter 18, it is becoming generally common practice to fabricate universal sections deeper than 600 millimetres, except in such special circumstances as those mentioned above.

The effect of this trend will be to increase the demand for plate mill products at the expense of those from heavy section mills.

Medium and light sections

The major development in this area has been the introduction of cold formed profiles for a wide range of light sections used for construction. Parallel flanges and right angle sections produced by this technique are more easily fixed, and the products can be made in smaller batch sizes allowing shorter delivery or smaller stocks. Cold formed shapes are likely to take over much of the market for smaller sections, and the availability of cheap purpose-made sections for particular applications will further increase the size of the market.

Columns fabricated from cold formed or hot rolled sections have found increasing application where architectural considerations are important because of their favourable stiffness characteristics and neat appearance compared with H or I sections of the same weight. This development is expected to continue, as is the use of special cold formed sections for road furniture such as motorway guard rail.

Bars

There has recently been a marked swing throughout the world towards the use by the construction industry of higher strength concrete reinforcement of the deformed bar type. This not only reduces the amount of steel required, but may also reduce the quantity of concrete used, which in turn will lower the overall imposed load capacity of the foundation; the result is lower costs throughout. Higher strength bars can be made both by the use of alloys and by cold physical deformation to produce added grip. The trend towards increased use of these products as an alternative to plain mild steel bars is expected to continue.

Extrusion of bar in comparatively small quantities is now beginning to receive serious consideration, but the technique is likely to be more useful for extruding sections not easily manufactured by rolling.

Rods

The developments indicated for bars in general apply equally to the use of rods for construction purposes.

Steels of increased strength have also been of advantage for the wire and wire rod used for concrete prestressing and post-tensioning. As the attainable concrete strengths have risen, so higher strength steels have been used.

Pipes and tubes

This section needs to be considered under three headings, which have been dealt with in turn - transmission line for pipelines, engineering tube and common piping.

The enormous increase in the use of natural gas and oil has produced a demand for a new range of tubes and pipes for distribution. The development of de-salination plants on a large scale, which is only just beginning, is also likely to create a major demand for special pipe products. Both spirally welded and butt welded pipes are being developed for use under the most extreme conditions of service, for example with pressures up to $10\ MN/m^2$ ($1\ kg/mm^2$), and temperatures down to -200°C. As discussed in Chapter 19, development of new welding techniques and methods of testing has meant that the majority of tubes, including those for high pressure applications, are now welded from flat mill products which have been bent to shape. Seamless tubes made from billets, which were widely used in the past, are now mainly used for special applications.

Structural engineering applications have provided increased markets for both existing and purpose made tube products of all sizes. Some large span buildings are now roofed with a spacedeck of tubular members. Considerable use is also being made of tubes in earth-moving equipment such as draglines and cranes. Finned tubes, which are difficult to produce by rolling, have recently been produced by extrusion, particularly for heat exchangers.

Tubes with a PVC lining have been developed for conveying materials which would react with uncoated steels, while for protection in corrosive surroundings PVC coated tubes have been developed. Both these applications appear to have growth prospects.

Plates

Mention has already been made of the use of hard wearing steel plates, which are used for earth-moving and agricultural equipment etc. High tensile plates have been developed for transportation equipment such as ships, railway rolling stock and heavy vehicles, where the saving in weight is particularly beneficial. Easy fabrication has been ensured by the selective use of alloys to make the steels weldable.

The introduction of bi-metals mentioned at the end of Article 28.1 particularly in plate and sheet form, enables previously incompatible mixtures of steel qualities to be achieved. Thus pressure vessels can be made with bi-metal plate giving high strength and corrosion resistance for use in high temperature conditions, or where high conductivity is required.

The use of chequer plating appears to be giving way to expanded metal grids but striped plate, which has a greater variety of uses, has been developed as an alternative. Because of its 'one way' characteristic, it can provide the grip required in stair treads and walkways and can also be used in applications where a plain plate would normally be used but where high strength mainly in one direction is required and the extra saving in weight is important.

Sheets

The most important development in sheet products is the improved 'shape' made possible by roll bending and other improvements discussed in Chapter 17.

Coated sheets

Electro-galvanised sheets are now replacing hot-dipped sheets for many uses because of the lower price which results from the thinner coatings. Further developments have been made in prepainted galvanised sheets; these too are increasing in use and are likely to continue to do so.

Hot dipping of tinplate is now used only for special containers for corrosive material, the majority of tinplate being electrolytic. Double reduced tinplate, which was developed to compete with aluminium, has allowed lighter, cheaper steel cans to be manufactured; a new development along these lines is being pursued, involving drawing followed by wall rolling of the formed sheet. Many of the tin cans at present used for edible products are required to have their internal surfaces lacquered, the coating usually being applied to the steel when it is in sheet form.

Although the total market for cans is growing, it is becoming more vulnerable to aluminium and non-metal substitutes, which partly explains the great interest shown in developing new steels for the canning industry. A range of chrome plated or chromic oxide finished sheets has been introduced in an effort to save the high cost of tinning. These sheets, usually known as 'tin-free' sheets, are likely to be used in future for many of the markets where tinned sheets have traditionally been used.

Plastic coated sheets, either plain or embossed, are also establishing new markets in areas where previously the lack of corrosive resistance or poor appearance of uncoated steel sheets made them unacceptable. These coatings enable tight radii to be formed on cold profile rolling or in presswork. These profiles are extensively used for both roof and wall cladding of buildings and for prefinished panels in a large variety of electrical and mechanical engineering applications, such as electrical control panels and automobile instrument clusters.

CHAPTER 29 - COMPETITION WITH OTHER MATERIALS

The main competitors of steel are such materials as concrete, ceramics, asbestos, glass, aluminium and plastics. There are certain market areas where steel is particularly vulnerable, notably the consumer oriented industries, construction, packaging and pipes.

29.1 Consumer oriented industries

The use of steel in these industries is being strongly challenged by plastics. Steel has had the advantage of stiffness, strength and relative cheapness with varying degrees of corrosion resistance from alloy steels, while problems of limited strength, rigidity and creep have in the past restricted the use of plastics in many engineering applications. However, many new plastics with better engineering characteristics are now available and have been replacing metals for a variety of applications; for example, blow mouldings made from rigid plastics are being successfully used for vehicle fuel tanks, a market previously held by terne plate.

Thus the range of markets in which plastic materials have already established their competitiveness is wide and increasing. The advantage of plastics over steel is that in addition to the cheapness of their own production techniques, their impact on the production techniques of large scale user industries produces significant reductions in manufacturing costs. Therefore, in forecasting the demand for steel in vulnerable markets, it is necessary to understand the customers' production techniques with existing manufacturing plant and equipment, and the likely changes in their production methods.

Because continuous flow techniques dominate various stages of plastics fabrication, a mass market for these plastics is necessary. The fast growing plastics users in the USA are motor vehicles (now using 50 - 100 lb. of plastics), other transportation equipment, radio and television equipment, and household and other furniture. These are industries with a sufficiently high volume of sales for their plastics components to be produced economically.

However, it would be unwise to assume that the extent to which plastics have been substituted for steel products in the USA will necessarily take place elsewhere. Manufacturers have always to evaluate the risk of replacing what they know works in their own country, by production methods and materials which have since been evolved elsewhere, perhaps under different climatic conditions and with a different relative cost of available materials. In order to forecast the future usage of steel by the consumer-oriented sectors of industry, it would be necessary to undertake an examination in depth of achieved and planned changes in the production engineering of consumer goods industries. Any involvement in export markets will also have some impact on the demands for competing materials of these consumer sectors, not only by increasing the scale of specific product markets, but through the continuous contact with changing production technologies elsewhere.

29.2 Construction

In construction, changes in demand for steel involve both the substitution of one steel product for another and competition from other materials. Changes in the steel specification may affect the weight or value of steel used in constructional activity - for example, high tensile reinforcing bars in place of mild steel.

The quantity of steel will also be affected by the choice between reinforced concrete and structural steel, and between galvanised sheets and other roofing or curtain walling materials. The choice may depend on the building needs of the industry involved - for example, heavy engineering tends to use structural steel rather than reinforced concrete, by comparison with consumer industries or small scale factories - or on the loading standards and safety requirements, which are now tending to favour a structural steel design in some countries. Changes in construction techniques will thus alter the steel requirement, because the use of structural steelwork will increase the volume of steel in a given building, by comparison with reinforced concrete (or vice versa), and because the increasing use of welded structures creates a greater demand for flat products in place of rolled sections.

For roofing, asbestos sheeting is the main competitor of galvanised sheets, although there may be some use of plastics where a plastics industry is well established. Galvanised sheet tends to be in particular demand for the rapid construction of new towns in rural areas, but in countries such as Australia and South Africa it has also been widely used for the construction of city suburbs.

Industrial development promotes new uses for steel, where stiffness is the key criterion for the material to be used - for example, motorway crash barriers, balustrading and telecommunications aerials.

Although changes in steel demand will be caused by the relative use of reinforced concrete and structural steel, and by possible inroads into steel use by asbestos and plastics products, there seems no reason at present to expect any major substitution for steel of any other material, in the field of construction.

29.3 Packaging

This area of activity is too large to cover in any great detail, but it is an area where steel is vulnerable to substitution, and a few possible developments can be indicated.

Developments in packaging have been significant in the USA during the last decade. The fibre cans and drums packaging industry now uses paper and aluminium for most frozen food concentrates and motor oils, and is aiming to include most liquids packaging. The fibre can in the USA is cheaper and lighter than a metal can, and can be handled more efficiently on the packaging line.

Certain plastics have excellent protective qualities - some have low absorption qualities and help to retain liquids such as the juices in meat, some are poor heat conductors and help preserve products, particularly those requiring refrigeration, and some are shock resistant and provide excellent protection for shipping delicate instruments. Plastics are also used as coatings for wire and for steel sheet, and as such assist steel to compete with other materials.

There have been three important developments in the metal can industry; the advent of the aluminium can, different forms and thicknesses of coating for steel sheet, and double reduction tinplate. In the USA aluminium has become the growth area in metal can production, mainly in beer cans, and similar cans where there are internal pressures. In the UK where the relative cost of aluminium to steel is higher and technical developments in the making of wall ironed cans have put this process on the horizon for tinplate, tinplate or tinfree steel competes with aluminium in the beer can market and is expected to continue to do so.

Tinfree steel is well established in the USA, but similar pressures by major users to change from tinplate to tinfree may not arise to the same extent in other countries, as its shelf life is much lower than that of tinplate. Since the major expansion of packaging is in food processing, much of it destined for overseas markets, distribution channels are likely to favour the continuance of tinplate. Two developments in coatings which improve the competitive edge of steel are the differential coating of tin and the use of aluminium as a coating material. Another development has been double reduction tinplate which, by reducing the weight of the plate, enables it to compete in price with other packaging materials.

29.4 Pipes and tubes

There are many markets for tubes and pipes, and there is some overlap in the suitability of materials and methods of fabrication to satisfy the technical and economic requirements of the user. Apart from steel, there is cast iron, copper, ductile iron, concrete, asbestos, pitch fibre and plastic. Where more than one material would satisfy technical requirements of the customer, the choice may differ from one country to another by reason of differences in such requirements as building bye-laws, or standards recognised by a specific industrial customer - for example, API requirements for oil pipes and tubes. Specification standards change as the particular technical weaknesses of a material are corrected, for example plastics for domestic plumbing, where creep is no longer a problem. Changes in technology are also reflected in changes in standards, as exemplified by the increasing acceptance of welded tubes for purposes which in the past would only have been satisfied with seamless tubes. This competition within the steel tube family has implications for planning in the steel industry, for whereas welded tubes set up a demand for flat products, seamless tubes require tube rounds.

CHAPTER 30 - TRENDS IN CONSUMPTION OF STEEL

30.1 Consumption of steel as related to industrial growth

Although the production facilities which will be required are determined by absolute changes in consumption, the rate of change is also important. Table 30.1 analyses the trends in growth of steel consumption for the 30 year period 1938 to 1968 for a number of different countries. It would appear that there is no strong link between the rate of growth of steel consumption per head and the population growth. There is, however, as might be expected, a relationship between rate of growth and the actual level of consumption, since it is easier to achieve a fast rate from low consumption levels. Thus, of the many countries that achieved a 50 percent increase in consumption per head over a decade (4.2 percent annual growth rate), only one - Canada - had a high initial level of steel consumption. In order to sustain a high growth rate, it is necessary to maintain a high degree of co-ordinated planning both in steel production and user industries since it is much more difficult to implement changes if the industry expands on a piece-meal basis.

Several 'routes' to economic growth have been pursued by different countries; for example agriculture in New Zealand and Australia; tourism, construction and leisure industries of the Mediterranean countries and the Bahamas; merchanting in Greece; mining in South Africa, Australia and the West Coast of Canada; and investment in manufacturing in Japan, Germany and the USA. These routes vary in their potential steel use: for example, in the UK in 1968, every $1000 of engineering, shipbuilding, or vehicle production required $120 or more of steel, as compared with less than $10 of steel for $1000 of final output in agriculture, services or distributive trades, while the steel intensiveness of transport, construction or mining comes half-way between these two figures. Clearly, the different 'routes' to economic growth stimulate the growth of different industries; thus in different countries the level and growth of GDP represents a very different level and growth in steel consumption. The growth of markets for steel also reflects the growth of transportation and urbanisation, of mechanisation, of changes in the distribution of income and wealth, of developments in international specialisation and the net export position of steel-using goods.

TABLE 30.1 - TRENDS IN GROWTH OF STEEL CONSUMPTION

Country	Population growth rate 1963 - 1968 (%)	1938 Apparent kg per head	Compound growth rate of steel consumption per head 1938 - 1968 (%)
W. Germany	1.0	298	2.2
S. Africa	2.5	103	2.5
UK	1.0	198	2.5
Australia	2.0	206	2.8
Netherlands	1.5	132	3.2
France	1.0	114	3.9
USA	1.5	206	4.1
Belg. - Lux.	1.0	122	4.1
Sweden	1.0	184	4.1
India	3.0	3	4.4
Canada	2.0	124	4.6
Chile	2.5	small	*4.7
Venezuela	3.0	37	4.7
USSR	1.5	-	*5.1
Japan	1.5	87	5.8
Italy	1.0	57	5.9
Czechoslovakia	1.0	98	6.2
Brazil	3.0	small	*7.2
Spain	1.5	23	7.2
Mexico	3.0	72	7.6
Poland	1.5	34	7.8

* **Based on 1958 - 1968 only.**

Table 30.2 sets out estimates of the growth of real Gross Domestic Product, the rate of growth of apparent steel use per head, and the 'elasticity' of steel use expressed as the ratio of compound growth rate of steel use per head to the growth in GDP per head.

TABLE 30.2 - ELASTICITY OF STEEL AND GDP

Country	Percent compound per year			Estimated elasticity of steel per head	Consumption kg per head	
	Real GDP Growth 1960-1968		Steel Use per head 1958-1968			
	Total	per head			1969	1970
Italy	5.2	4.4	9.9	2.3	352	394
Spain	7.5	6.5	12.1	2.0	240	-
Japan	10.3	9.2	15.9	1.7	602	675
Australia	5.2	3.2	4.7	1.5	-	-
W. Germany	4.3	3.2	4.5	1.4	659	683
USA	5.1	3.7	4.7	1.3	682	620
UK	3.0	2.3	2.6	1.0	438	457
France	5.6	4.4	1.8	0.4	443	473

The following factors affected the 'elasticity' of steel use in these countries during the 1960's:

Italy:	Export orientation of consumer durables which are steel intensive, the acceleration of the shift in employment from agriculture to mechanised manufacturing and the associated demands for steel for urbanisation, transportation, etc., reflecting major changes in the economy.
Spain:	Engineering growth faster than the less-intensive construction of the initial development phase.
Japan:	Increasing proportion of fixed capital formation in GDP (e.g. steel expansion). Emergence of the dominance of engineering in export income, keeping elasticity above that of the USA.
Australia:	Rising consumer durable production and investment in transport generally within an agricultural and mining economy, reflecting a shift

	in income distribution due to the industrial diversification now being pursued.
W. Germany:	Reconstruction completed, and GDP growth increasingly sensitive to changes in export surplus in a wide range of goods.
USA:	Relative growth of investment in services as a contribution to GDP growth, but this investment is not steel intensive. Even though exports of most products are large absolutely, not really an exporter in terms of contribution to GDP growth. Home income distribution a key factor for changes in steel consumption, and associated stimulus to manufacturing machinery. .
UK:	Exports contributed more to GDP than gross fixed investment, and 60 percent of the steel was consumed by customers exporting about 40 percent of their output; thus overseas factors had more influence on steel elasticity than internal changes in income.
France:	Major GDP growth factors were the rise in output from agriculture and its associated mechanisation, and in services and construction activities associated with increased urbanisation and transportation; these are not as steel intensive as the relative growth of engineering in Spain or of consumer durable exports in Italy.

As can be expected, shifts in major factors, such as large changes in employment and living patterns from agriculture to manufacturing, or changes in investment from infrastructure to manufacturing not only affect the rate of increase of GDP itself but tend to be reflected in higher elasticities of steel consumption than those associated with economies which are not being restructured. A further factor affecting elasticity of 'steel' is the contribution of external trade to GDP growth and the extent to which this is steel intensive. If it is an important source of growth and yet is primarily agricultural, steel 'elasticity' with GDP growth is low.

The recently published IISI Projection 85 * forecasts the expected relationship between apparent steel consumption and Gross National Product per head of population (at 1963 values): this demonstrates clearly that the absolute level of the steel intensity curve for each geographical area varies according to the economic structure of the area. However, although the level of the steel intensity curve varies, its shape shows a striking similarity in all countries (see Figure 30.1).

Figure 30.2 compares growth rates of steel consumption over the period 1955-70 with forecast consumption 1970-1985, while Figure 30.3 compares consumption on a regional basis.

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* **Projection 85 : World Steel Demand, IISI, Brussels (1972)**

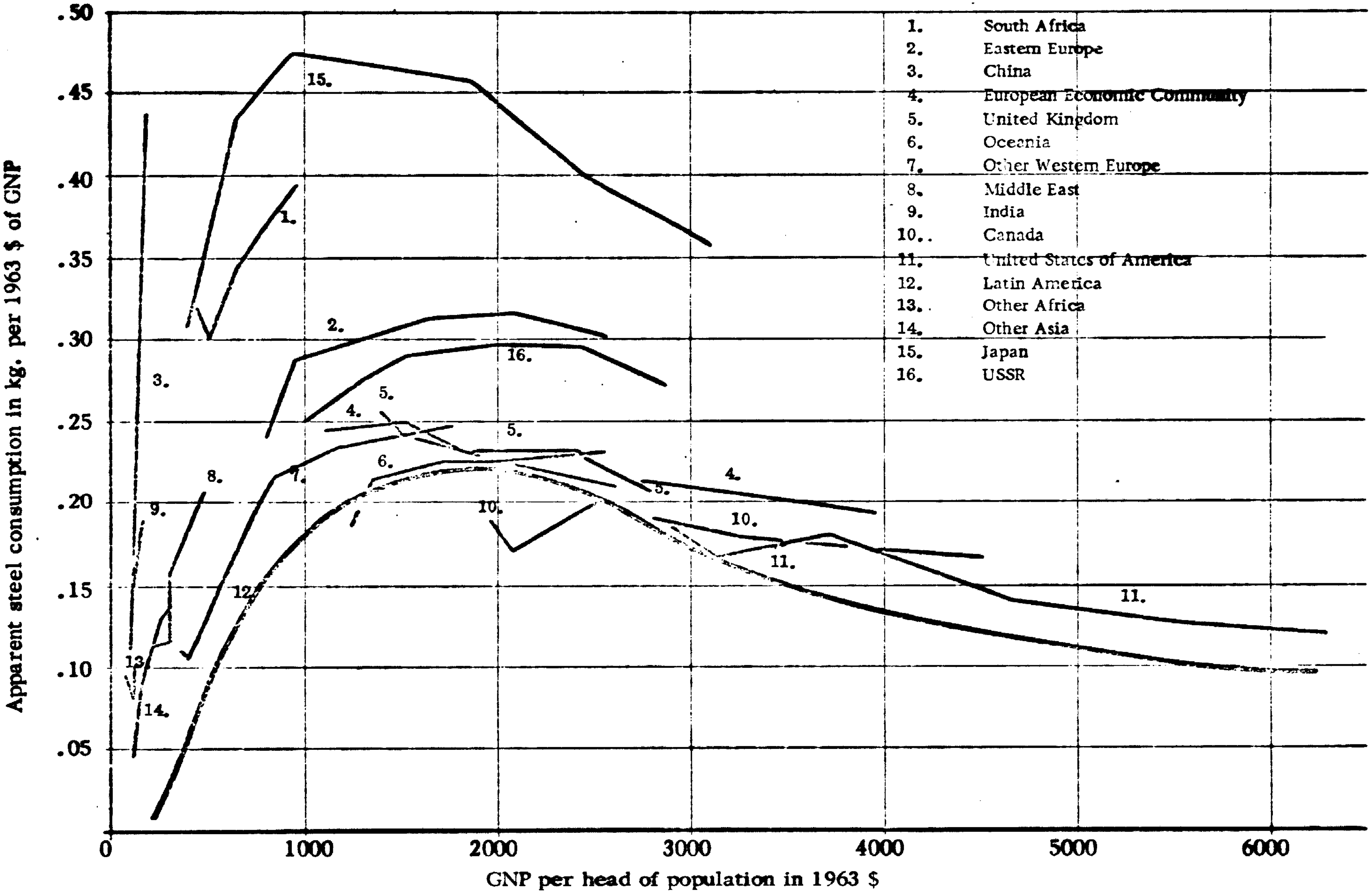

FIGURE 30.1 - STEEL INTENSITY CURVES (APPARENT STEEL CONSUMPTION PER HEAD OF POPULATION)

Based on Projection 85: World steel demand IISI Brussels (1972)

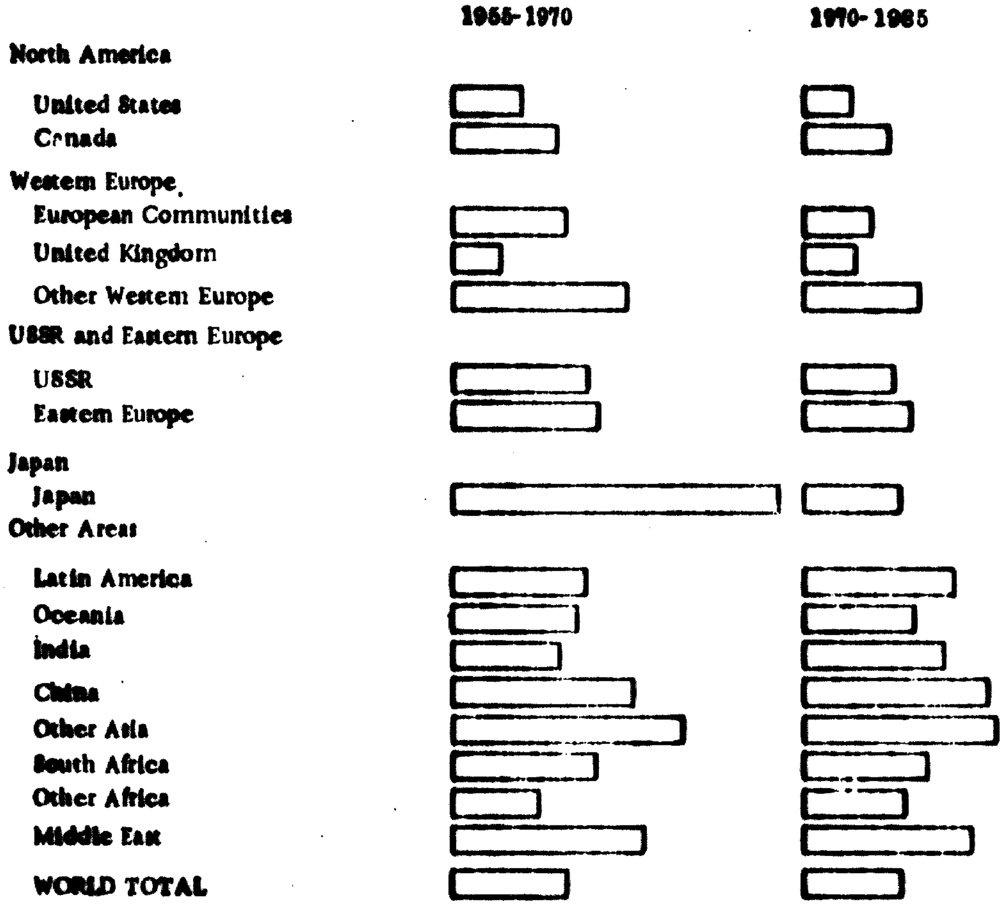

FIGURE 30.2 - STEEL CONSUMPTION GROWTH RATES
(PERCENT PER ANNUM)

Based on Projection 85: World steel demand IISI Brussels (1972)

	1960-62	1967-69	1985
North America	27	27	18
Western Europe	27	25	23
USSR & Eastern Europe	27	26	27
Japan	7	10	12
Other Areas	12	12	20
WORLD TOTAL	100	100	100

TABLE 30.3 - REGIONAL DISTRIBUTION OF STEEL CONSUMPTION (PERCENT)

Based on Projection 85: World steel demand IISI Brussels (1972)

30.2 Evolution of product mix

The development period of a predominantly agricultural country initially creates a steel demand which is largely for non-flat products, to meet the housing needs and railway construction programmes associated with this phase of development. An early steel production programme is likely to cover rails, sections and reinforcement steel, with any demand for other products still being met by imports. The result may be a small-scale, fragmented steel industry, based on re-rollers and semi-integrated plants - as, for example, in Africa, Italy and many Far Eastern countries - which can produce the non-flat products economically in small quantities.

It is the mechanisation of manufacture and distribution, together with the accompanying change in employment pattern and density of urbanisation, which bring the big changes in demand. Not only are there changes in total steel volume, but also large potential markets for specific products arise. It is at this stage that the choice of whether to make or import steel becomes critical, as in the long term the major manufacturing objective both for steel and for steel using goods is the supply of bulk low cost steel to known specifications to suit the mass market methods of modern manufacturing and distribution.

Manufacturing acitivities in their early stages create demands for a large range of products but limited in volume. While such markets are adequate for efficient local production of non-flat products, it is the income distribution effect on urban standards and on the mass demand for consumer durables that determines the timing and location of the installation of large modern flat product facilities. In small population centres, for example, Sweden, Yugoslavia or Eire, local production of vehicles or domestic appliances may be established for many years on imported steel supplies before the long term markets justify the scale of the modern steel flat product mills which are needed to compete on costs with delivered imports from large scale producers.

Changes in income levels and in income distribution have had a very marked impact on steel consumption and the growth of specific products within the EEC. Between 1952 and 1970 the rate of growth of production of flat products was nearly twice that of non-flats, as shown in Figure 30.4, and from 1970 to 1974 this divergence is expected to increase. This reflects the steel intensiveness of demand for vehicles as against say a similar demand for agricultural or construction output. For the most part this spectacular growth in finished flat products has been in cold reduced sheet. While some part of this growth was to meet not only direct steel exports but also exports of manufactures, the confidence in the internal economy and of rising personal incomes throughout the EEC were important factors in planning flat product capacity expansion on this scale, in view of the high capital cost per ton of modern finishing capacity.

An example of the relevance of income distribution to the demand for flat products is the USA. Here there is a broad platform of high incomes, and in this "replacement rather than repair" society, recent changes in real GDP of around 5 percent per year have been associated with changes up to 12 percent

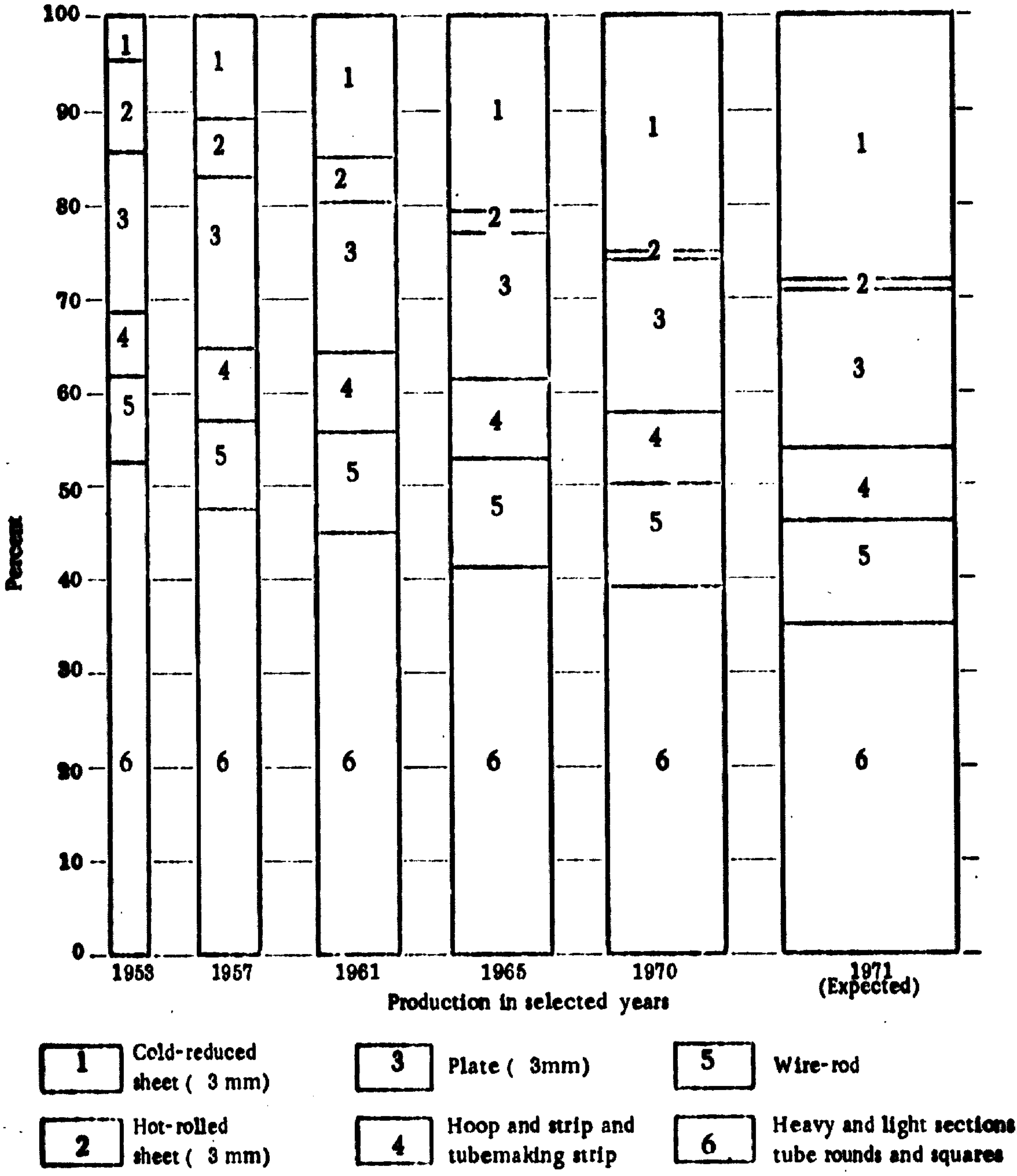

FIGURE 30.4 - BREAKDOWN OF TOTAL PRODUCTION OF FINISHED ROLLED PRODUCTS BY TYPES OF PRODUCTS

in the consumption of flat products, a large proportion of which is accounted for by the automotive industry. This same pattern, a faster relative growth of flat product production than of non-flat, is also observed in Japan, but in this case 30-40 percent of flat finished steel is directly exported and a drive on exporting consumer durables has been mounted.

The pattern of product mix development in Canada has been shaped and influenced on the one hand by an automotive agreement with the USA, and on the other by specialization in the manufacture and export of agricultural machinery, in which that country has achieved an eminent position. Consequently, the proportion of flat products in the consumption of steel in that country is relatively low.

A factor that can affect both the total consumption of steel and the development of the product mix is the extent to which other materials are developed to the stage at which they become competitive with, and may partly replace, steel. This aspect has been dealt with in Chapter 29.

CHAPTER 31 - TRENDS IN INTERNATIONAL STEEL TRADING

31.1 Balance of trade

Table 31.1 shows the relationships between production, consumption, imports and exports of steel by a number of countries. Japan can be seen from the table to have negligible imports, but exports account for 25 percent of her production. This is consistent with the analysis in Chapter 27, Article 27.7 of Japan's steel industry development, whereby her large production facilities are intended not only to serve her own markets, but also to form the basis for her export markets.

The position of the European Community as a whole is similar, with a low level of imports and a high level of exports, although not quite as high as that of Japan. However, if the individual countries within the Community are examined, a different picture is obtained. The figures in the table show that there is a considerable amount of trading between these countries. Even in countries such as France, where there appears to be a reasonable balance between consumption and production, the actual products which are produced and consumed are clearly different. The picture for Belgium-Luxembourg shows an extreme case of internationalisation of steel planning, in which a works has been built in that region to supply other countries within the Community. The implications behind the figures are that the pattern of development within each country's markets did not justify the unit of production which it was thought economic to install. The planning of facilities was, therefore, done on a regional market basis which, at any point in time, required the specialisation of production in different countries.

The lesson would appear to be that if a country wishes to be competitive then it must take due account of what it is possible to achieve within the steel industry internationally. It is clear from the export position of both Japan and the EEC that if the steel industry in a country or region is expanded in a modern economic manner, the potential for international trading is large. If trade in steel products could be negotiated in a similar manner to the EEC, the potential for some product specialisation up and down the coastlines of the Americas might also be realised.

TABLE 31.1

RATIOS OF IMPORTS, EXPORTS AND CONSUMPTION TO PRODUCTION

	Imports/ Production %	Exports/ Production %	Consumption/ Production %
France	39.6	39.9	99.7
W. Germany	25,9	36.9	89.0
Italy	31.7	15.8	115.9
Belgium-Luxembourg	14.7	90.1	24.6
Netherlands	94.0	90.3	103.7
ECSC as an entity	6.5	21.7	84.9
UK	10.0	18.9	91.1
USSR	2.7	7.0	92.4
Poland	15.9	16.8	99.1
Czechoslovakia	8.3	26.9	79.6
Japan	0.2	25.0	75.2
USA	12.6	5.0	107.6
Canada	16.0	20,2	95.7

Source : BSC Statistical Handbook (1969)
(**Statistics** for 1970 are incomplete)

Changes in stocks are not included

31.2 Geographical pattern of trade

In 1970 about 100 million tonnes of steel products were traded throughout the world. The level of steel production was about 590 million tonnes, and hence international trading was about 17 percent of production. However, some of this trading was within the European Economic Community (EEC) and was therefore not a real market opportunity for third parties. Of the 53 million tonnes of steel being exported by the EEC countries, 23 million tonnes went to countries inside the EEC. If the tonnage of internal trading is subtracted from the total figure for international trading, the remaining tonnage amounts to 13 percent of total steel production.

The three major traders, excluding the USSR from whom it is difficult to obtain data, are the EEC, Japan and the USA. These together account for 72 percent of the total amount of steel traded internationally. An overall breakdown of the pattern of importing by the various regions in the world is shown in Table 31.2, together with the three major sources from which they obtained their steel. Information on the trading between countries within the same geographical group is difficult to obtain. This table, therefore, represents only part of the steel which is traded, but is sufficiently complete to show the trading pattern.

The table shows that the geographical pattern of trade of the three major exporters is as follows :

(a) The European Economic Community countries which have about a 50 percent share of the international market, or about 33 percent if their own internal trading is excluded, are the major traders in Europe, the Middle East and Africa and to a lesser extent in the Western Hemisphere.

(b) Japan is dominant in trading in East Asia, Oceania, and the Western Hemisphere, but also has a large share in the markets of the Middle East and Western European regions, outside the EEC and EFTA areas.

(c) The USA has a much smaller share in any of the markets, but sells principally in EEC, EFTA, Western Hemisphere, and East Asia regions.

31.3 Products traded

International trading in steel products has also been analysed for five products :- plate (over 4.75 mm), wire rod, sheets (under 3 mm), tinplate and sections. The percentage of own production exported is summarised below :-

Plate - Belgium/Luxembourg exports 87 percent, Germany 30 percent, Japan 30 percent and France 20 percent.

Wire rod - Sweden exports 40 percent, and Japan and Germany 20 percent.

TABLE 31.2 - EXPORT TRADE IN SEMIS AND FINISHED STEEL PRODUCTS

(Millions of tonnes)

1968			1969			1970		
Country of destination	Main countries of consignment		Country of destination	Main countries of consignment		Country of destination	Main countries of consignment	
EEC: 18.68	EEC	16.87	EEC: 23.09	EEC	19.30	EEC 24.73	EEC	20.15
	Austria	0.64		USA	1.07		USA	1.95
	Sweden	0.41		Japan	0.95		Japan	0.95
EFTA: 5.99	EEC	4.29	EFTA: 7.79	EEC	5.41	EFTA 8.67	EEC	5.19
	Sweden	0.54		UK	0.67		USA	1.11
	UK	0.52		Sweden	0.67		UK	0.81
Other: 2.39 Western Europe	EEC	1.36	Other: 3.20 Western Europe	EEC	1.48	Other: 3.62 Western Europe	EEC	1.52
	UK	0.51		Japan	0.60		Japan	0.98
	Japan	0.13		UK	0.51		UK	0.50
Eastern: 2.34 Europe	EEC	1.53	Eastern: 2.39 Europe	EEC	1.52	Eastern: 3.62 Europe	EEC	1.63
	Austria	0.33		Japan	0.33		Japan	0.49
	Japan	0.21		Austria	0.28		Austria	0.23
Middle: 1.95 East (1)	EEC	1.16	Middle: 1.85 East (1)	EEC	0.83	Middle: 1.69 East (1)	EEC	0.81
	Japan	0.40		Japan	0.67		Japan	0.61
	UK	0.29		UK	0.25		UK	0.19
East: 4.33 Asia	Japan	2.11	East: 6.06 Asia	Japan	3.97	East: 6.80 Asia	Japan	4.05
	EEC	0.93		EEC	0.75		USA	0.75
	UK	0.49		USA	0.60		EEC	0.71
North 16.21 America	Japan	6.73	North 13.28 America	Japan	5.61	North 13.24 America	Japan	5.97
	EEC	6.48		EEC	4.76		EEC	4.33
	UK	1.25		USA	0.94		Canada	1.13
	Canada	1.13		UK	0.92		UK	0.88
Other: 2.29 Western Hemisphere (2)	EEC	0.80	Other: 3.83 Western Hemisphere (2)	Japan	1.38	Other: 3.97 Western Hemisphere (2)	Japan	1.52
	Japan	0.58		USA	1.06		USA	1.10
	USA	0.44		EEC	0.96		EEC	0.89
Africa: 2.29	EEC	1.56	Africa: 2.34	EEC	1.51	Africa: 2.94	EEC	1.63
	Japan	0.31		Japan	0.49		Japan	0.79
	UK	0.26		UK	0.22		UK	0.28
Oceania: 1.61	Japan	0.87	Oceania: 1.88	Japan	1.07	Oceania: 2.10	Japan	1.26
	Australia	0.40		Australia	0.52		Australia	0.42
	UK	0.17		UK	0.13		USA	0.13
Total: 59.57	EEC	35.29	Total: 66.04	EEC	36.67	Total: 70.77	EEC	37.12
	Japan	12.55		Japan	15.29		Japan	17.56
	UK	4.18		USA	4.76		USA	6.52

(1) Middle East: Bahrain, Egypt, Iran, Iraq, Israel, Jordan, Kuwait, Lebanon, Saudi Arabia, Syria, other Arab States.

(2) Other Western Hemisphere: All American countries other than USA and Canada.

Source: BSC (Statistical Services) World Trade - Steel

Sheet - Germany, France and Japan all export about 30 percent.

Tinplate - Japan, Germany, UK and France all export about 30/40 percent.

Light Sections - West Germany and Sweden export about 20/30 percent.

31.4 The trading pattern and its evolution

The structure of markets served by steelworks in the world to some extent reflects the evolution of those working during a number of development and recession phases. The steelworks of Japan were designed initially for export as well as domestic consumption under pressure to earn foreign exchange; those of the ECSC were built up after the last war to contribute to reconstruction and subsequently evolved to match export opportunities and the rising economic prosperity of the EEC as expressed in demands for steel for consumer durables; while those of Poland and Czechoslovakia were designed largely to provide engineering goods for COMECON and specific steels products for the USSR. The UK steel pattern is an example of changing market pressures; it was based originally on exporting engineering goods, but the traditional steel export markets are changing with the industrialisation of those countries. Imports and exports of steel now tend to fluctuate in response to the trend in home demand. The USA steel pattern exemplifies a transition from a phase during which domestic steel was challenged by imports on a large scale to a phase in which American steel is becoming increasingly cost competitive overseas, as the incorporation of new technology proceeds. Only the USSR is self-sufficient in steel. Any development of a steel industry today on a large scale will need to look to competition from Japanese and ECSC steelmakers.

The analysis of the pattern of international trade suggests that the total trade has three major constituents:

- Community trading within confined geographical areas.
- Trading arising from capacity planning.
- Opportunity trading.

The EEC has not only demonstrated the high levels of community trading possible within a geographical trading area, but has now regained the high position in international trading that its constituent members held in pre-war days. This results from product specialisation to sell in rapidly growing markets, which was then found to give a competitive edge with which to penetrate international markets. The development of highly efficient sales organisations to handle the large changes in output as modern units came on stream has also played an important role.

Capacity planning for the home and export markets is one of the features that have contributed to the emergence of Japan as a major international steel producer. In particular, the ability to export flat products permitted a production strategy based on high capacity mills, which at high levels of utilisation provide considerable economies of scale. It is also significant that this production and marketing strategy was one which it was not possible, at that time, for her customers or even her competitors to pursue. On the one hand the size of production units which Japan was installing were far too large to be contemplated in the export markets with which Japan trades. On the other hand, the rate of growth of a number of her nearby competitors was not such as to be able to justify such large units.

Finally, it would appear that many steelworks indulge in what has been described as opportunity exporting, in which they seek, at any point in time, to utilise a capacity which is in excess of that required for the home market.

However, this is a highly competitive market associated normally with the trading of small tonnages of products at low price levels, and the opportunities may arise in any geographical area.

31.5 Trade in semi-finished products

Reference has been made earlier to the way in which the factors which will determine the world pattern of production have changed and will continue to change. The question then arises as to what impact these changes might have on international trading. Although the patterns of trading described above may persist, there is one further area in which a new kind of trade could be initiated, the trading of semis of which, at the present time, only a small tonnage is traded internationally.

With the major increase in the international trade in iron ore and coal, a great many countries are in effect involved in the international production of steel. The growth of steel-using industries in many countries has contributed to the international demand for steel and, inasmuch as this arises from traded manufactured goods, the search for sources of low cost steel will continue. The significance of overseas markets to producers using large scale plant, and the scale of international investment in iron ore extraction and distribution lead major steel producers to consider participating in the building of steel works in a foreign country.

There are no examples of companies setting up such a pattern at the present time though, in the past, there were British and German ventures overseas. The British Steel Corporation has been looking into the possibility of investing in such a works; some examination of this prospect is also being made by Japanese and other European steelmakers. The existence of a number of examples of Japanese, German, Belgian and British financial participation in steel companies in other countries suggests that general acceptance of the internationalisation of steel production may not be far away.

One of the major practical problems is the transportation of the products. The rapid increase in the trade of iron ore was associated with the development of the bulk carrier. At the present time, quoted rates for the transport of iron ore and for semis or finished products are different, because iron ore is transported regularly in bulk whereas products tend to be transported on a part cargo or special shipment basis. Sophisticated handling facilities have already been developed for iron ore, but handling products presents greater problems.

If similar effort were devoted to the design of shipping and handling facilities for semi-finished products, it might well be that the differential in the shipping costs of iron ore and semis could be considerably reduced. The question of siting facilities is one of optimising the transport costs from the iron ore mine to the final consumer, and it may well be that until the design problems of shipping products have been settled, the commercial issues which are also significant will not really be tackled. Clearly the building of an export-oriented works on this basis would not be undertaken until some form of contract with consumers had been established. There still remain other commercial problems; if the consumer is rolling finished products to order, the delay occasioned by shipping may impose too great a restraint on delivery times or, alternatively, require rolling of semi-finished products to stock.

31.6 Home prices

Technological innovation tends, in the long term, to lower prices. This effect is illustrated in Figure 31.1. The Danish market was chosen as an example because there have long been no tariffs on steel products and the market is completely free to outside influences. Its nearness to Europe means that it reflects developments within the steel industries of the ECSC. Consequently, prices are as low as in the international market and fluctuate accordingly.

The actual price of merchant bars sold in Denmark has been steadily increasing, but when corrected for movements in the wholesale price index of domestic goods, it can be seen that the real price fell between 1.5 percent and 2 percent per year in relation to the price of other goods. The falling trend is not surprising in view of the product specialisation taking place within European steel industries, and the level of investment, somewhere between US $800 and 1000 million per year, in the decade 1958-1968.

Technological changes produce stresses within markets because they are not instituted at the same time in all works, but are spread over a period. Price leaders who are the first in the field with a technological advance will therefore cause difficulties for those works or countries that are not in a position to make such a change at that point in time. Similarly, the sheer output of a modern steelworks coming on the market in any one year could have a considerable impact on price levels for specific products in certain geographical areas. Complaints voiced in the past few years by individual steelworks in different countries of the ECSC concerning the price of specific products suggest that the price leadership from the newest works is reflecting their low costs.

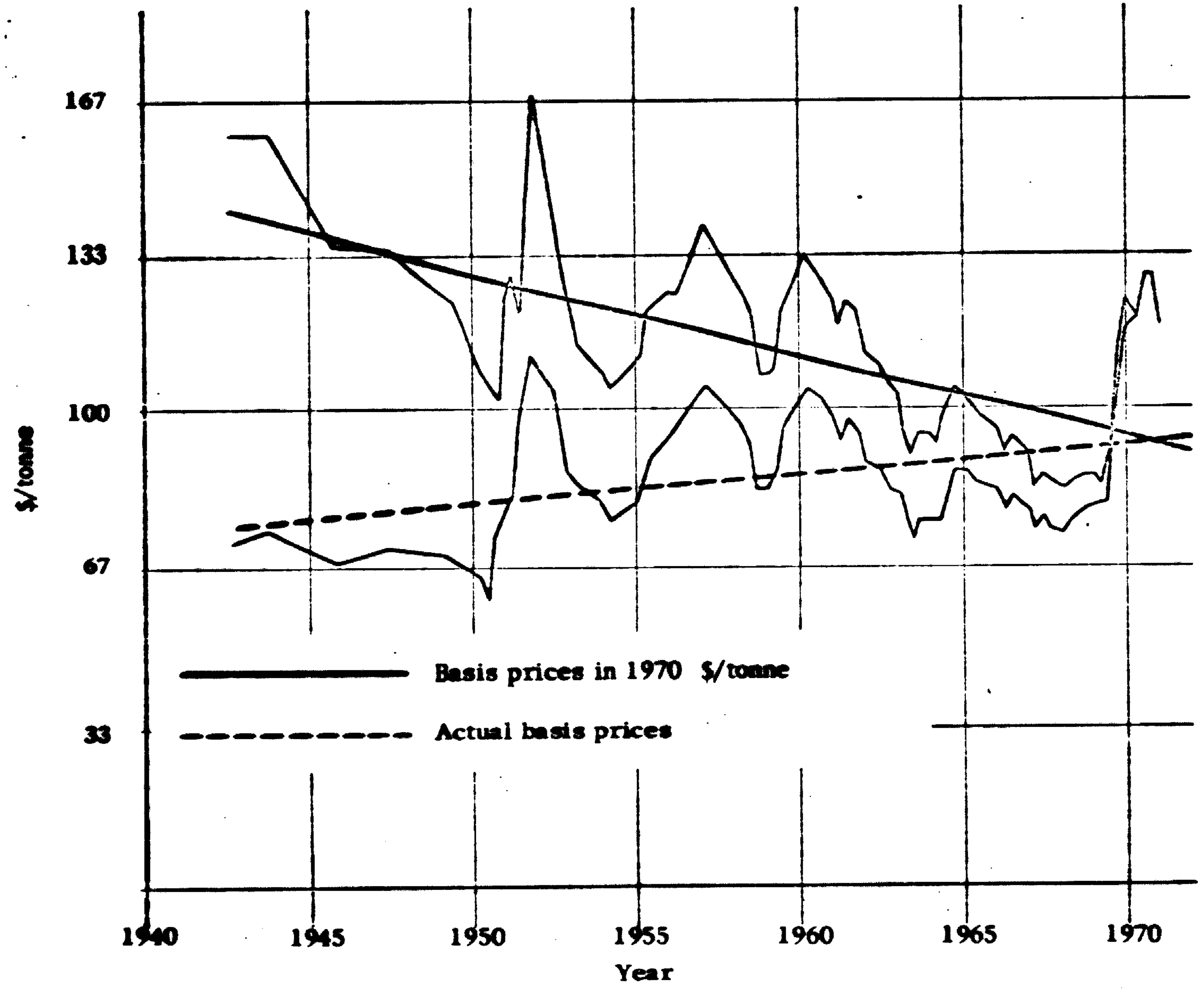

FIGURE 31.1 - PRICES OF MERCHANT BARS IN DENMARK

Table 31.3 compares indices of steel prices in 1970 in terms of the monetary values of those countries, and in their real terms after correction for inflation since 1953. In monetary terms, the prices of steel products of Italy and West Germany have shown the least increase since 1953, and it will be recalled that investment in modern steel technology not only represents the major portion of capacity in these two countries, but has been developing at its fastest pace since 1965. This small change also reflects the high base prices in 1953, those in Italy due to protection and those in West Germany to its early leadership in a seller's market. The UK price movements, on the other hand, started from a very low base price because of a policy of supporting engineering exports by cheap steel. This low price policy in conjunction with the low elasticity of steel to growth in GDP in the UK were unattractive conditions for investment in steel, as evidenced in the low figures in Table 27.3 (Chapter 27). A significant proportion of capacity is still based on older steel technology, and even higher prices may be required to bring the kind of earnings its competitors in Germany and Japan have enjoyed. The rapid rise in steel prices in France reflects the general pressure on costs from rising incomes and competing developments.

TABLE 31.3 - 1970 STEEL PRICE INDICES, 1953 BASE

Country	Industrial Price Index mid-1970 1953 = 100	Billets		Wire rods		Light Merchant Bars		H.R. Strip	
		(a)	(b)	(a)	(b)	(a)	(b)	(a)	(b)
France	181	213	118	204	113	202	112	197	109
U.K.	158	169	107	179	113	162	103	137	88
Belgium	136	143	105	143	105	151	111	138	101
Luxemburg	136	120	88	155	114	149	114	137	101
Netherlands	130	-	-	145	112	136	112	126	97
Italy	130	94	72	114	88	101	88	100	77
W. Germany	114	113	99	112	98	112	98	100	94

Notes:

(a) at 1970 money values

(b) corrected for movement in the industrial price index 1953-1970.

31.7 Export prices

Figures 31.2 and 31.3 give published Japanese and European producers' export prices for certain steel products.

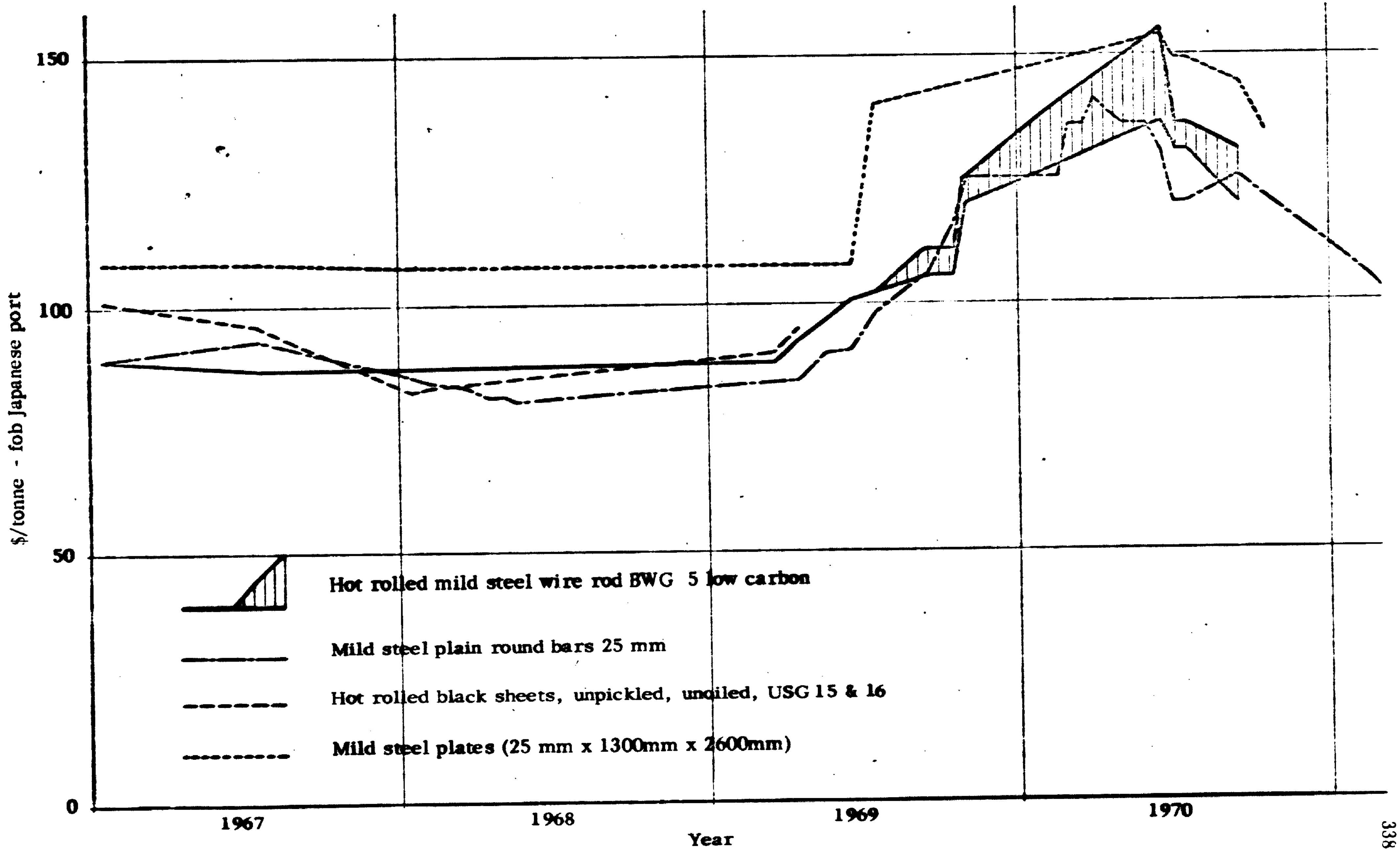

FIGURE 31.2 - JAPANESE EXPORT PRICES

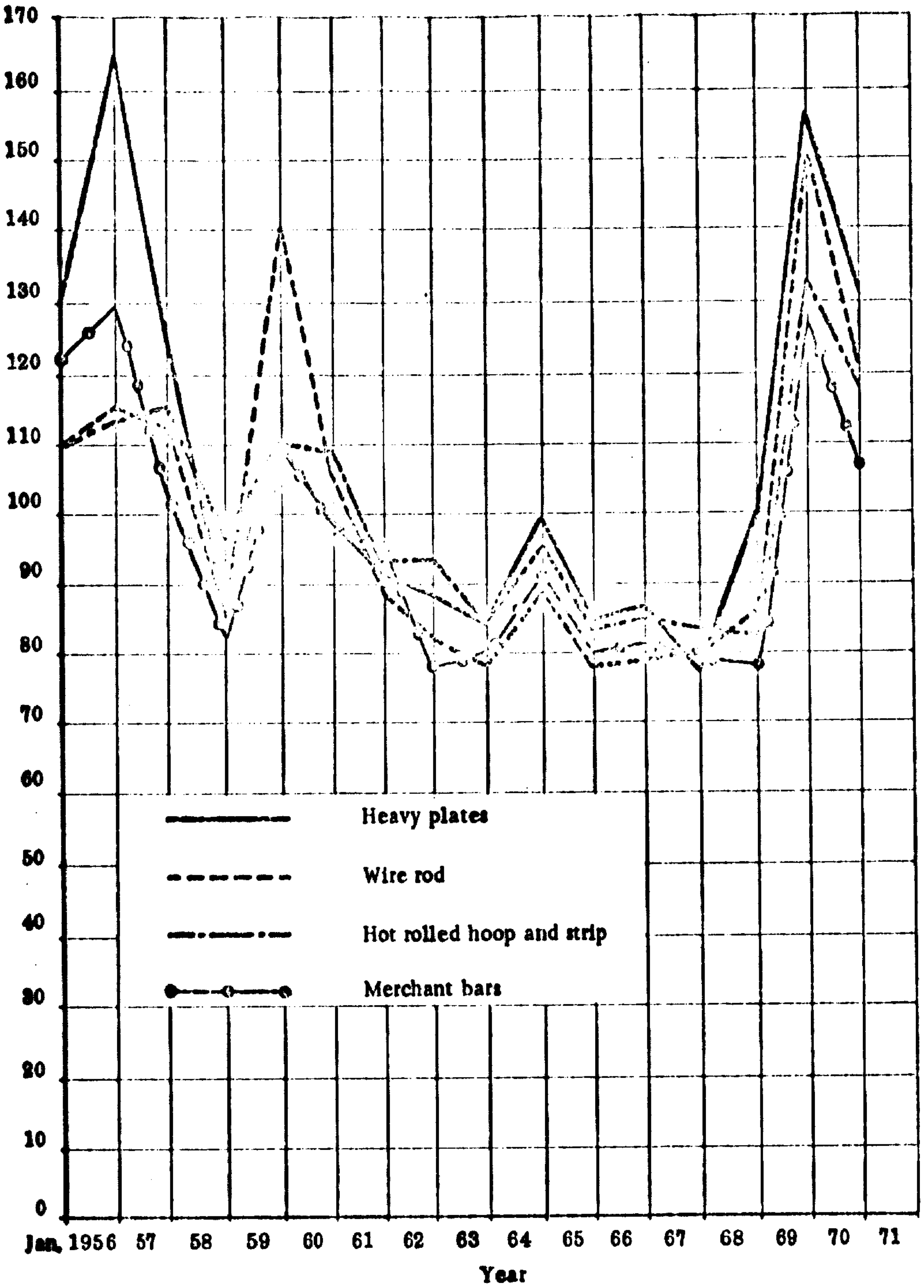

FIGURE 31.3 - EUROPEAN PRODUCERS' EXPORT PRICES FOR CERTAIN IRON AND STEEL PRODUCTS

Export prices fluctuate to a greater extent than home prices. Over a period of time, the trend of the low export prices for substantial tonnages gives an indication of change in the marginal production costs of the steelworks, for in difficult trading conditions prices will tend to fall to the costs of the newer works incorporating the latest technology and economics of size. For a short period of time these works can sell at prices nearer to marginal costs than to average costs, but clearly over any length of time there must be a movement so that total costs are covered. As can be seen, the Japanese fob prices of rods, bars and black sheets during the period 1967-1969 were between $80 and $90 per tonne which is very similar to European export prices of similar products during that period. During the same period the fob price of Japanese plates was higher than that of European: this may reflect the internal Japanese price, for at that time there was a pressure of internal demand for shipbuilding plates and the proportion of production exported was below 20 percent.

The practice of differentiating between home and export prices in steel products is diminishing, especially within the ECSC where export markets are planned as part of the product specialisation within the area, and increasingly so in Japan, where a high proportion of specific products are exported and there are large tied markets at home.

31.8 Price fluctuations

Late 1969 to early 1971 was a period when steel export prices rose dramatically above the long term costs of production. This price boom was due more to fears of rising prices than to a major upsurge in consumption. In the UK, for example, there was a stockbuilding boom in anticipation of major changes in BSC list prices, and actual consumption changed very little. In the USA, during a period of replacement and expansion of steel capacity, a high level of steel prices was maintained by steelmakers notwithstanding excess capacity in older steel plant. Substantial quantities of Japanese steel were attracted by this more profitable market, even though there were rising pressures on capacity from Japanese home demand. Within the EEC there were genuine consumption demands for steel.

A number of changes have since taken place. Chief among these are BSC price increases and the voluntary limitation on steel imports into the USA. But there could be another stockbuilding boom due to genuine anticipated demand factors at any time.

31.9 A comparison of delivered price and basing point pricing systems

On the delivered price system the price charged is independent of the distance from the works, and therefore the net income per tonne of product and hence the contribution to fixed costs and profits is reduced by the extent of the transport costs as distance from the works increases. Although the presence of other works may affect sales volume, they do not influence the contribution obtained from each tonne of product delivered to a given customer.

On the basing point system, as in force within the ECSC, each works declares its prices at a named basing point, which is usually either at the works or a major town in its vicinity. Customers then pay freight from the basing point to the point of delivery. Other works have the option to sell to a given customer at the lowest price quoted by competitors to that customer, but they must quote in the first instance at their own published base price plus freight (also published). Each works may fix their own prices at their own basing point, and may alter them at will, provided they report such action to the Commission. In practice, a group of works in one general location may use a single basing point.

Figure 31.4 shows as an example the effect of the two pricing systems from the viewpoint of a works A. The abscissa represents distance from the works and it is assumed that the cost of delivery is proportional to the distance.

Part I of the figure shows how the net income falls off with increasing distance from the works under the delivered price system. Part II illustrates the operation of a basing point system where Works A is in competition with Works B and C. For simplicity it is assumed that each works sells the product at the same price at a basing point located at its works. As the delivery distance from the works is increased, the delivered price rises, and the net income (and hence the contribution) remains constant. However, after a point midway between two works is passed, the delivered price from the other works is lower, but Works A is allowed to equalise his delivered price with the other works. If Works A does this, then when the midway points (p and q on Fig. 31.4) are passed, the net income falls rapidly with increasing distance, because Works A's transport cost continues to rise, whilst the delivered price is falling. After Works B and C are passed the delivered price rises again and the contribution becomes constant until another works is approached.

Thus on the delivered price system the attractiveness of an order - as measured by its contribution per tonne - falls off steadily with increasing distance from the works. Deliveries to very remote parts could even result in a loss to the company if the fixed price is adhered to.

On the basing point pricing system, each works has a 'zone of influence' around it in which the contribution per tonne is constant, and thus orders delivered to any point within this zone are equally attractive to the works. However, outside this zone - the boundaries of which are determined by the location of the competing firms - the attractiveness of an order falls off rapidly as the contribution is reduced by the difference between the transport costs from the works under consideration and the transport costs from the nearest supplier.

Because the basing point system encourages works to concentrate sales within their zones of influence, it is economically desirable,as it tends to reduce unnecessary transportation, whilst it does not penalise a works for supplying a distant customer who cannot obtain alternative supplies. The basing point system may have an application in any large region where transport costs are a significant element in pricing policy.

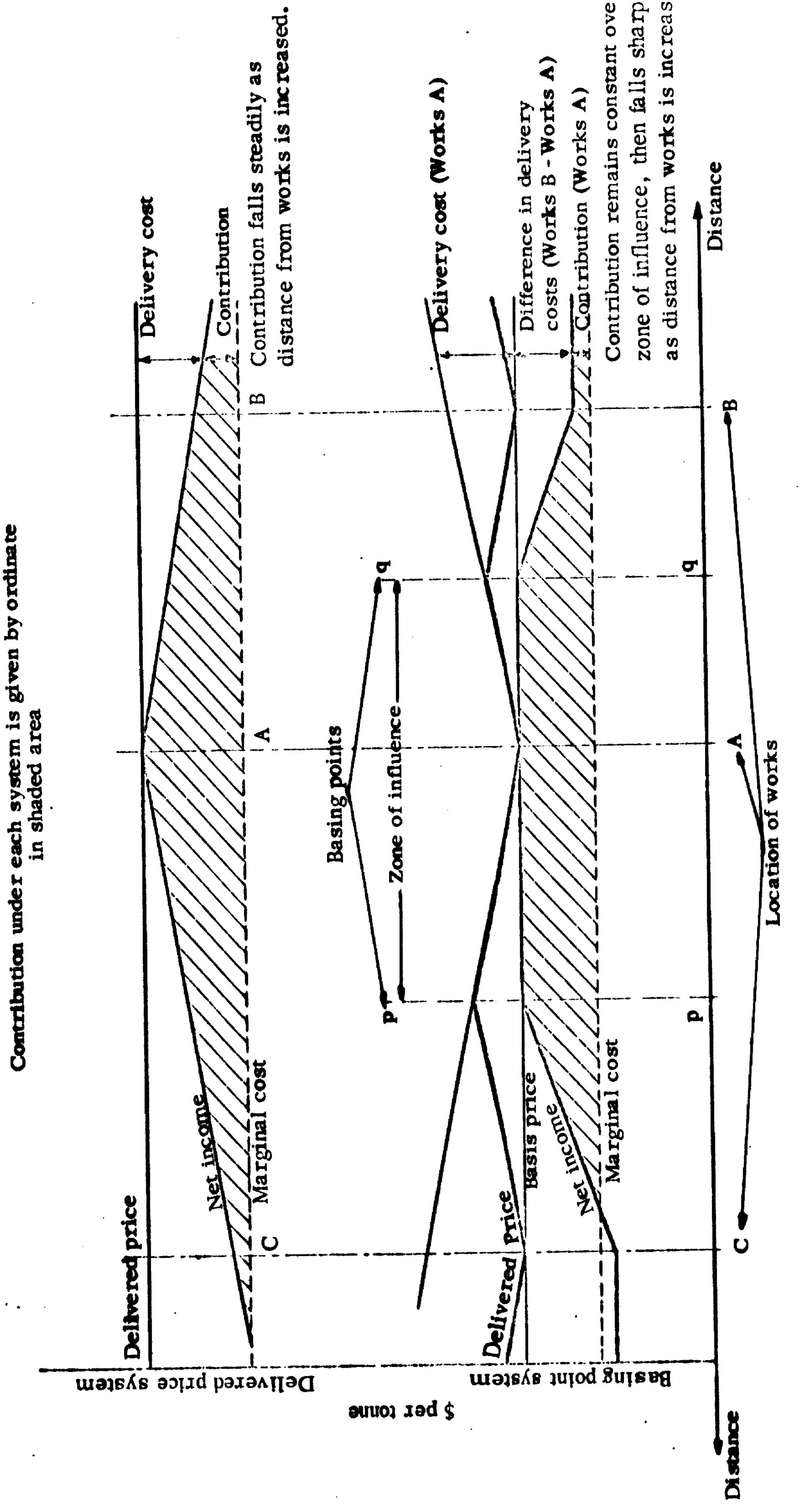

FIGURE 31.4 - COMPARISON OF DELIVERED AND BASING POINT PRICE SYSTEMS

31.10 Profitability of steel industries

Japan

In Table 31.4 the profitability of the Japanese steel industry is compared with that of Japanese industries in general. To gauge the profitability of steelmaking in Japan, some understanding of its financing is essential. The industry's total net debt, short and long term liabilities, have been increasing; between 1965 and 1970 its capital gearing had risen from the already high value of 72 percent to the even higher 83 percent. Gearing in manufacturing generally is also high, but rose less fast, from 70 percent in 1965 to 78 percent in 1970.

This was a period of relatively low and stable interest levels; the bank discount rate, which influences the general trend of interest rates, fluctuated only between 5.48 percent and 6.25 percent. Thus an increasing proportion of capital charges was required to be met at a relatively low rate of return. While total assets rose from about $3,700 million to $7,600 million in 5 years, shareholders' funds rose from only $1,000 million to $1,300 million in the same period.

The value added to materials index in the iron and steel industry (1965 base 100) grew to 231 by 1970, compared with manufacturing at 218, or all industries at 214.

As can be seen from the Table 31.4, productivity changes due to improved steel technology significantly reduced the labour cost component of value added. The highly geared financing during the industrial boom permitted a high rate of depreciation to be maintained, so that considerable investment could be financed internally without going to the market, and a policy of early replacement, incorporating the latest technology, could be pursued.

Net profit before tax rose from 3.2 percent of sales in 1965 to 6 percent in 1970. Gross profit before payment of interest or charging depreciation rose from 16 percent of sales in 1965 to 18 percent in 1970.

The intensity of use of total capital also increased during this period, the turnover ratio of total assets increasing from 0.6 in 1965 to 0.8 in 1970. This would give a gross return on total assets, before payment of interest, tax or depreciation, of 10 percent in 1965 and 14 percent in 1970. Expressed as a return on shareholders' funds after interest payment, but before charging depreciation, this would give 20 percent before tax in 1965 and about 70 percent in 1970. The policy of a high rate of depreciation practiced in Japanese steel would reduce the profit, after payment of interest and depreciation, to about 7 percent of net worth in 1965 and 28 percent in 1970, before charging company tax.

The profit after tax, depreciation and interest charges, rose from 1.4 percent of total assets in 1965 to 3.8 percent in 1970. It is important to recall that the total assets more than doubled during these five years, so it is an increasing rate of return on an increasing capital base, and that the servicing cost of the debt, that is of about 80 percent of the capital base, has already been

TABLE 31.4 - PROFITABILITY ESTIMATES, STEEL AND MANUFACTURING, JAPAN

	Iron and steel			Manufacturing industries	
	1965	1968	1970	1965	1970
	$ x 10^6	$ x 10^6	$ x 10^6	$ x 10^6	$ x 10^6
Estimated total assets (debt plus net worth)	3,700*	5,600*	7,600*	24,500*	38,000*
Estimated net worth	1,000*	1,100*	1,300*	7,600*	8,300*
Sales	2,300	3,900	5,900	17,500	38,000
Net profit before tax (after interest and depreciation)	75	180	360	750	2,300
Estimated net profit after tax	53*	150*	280*	560*	1,500*
Turnover ratio (sales/total assets)	0.6	0.6	0.8	0.7	1
	percent	percent	percent	percent	percent
Capital gearing (debt proportion of total assets)	72	80	83	70	78
Gross return (profit before tax, interest and depreciation)					
on total assets	10 *	12 *	14 *	10 *	14 *
on sales	16 *	17 *	18 *	14 *	14 *
Net profit before tax return on: sales	3.2	4.6	6.0	4.3	6.0
net worth	7 *	16 *	28 *	10*	27*
Net profit after tax return: Total assets	1.4	2.7	3.8	2.3	4.0
on net worth	5*	13*	21*	7*	18*
Wages as a proportion of value added	43	41	38	42	41
Wages as a proportion of sales	14 *	13 *	12 *	11 *	12 *

Sources: Statistical Year Book 1971, The Japan Iron and Steel Federation.

Notes:
1. *Estimates are calculations from reorganised data.
2. The above information relates to industry aggregates, and as such can be influenced by a few single large results: it does not reflect the median characteristics of the companies.
3. Depreciation in iron and steel, excluding land and working capital, appears to be around 10 percent per annum.

paid. Related to shareholders' funds, net profit rose from 5 to 21 percent between 1965 and 1970 for the whole industry, though this would have varied from company to company.

In 1965, after 10 years of major investment in the industry, expanding its output from 9 million to 41 million tonnes of crude steel capacity, the return on shareholders' funds, after payment of interest, depreciation and company tax, was 5 percent. This figure was below the average return to shareholders in manufacturing industry as a whole, which was similarly high geared, but was similar to the general level of interest rates. Returns to steel shareholders were thus not attractive to raising equity and it is interesting to note that by 1970 steel capacity gearing stood at 83 percent while that of manufacturing generally stood at 78 percent.

This high gearing generally signifies the low priority of shareholders' objectives in Japanese industry, and highlights the capability of banking and government institutions to mobilise the savings of individuals and organisations. Without both the social custom of saving and this mobilisation, the total cost of steelmaking and selling would have been higher and higher steel prices would have been necessary. Modern techniques permit operating economics in resources used, but the price level will reflect the level of labour and capital costs in the country, which in turn reflect attitudes to work, managerial objectives and general educational levels. The impact of Japanese steel price trends on world steel prices has been significant, for it has come not only from modern technology, but from typical social factors, namely high capital gearing at modest interest rates and secure labour contracts which have demanded high educational standards. These may not be transferable to other locations.

By 1970 Japanese crude steel output reached 93 million tonnes, similar to that of the ECSC as a whole, and approaching the USA and USSR outputs. Steel exports constituted over 25 percent of production, and in the higher value-added flat products and special steels the proportion was much higher. Export profitability was essential, and it was thus constrained externally and internally from deviating too often or for too long periods from total-cost based prices.

In the period 1965-70, both the gross return to capital and the return to equity shareholders increased. The 1970 results to some extent reflect the export trade price boom, but because increased capital utilisation is significant in capital intensive industries, a net after-tax return to total assets of about 3.5 percent would probably have been achieved, with a net availability to shareholders' funds of about 20 percent. Seen from the position of 1965, the total-cost based 'low' price of steel has paid off, in the context of expanding markets and capacity planning, and raising equity finance in the years ahead should now be attractive.

The close identity of objectives of industry and government in national planning and in the actual commitment of resources in Japan has permitted steel to be developed at a gross return to capital similar to manufacturing generally, but for a long period at a less net return to shareholders' funds.

Germany

High annual investment in steel and high capital gearing have been pursued in Germany. From the incomplete evidence on profitability given in Table 31.5, it appears that net profit after tax, interest and depreciation in 1968/69 was below that in Japan. Turnover of capital, that is sales/assets, appears to be slightly higher than that in Japan, and differences in taxation, interest rates and depreciation policies are therefore the most likely explanation of the lower net return to assets in Germany.

TABLE 31.5 - INDICATIONS OF PROFITABILITY IN STEEL IN GERMANY, 1968/69

(This is based on the combined results of two of the leading steelmaking groups)

	$ million
Sales	2,753
Assets net of depreciation plus current assets	2,400
Net worth	625
Net profit after tax	53
	Percent
Capital gearing (debts as a proportion of total assets)	74
Net profit after tax return on:	
Sales	2.0
Assets	2.2
Net worth	8.5

Source: Fortune

Compared with Japan, interest rate levels during the 1960's have not been too dissimilar, the discount rate rising from 3 percent to 6 percent and mortgage bond yields and local authority bond yields being around 7 to 8 percent for most of the period.

Tax rates in the two countries differ according to both the level of profits and whether distributed or retained. From 1962 to 1970 the top corporation tax in Germany was 51 percent but distributed profits attracted only 15 percent tax. The general level of 40-45 percent compares with not more than 30 percent in Japan.

Pre-tax gross returns on total assets are very similar in Japan and Germany, but the German steel industry will be more sensitive to post-tax returns on shareholders' funds; while high capital gearing is not unusual historically in Germany, much of manufacturing is now more equity based, and equity shareholders' objectives play an important role in German business. Thus the low net return to shareholders' funds would be viewed much more seriously than the Japanese lower return of 1965, even though it constitutes such a small proportion of steel capital.

U.S.A.

Aggregate financial information of the top 30 companies is set out in Table 31.6. The capital is not highly geared: this is in line with the general preference for equity financing in American manufacturing, and the prominence of equity shareholders' objectives in American business management and in social values.

Comparing 1969 and 1970 there is a collapse in absolute profits, and in all the profitability measures. Sales revenue declined by only 0.5 percent, but employment costs rose 2.7 percent, and operating cost s rose so that the gross return declined by 23 percent. The heavy incidence of service charges and depreciation left a net profit before tax nearly 50 percent lower than that of 1969, and total assets 1.9 percent greater from the investment programme still under way. This net profit was soon restored by the second quarter of 1971 when sales revenue rose by 20 percent and gross return by 60 percent. By then, increased prices and increased capacity usage had resulted in a net profit to shareholders' funds of 15.2 percent before tax, 8.5 percent after tax. The combination of excess capacity, a fundamental investment programme with all the reorganisation it entails, and increased wages has produced a highly volatile profitability record.

Steel industry profitability in 1970 and 1971 was below that of manufacturing industries generally, in contrast to the position of Japan. The gross return on total assets was considerably below that of Japan in 1970, but the 1969 value of 12.4 percent was similar to that of the Japanese steel industry in 1968. Figures for Germany also result in a 12 percent gross return on total assets in 1968-1969 if calculated with the Japanese depreciation rate.

Conclusions

A gross return on total assets of 12-13 percent appears to be appropriate to a modern iron and steel industry when the technology has been consolidated. This is higher than in the past, possibly to accommodate the higher depreciation policies relevant to a changing technology compared with past norms.

Differences in gearing, interest rate levels, taxation and depreciation policies, result in different allocations of the gross return of 12-13 percent on total assets when expressed as net profit available to equity shareholders. Whether the equity return in steel is called good or bad, depends on the social values of the business community and of the Government concerned rather than

TABLE 31.6 - PROFITABILITY OF THE USA IRON & STEEL INDUSTRY

	Top 30 Companies		All Companies	
	1969	1970	4th qtr 1970	2nd qtr 1971
	$10^6 \$$	$10^6 \$$	$10^6 \$$	$10^6 \$$
Net Sales	19,400	19,300		~ 23,000*
Net Worth	12,700	12,750		
Employment costs	7,440	7,640		
Total assets(short and long debt and net worth)	21,400*	21,800*		31,000
Net profit before tax (a)	1,340	690		
Depreciation, depletion (b)	1,060	1,060		
Interest, expense on long term debt(c)	250	290		
Gross return (a+b+c)	2,650*	2,040*		~ 3,200*
Net profit after tax	890	510		
Turnover ratio (sales/total assets)	0.9*	0.9*	0.9*	1.1*
	percent	percent	percent	percent
Capital gearing(debt proportion of total assets)	41*	42*	46	46
Gross return:				
to sales	13.7	10.6		
to total assets	12.4*	9.4*		
Net profit before tax return to sales	6.9	3.6	1.5	7.3
Net profit after tax return to total assets	4.2*	2.3*	1.4	4.6
Net profit before tax return to net worth	10.5	5.4	2.5	15.2
Net profit after tax return to net worth	7.0	4.0	2.5	8.5
Employment costs as a proportion of "value added"	74 *	79*		
Employment costs as a proportion of sales	38	40		

Sources: Industry Week
Quarterly Financial Report Federal Trade Commission

Notes:

1. *Estimates are based on reorganised data.
2. "Value added" estimated as an aggregate of gross return plus employment costs; as such it was low, for data on rents, rates, leasing etc. was not available.
3. The information is based on aggregates; as such it can be influenced by a few single large results.
4. 1969 and 1970 depreciation expressed as a percentage of net property, plant and equipment was 7 - 8 percent.

on industry comparison between countries. International investment in steel will continue to reflect this aspect.

To pursue a policy of steel development may require a general industry or public commitment to giving the industry the period it needs to consolidate its experience of the newer technologies, and not applying the short-term profitability horizons of the free capital market. To pursue such a development with high capital gearing in order to provide total cost-based 'low' pricing, may require a commitment to periodic financial support if the long-term management of the economy falters in its demand for steel below the agreed capacity planning; without such a commitment, a policy of retaining a large proportion of profit, with consequently higher prices, may have to be pursued.

CHAPTER 32 - ROLE OF THE DEVELOPING COUNTRIES

In Chapters 27, 30 and 31 the trends in world production, consumption and international trade in steel in its various forms, have been discussed. It is now possible to consider the position of the developing countries. The countries taken to be in this classification are those so defined in the UNIDO report "Steelworks projects in developing countries".

World crude steel production has increased steadily over the past decade from some 350 million tonnes in 1960 to more than 590 million tonnes in 1970. The developing countries have, during this period, increased their production from 10 million tonnes to 28 million tonnes. Hence, over 96 percent of the world's production remains concentrated in the developed countries, most of it located in the highly industrialised centres of Europe, USA, USSR and Japan, where the trend has been to construct large integrated plants utilising much imported ore secured on long-term contracts from developing countries.

Process selection for the production of steel in the developing countries changes as the industry grows. It has been usual in the initial stages of industrial development to install rolling facilities only, for manufacture of rods and bars from purchased billets, and then to proceed through to scrap based steelmaking. Finally, there is the transition to the blast furnace/BOF steelmaking route. Developing countries which have completed this chain of development are Argentina, Brazil, India, Turkey and Mexico. Steel production in these countries represents approximately half the total produced within the developing world.

Expansion plans for the developing countries are summarised in Table 32.1. The projects have been listed under two headings:- agreed expansion plans and future intentions. The former category includes steelworks plants under construction (which in some cases may have recently come on stream) and agreed projects not yet under way. The second category includes both firm plans still awaiting formal agreement, and long term proposals which may never materialise. Most countries have plans of some kind, but as would be expected, the major developments are scheduled for those countries already having a heritage of iron and steel production and who have, therefore, a demand large enough to justify investment in larger, more economic plants. Those countries whose markets are at present only small are clearly planning to base their steel production on scrap melting and continuous casting.

TABLE 32.1 - EXPANSION PLANS FOR STEELWORKS IN DEVELOPING COUNTRIES

million tonnes per year

Country	BOF Route		Electric Arc Route (including direct reduction)	
	Agreed Plans	Future Intentions	Agreed Plans	Future Intentions
Algeria	2.50	-	-	-
Libya	-	-	-	0.32
Tunisia	-	-	-	0.05
Liberia	-	0.19	-	-
Nigeria	-	-	-	0.10
Angola	-	-	0.12	-
Zaire	-	-	0.15	-
Kenya	-	-	0.03	0.20
Uganda	-	-	-	0.10
Argentina	3.90	2.17	0.07	0.06
Brazil	5.33	5.90	0.95	0.60
Chile	0.34	1.00	-	-
Colombia	0.20	-	-	-
Peru	-	5.25	-	-
Venezuela	0.75	13.00	-	-
Mexico	4.17	2.00	1.60	0.70
Central America	-	0.11	-	0.29
Egypt	1.70	-	-	0.20
Iran	1.40	-	-	-
S. Korea	2.40	2.60	-	-
Malaysia	-	-	0.02	-
Philippines	-	1.50	-	-
Taiwan	-	2.30	-	-
Thailand	-	0.40	0.11	-
Ceylon	-	-	-	0.07
India	4.92	7.95	0.05	1.90
Pakistan	0.75	0.50	-	-
Greece	-	-	-	0.30
Ireland	-	-	0.06	-
Turkey	2.10	2.00	-	-

Note: All expansion plans are intended to be implemented by 1980.

Reference has been made in an earlier chapter to the future structure of the steel industries within the developed countries, and although it must be accepted that because of the massive capital investment involved, changes in the structure of the industry will not occur quickly, there is a possibility that future large scale production may be split into two units, one for basic steel-making to produce slabs, blooms or billets and situated close to the ore reserves, the other for rolling these into finished products located near to the markets. The underlying technological reasons for such thinking are the growing problems of siting and pollution.

Those countries who have large ore resources would have an important role to play in such a development. The massive capital investment, organisation of human resources and training to achieve the rapid transformation from a mining based industry to a manufacturing one requires close co-operation, even partnership, with the interested developed countries.

Such developments would also have an effect on the trading pattern of steel products. Semi-finished steel, blooms, billets and slabs could be marketed on the basis of secure long-term contracts which could influence the development of the steel industries in the smaller countries. Developments from scrap melting to iron and steel manufacture in small integrated works, which are questionable on economic grounds, may be superseded by purchase of semis from the large mine-based works, thus allowing better utilisation of available funds within those developing countries lacking iron ore resources of their own.

SECTION C

INDICATION AND ANALYSIS OF THE IMPLICATIONS OF THE TECHNOLOGICAL, FINANCIAL AND ECONOMIC TRENDS IN THE WORLD'S IRON AND STEEL INDUSTRY FOR THE LONG TERM PLANNING OF THE BRAZILIAN IRON AND STEEL INDUSTRY

CHAPTER 33 - EXPANSION OF THE INDUSTRY

The Terms of Reference commence with a brief statement of the expected demands for steel by the Brazilian economy during the 1970's. The statement continues - "to satisfy this increasing demand an expansion of the Brazilian iron and steel industry will be required, beyond that contemplated in the plan already available........ Accordingly, plans for expanding the steel production capacity may involve the addition of 10 - 15 million tonnes per year of new capacity until 1980, to reach an overall capacity of some 20 million tonnes per year by 1980." This expansion of production capacity is clearly not to be concentrated in one vast production unit, nor devoted to the manufacture of a single product. Thus, in order fully to assess the implications of trends in world technology for the planning of an expansion of this magnitude, the broad statement made in the Terms of Reference needs to be analysed in some detail. It is necessary to forecast the future demand for different products, or groups of products, which the Brazilian steel industry will need to supply, and to estimate what capacity the industry is likely to have available in 1980, both from the existing works and from the plan currently being implemented.

This chapter presents the available information on the likely future capacity requirements and the actual capacity expected from the implementation of the current expansion plan. The following Chapters 34 and 35 compare the two in order to assess what further expansion in production capacity will be required in each process area to meet the 1980 steel demand.

33.1 Total capacity required by 1980

The future capacity requirements have been calculated from the forecast of home demand for steel products made in a market study of national demand through to 1980, carried out in Brazil by Technometal - Estudos e Projetos Industriais S.A. in 1969. The report of this study was made available to us by CONSIDER, who also laid down the allowances for two major variables - exports and fluctuations in market conditions - necessary for us to calculate what capacity will be required to meet the estimated future steel demand.

The market forecasts were made by Technometal on the basis of an extrapolation of past trends, which could be affected by subsequent changes in world technology that were not anticipated at the time. We have therefore reviewed these forecasts in the light of the relevant technological trends (discussed in Chapters 7 to 32). We have in general found no cause to suggest changes in the forecasts but we do consider that it would be wise to monitor the developments in one or two market sectors at regular intervals, and to undertake more research in other sectors.

Home market demand

The forecasts of the demand in 1980 for flat products are shown in Table 33.1 and for non-flat products in Table 33.2. The actual consumption for 1969 is also shown for comparison. The product groups correspond to those in the Technometal report. A regional breakdown of demand for 1969 and 1980 is given in Table 33.3 for these two main product groups, with the exception of railway products, for which figures were available only on a national basis.

Brazilian export potential

CONSIDER laid down a fixed allowance for exports of all products, which was to be calculated by taking $12\frac{1}{2}$ percent of the forecast home demand. In 1980 this amounts to 1.4 million tonnes of products, against the reported total in 1969 of 326,000 tonnes of steel products of almost every classification, but the majority being common steels. For comparison, we note in Chapter 31 Article 31.2 that the tonnage of products exported is 17 percent of total world consumption today. If the proportion remains constant, then worldwide exports will amount to more than 150 million tonnes by 1980.

It is important to distinguish between product exchange and true exports. Community trading as a result of rationalisation of production is becoming increasingly a feature of world trade, especially in specific trading areas such as the EEC. A similar trend may be expected within the LAFTA, and therefore, as the largest producer within that group, Brazil is in a strong position to play a leading role as a major participant in this form of trading.

In Chapter 31 Article 31.5, attention is drawn to the current interest in the large scale export of semifinished products. Such a venture is clearly of interest to Brazil as a means of adding value to potential exports of ore. At the present time, it is not possible to forecast the tonnages of such products likely to be exported by 1980, but even if this were possible, such projects would have to be treated separately from the general development of the steel industry because of their special tied financing and market conditions. Consequently, no provision for such exports is included in this forecast.

We regard the allowance chosen by CONSIDER as a good compromise between the amount of capacity that may be spared for export and the full opportunity that might be grasped.

Product development and substitution

The Technometal forecasts are based on the development of end user industries, assuming a continuation of present technology. In Chapters 28 and 29 we review the influence of technological trends on steel products. In brief, we

TABLE 33.1 - FLAT PRODUCT DEMAND

(thousand tonnes)

Product	1969	1980
Coated products -		
Tinplate	272	840
Galvanised sheet	48	240
Terne plate	2	8
	322	1088
Cold rolled products	512	1470
Hot rolled products	524	1600
Plate	358	1430
Slabs	6	20
sub total (common steels)	1722	5608
Special steel products		
Stainless steel sheets	13	42
Silicon sheets	30	80
Others	19	60
	62	182
TOTAL	1784	5790

Based on Technometal report

TABLE 33.2 - NON-FLAT PRODUCT DEMAND

(thousand tonnes)

Product	1969		1980	
Wire Rod		394		1260
Commercial bars -				
Rod	582		1860	
Common steel bars	110		310	
		692		2170
Light sections		136		370
Medium and Heavy sections	161		420	
Rails and accessories	93		170	
		254		590
Seamless tubes		119		410
Semis				
Blooms	2		7	
Billets	6		6	
Ingots	31		87	
		39		100
sub total (common steels)		1634		4900
Non common steel bars		259		730
Special steel products -				
Tool steel bars	6		-	
Stainless bars	2		-	
High alloy bars	1		-	
		9		30
TOTAL		1902		5660

Based on Technometal report

TABLE 33.3 - REGIONAL MATRIX OF STEEL PRODUCT DEMAND
(thousand tonnes)

REGION		Flat Products		Non-flat Products	
		1969	1980	1969	1980
1.	North	6	21	15	49
2.	North-North East	26	73	22	66
3.	North East	41	131	58	181
4.	East	16	79	40	144
5.	Minas	75	265	335	1022
6.	Central	6	9	25	75
7.	Rio de Janeiro	300	1212	295	957
8.	Sao Paulo	1184	3598	832	2433
9.	Parana	21	57	41	124
10.	Santa Catarina	17	46	16	48
11.	Rio Grande do Sul	92	299	130	391
National railway demand		-	-	93	170
TOTAL		1784	5790	1902	5660

Based on Technometal report

find in product development a trend towards steels of specialist specifications for particular duties, such as high- or low-temperature service, corrosion or abrasion resistance, and steels with characteristics specially suited to particular manufacturing processes such as machining, cold forming, deep drawing, welding or heat treating. As regards product substitution, the markets in Brazil where changes are likely to occur are packaging and tubular products.

The trend towards a more closely defined specification of product characteristics is unlikely to affect significantly the total demand for steel, but may well alter the relative demand for different product groups. This will chiefly affect the bar market, in which the tonnage of bars classed as non-common may be expected to increase at the expense of common bars. In flat products, a greater proportion will be subject to inspection procedures of the kind already common for ship plate.

The two products most likely to be influenced by product substitution are tinplate and seamless tubes. Plastic wrapped vacuum packing of some products is an alternative to canning, and tinfree steel is an alternative to tinplate for some markets. It will be important to determine how these alternatives will develop in Brazil. Developments in welded pipe have already affected the demand for seamless tube, and this trend must be expected to continue. There is also a need to identify in detail the different classes of welded pipe to make process selection possible. We recommend that a market survey be undertaken in these two areas to clarify the situation.

Market fluctuations

The demand for steel fluctuates in the short term by as much as 20 percent about the trend line. The unpredictable size and frequency of the fluctuations is a source of continual embarrassment to steelmakers.

For many years an allowance of 15 percent of capacity has been considered desirable to cater for surges in demand. CONSIDER propose an allowance of $12\frac{1}{2}$ percent of home demand which is, in effect, 10 percent of the proposed capacity.

It is perhaps technological trends in data handling rather than in steelmaking that are likely to affect this phenomenon. The factors causing market fluctuations are numerous and not all have been identified, but with the better flow of information that now exists and the closer co-ordination of industries by national and supra-national bodies, we consider the lower allowance adopted by CONSIDER to be justified.

Demand for production capacity

The production capacity required by 1980 will be the sum of the home demand, the export potential and the contingency allowance for market fluctuations. The total is based on the Technometal forecast for home demand plus $12\frac{1}{2}$ percent for export and $12\frac{1}{2}$ percent for market fluctuations. The increases have been assumed to be evenly distributed over all the products manufactured. The total capacity requirements for each of the product groups considered are summarised in Table 33.4.

TABLE 33.4 - CAPACITY REQUIREMENTS BY PRODUCT IN 1980

(thousand tonnes)

Flat product sector		Non-flat product sector	
Product	Capacity	Product	Capacity
Tinplate	1050	Wire rod	1580
Galvanised sheet	300	Commercial bars	2710
Terne plate	10	Light sections	460
Cold rolled products	1840	Medium & heavy sections	530
Hot rolled products	2000	Rails and accessories	210
		Seamless tubes	510
Plate	1780		
		Semis	125
Slabs	25		
sub total	7005	sub total	6125
Special steel products	230	Non-common steel bars	915
		Special steel products	35
TOTAL	7235	TOTAL	7075

33.2 Estimated capacity in 1980 of the existing industry

The production capacity of the present industry has been set down in Chapter 1. The present industry has been defined by CONSIDER as those plants which are already operational, together with such extensions and new installations as have been authorised by CONSIDER up to September 1971. By 1980, all these new facilities will have been in operation for some years but some of the existing plants will have been closed due to age or obsolescence. The contribution that the present industry will make to the total forecast capacity requirements in 1980 will therefore depend on the numbers of plants that close down, and on the performance levels attained by the plants still in operation.

We have based our estimates of capacity on the expectation that the industry will respond to the short term improvement recommendations in Chapters 3 to 6. We have also taken a view of the reduction in production capacity likely to result from plant closures. We have related capacity as closely as possible to the product classification set out in the market survey data but we are aware that the information at our disposal precludes a precise allocation of capacity. The foregoing figures have been used to derive the estimate of additional capacity that has to be planned for, during the rest of the decade.

Performance levels in 1980

Performance levels within the steel industry throughout the world are expected to continue to rise and a summary of the predicted levels which may be generally expected to obtain in major steelmaking countries by 1980 is given in Appendix 1. This assessment of the Brazilian steel industry is based on these levels, due account being taken of the size and age of existing plant.

The implementation of short term measures for raising performance levels, as discussed in Chapters 3 to 6, together with the modernisation programmes that will undoubtedly be carried out during the next few years, should enable the industry to reach a high level of performance. This we have taken into account.

In making our assessment we have assumed different performance levels for existing and new plant. For the existing ironmaking facilities, including cokemaking and sintering installations, we have assumed performance levels between 80 and 90 percent of those predicted for new plant in 1980. The existing BOF steel plants and the casting and rolling installations of the flat product sector are assumed to be operating practices comparable with new plant but the steelmaking and rolling facilities in the non-flat sector are assessed at levels about 80 percent of those for new facilities.

The new works equipped with modern plant are assumed to be up to the world levels given in Appendix 1.

Production capacity of the flat product sector

The flat product sector consists of three works - CSN, Usiminas and Cosipa. Production is rationalised to the extent that CSN specialises in coated products and the other two are the plate producers. All three produce hot and cold rolled strip products. Due to the integrated nature of the operation in flat product works, plant capacity at each of the major process centres is shown in Table 33.5 for the three plants individually. In the table, 'existing' refers to plant already installed and 'authorised' refers to planned capacity sanctioned by CONSIDER at September 1971.

In making our assessment, we have assumed that:

the blast furnaces will be operating on a 100 percent self-fluxing sinter burden;

the CSN open hearth melting shop is closed down;

TABLE 33.5 - FORECAST CAPACITY IN 1980 (FLAT PRODUCT SECTOR)

(Million tonnes)

Plant	Product	Forecast Capacity			Remarks
		Existing	Authorised	Total	
Coke ovens					
CSN	Coke (all grades)	0.78	0.50	1.28	
Usiminas		0.57	0.52	1.09	
Cosipa		0.59	0.56	1.15	
		1.94	1.58	3.52	
Sinter plants					
CSN	Blast furnace sinter	2.57	1.75	4.32	
Usiminas		1.30	2.50	3.80	
Cosipa		2.25	-	2.25	
		6.12	4.25	10.37	
Blast furnace					
CSN	Hot metal	2.00	2.80	4.80	
Usiminas		1.23	2.50	3.73	
Cosipa		1.10	2.50	3.60	
		4.33	7.80	12.13	
BOF plants					
CSN	Liquid steel	-[1]	2.70	2.70	1. existing OH shop closed
Usiminas		1.02	3.10	4.12	
Cosipa		1.45	1.31	2.76	
		2.47	7.11	9.58	
Slabbing facilities					
CSN	Slabs	1.03[2]	0.95[3]	1.98	
Usiminas		1.62[2]	0.60[3]	2.22	2. ingot casting & primary rolling
Cosipa		2.45[2]	-	2.45	
		5.60	1.55	6.65	3. continuous casting
Plate mills					
CSN	Plate	-	-	-	
Usiminas		0.25	0.85	1.10	
Cosipa		-	0.85	0.85	
		0.25	1.70	1.95	
Hot strip mills					
CSN	Hot coil and sheet	1.60	-	1.60	
Usiminas		1.80	-	1.80	
Cosipa		1.50	-	1.50	
		4.90	-	4.90	
Cold strip mills					
CSN	Cold coil and sheet	1.10	-	1.10	
Usiminas		-[4]	0.60	0.60	4. existing mill becomes temper mill
Cosipa		0.83	-	0.83	
		1.93	0.60	2.53	

500, 000 tonnes of CSN's casting and primary mill capacity is allocated to bloom production:

CSN does not roll plates.

The facilities for producing coated products are located at CSN. When present authorised plans are fully implemented, these will be able to produce 550,000 tonnes of tinplate, 200,000 tonnes of galvanised sheet, and 5,000 tonnes of terne plate.

Production capacity of the non-flat sector

The non-flat product sector, being fragmented, cannot be treated in quite so systematic a fashion as the flat product sector of the industry. The capacities given are aggregates both of several plants and also of existing and authorised planned works.

The age, size and type of some plant will make it unsuitable for modernisation. Thus, in this sector some allowance has to be made for closures which will offset increases in capacity attained by works more suitable for development. The open hearth and electric arc steel plants are most affected by this. The assessed potential plant capacity for the sector is summarised in Table 33.6, classified under the main process areas.

In making this assessment, we have assumed that:

the existing blast furnaces in this sector all operate on charcoal;

the direct reduction plants at USIBA and Piratini will be in full commercial operation;

about one million tonnes of existing open hearth and electric arc capacity will be taken out of service by 1980;

the CSN section mill will still be in use;

a nominal amount of mill capacity is closed down.

It should, however, be borne in mind that developments in processes such as SIP (Chapter 12, Article 12.4) could influence the timing of the closure of some open hearth shops.

Capacity of special steels production

Production capacity in this section is very sensitive to product mix, so that our assessment is not detailed beyond an indication of approximate mill and steelmaking capacity in the two main product classifications. This is set out in Table 33.7.

TABLE 33.6 - FORECAST CAPACITY IN 1980 (NON-FLAT PRODUCT SECTOR)

(million tonnes)

Plant	Product	Forecast capacity
Ironmaking plant		
Charcoal blast furnaces	Hot metal	1. 40
Electric smelters		0. 25
Direct reduction plant	Sponge iron	0. 32
Steelmaking plant		
Open hearth furnaces	Liquid steel	0. 31
BOF		0. 82
Electric arc furnaces		2. 55
		3. 68
Bloom and billetmaking plant		
Ingot casting & rolling	Blooms	0. 50
	Billets	2. 84
Continuous casting	Billets	0. 43
		3. 77
Rolling mills		
	Wire Rod	0. 80
	Commercial bars	1. 65
	Light sections	0. 30
	Medium sections and rails etc.	0. 73
	Seamless tubes	0. 15

TABLE 33.7 - FORECAST CAPACITY IN 1980 (SPECIAL STEELS)

(million tonnes)

Plant	Flat products	Non-flat products
Steel plant	0.04	0.61
Rolling mills	0.04	0.52

In the non-flat sector we would classify most of the steelmaking capacity as able to produce non-common steels with only about 11,000 tonnes capacity suitable for high alloy special steel production.

CHAPTER 34 - IMPLICATIONS FOR CASTING, ROLLING AND FINISHING IN BRAZIL

The yield at each stage in the manufacture of finished steel products is less than 100 percent. It is, therefore, convenient to consider the implications of capacity demand by dealing first with finishing processes, and working back from them to derive the demand for ironmaking capacity.

In this chapter, the three main product sectors - flat, non-flat and special steels - are dealt with in turn. The shortfall in capacity in 1980 is deduced, for each sector, by establishing the needs of the main production stages from the base data in Chapter 33 and the process yields in Appendix 1. In general, no attempt is made to break the shortfall down to individual works level, although in the flat sector, where individual units are large, some reference is made to particular works to ensure a realistic understanding of the situation.

The technological trends relevant to the situation obtaining at each production stage are presented, and the implications for planning the necessary expansion are discussed. In general, world trends in casting, rolling and other shaping processes, and finishing are towards the development of larger and faster production units, with a bias towards specialisation either of product type or size range, for some plant. Improved productivity of plant and higher quality in the product are being achieved by the increasing application of computer control of processes.

34.1 Flat product sector

The demands for capacity for low carbon steel products in the flat product sector are set out in Table 33.1 in Chapter 33. In Table 34.1 these demands are shown converted to equivalent demands for capacity in the main process centres, back through the works, to derive a demand for slabbing capacity. For comparison, the forecast capacity available in each of the three existing works has been re-presented from Table 33.5.

Tinplate - coating and rolling

The capacity shortfall for tinning by 1980 will be 500,000 tonnes, and for cold rolling of tinplate feedstock the shortfall will be 400,000 tonnes.

TABLE 34.1 - PLANT CAPACITY DEMAND AND AVAILABILITY IN 1980 FOR THE FLAT PRODUCT SECTOR

(thousands of tonnes)

Plant type	Capacity required for the production of					Total capacity required	Total capacity available	Capacity available at			Plant type
	1,050 Tinplate	310 Galvanised Sheets and terne Plate	1,840 Other Cold rolled Products	2,000 Hot rolled Products	1,780 Plates			CSN	Usiminas	Cosipa	
Cold strip mill	1,130 -	- 320	- 1,960	- -	- -	1,130 2,280	750 1,780	750 350	- 600	- 830	Cold strip mill
Hot strip mill	1,200	340	2,090	2,150	-	5,780	4,900	1,600	1,800	1,500	Hot strip mill
Plate mill	-	-	-	-	1,780	1,780	1,950	-	1,100	850	Plate mill
Slab rolling & casting	1,250	350	2,180	2,240	1,980	8,025(1)	6,650	1,980(2)	2,220	2,450	Slab rolling & casting

Note: (1) Includes 25,000 tonnes slabs for sale.

(2) A further 500,000 tonnes of capacity has been provisionally allocated to bloom production (see Table 34.2)

The principal technological trend in tinning has been the speeding up of the process lines. Modern lines have annual capacities of up to 250,000 tonnes. There are no significant trends in temper rolling but there is a move towards the adoption of continuous annealing, giving improved yields.

Modern mills for cold rolling strip for tinplate production are six-stand tandem mills with hydraulic roll gap control and automatic work roll changing equipment. The mills are computer controlled and have an annual capacity of about 700,000 tonnes. With the continuing growth of tinplate demand in the 1980's a complete tinplate works based on the capacity of such a cold mill is probably the most economic option for Brazil. Continuous rolling has now been developed and may be applicable for this installation.

As was noted in Chapter 33, tin-free steel could become an important product for Brazil and it may be necessary to plan for the installation of TFS units into the tinplate line at a later date. A change to TFS would have no effect on the cold rolling capacity.

Other coated products

There have been no particularly noteworthy developments in the production of galvanised sheet and terne plate. It is anticipated that the capacity shortfall of 310,000 tonnes of galvanised sheet will be met by the installation of two standard lines with capacities of about 150,000 tonnes each.

Cold rolled products

In addition to the requirement for a cold strip mill for tinplate, noted above, there is also a shortfall of some 300,000 tonnes in the production of cold rolled sheet, some of which will be coated.

This demand is probably best met by a four- or five-stand, tandem mill. The mill should incorporate the latest advances in automation available at the time and should have automatic gauge control and built-in work roll changing equipment. The width, and hence output, of the mill will depend on the requirements of auto body manufacturers. A 2-metre wide mill would have a capacity of about 1.2 million tonnes. Such a high capacity mill might necessitate some correction of imbalance by interchange of products between the three works in the flat product sector.

Hot rolled strip

It can be seen from Table 34.1 that the demand for hot rolled strip, whether sold as hot finished or sheets, or supplied as feedstock for cold mills rolling either sheets or tinplate, will give rise to a shortfall in capacity of approximately 900,000 tonnes by 1980.

The trend today is to install modern fully continuous wide hot strip mills of between 3 and 5 million tonnes capacity. A mill of this output could not be justified in Brazil on the basis of the 1980 shortfall alone, but the rapid growth in demand for hot strip will fill such a large capacity mill by the mid-1980's. The actual capacity will depend primarily upon the width and product mix.

The mill should incorporate the features discussed in Chapter 17, Article 17.2, and its configuration should be a matter for discussion with the mill engineering companies at the time of purchase. The determination of the optimum size and configuration will require a major engineering study.

Plate

Up to the year 1980, there is no anticipated shortfall in plate capacity and the question of installing further plate mills does not arise.

Slabs

The capacity shortfall for slabs, as indicated in Table 34.1, is some 1.4 million tonnes by 1980.

As noted in Chapter 15, the leading steelmakers still disagree about the suitability of continuous casting for the production of slabs for hot strip. The demands of mill operators for a wide range of slab widths, and the continuing demand for rimming steels, are likely to defer the wholehearted acceptance of continuous casting for some time to come. On the other hand, continuous casting is ideal for slab production for plate where a limited range of slab cross sections is needed and fully-killed steels are to be cast.

The flat product sector already has a mix of slabbing facilities - both ingot casting and primary rolling, and continuous casting. It is possible that the small increase in capacity which is needed can be satisfied by additional continuous casting capacity. However, the requirements in each works will have to be studied carefully to ensure that the necessary range of slab sizes can be produced.

34.2 Non-flat product sector

The demands for capacity for low carbon steels in the non-flat product sector are set out in Table 33.2 in Chapter 33. In Table 34.2 these demands are shown related to the appropriate type of mill and also converted to equivalent demands for bloom and billet production capacity, as applicable. For comparison the potential capacity available in existing works has been re-presented from Table 33.6 in Chapter 33.

The products considered are those covered by the Technometal report: wire rod, merchant bars, light sections and billets; medium and heavy sections, rails and accessories, and blooms; and seamless tubes.

Wire rod

The capacity shortfall for wire rod by 1980 will be approximately 800,000 tonnes.

The principal technological trend has been towards higher speeds through the use of no twist finishing blocks together with controlled cooling. This has been accompanied by a trend towards the use of larger billets to improve productivity and yield.

TABLE 34.2 - PLANT CAPACITY DEMAND AND AVILABILITY IN 1980 FOR THE NON-FLAT PRODUCT SECTOR

(thousands of tonnes)

Capacity Required				Capacity Available	
Product		Semifinished Feedstock			
Type	Tonnage	Type	Tonnage	Tonnage	Plant type
Wire rods	1,580	Billets	1,740	800	Rod mill
Commercial bars	2,710	Billets	2,850	1,600	Bar mill
Light sections	460	Billets	510	300	Merchant mill
Medium & heavy sections	530	Blooms	590	725	Medium and heavy section mills
Rails & Accessories	210	Blooms	230		
Seamless tubes	510	Blooms & Billets	590	150	Tube mill
Semis for sale	125	Blooms & Billets	125		see below
		Total Semis	6,635	3,800[1]	emis plant[2]

Note:

(1) Includes 500,000 tonnes of bloom capacity at CSN.

(2) Semis plant comprises ingot casting and primary mills, billet casting and continuous casting plant.

A modern high capacity wire rod mill should incorporate these features and its precise configuration should be a matter for discussion with the rolling mill engineering companies at the time of purchase. The shortfall by 1980 is likely to permit the installation of at least one large capacity specialist wire mill, devoted to bulk production of a limited range of products. Whether a second specialist mill can be justified at this time will depend on the degree of rationalisation that can be achieved in the industry as a whole.

Merchant bars

From Table 34.2 it can be seen that there will be an approximate shortfall in capacity by 1980 of 1,000,000 tonnes.

Most of the recent developments in merchant mills have been directed towards improving the quality of the product, and increasing mill productivity. Mill capacities of up to 500,000 tonnes are now available.

As with wire rod mills, advantage should be taken of high capacity bar mills operating on a limited product mix. Again, the degree of rationalisation achieved will govern the extent to which such a policy can be followed. The location of the markets in relation to the mill will also have an influence on the most economic size of plant.

Light sections

Table 34.2 indicates a capacity shortfall of some 160,000 tonnes of light sections by 1980. This would not justify a specialist mill, and it is probable that sufficient capacity will be available in the existing merchant mills to roll this small quantity.

The need to provide for light sections, in this way, underlines the value of a detailed study and understanding of the requirements of the rod, bar and light section market before reaching any decision on the installation of new mills.

Medium and heavy sections

The capacity demand for medium and heavy sections by 1980 cannot be clearly deduced from the Technometal report. The figures in Table 34.2 suggest that there is no shortfall, but this is misleading since none of the installed capacity is capable of producing heavy universal or parallel-flanged sections.

The demand for heavy sections will depend mainly on the pattern of civil and structural engineering construction, and the demand figures will need to be re-assessed in the light of the trends in structural engineering. The ship-building industry may also be an important market.

If a demand is established, this can be satisfied by the installation of a universal beam mill, the size of which would depend on the product mix. Modern mills of this type have annual capacities of 500,000 tonnes, with the latest designs achieving 750,000 tonnes. Such tonnages are large compared with the forecast requirements by 1980, so that the planning of such a mill would also have to take into account the growth in demand during the 1980's. As noted in Chapter 18, it is the current trend to limit the beam size produced to 500 or 600 millimetres maximum dimension, larger sections being produced as fabricated three-piece beams.

Rails and accessories

There is no apparent shortfall in production capacity for rails and accessories up to 1980. If the demand were to increase, or there were requirements for different section sizes, the additional output could probably be obtained from a new universal section mill.

Seamless tubes

It can be seen from Table 34.2 that there will be a considerable production shortfall for seamless tubes. This must, however, be qualified by the unknown factor of the existing welded tube production. A major trend in tube production is the growing acceptance of welded tubes for applications which had been previously supplied by seamless tubes. It is, therefore, most important, as already stressed in Article 33.1, that the product size, quality and usage of the tubes be established before commitments are made for seamless tube plants.

In the seamless tube production process itself, the trend is to install plant of increasingly sophisticated engineering specification, enabling higher outputs and closer tolerance products to be produced. The choice of a particular type of seamless tube mill will be highly dependent upon the types of product to be produced, rather than the quantity, and should be discussed with the specialist mill suppliers at the time of purchase.

It is worthy of restatement to say that most careful consideration should be given to the production of continuous butt-welded pipe for the smaller end of the commercial pipe market, and the production of large line pipe by the U and O process, and above that range by spiral welding.

Blooms and billets

As shown in Table 34.2, there is a total shortfall in bloom and billet production capacity of some 2.8 million tonnes by 1980, if the capacity requirements for non-flat products in common steel are to be satisfied. Of this total, 2.3 million tonnes is estimated to be billet stock, while the remaining 0.5 million tonnes is required as blooms.

The development of continuous casting has led to a major reappraisal of bloom and billet production, especially the latter. The better yield, compared with ingot casting and primary rolling and, for small outputs, the lower capital costs, have led many steelmakers to select or change to continuous casting. It does, however, suffer as a process from some inflexibility due to the time needed to change moulds and roller guides for different product cross-sections. This may not be much of a restraint for the bloom caster, or for the billet caster of a miniworks where a limited range of products is offered. However, for most billet works a wide range of billet cross-sections is required; this is even more the case if the billet producer is supplying re-rollers as well. To retain flexibility, while still taking advantage of the gains in yield from continuous casting, several works have been designed to produce continuously cast blooms which are then rolled to billets. This arrangement is the only practical alternative to ingot casting and primary rolling for production levels over a million tonnes per year, because the number of strands in a billet casting machine necessary to handle the throughput becomes too large.

The majority of non-flat product works in Brazil are currently producing less than 100,000 tonnes per year. Even with three- or four-fold expansions these are not going to contribute extensively to the total need for capacity. The provision of a large-scale producer of billet stock would have the advantages of meeting the needs in one stage instead of in many, and of enabling management in existing works to concentrate on expanding finished product capacity. A works of about three million tonnes capacity producing continuously cast blooms could supply, through a billet mill, the non-flat sector generally, and could also be the site for bloom-using plant such as a universal beam mill or a seamless tube mill.

34.3 Special steel products sector

The following product groups in the flat and non-flat category have been considered under this heading:

Flat products	Non-flat products
Stainless steel	Non-common bar
Silicon steel	Tool steel bar
Special steel sheets	Stainless steel bar
	Other high alloy bars

Table 34.3 summarises the demand for, and availability of, capacity in the special steel sector. The information in the table has been derived from Tables 33.1, 33.2 and 33.7 in Chapter 33. It can be seen that in both the flat and non-flat sectors of the market there will be serious shortfalls by 1980.

Flat products

The total shortfall in capacity for finished steel products is approximately 200,000 tonnes. Undoubtedly some portion of this will be cold rolled grain oriented sheet which is normally rolled on plant used exclusively for this purpose. It will thus be necessary to install two or maybe three small mills, probably Sendzimir cluster mills, to handle these demands. By hot mill standards the shortfall is small, so that the most economic solution may be to arrange hire rolling agreements with the large flat product works to provide this capacity. The new developments on the Steckel mill noted in Chapter 17 make such a mill a possible alternative.

TABLE 34.3 - PLANT CAPACITY DEMAND AND AVAILABILITY IN 1980 FOR THE SPECIAL STEEL SECTOR

(thousands of tonnes)

Sector	Product	Capacity required	Capacity available
Flat products	Stainless steel	55	
	Silicon steel	100	
	Other special steels	75	
	Slab feedstock(1)	280	40
Non-flat products	Non-common bar	915	
	Stainless steel bar		
	Other high alloy bar	35	
	Tool steel bar		
	Billet feedstock(2)	1,060	520(3)

(1) Slab to sheet yield : 82%
(2) Billet to bar yield : 90%
(3) It is assumed that small quantities of stainless and other bars are produced.

Non-flat products

The major part of the capacity shortfall of about 500,000 tonnes is in the category of non-common bar.

Technological trends in rolling non-flat special steel products are similar to those for common steels and, provided care is taken to avoid excessive decarburisation in the reheat furnaces, non-common steel bar can be rolled very satisfactorily on bar mills of the type used for merchant bar production. However, some high carbon and alloy steels require normalising or slow cooling immediately after rolling, which calls for special facilities.

Semi-finished products

Continuous casting is technically suitable for most special steels and economic for the small tonnages required. However, hire rolling of ingots may prove more advantageous if a wide range of sizes of semis are to be produced.

34.4 The demand for steel

In the previous three articles, the casting capacity required by 1980 has been identified in terms of slabs, blooms and billets as follows:

Sector	Capacity (million tonnes)	
Flat products	8.02	Slabs
Non-flat products	6.64	Blooms and billets
Special steel products	1.34	Slabs and billets
All products	16.0	Semis

The existing capacity is already a mix of ingot and continuous casting facilities. Various options are open to fill the remaining shortfall, each having a different yield. It is thus impossible to determine the liquid steel required, precisely, without first deciding which processes shall be used. To carry the discussion forward, a view has been taken on the average yield likely to be achieved in each sector, leading to the following demands for steelmaking capacity.

Sector	Capacity (million tonnes of liquid steel)
Flat products	8.9
Non-flat products	7.4
Special steel products	1.7
All products	18.0

CHAPTER 35 - IMPLICATIONS FOR IRON AND STEELMAKING IN BRAZIL

In Chapter 34 we established the level of steel production required - in each of the flat, non-flat and special steel products sectors - to satisfy the forecast 1980 demand for finished products.

The principal choice of process route is between hot and cold metal steelmaking. In general, both flat product mills and hot metal steelmaking are more economic when operated on a large scale, whereas non-flat product mills and cold metal steelmaking can both be operated economically at modest levels of output. However, decisions on iron and steelmaking facilities are influenced as much by the availability of raw materials as by the type of end-product.

As the main cold charge feedstock - scrap - is the cheapest source of Fe, it is desirable to use as much as possible. On the other hand, we have shown in Chapter 14 that if the demand for scrap exceeds the supply, the value of the scrap rises and hot metal steelmaking becomes the cheaper process.

From a national viewpoint, therefore, an ideal solution would be to strike a balance between hot and cold metal steelmaking capacity which leaves the scrap demand of the industry slightly less than the available supply. Before considering the iron and steelmaking needs of the various sectors - and the technological developments which are relevant to them - it is thus necessary to determine the approximate balance between the hot and cold metal routes. Crucial to establishing this is an estimate of scrap availability in 1980.

35.1 Balance between hot and cold metal steelmaking

Reference to Chapters 12 and 13 shows that hot metal steelmaking is dominated by processes based on oxygen blown converters while the dominant cold metal process is the electric arc furnace. The amount of scrap consumed by oxygen steelmaking processes can be varied quite widely; we have assumed that the normal practice of consuming internally arising scrap is adopted. The amount arising will vary from product to product but on the basis of the yields assumed in Chapter 34 the Brazilian industry will have an average total internal scrap rate of about 20 percent. It is expected that there will be no difficulties in operating steelmaking furnaces with a 20 percent scrap charge, although with the larger furnaces this level of scrap may be insufficient to provide the necessary cooling. An increase to 25 percent scrap would reflect on the plant capacities upstream of steelmaking, but since scrap is likely to be in short supply, it is more likely that alternative coolants would be a more practicable solution (See Article 35.5). The electric arc furnace charge has been assumed to be 95 percent scrap. (See Appendix 1).

Scrap Available in 1980

Estimates of the amount of scrap available in Brazil by 1980 are given in Table 35.1; the internally arising scrap has been calculated on the basis of an assumed average yield of 80 percent of finished product from liquid steel.

TABLE 35.1 - ESTIMATED SCRAP AVAILABILITY IN BRAZIL
1980
(million tonnes)

Source	Scrap availability in 1980
	20 percent circulating
Steelworks internal	3.6
Process scrap	1.3 *
Capital - home goods	1.6 **
- imported goods	0.4 **
TOTAL	6.9

* IBS forecast. The Atkins Planning forecast is 1.4 million tonnes

** IBS forecast.

Existing steelmaking capacity

By 1980 the industry, with its present authorised expansion plans, will have sufficient capacity to produce the steel required for all flat products demands, and for about 5 million tonnes of non-flat and special steel products. The actual quantities are set out in Table 35.2, together with the scrap requirement for each type of steelmaking. The tonnages for flat products are taken from Chapter 34 (Table 34.2 and Article 34.4) since the forecast available capacity exceeds the forecast demand, while the tonnages in the non-flat and special steels sectors are taken from Chapter 33 (Tables 33.6 and 33.7).

TABLE 35.2 - FORECAST OF STEELMAKING CAPACITY AND SCRAP REQUIREMENT FOR EXISTING PLANT IN 1980

(million tonnes)

Sector	Liquid steel capacity	Estimated scrap requirement (20 percent charge unless otherwise stated)
Flat product:		
to satisfy demand	8.9 *	1.96
to supply blooms **	0.57 *	0.13
Non-flat product:		
open hearth	0.31	0.23 (70 percent)
BOF	0.82	0.18
electric arc:		
(i) scrap-based	2.20	2.23 (95 percent)
(ii) sponge iron based	0.35	0.08
Special steels:	0.65	0.48 (average 70 percent)
Total	13.80	5.29 (say 5.3)

* The forecast total capacity will slightly exceed this figure (see Table 33.5)

** See Table 34.2

Shortfall in capacity

The shortfall in overall steelmaking capacity in 1980 will be some 4.2 million tonnes per year, concentrated in the non-flat and special steel sectors. The scrap available, surplus to the demands of the existing industry, will be about 1.6 million tonnes, so that the shortfall could be supplied by hot and cold charged steelmaking in the following proportions:

Process	Capacity (million tonnes)	Scrap required (million tonnes)
Oxygen steelmaking	3.3	0.6 (20 percent)
Scrap-based electric arc	0.9	0.91 (95 percent)
Total	4.2	1.6

35.2 The needs of the flat product sector

As noted in the previous article, the flat product sector has, nominally, sufficient capacity to meet the demands of the market in 1980. Nevertheless, by that time, it will be necessary to have in hand plans for further expansion.

The installation of a continuous hot strip mill, as discussed in Article 34.1, is likely to cause some imbalance between the three works in the sector, so that a decision to add steelmaking capacity may have to be taken somewhat earlier than is at first apparent.

In Table 35.3, the capacities required by 1980 for steelmaking, ironmaking, sintering and cokemaking are set against the forecasts of capacity available in the existing industry (from Table 33.5). The capacities are also broken down between the three works to indicate the degree of self sufficiency in each.

There is clearly ample ironmaking capacity - Usiminas being the only works which does not have a substantial surplus of capacity in relation to its steelmaking requirements. Expansion of the CSN BOF shop from two to three furnaces would bring the facilities there also roughly into balance.

On the other hand, CSN is the only works with sufficient sintering and cokemaking capacity to service its available steelmaking capacity, and even then there is too little sintering capacity to match the total installed and authorised iron-making capacity.

The process of gradually increasing the output of an integrated works tends to give rise to imbalance of capacity between individual plant items, since each increment of plant must allow for growth beyond the current level of output. It is an important function of planning to minimise the cost of this imbalance.

From Table 35.3 it can be seen that imbalances will exist by 1980 in terms of cokemaking and sintering, in particular; since it is not practicable to move sinter, coke or hot metal between the three works, it is necessary to maintain a measure of balance at each works. In planning to meet the sintering and cokemaking capacity deficit in 1980, therefore, account must also be taken of the probable rate of growth in demand for the few years following 1980.

Additional steelmaking capacity for the period beyond 1980 could be provided for example, by adding further furnaces at CSN and Usiminas; together these could provide between 4.0 and 4.5 million tonnes per year of additional steel, but Usiminas will also require further ironmaking capacity.

The apparent surplus of sintering capacity at CSN cannot be used at the other two works where the total imbalance between sintering and steelmaking capacity is about 3.6 million tonnes per year. The surplus at CSN will, in any case, become a deficit as soon as a third BOF furnace is installed.

TABLE 35.3 - STEELPLANT CAPACITY REQUIRED AND AVAILABLE IN 1980
FOR THE FLAT PRODUCT SECTOR
(millions of tonnes)

Department	Capacity Required	Total Capacity Available	Capacity Available At			Department
			CSN	Usiminas	Cosipa	
Steelmaking	9.47	9.58	2.70	4.12	2.76	Steelmaking
Ironmaking	8.33	12.13	4.80; 2.38*	3.73; 3.63*	3.60; 2.43*	Ironmaking
Sintering	12.66	10.37	4.32; 3.61*; 7.30**	3.80; 5.52;* 5.67 **	2.25; 3.69*; 5.47**	Sintering
Cokemaking	4.17	3.52	1.28; 1.19*; 2.16**	1.09; 1.81* 1.87 **	1.15; 1.21*; 1.80**	Cokemaking

Notes:

(i) Cokemaking capacity assumes an actual coke rate in 1980 of 420 kg per tonne of hot metal and includes for providing breeze for sintering.

(ii) The demands for ironmaking capacity assume a BOF charge 80/20 hot metal scrap.

* Capacity required to match installed steelmaking capacity.

** Capacity required to match installed ironmaking capacity.

Clearly it will be necessary to install some large additional sintering capacity in the flat sector, especially when the increase in demand beyond 1980 is taken into account. Economies of scale of sinter plants continue up to high outputs, and advanced continuous travelling grate sinter plants will, by the end of the decade, be capable of producing over 5 million tonnes per year. A problem with sinter plants, however, is that they cannot be continuously operated at a high degree of under-utilisation without impairing the sinter quality. Thus, it is likely that the Brazilian industry will be constrained to install plants smaller than the maximum sizes available.

The performance, in the blast furnace, of sinter and pellets is very similar and the practice of pelletising is growing throughout the world, but in the flat product sector in Brazil it does not appear to offer significant advantages. The possibility of a large central pelletising plant serving the three works could be considered, but is likely to be proved uneconomic. In the first place, the economies of scale would be small since the plant would have to consist of several pelletising lines. Secondly, there would be an increase in transport costs and some administrative disadvantage. One advantage, however, would be the ability to plan a long-term expansion programme together with the minimum under-utilisation. The possibility of supplying the flat product sector from a pelletising plant also serving the export market may be worth detailed consideration.

A further possibility which should be studied is that a large pelletising plant could be installed at either Usiminas or Cosipa. It should have sufficient capacity to satisfy the demand for agglomerated burden at both Usiminas and Cosipa. Let us suppose, for example, that it were to be installed at Usiminas. By 1980 it would be sending some 1 million tonnes per year of pellets to Cosipa to satisfy the deficit there. In due course, it would no longer be able to meet the growing demand at both works. Then a new plant would be built at Cosipa - either sintering or pelletising - and the pellet plant at Usiminas would revert to supplying only that works. The merit of the scheme would have to be determined in the light of transport costs.

It is apparent from Table 35.3 that by 1980 cokemaking capacity in excess of authorised plans will be required only at Usiminas. With coke oven batteries being capable of producing, by the end of the decade, up to 1.6 million tonnes per year of coke, the required quantity of 0.7 million tonnes per year would represent a rather small unit, with limited economies of scale. It would probably be advisable to install a larger plant and heavily under-utilise it for a period. This could be justified in the longer term, since beyond 1980 extra quantities of cokemaking capacity will be needed.

35.3 The needs of the non-flat product sector

In contrast to the flat product sector, the non-flat sector will have a substantial shortfall in capacity by 1980. The total requirement for liquid steel is 7.4 million tonnes (Article 34.4) while the forecast capacity of the sector is only about 3.7 million tonnes; a further 0.57 million tonnes is assumed to be available at CSN for the production of blooms for the non-flat sector. In the interest of long-term rationalisation this capacity at CSN must be expected to be transferred eventually to the production of flat products.

There is thus a need to provide between 3.1 and 3.7 million tonnes of additional steelmaking capacity in the sector and, as has been discussed in Article 35.1, the supply of scrap is likely to dictate that the bulk of this capacity is provided by hot metal steelmaking processes.

None of the existing works in this sector are suitable for an expansion of this magnitude, so it will be necessary to build completely new works. Economies of scale favour large units of blast furnace and oxygen steelmaking plant, so there would be some advantage if the shortfall in hot metal steelmaking capacity could be made good in a single installation integrated with a bloom and billet casting plant, as discussed in Chapter 34, Article 34.2. On the other hand, at some small sacrifice to economy in steelmaking, an installation of two to two-and-ahalf million tonnes per year could supply blooms and billets, while the remaining shortfall could be produced in a one million tonne per year plant for continuously casting billets, taking advantage of the lower cost of distribution to users by locating the plant at the centre of demand.

Figure 35.1 illustrates the geographical distribution of demand for non-flat products; from this it is clear that Sao Paulo is the most likely location for a large works, but that Sao Paulo, Belo Horizonte and perhaps Rio de Janeiro are all possible sites for a smaller billet producing works.

In addition to the hot metal steelmaking capacity required there will also be a requirement for some additional cold-metal steelmaking capacity. The exact amount which can be provided will depend upon the supply of scrap or scrap substitutes, and the demands of the special steels sector.

35.4 The needs of the special steels sector

The estimated demand for capacity for making special steels is given - detailed by sector and quality - in Table 35.4; the forecast capacity of the existing industry is also shown. The demand for increased capacity in the flat product sector calls for an eight-fold expansion of present facilities. However, much of the steel classified as 'special' consists of low silicon, high carbon or low alloy types which can be produced in oxygen converters. The tonnages which are required, of these more commonly used steels, may justify their production in one of the large flat product sector works.

The non-flat special steels sector is better equipped to respond to future market demands. The demand in 1980 is estimated to be only a little more than double the capacity already available; however, most of this capacity is only capable of producing the non-common and simpler special steels. A fourfold expansion of capacity for high alloy steels is required by 1980.

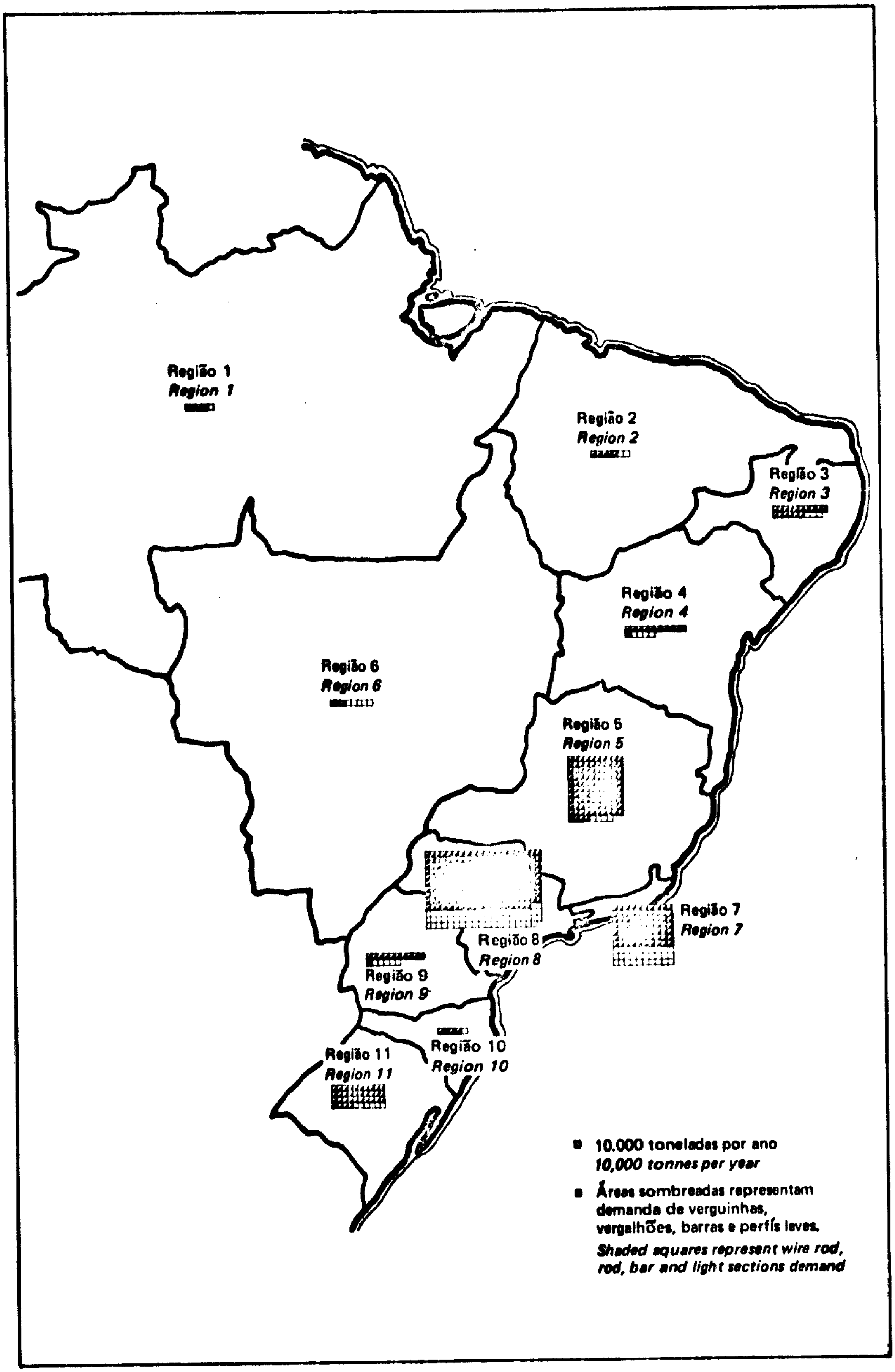

FIGURA 35.1 – PADRÃO DA DEMANDA PARA PRODUTOS NÃO PLANOS EM 1980
FIGURE 35.1 – NON FLAT PRODUCTS PATTERN OF DEMAND 1980

TABLE 35.4 - SPECIAL STEELS CAPACITY REQUIRED AND AVAILABLE IN 1980

(tonnes of liquid steel)

Sector	Capacity required	Forecast capacity available
Flat product	350,000	42,000
Non-flat products	1,350,000 (39,000)*	610,000 (11,000)*

*Figures in brackets are the tonnages (included in the total) for high alloy steels.

As in the flat product special steels sector, a large proportion of the tonnage of steel defined as 'special' is in the non common category and can be made by bulk steelmaking methods, provided quality control is adequate.

The bulk of present special steel products are produced in 14 of the works included in this study; much of this capacity - estimated to be 0.5 million tonnes per year in 1980 - is devoted to the production of non-common, low alloy steel. A possible solution to the needs of the sector would be to up-grade and expand these works to handle the higher and more sophisticated grades of special steel, leaving the simpler, non-common, types to the new large billet works suggested in the previous article.

The expansion of special steel manufacture cannot be planned in detail without an accurate market assessment of the growing demand for each of the two main groups of steel defined as electric arc or induction melted steels. These groups need further sub-division into what has to be ingot cast and what may be continuously cast, and still further into that requiring additional refining equipment, such as vacuum degassing. With such a process requirement pattern, it is then possible to allocate production to existing works in order to fill up their facilities and then, by difference, to determine the shortfall in facilities.

In determining the future location for manufacture of high alloy steels, it should be borne in mind that many such steels are often made in small quantities, particularly when destined for non-flat products. This allows a certain flexibility of location because the cost of transporting either scrap or finished product is relatively insignificant, due to the high intrinsic value of the product.

35.5 Technological trends in iron and steelmaking with significant implications for planning in the Brazilian iron and steel industry

In the context of the needs of the three products sectors discussed in the preceding three articles we can now draw attention to the advances in technology which are relevant to these needs. More extensive discussion of these topics will be found in the chapters on technological trends to which references are given.

The flat product sector is already fully committed to hot metal steelmaking using oxygen blown converters, and is thus in line with modern world trends. The units of plant being installed in the current expansion programme are large enough to justify developing each of the three existing works fully, before planning the construction of a fourth works. In this sector, therefore, the most significant developments to be studied are those relating to operating practice and plant modification.

In the non-flat and special steels sectors, on the other hand, the magnitude of the shortfall in capacity is such that new works will have to be built; this provides an opportunity to introduce the latest technological developments in process and plant into the Brazilian iron and steel industry.

Trends in BOF steelmaking (Chapter 12, Article 12.2)

The most noteworthy developments are: the reduction in tap-to-tap time; the practice of varying a standard specification steel by additions of alloying elements in the ladle; the more effective control of fume emission; and the trend towards a three-operating-out-of-four furnace configuration.

Probably the most important index of performance in BOF steelmaking is the average tap-to-tap time consistently maintained over a long period. Current cycle times in BOF's operating in Brazil vary from 80 minutes to 35 minutes. The slowest times result from delays due, for example, to hot metal shortage or scrap pre-heating. The fastest times are satisfactory when compared with current good practice in industrialised countries. By 1980 Brazil should expect to achieve times around 30 minutes for smaller furnaces, perhaps a little more for furnaces of over 100 tonnes capacity. Provided this time is maintained over long periods, this will enable a two 100-tonne furnace shop to produce a little over 3 million tonnes per year. For this, it is important that availability matches world practice; calculations have been based on 8,000 hours per year, which represents over 90 percent availability. Current availability is less than this, so some improvement will be necessary here. As indicated in Article 35.1 the relatively low scrap content of the charge (20 percent) which has been assumed may give rise to some difficulty in cooling. In these circumstances it will be necessary to increase the scrap content of the charge, or provide alternative coolants, if the desired tap-to-tap time is to be achieved. It is important, from a national point of view, to reach agreement quickly on an overall policy with regard to scrap content in the BOF charge, since it could influence the balance between hot and cold steelmaking capacity to be installed in new works. Furthermore, a decision to use more scrap would lead, in the light of an anticipated shortage of scrap, to an appraisal of the merits of increasing sponge iron production as against importing scrap.

The steel yield obtained in good BOF practice is around 91 percent of the iron-bearing charge materials. Current Brazilian performance appears to be slightly lower than this. With new plant the aim should be to achieve higher yields.

With a BOF shop operating two furnaces out of three, lining time is not critical and so very long campaign lives are not essential, but for smooth operation of the shop, campaign lives in excess of the present values in Brazil of around 400 heats should be sought. As was stated in Chapter 4, this poor value can be attributed to the unsatisfactory quality of the lining bricks; improvements in quality should enable the industry to reach the values of up to 1200 heats which are expected in good practice. When these long lining lives are achieved consistently, consideration could be given to increasing BOF shop capacities by the addition of a fourth furnace, where space permits.

At present the limitations on the designs of BOF steel plants and continuous billet casting installations, but chiefly the latter, make it impracticable to attempt billet casting with steel ladles of more than 100 tonnes capacity. This in turn limits the steelmaking furnaces to 100 tonnes capacity. The difficulties of operation of BOF shops with three vessels operating make it advisable to plan for the present, to work two furnaces out of three leaving space for the addition of a fourth furnace later. Thus, the maximum practicable size of a blast furnace - BOF - 100 x 100mm billet casting works should be taken as around 3 million tonnes per year. Improved design of steelmaking and casting shops may, within a few years, allow plans to be safely laid for a billet casting works of half as much again, that is about 4.5 million tonnes per year, but we do not recommend this at present. Proven technological and economic success of billet machines with eight or more strands, or of long-term sequence casting, or of BOF shops with three operating furnaces, would immediately allow the figure of 3 million tonnes to be increased. A higher billet output is also, of course, possible with billets of larger cross-section.

If a works is built producing rolled billets from continuously cast blooms, then the restriction on ladle size is no longer applicable and a single works could for example, easily fill the whole additional requirement in the non-flat sector in 1980, and for some years beyond.

BOF steelmaking evolves large quantities of fine iron oxide fume and dust. Thus, in populated areas it will be necessary to instal pollution control equipment. Concern with the quality of the environment in Brazil is certain to become a matter of increasing public interest. In addition to meeting the needs of public opinions, pollution control processes such as the OG and IRSID systems also improve overall process yields. (Chapter 23, Article 23.3).

OBM Steelmaking (Chapter 12, Article 12.3)

The promoters of this process, and the similar bottom-blown oxygen processes, state that they have two main advantages over the BOF process: the ability to accept a higher proportion of scrap in the charge, and a reduction in oxide fumes.

In the light of the scrap situation in Brazil, the first is not likely to be of general significance. The lower fume emission has to be considered against the costs of fume control on existing BOF furnaces.

However, as noted in Chapter 12, cost advantages have been claimed for OBM, and these should be examined in the light of Brazilian conditions. Detailed study might show, for example, that regional variations in scrap availability favour the use of OBM in areas such as Sao Paulo, Belo Horizonte or Rio de Janeiro. This would have the added benefit of assisting the control of polution in an existing industrialised area.

Trends in electric arc steelmaking (Chapter 13)

Additional electric arc capacity will be justified in Brazil in the future. The installation of capacity up to a maximum of around 1.5 million tonnes per year by 1980 can be considered, but in practice, the scrap availability will probably limit the capacity to closer to half a million tonnes.

Since the economies of scale of scrap-based electric arc shops are largely exhausted by about 1 million tonnes per year, it is unlikely that Brazil would wish to consider installing a scrap-based works of more than that capacity - even if total scrap arisings were sufficient. The economy of scale obtained between 0.5 and 1 million tonnes per year, however, is more than $2 per tonne, so that a works of 1 million tonnes per year may be seriously considered when sufficient scrap is available.

In order adequately to feed a continuous billet casting plant, an electric arc shop should consist of two or more furnaces. Otherwise steel supply to the casting shop will be intermittent and will result in under utilisation of the billet casters. This then places a restriction on the maximum size of furnaces. Assuming modern arc furnace practice, then 1 million tonnes per year of liquid steel can be produced by three furnaces, each of a little over 100 tonnes capacity. At 0.5 million tonnes per year the furnaces would be about half this size.

Shorter tap-to-tap times have now become possible by the use of transformers allowing high power inputs. Some medium and large installations now use ultra high power inputs of over 250 kVa per tonne and with small furnaces power inputs range up to 5kVa per tonne. New electric arc furnaces in Brazil should be planned within this range, and the ease with which existing furnaces can be converted makes it worthwhile to consider converting them. A further advantage of high power input resulting in short tap-to-tap times is that it allows a frequent supply of metal to the continuous casters without the need for four or five furnaces which would be necessary with the tap-to-tap times of low power practice.

A factor to be taken into account at an early stage in consideration of electric arc steelmaking is the total electricity requirement in relation to supplies in the area. A 1 million tonnes per year works would have a maximum demand of about 80 MW or the equivalent of a large power station. Even if area generating capacity is greatly in excess of this, the effect of such a large steelworks on the supply network would be pronounced.

The problems of providing adequate electricity supply and of meeting maximum demand can be eased by the use of charge pre-heating or of double furnace refining (SKF-MR process). The use of liquified petroleum gas for pre-heating in the first of the twin furnaces, combined with the short cycle time (2 - 2½hours) allows electricity consumption to be reduced by over 200 kWh/tonne.

In order to achieve high productivity and low cost in scrap-based electric arc practice, it is of the greatest importance for the Brazilian steel industry to ensure that scrap is correctly sorted and prepared.

Trends in special steelmaking (Chapter 21)

Although the bulk of special steels are made in electric arc furnaces, since this is the most economic method for most of the types and tonnages required, a number of special quality grades. together with a large proportion of non-common steels, are frequently produced in large integrated works.

Many non-common steels have sufficient alloying elements present to make them borderline between non-common steel and special steel in any simple classification. Such facts must be clearly established before capacity planning can proceed. These steels include, in particular, the high silicon electrical steels, the silico-manganese spring steels and the low alloy special purpose structural steels, which for many years were invariably produced in open hearth furnaces and have more recently been produced in BOF plants, as the ability to control the much faster BOF process has improved with improved technology. This improvement in control of the process has led to investigations into the production of some of the more sophisticated steels, including some of the stainless grades, in the oxygen converters. Although there is no doubt about the ability to produce many of the non-common grades using oxygen processes, it is doubtful whether oxygen processes using a large percentage of liquid iron can compete in the production of the stainless grades with standard electric arc practice. The basic reasons for this are the cost of the charge and the yield, in particular the chromium yield. The electric arc process, which has been considerably speeded up by the use of increased power, can be manipulated to give the highest possible chromium yield and full advantage can be taken of its ability to utilise chrome ore in the charge. This together with high alloy and common scrap utilisation, and possibly nickel oxide in the charge, enables a minimum cost charge to be used which cannot be improved by a blown process.

Trends in blast furnace ironmaking (Chapter 10)

The largest planned blast furnace in Brazil will have an annual output of 2.8 million tonnes per year, or a little under 8,000 tonnes per day, which is comparable with the largest blast furnaces in the world, situated in Japan.

By 1980 we expect, as discussed in Chapter 10, to see furnaces in operation with outputs of up to twice this value. Thus, while by 1980 an 8,000 tonnes per day furnace will probably still be considered very large, it will be well within the technological competence of world experience, and there should be no difficulty in fully exploiting its potential.

The output of existing Brazilian blast furnaces is extremely low by comparison with modern installations in, for example, Japan and the USA. By present day standards a Blast Furnace Output Index (BOI) of 100 is considered good practice. * By 1980 this figure will probably have risen to between 120 and 130. Current Japanese best performance is about 170, a figure which is regarded as approaching the maximum attainable. It is clear that the Brazilian average BOI of around 50 could be very greatly improved upon and if high output furnaces are to be built must, indeed, be greatly improved.

The important changes in design and operation which could be effected in the new furnaces are:

Burdening practice: (Chapter 10, Article 10.6)

Efficiency of furnace operation is closely related to the particle size distribution of the burden materials. The trend is towards the use of smaller and more uniform sizes of lump ore and sinter. The friable nature of the Brazilian ore means that it will be worthwhile, particularly on new high-performance blast furnaces, to charge 100 percent of the iron ore in a prepared form, either sinter or pellets.

The choice between sinter and pellets is not always an easy one to make, and the practice of pelletising has been growing fast throughout the world. In terms of blast furnace operation there is really very little to choose between pellets and well-sized sinter. The capital cost of pelletising is slightly higher than that of sintering, while the conversion cost of sintering, when the coke breeze is taken into account, is higher than that of pelletising. Much depends on the form of the iron ore feed. If it is fine enough to need little grinding then pelletising will be the best choice. Grinding, however, is a costly operation and should be avoided if possible. On balance, it is likely that most of the ore will be sintered. This permits the possibility of adding fluxing materials to avoid the need for charging limestone to the blast furnace.

Together with 100 percent prepared burdening practice should be the use of optimum particle size of burden materials and the practice of rescreening prior to charging. The best performance can only be obtained after metallurgical tests to determine the most suitable particle size for the Brazilian materials. Modern practice involves removing all minus 10mm particles from the furnace charge. The optimum coke size, also, cannot be determined without tests. It is possible that the coke while conforming to the same lower size limit may be able to have an upper

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* See Appendix 1

size limit appreciably above the 25 mm typical of iron ore material in good practice.

Coke rate: (Chapter 10, Article 10.3)

The coke rates, as discussed in Chapter 10, is dependent on many factors. The coke rate which has been assumed in calculations in this chapter is 420 kg per tonne of hot metal, to which must be added the coke equivalent of the injected oil. The corrected fuel rate in Brazil is currently very much higher than this. The shortage of coking coal in Brazil, however, will be a very strong incentive to improve practice by 1980 to the level of current world best performance.

Oil injection: (Chapter 10, Article 10.4)

Some existing Brazilian blast furnaces utilise oil injection, but it should be standard practice on all new furnaces. Indeed, such are the advantages of oil injection that it would be advisable to undertake development projects on most of the existing blast furnaces with a view to introducing oil injection on them. With Brazilian coke costing over $40/tonne and oil at only about half that value, a furnace could certainly afford to use oil injection, even if oil replaces less than its own weight of coke. Typical oil injection in 1980 will be 50 - 75 kg per tonne; the case for oil injection in Brazil is very strong and higher values than this may be warranted as long as furnace productivity is not reduced. Recent research has shown that by the use of steam, to atomise the injected oil at the tuyere, very high oil injection rates can be achieved without producing tuyere zone cooling. This development should be of interest in Brazil.

Gas injection: (Chapter 10, Article 10.4)

Injection of gas into tuyeres is not as common as that of oil, although it is widely practiced in some parts of the world. Natural gas does not seem to be available in Brazil for this purpose but transported liquified natural gas or liquified petroleum gas could, of course, be used. One tonne of coke could be replaced by between 800 and 900 kilogrammes of LNG. This means that, under Brazilian conditions, LNG would have to be obtained at the works for between $45 and $50 per tonne for its use to warrant consideration; this is unlikely to be possible.

Coke oven gas can also be used as a coke replacement but its availability depends on the demand from other sources and it is unlikely to warrant consideration except where a continuing surplus exists.

Trials have been undertaken on the injection of reformed gases into the bosh to increase the reducing potential of the stack gas. This results in an increase in the calorific value of the top gas but will also increase the value of the gas credits. This procedure involves the installation of a gas reforming plant, which costs more than the plant to inject oil or gas into the tuyeres, but some operators have claimed that the practice successfully reduces coke consumption. This is an area where developments could be worth monitoring.

Blast temperature: (Chapter 10, Article 10.5)

Blast temperatures on Brazilian furnaces are, in general, low. Existing furnaces could have their blast temperatures increased to 1050°C but this will still be well below current practice on modern furnaces, which is around 1150°C. By 1980, advanced practice will have increased to 1200°C - 1250°C. High blast temperatures can only be achieved on stoves specially built to produce them; this seriously limits the extent to which existing plant can be improved.

The coke rate falls by around 10 kg per tonne for each 100°C increase in blast temperature. In addition to its use as a coke saver, high blast temperature can be used to compensate for tuyere-zone heat loss on fuel injection.

Some interest has also been shown in the use of cold blast enriched with oxygen to produce the necessary tuyere-zone temperature. This has the advantage of considerably reducing the cost of the installation, since hot blast stoves form a substantial proportion of the total cost. The increase in the coke rate is offset by oil injection. The further redevelopment of this practice should be monitored for its possible application in Brazil in the future.

High top pressure : (Chapter 10, Article 10.5)

The use of high top pressure has only a small beneficial effect on coke rate and so from this point of view will not be of interest to Brazil. It does, however, produce an improvement in productivity of around 1 percent for each 0.1 atmosphere. It is now generally accepted that all blast furnaces can economically justify some increase in top pressure above atmospheric as long as demand justifies the extra output. Pressures between 0.5 and 1.0 atmosphere can usually be achieved by modification of existing furnaces. Further increases must be built in at the design stage. The very high output blast furnaces operate at a top pressure of around 2 atmospheres, and the new furnaces to be operating in Brazil at the end of the decade should be designed to be able to approach this figure.

Use of partially reduced iron ore as a blast furnace feed: (Chapter 10, Article 10.7)

This subject is discussed in detail in Chapter 10. The advantages of the practice are clear; productivity is increased and coke rate decreased. The disadvantage is equally clear; to secure an economic advantage the cost of pre-reducing the pellets must be around $6 - 12. At present the cost of pre-reduction is considerably in excess of this and we do not expect it to fall to a level which will warrant serious consideration of pre-reduced pellets on a long term basis. The only occasion on which pre-reduced burdens can be seriously contemplated is when a small increase in blast furnace output is required to maintain balance in a works and delay the building of a new furnace. It should be possible to draw up the expansion plan for the

Brazilian industry without needing to utilise pre-reduced material in the blast furnace.

Trends in sintering and pelletising (Chapter 7)

The various types of sintering plant have been discussed in Chapter 7, Article 7.2., and the continuous travelling grate would certainly be the preferred choice. The performance of the best of the two Brazilian continuous sintering plants was noted in Chapter 3, and exceeds average good world practices.

When coke rates in ironmaking are reduced and the whole of the burden sintered, the necessary amounts of breeze will not be available without crushing lump coke; for every tonne of coke charged to the blast furnace about 200 kilogrammes of breeze are required. With good cokemaking practice and good quality coal, breeze production would not be anywhere near this level. Several alternatives present themselves. First, good lump coke could be crushed. Second, the deficiency could be made up with charcoal. (While this is technologically feasible it is not very practicable. In any case, charcoal is not as satisfactory as coke breeze in sintering, and this fact may be reflected in productivity or sinter quality). A third alternative involves making up as much of the deficit as possible with gaseous fuels which can be used to preheat the air, thus reducing the solid fuel requirement.

Pellet plants do not exhibit economies of scale in the way that sinter plants do, because the largest single units are not much above 2 million tonnes per year. The costs of pelletising only fall by about 25 percent between 10 million tonnes per year and 1 million tonnes per year. There is thus no loss in having to build several small plants. The only satisfactory way of making cold bonded pellets has been to mix the fines with around 10 percent of Portland cement and leave the soft pellets for about 5 weeks to reach full strength. Even then they do not travel as well as fired pellets. Such pellets would behave badly in the blast furnace due to the high cement content.

There is then, in Brazil, no alternative to firing as a means of producing oxide pellets. There are several commerically proven methods of pelletising. All have similar costs. The grate kiln cooler machine appears to produce the most consistent product.

Pellets, being capable of replacing sinter in any quantity and of being transported, offer a good solution to the problem of maintaining a balanced burden preparation facility during steady growth of iron and steelmaking. With the rapid expansion of works in both the flat and non-flat product sectors, there appears to be, in Brazil, a possibility of using one or more pellet plants to provide marginal extra burden preparation capacity to various works, to carry them through the periods when extra sintering plant, if installed, would be heavily under-utilised. A number of commercial complications may attend such an arrangement, not least of which is the fact that works do not like to have burden preparation outside their control, but there could be definite advantages.

The current trend is to add as much of the fluxing as possible in the burden preparation plant . In this way the flux is fired prior to charging to the blast furnace and the thermal load and coke rate in the blast furnace is reduced. Less success has been achieved in the fluxing of pellets than of sinter because it has not yet proved possible to achieve adequate pellet strength when substantial amounts of flux are present. Research on this subject is in progress and the developments should be followed.

It is common practice to include substantial quantities of limestone in the sinter mix. But inability to obtain full control of the recirculating percentage on the strand and of the basicity in the furnace has in the past made it impossible to predict exactly how much limestone should be added to the sinter strand to flux the sinter. Developments in sinter practice have made it possible in certain instances to obtain a very strong superfluxed sinter. This possibility should be examined by the Brazilian steel industry as it may prove to be applicable on modern plant in Brazil. It is likely, however, to remain normal practice to retain, at the blast furnace, some control over slag basicity. Thus a small portion of the flux will in almost all cases continue to be charged direct to the blast furnace.

Trends in conventional cokemaking (Chapter 8)

Several important developments in conventional cokemaking practice have been discussed in Chapter 8. Some of these developments allow the cost of the coal feed to be reduced; some reduce the cost of converting the coal to coke and some merely increase the output of ovens without exerting much overall effect on costs. All are worthy of consideration in Brazil.

Selective crushing of the coal charge ensures more uniform distribution of the various constituents of the coal and can be used to produce a stronger coke. Of interest in Brazil should be the fact that it can also allow the coal blend to include a larger proportion of weakly coking or non-coking coal while maintaining the same coke strength. It is claimed that in some circumstances a blend containing only 45 percent coking coal can produce a coke of satisfactory strength. The cost of preparing the coal charge by selective crushing is estimated to be about $1 per tonne of coke produced. This cost is so small that it can be recovered by the inclusion in the blend of fairly small quantities of cheaper non-coking coals.

Improvements in other areas show less dramatic advantages although the practice of drying and preheating coal blends, prior to charging, allows such large increases in oven throughput that its cost can be much more than covered by the saving in capital charge per tonne on the ovens. Claims have been made that preheating can produce an overall saving in coke costs of up to $1.5 per tonne.

The increasing dimensions of modern ovens has resulted in increased output from single ovens. In this respect, the planned new ovens in Brazil appear to conform to the current trend. Modern plants now provide for carbonisation at up to 35 mm per hour compared to the traditional rates of about 25 mm per hour. These developments require high grade refractories, a subject which requires careful examination in Brazil.

On the basis that at present the largest size of works designed to produce

100 percent billets will produce around 3 million tonnes per year of liquid steel, about 1.2 million tonnes per year of coke will be required for ironmaking. Additional coke in the form of breeze would have to be charged to the sinter plant. The quantity of breeze would depend on the fuel practice adopted at the sinter plant but could be up to 0.3 million tonnes per year. If the coke and all the breeze are provided from the same coke oven plant, then it would need to produce 1.5 million tonnes per year of coke and breeze. In Chapter 8 it was pointed out that by the end of the decade the most advanced single coke oven battery should be capable of producing about 1.6 million tonnes per year of coke. Thus, the form of conventional cokemaking plant in a large billet works seems clear. It would consist of two coke oven batteries, the second being built onto the end of the first, when demand warrants it.

Trends in the development of formed coke production (Chapter 9)

Formed coke as an alternative to conventional oven coke should be of very great interest to Brazil, since it offers the opportunity to use cheaper non-coking coal in place of the costly imported metallurgical coking coal. The physical properties of formed coke have been shown to be comparable to those of oven coke.

A number of processes have been developed and of these there are three which are receiving serious consideration and which will undoubtedly be developed further during the next few years. They are:

(a) Bergbau - Forschung (BBF) process
(b) FMC process
(c) Sapozhnikov process

Each of these processes is discussed in Chapter 9.

Commercial production of formed coke will gain ground most rapidly in those countries where two circumstances favourable to formed coke exist. First, these countries will lack suitable coking coals but may be able to obtain cheaper non-coking coals of acceptable analysis. Secondly, they will exhibit an above average long-term rate of growth of iron and steel production, with a consequent demand for substantial new cokemaking facilities. Brazil is such a country and should begin at once to develop a study programme which will enable it, in a few years time, to make confident decisions regarding the applicability of formed coke to its own steel industry.

Since those countries which are at present operating formed coke plants are likely to continue to maintain secrecy about details of costs and results, there is no substitute for Brazil setting up one, or more, small formed coke plants based on processes referred to in this section.

Certain other possible advantages of formed coke should be taken into account. Its regular shape and size may make it possible to transport formed coke between works. This could greatly assist in maintaining a reasonably balanced overall cokemaking capacity as ironmaking demand grows. A further possibility is that formed coke breeze could be used in the sinter plant. As we have seen, with low coke rates and 100 percent of iron ore being charged as sinter, the total quantity of coke breeze used in sintering approaches a quarter of the coke used in the blast furnace. Formed coke breeze or perhaps carbonised but unbriquetted material should be suitable for sinter plant application; this is an area where strength is unimportant and reactivity a little less important than in the blast furnace.

Trends in direct reduction ironmaking (Chapter 11)

The high cost of metallurgical quality coal, and a possible shortage of scrap are reasons for giving careful consideration to the production of sponge iron.

The HyL and SL/RN plants at present being built in Brazil will provide useful data on the value of these processes under Brazilian conditions. SL/RN plants have yet to prove themselves in operation, but the HyL process is by now well-established and commissioning the plant in Brazil should present no particular problems.

The Brazilian steel industry will remain sensitive to the price of imported coking coal. Even with the very low coke rates envisaged later in this decade, the blast furnace route will still require around 580 kilogrammes of imported coal per tonne of liquid steel. On this basis, if the price of imported coal increased from $29, its present level, to $39 then the cost of liquid steel will increase by $6. Such a change would make the naphtha-based HyL process route to steel, via electric arc furnace, much more competitive if the price of naphtha remains steady. It is probably also true, however, that such a change would lead more rapidly to the adoption of 'formed' cokemaking from cheaper coals.

There is no reason to suppose that changes in technology or demand will lead to an important change in the price of naphtha. Nor is it likely that, by 1980, gasification of other fuels such as oil or coal could produce a reducing gas appreciably cheaper than the current Brazilian naphtha price. The widespread availability of natural gas for ironmaking could markedly reduce the costs of the HyLprocess route. This remains an open question, but the availability of natural gas at 3.5 cents per therm could reduce the cost of liquid steel by $6 per tonne; at 2.5 cents per therm the cost of liquid steel could be reduced by around $8.5 per tonne.

On the other hand, under conditions of scrap shortage, even more modest decreases in the cost of sponge iron produced by the HyL process could be enough to justify the use of sponge iron as a temporary supplement to the feedstock for electric arc steelmaking processes.

CHAPTER 36 - IMPLICATIONS FOR STRATEGIC PLANNING IN THE STEEL INDUSTRY IN BRAZIL

In the previous two chapters we have discussed the implication for Brazil of world technological developments in the shaping and treating of steel, and in iron and steelmaking. As a result, it has been possible to indicate likely technological strategies for the development of the Brazilian steel industry.

To prepare a complete strategic plan for the industry, however, wider issues have to be considered as well as the technological options. In this chapter we shall indicate those topics which require further studies in depth, before a definitive strategic plan for the whole industry can be drawn up.

As in the previous chapters we have considered the flat, non-flat and special steel product sectors in turn.

36.1 Structure of the flat product sector

It is almost always cheaper, in capital cost, to expand or modify existing plants than to build new ones. We do not see a need to build a new flat products plant before 1980. The shortfall can be met by expansion at the existing plants.

The salient features of the flat product sector which stand out from previous chapters, and which need careful consideration, are these:

(i) That there is an estimated shortfall, in 1980, of 900,000 tonnes of hot-rolled strip. This may reasonably be expected to increase, perhaps rapidly, in the early years of the following decade.

(ii) The next hot strip mill to be installed in Brazil should be a fully continuous mill if advantage is to be taken of the technological trends described in Chapter 17. Such a mill will have an output of at least 3 million tonnes per year, and could be designed for much higher outputs. The location of this mill will be an important matter for study. It will be equally important to consider the future of the existing hot mill at CSN which, by 1980, will be 34 years old and perhaps due for retirement.

(iii) There is an estimated shortfall, by 1980, in tinplate and cold-rolled sheet production, both of which use hot-rolled strip as a feedstock. Prima facie, it appears that an additional tinplate plant will be required and that one of the existing sheet plants may require expansion.

The foregoing embrace a number of technological and logistic problems which require specialist studies that go well beyond the boundaries of this report. We are aware that some thought has already been given to the next flat products expansion programme, but we recommend that a formal study should be put in hand at an early date. For example, to be fully effective by 1980, a hot strip mill would have to be ordered by early 1977, at the latest. The studies, pre-contract engineering and mobilisation of finance could take three years, so the study should begin not later than 1974.

The difference between the estimated shortfall of hot strip capacity in 1980, and the capacity of a new mill is considerable. This serves to demonstrate that expansion of one process unit in the total sequence of processes in the production of sheets or tinplate, starting from iron ore, usually results in a situation of imbalance. Furthermore, the development of demand is a continuous process which does not stop short at a particular point in time, such as 1980. Thus, it is necessary to look even further ahead in formulating investment policy and decisions.

For these reasons, it is important for the planning of strip production to consider this sector of the industry as a whole. This should have been facilitated by the recent decision to bring together the three main flat product companies under a single state-owned holding company. Although it is attractive in theory to have, on one site, a production unit which is in balance throughout its entire sequence of processes, this seldom happens in practice. There is scope for the transfer of semi-finished material, such as slabs and hot-rolled coils between different plants. This method of correcting imbalances at individual plants should be exploited to the fullest practical and economic extent.

By the time the new hot and cold mills come to be ordered there may well be further technological advances. We strongly recommend, therefore, that the most up-to-date engineering thinking should be embodied at that time. The establishment and maintenance of first class quality is of paramount importance in the field of wide strip production. It is vital that Brazil should be internationally competitive in this regard and also that the yield of top quality products should be high. This will require equipment of the necessary high standard.

36.2 Structure of the non-flat product sector

In the non-flat sector, the need for the construction of steelmaking facilities on a greenfield site removes the planning complication normally associated with the expansion of heritage plant. In considering the future structure of this sector, we have taken account in this article of such questions as the processes to be employed, the unit sizes of plant to be installed, the location of plant and the timing of decisions.

It will be clear, from the previous chapter, that we envisage the additional steelmaking capacity being divided between blast furnace - oxygen steelmaking and scrap-based electric arc furnaces, in the period up to 1980.

The ability to transport semi-finished products in the non-flat sector conveniently, makes it possible to undertake the planning of additional capacity for semi-finished products quite separately from the planning of the additional finished product rolling facilities. The key issue, therefore, is the choice between hot metal and scrap-based routes for steelmaking. This choice may well be to some extent restricted by the availability of scrap.

The collection of scrap in an organised and properly classified fashion will place a heavy load on the scrap merchants. If the scrap industry fails to respond to the challenge the reclamation of scrap will fall behind and the availability will certainly not be as shown in Table 35.1. It is worth remembering that if the scrap price falls due to a balancing of supply and demand, then there will be less incentive to collect certain kinds of scrap. If the steelworks yield reaches the maximum value given then it is absolutely essential that all the available process and capital scrap is promptly collected, classified and transported. Failure to collect 10 percent of the available process and capital scrap could result in a scrap shortage under such circumstances. Where the average yield of finished products from liquid steel is 80 percent, the position is less acute. All calculations have been based on the assumption that Brazil will not wish to import scrap. If scrap were imported, then quite apart from the balance of payments problem, Brazil would have limited control over scrap prices. Should it be considered advantageous to import scrap at some time in the future, however, then additional scrap could easily be consumed in the BOF plants.

It is clearly essential to undertake immediately a detailed study of the demand and supply situation for scrap in Brazil. The study should include thorough examination of the organisation of the scrap industry and its capability to collect, classify and transport scrap to steelworks, remembering the possibility that the revenue per unit of scrap handled may fall if, as expected, the price of scrap falls from its present high level of $40 per tonne. The scrap arisings in the capital and process sectors may need further study and the quantity arising within the works is a crucial factor requiring reappraisal of expected process yields. The effect of regional distribution of the arisings of capital scrap, should be an important aspect of the study.

The form of new hot metal based steelplant

Because of the scrap supply limitation it is likely that the additional requirement for hot metal steelmaking will be, in round terms, between 3 and 4 million tonnes per year. This does not include the non-common steels at present covered by the special steel category, which are discussed in the next article. Two questions arise regarding the new steelworks; whether the works should have ingot casting and primary rolling to billet, continuous bloom casting followed by rolling to billets, or continuously cast billets; and whether the capacity should be installed as one or two new plants. (The economies of scale mean that division into three works is bound to be impracticable).

Choice of casting plant:

The decision whether to install continuous bloom casting followed by billet rolling, or the alternative of continuous billet casting, depends partly on the size of the works, and partly on the range of semi-finished product sizes required by customers both at home and abroad. The multiplicity of billet sizes may demand a range of continuous casting machines which, when combined with the range of compositions to be cast may cause heavy under-utilisation so that one hundred percent continuous billet casting is precluded on economic grounds. In this case all or part of the output may need to be bloom cast and then rolled. A decision to construct a single works, particularly if it is of over 3 million tonnes per year, may present technological problems which lead planners seriously to consider bloom casting as opposed to billet casting. The total demand for blooms for direct sale, rolling and tube rounds may in itself be such that existing works will not be able to supply the requirements and part of the new works output will be needed other than for billet production.

The whole question of the choice between bloom casting or billet casting should form the subject of a special study. The study should involve a detailed examination of billet dimensions and compositions required both for home consumption and export. It should also include further study of the technological factors affecting choice of casting plant. The development at US Steel's South Works, Chicago, of high speed continuous casting of blooms, integrated with billet rolling facilities, will no doubt set standards of performance which will be widely copied in future. The choice of casting plant is also closely associated with the decisions regarding location of new plants.

Location of additional hot metal steelmaking plant:

The location of new works in Brazil will depend on the relative positioning of raw material supplies, finished product markets and users of semi-finished products. The latter will comprise rerolling works (currently under 0.2 million tonnes per year and located around Sao Paulo), existing integrated and semi-integrated plants where potential rolling capacity exceeds potential steelmaking capacity, and associated industries such as tubemakers and wire-drawers.

Most of the existing non-flat production capacity is located in the Minas, Rio de Janeiro and Sao Paulo regions, which is also where the major part of the demand arises. Table 36.1 compares projected home demand in 1980 with available capacity. It will be seen that outside the three regions mentioned above, although the capacity and demand are not balanced, the shortfalls are such that there is no major need for additional capacity, bearing in mind that product specialisation by works must mean that no area is totally self-sufficient.

TABLE 36.1 - LOCATION OF CAPACITY AND 1980 ESTIMATED HOME DEMAND IN THE NON-FLAT PRODUCT SECTOR

(thousand product tonnes)

Region		Expected Capacity	1980 Demand	Shortfall (1)
No.	Location			
1	North	44	49	5
2	North-North East	-	66	66
3	North East	144	181	37
4	East	(302)	144	(-162) (2)
5	Minas	1032	1022	-10
6	Central	-	75	75
7	Rio de Janeiro	677	957	280
8	Sao Paulo	1111	2433	1322
9	Parana	20	124	104
10	Santa Catarina	-	48	48
11	Rio Grande do Sul	239	391	152

Notes (1) A negative short fall indicates an excess of capacity over demand.

(2) In region 4 the capacity shown includes USIBA which is only planned to produce billets at this stage.

Source: Based on 1969 Technometal report.

To meet the need for some 3 to 4 million tonnes per year of hot metal, based on non-flat product capacity within the Sao Paulo - Rio de Janeiro - Minas triangle, three different approaches, each of which requires detailed examination, could be adopted. These are:-

an integrated works on an inland site;
an integrated works on a coastal site:
various sorts of 'dispersed production'.

An inland works could be situated near to the iron ore mining area. Imported coal would constitute a return load from the coast to the mining area, and would therefore be carried at low cost. Finished products could either be shipped out to the coast by rail and then distributed via coastal transport, or could be distributed direct to the main consuming areas by road and rail. For transport to areas of smaller demand, and for exports, sea journeys would almost invariably be desirable, in spite of the need for transhipment. The disadvantages of such a scheme would be that the works would be remote from much of its market, and that transport of finished products by rail would be relatively expensive, calling for different rolling stock from that used for ore and coal.

A coastal works could be established either close to a centre of demand or at a point convenient for the transport of iron ore to the coast. In the latter case the products would largely be distributed by sea, whilst in the former much of the production would be locally distributed by road and rail. Establishment of the works close to a centre of demand would have several advantages. Coastal movement of ore would constitute a regular run and could use specialised vessels, thus significantly reducing the cost in comparison with the shipment of finished products. Furthermore, the value of the goods in transit would be lower, which would reduce the working capital. Proximity to the main market would improve the information feedback and provide a speedier service.

Dispersed production at different works could take several forms, for example, a single billet manufacturing plant distributing most of its output to rerollers situated close to their markets; several small integrated works, each located close to a market; or several semi-integrated works, also located close to their markets. Centralised billet production would permit blast furnace/BOF steelmaking to be employed at a level which gives reasonable economies of scale whilst the re-rollers could be located close to their markets and could specialise where appropriate. The billet works would probably have sufficient rolling capacity to supply local finished product demand, and could either be located near the iron ore mine or on a coastal site, as discussed above. The shipment of billets to the re-rollers would constitute a regular run and the limited range of sizes would greatly simplify handling; hence transport costs would be lower than for finished products travelling over the same route.

Any choice between these three types of works would need to be based on a careful evaluation of the precise nature of the market demand, the transport costs pertaining to the particular locations under consideration and the other economic and commercial factors.

In general, coastal sites have been favoured rather than mine-based sites, since the cost of transporting the ore to the coast is less than transporting the equivalent tonnages of coal to the mine and the finished products to the coast.

Dispersed production has some advantages which could offset any higher cost. It permits a high level of contact with the individual markets and encourages effective specialisation. It is probably easier to adapt to changing conditions and it could prove to be justifiable on direct economic grounds.

The form of possible new scrap-based electric arc steelmaking plant

Very little can be said concerning size and possible location of new scrap-based steelmaking. The total installed capacity, as discussed previously, will depand on an examination of the scrap situation. If the quantity of available scrap turns out to be large then there is clearly the possibility of a large electric arc works. In this case a location study similar in nature to that for the hot metal works should be undertaken. Most of the scrap will arise in the south-east and a large works would probably be confined to that region. Smaller quantities of scrap may justify one or more small works on a gap-filling basis.

The location of both a scrap source and a small capacity short-fall in the northern coastal regions strongly suggests a study of the possibility of new scrap-based steelmaking in that area.

The form of new finishing mill capacity in the non-flat sector

The possibilities raised by the capacity short-fall are briefly repeated below. All the plants can be located independently of the billet producers if this proves desirable.

The forecast short-fall in wire rods is approximately 800,000 tonnes. This capacity can be met by two or more mills. The mills would probably have outputs of about 300,000 to 600,000 tonnes per year.

The forecast short-fall for merchant bars is about 1 million tonnes and for light sections about 160,000 tonnes. Merchant bars will probably be produced on high capacity bar mills and two, or possibly three, mills will be required to meet the capacity demand; capacity will then be available on the existing merchant mills to make up the short-fall in light section production.

The forecast short-fall in seamless tubes is 360,000 tonnes but it must be stressed that this is dependent on the extent of the substitution of welded tubes for seamless tubes, a subject which requires detailed study together with an assessment of the product range, since this will influence the number of mills to be installed. It is likely, however, that the extra demand will require two or three additional tube mills.

Medium and heavy sections: According to the quoted mill capacities and the market survey, there does not appear to be a demand for additional medium and heavy sections capacity in 1980 but it would be prudent to reappraise this situation since Brazil is not currently capable of rolling very heavy sections, a product for which appreciable demand could materialise.

Timing of decisions in the non-flat product sector

It is possible to discuss this subject only in the most general terms until more specific plans have been developed. If we assume that a single large blast furnace works will supply the entire demand for additional hot metal-based steelmaking, and that it must be fully commissioned by 1980, then work on site would have to begin in 1974/5. The preliminary engineering would require at least one year and this would have to be preceded by the range of special studies recommended in this report.

Finish-rolling facilities present a simpler problem in timing, since they would take the form of a series of smaller installations phased to meet demand.

36.3 Structure of the special steel sector

Where rolling is concerned, the special steel sector can be divided into flat products and non-flat products, although this division cannot be drawn as clearly as in the common steel sector. No such division is possible in steelmaking.

Flat product rolling

Flat products can be classified as:-

plates - mostly stainless. It is assumed that some of the higher carbon or low alloy steel plates requiring heat treatment are included in the sector dealing with common steel flat products.

wide strip - mostly stainless and similar, but also silicon steels and, particularly, grain oriented silicon sheet.

relatively narrow strip, up to about 500 millimetres wide, in medium carbon and low alloy steels, most of it required cold rolled.

The stated shortfall in capacity for these products is 240,000 tonnes by 1980, in relation to existing capacity of 40,000 tonnes for silicon steel, not grain oriented. We have no analysis of the shortfall of the individual product groups, but in any case, the validity of the estimated demand is bound to depend heavily on the growth in demand for stainless steel strip which in turn will depend upon its availability. We think, therefore, that the figure should be treated with some reserve for the present.

It seems to us that the demand for stainless steel plates in Brazil will not be sufficient to justify a special plate mill for a good many years. It is, however, normally quite practicable to roll limited quantities on one or other of the existing plate mills by hire-rolling, and this policy should certainly be adopted.

Hot and cold rolled stainless strip (sold as cold rolled) is the main issue. Brazil has just the same difficulties as every other country going into stainless steel production - should capacity be created initially which is bound to be in excess of immediate requirements or should the market be allowed to build up first by allowing substantial imports? We think the answer will be found by compromise. We have suggested, in Chapter 34, a possible pattern for the progressive build-up of mills to produce stainless and grain oriented silicon sheet. This subject also, however, warrants special study.

Special quality narrow strip up to about 500 millimetres wide is produced in industrialised countries on small continuous or semi-continuous mills, sometimes with cold rolling on reversing mills. Once again, only a special study will show whether an operation of this kind is warranted in Brazil.

Non-flat product rolling

In the non-flat special steel product sector existing rolling capacity will satisfy around half the demand in 1980, and some 540,000 tonnes per year of additional capacity will be required. Almost all of this extra capacity will be for non-common rather than high alloy steels. At least two new bar mills will be required to meet the demand and the questions which must be answered are, how much of this non-common steel could, on purely technological grounds, be processed at works producing common steel non-flat products, and on organisational grounds, to what extent it is considered acceptable to fragment the special steel industry in this way.

Steelmaking in the special steel sector

In this sector steelmaking is divided between those steels which can be made by the blast furnace - BOF route, and those which require electric arc melting. As has already been noted, the data available to us does not sufficiently distinguish between the various categories of special and non-common steels to enable us to determine the relative capacity demand for these two routes. While this will have to be established by further study, it is already apparent that there is likely to be a need for additional electric arc steelmaking capacity.

On the other hand, the non-common and low alloy steels which could be made by the blast furnace route are also usually suitable for continuous casting. This, then, introduces the possibility of providing capacity for these grades in a new large common-steel blast furnace - BOF works if additional processing facilities, such as vacuum degassing, are incorporated.

36.4 Planning considerations that are common to all sectors of the industry.

So far we have concentrated upon the planning of individual sectors of the industry in the light of the differing implications for each, of the relevant technological, financial and economic trends in the world's steel industry. In many instances we have shown that the technological choices open to the Brazilian industry may be restricted by availability of materials and energy sources. Similarly, location of plants will be governed by their relationship to sources of supply and centres of demand. Factors such as these are of general relevance, and not just confined to one particular sector. All of these factors have to be drawn together in planning the industry as a whole.

Raw materials and reductants

In Chapter 35 we indicated that the major determinant in the continuing growth, in Brazil, of hot metal steelmaking is the supply of reductant. There are two options: firstly, to continue to buy imported coking coal; and secondly, to use reductant derived from cheaper coals using such developing techniques as formed cokemaking. We repeat that it is essential that the Brazilian industry should carefully monitor and conduct trials, where appropriate, into the alternative formed cokemaking processes.

We have also seen that it is necessary for the health of the industry that the supply of prime quality scrap is assured, and that this would require the establishment of a national scrap industry. Alternatively, scrap may be substituted by another high quality feedstock, such as reduced products (sponge iron) manufactured from high grade indigenous iron ores. We emphasise the need for detailed study of both scrap mobilisation and sponge iron production.

Refractories, additions and alloys

Brazil has adequate resources of most of these materials. It is important to ensure that enough processing capacity is available to provide the desired tonnages in the prepared forms and at the required quality, for the needs of the industry.

Home Markets

Although market research has been undertaken, and is continuing, it must be borne in mind that one of the most significant influences on the demand for steel will, in fact, be the increasing supply. This, coupled with the development of new uses for steel and the replacement of steel by other materials, makes it especially important to keep a close watch for possible changes in the demand pattern that could affect the planning of the industry.

One development indicated by world trends in trade is an increase in the trade in semifinished products, particularly billets. This could provide a means of exploiting temporary imbalances in capacity, and might, in time, become a substantial market in its own right.

The potential for exports by the Brazilian steel industry

The expansion of the industry by using modern world best technology will place Brazil in a satisfactory competitive position in world markets.

Provided that control is maintained over the scrap demand to ensure that the price is controlled by the cost of hot metal steelmaking rather than by scarcity, new materials will be fairly cheap in comparison with those of other exporting nations. This will be, to some extent, offset by the need to import reductants; nevertheless, Brazil will be well-placed to service the needs of her Latin American neighbours, and should also explore the potential of the market in West Africa.

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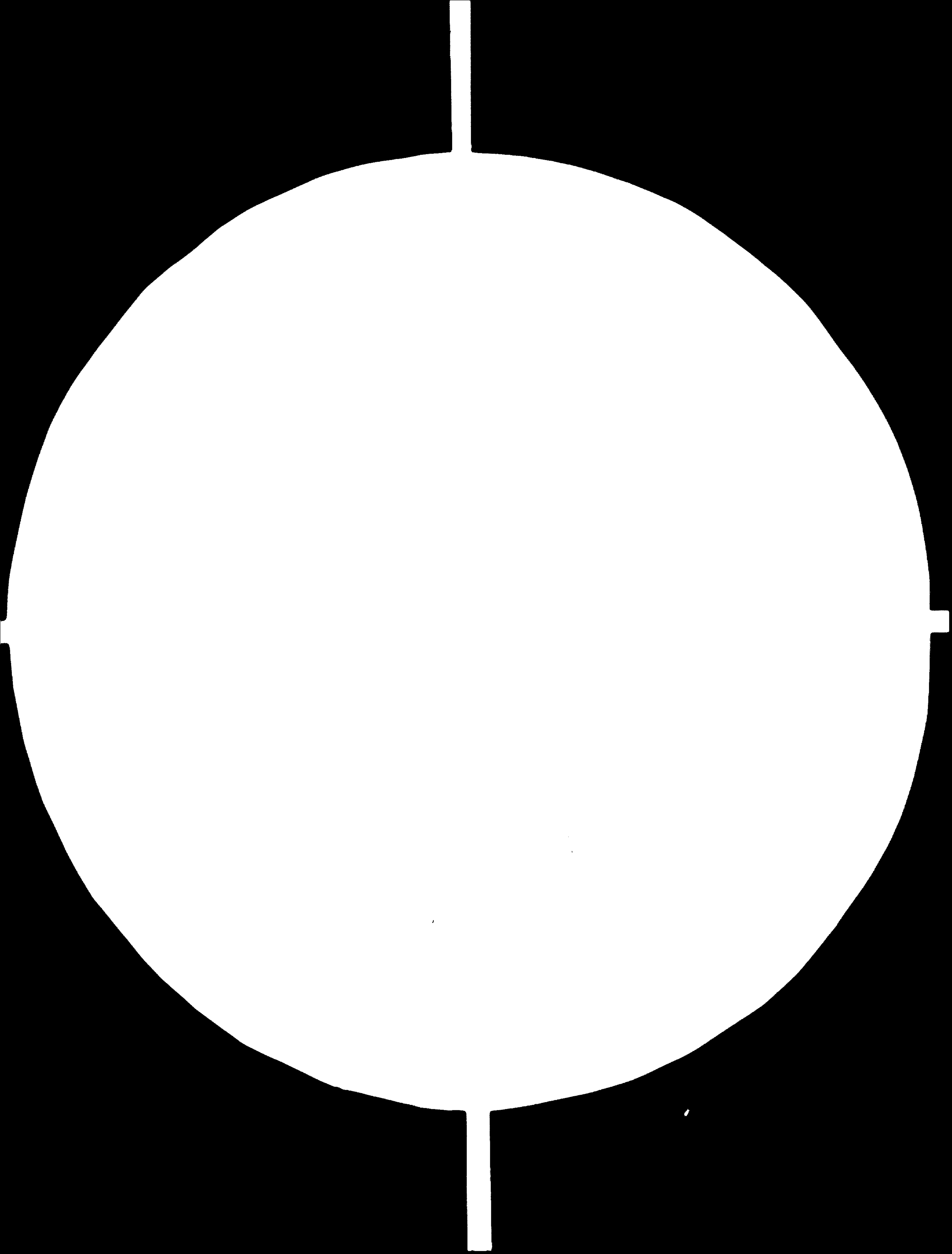

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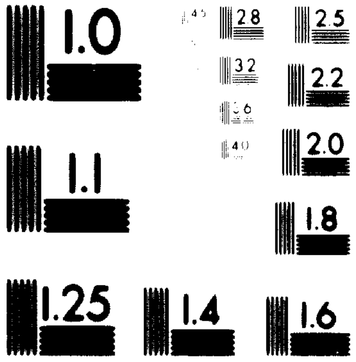

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The possibility of constructing a works for supplying intermediate products overseas should also be considered. Japan or the EEC could be potential investors in large-scale works, in suitable locations, producing semi-finished products for a captive long-term market. The effect of such an arrangement in Brazil would be to increase the added value of Brazilian ore exports.

Transport

The availability of adequate transport systems must be established to select the optimum siting of production units in relation to raw materials sources and the market for finished products. The ultimate object of studying the transportation systems is to minimise the total handling costs by balancing those for raw materials (both indigenous and imported) against those for finished products.

The bulk transportation systems available to the existing industry are complicated by such factors as differing gauges on the railways. However, in general the rail network connects the raw material sources to the market, through the production centres. The extent to which these facilities will be adequate in 1980 to serve the industry in terms of carrying capacity, and from the point of view of constraints on the location of new works, will have to be studied in detail.

Supporting industries and services; research; and training of manpower

These subjects are of major significance and are dealt with accordingly in a separate chapter for each subject - Chapters 37 to 39.

CHAPTER 37 - DEVELOPMENT OF CAPABILITY FOR ENGINEERING AND PLANT MANUFACTURE

In this chapter the steps that have to be taken before an iron and steelworks comes into operation are examined with a view to determining how Brazil can eventually develop full local capability for the whole sequence of operations.

The engineering, design and construction of a fully integrated iron and steelworks is a major enterprise which calls for the assembly, at the right place and time, of numerous specialised skills and technologies. Directly and indirectly several thousand people will be engaged for periods ranging over two to three years.

From the initiation of a project to the commissioning of the plant involves the following principal steps :

Feasibility study
Project engineering
Project management
Civil and structural engineering
Plant and equipment design
Plant and equipment construction

In some of these fields Brazilian engineers are already skilled, while in others more or less reliance has at present to be placed on experts or organisations from countries that have developed their steel industries to a greater extent than Brazil.

37.1 The feasibility study

Because of the magnitude of the task of designing and building an integrated iron and steelworks and the large sums of money involved, there is a need for careful and detailed study before any decision to start can be made; this phase is usually known as the 'Feasibility Study'. Indeed, it is sometimes necessary to go back even further and have a 'Pre-feasibility Study', the object of which is to examine whether a prima facie case exists which would warrant the expenditure on the main Feasibility Study.

The principal areas which this main study will cover are :

A market study to determine what products can be sold, to what markets and in what quantities.

The available raw materials and supplies.

The selection of the process route most appropriate to the products to be made and the supplies available.

The approximate calculation of mass and energy balances with a view to determining the quantities of materials and supplies required.

The selection of the site, which is usually determined on the basis of minimising total transport costs of raw materials and products but may have to take account of other environmental factors.

The layout of the works upon the site and the determination of civil engineering and building requirements.

Estimation of capital required.

Estimation of operating requirements with their costs, the revenue to be earned and the profitability.

Estimation of cash flow and examination of method of financing.

The end product of such a feasibility study will be an outline plan of the works most suited to the particular circumstances, a statement of the requirements in terms of materials, manning and money, and an estimate of the profitability and/or other benefits that will arise if the works is built. Such a study can, of course, sometimes yield a negative answer - that the kind of works envisaged will not be a profitable venture.

This study and the establishment of a viable scheme call for much experienced judgement and are invariably the product of a team of expert engineers and metallurgists working togerher under competent leadership. The experience arises from working on similar studies before, coupled with access to information on the successes and failures of others in former years. A large established steel company, seeking to construct a new plant, may well have on its staff men of the required experience who can be formed into a team for the purpose; and may perhaps bring in specialist advice on particular aspects of technology. Indeed, this treatment is very common in the large producing countries, where steel is already a way of life.

In countries where this internal expertise is not readily available, or does not even exist, it is customary to engage the services of consulting engineers having experience in this broad area of technology. The number of firms active in this field is not great, but their employment has the advantage that, since their work takes them into many countries and many different sets of circumstances, their experience is usually very wide. A few of the large steel companies in developed countries are also willing to provide similar services, in whole or in part. Their advice has the merit that much of it will be based on their own hard practical experience, but its base may, of course, be correspondingly narrow. Some of the plant engineering companies also offer consulting services and this can be valuable in specific cases.

With regard to establishing full local capability in Brazil, the three large flat products companies are already quite well equipped with experienced engineers who understand the nature of the problem very well. All were built initially on the basis of schemes submitted by overseas consultants or steel companies. Their expansion plans have been similarly treated and they are, technologically speaking, sufficiently mature to form their own judgement on the merits of external advice received.

In the non-flats sector, those companies with established overseas affiliations will have the advice of their parents or licensors in regard to expansion plans, and it is really in the possible establishment of a new plant on a 'greenfield' site that problems will arise in the short or medium term. Engineers of sufficient experience exist in Brazil, but the question is whether there will be enough to carry the load which will arise in the short term, having regard to the projected rate of growth.

In considering local capability in this context, it would be sensible prima facie to look at the scope for building on what exists. There are firms of Brazilian consulting engineers in practice at present, who are believed to have worked on relatively small schemes within the steel industry, but who may not yet have carried out a full scale feasibility study for a large integrated iron and steelworks. Any consulting firm which has on its staff an adequate number of engineers well versed in the various aspects of iron and steel technology should, with the right scale of support activities behind them, be able to carry out feasibility studies effectively; but the problem with a young firm is usually to establish the reputation which only comes from having carried through major projects successfully.

It is suggested that CONSIDER might take an initiative by encouraging two or three of the leading Brazilian consulting engineering firms to take the steps necessary to equip themselves technologically to be in the first rank in the specialised area of iron and steel. This could perhaps be done by either or both of two methods. Either they would recruit experienced steelworks engineers to their staffs, if necessary from overseas; or they would seek association with one of the internationally experienced consulting firms, whereby the experience which only comes from actually doing the job will be made available to them on specific projects. Indeed, it is understood that two Brazilian firms of consultants have already done this.

An alternative would be for CONSIDER to act more directly by inviting one of the most experienced Brazilian steelworks engineers to form a small study team drawn from young people with some practical background of experience in steelworks operations and their economics, who would study the various disciplines which enter into the total technology in developed countries. When the next steel plant comes to be designed, it may still be desirable to engage the services of overseas consultants, but it should be a condition of any contract that men from the study team are to be attached to the different phases of the work in a manner which affords the maximum opportunity to learn by experience. Subsequently, the study group would be in a position to act as a consulting group with outside assistance brought in as necessary. Such a scheme would have to receive both official support and sufficient financial backing.

37.2 Project engineering and management

Following the feasibility study, and assuming that as a result a decision is made to proceed with the project, the design of the works defined by the study must proceed in greater detail to the point where specifications can be written for all the plant items or assemblages, in order to invite tenders from manufacturers. Plant layouts must also be drawn in sufficient detail to establish civil engineering and building requirements and define the requirements for all services, such as electricity and water, to be provided on the site.

This phase of plant engineering is the first part of a wider activity of project management, which includes :

Division of the work into suitable contracts

Inviting tenders for the contracts and selection of contractors

Programming of work and controlling to programme

Site management and supervision of contractors' work

Cost control

Commissioning of plant

The setting up of a suitable management organisation, if it does not already exist, must be the first activity to be carried out once the decision is made to proceed with the project.

In private enterprise, a Board of Directors will be appointed, representing the shareholders in accordance with the company law of the country. If the plant is to be state owned, Government will presumably appoint a governing or managing body. This body, which carries ultimate responsibility, will have a Chief Executive and he, in turn, will establish a project organisation. Figure 37.1 shows the main functions which will have to be fulfilled.

The functions ascribed to the finance and personnel directors do not call for special comment.

The main operational responsibility will fall upon the Project Manager. He, in turn, will have responsible to him the Chief Engineer; a unit which will assist him in the planning of the project and informing him on progress in relation to the plan; a Purchasing Officer, who will be responsible for the placing of contracts; a Stores Superintendent, who will be responsible for the proper custody and management of the very large quantities of materials and equipment which will be delivered to the site; and a Security Officer. It is

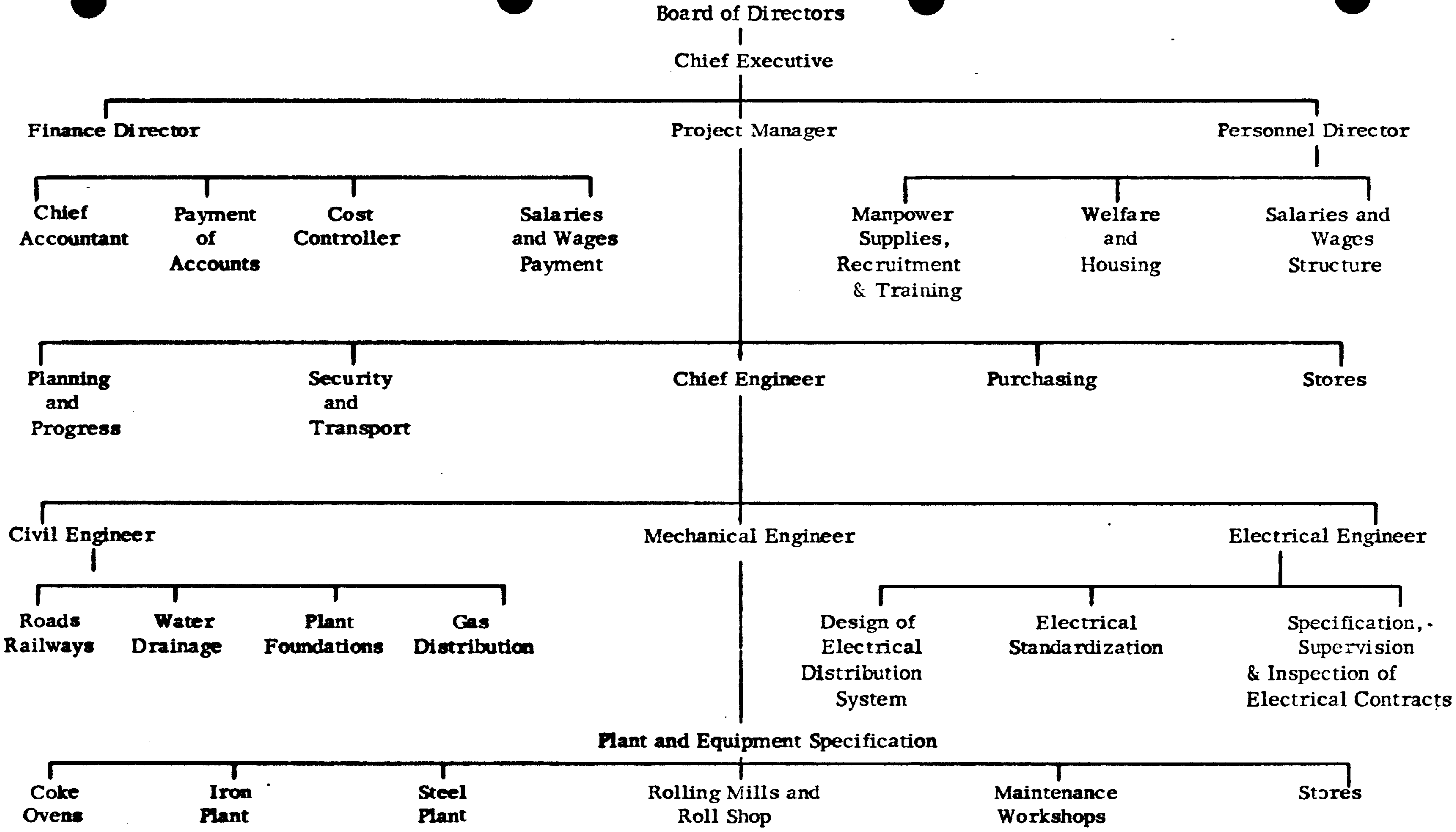

FIGURE 37.1 - TYPICAL OUTLINE CHART OF ORGANIZATION FOR ENGINEERING, MANAGEMENT AND CONSTRUCTION OF INTEGRATED IRON AND STEEL PLANT

probable that the same officer can also manage transport facilities, but this must depend on local circumstances

The Chief Engineer has under his command a Civil Engineer, a Mechanical Engineer and an Electrical Engineer. The functions ascribed to each of these is shown on the chart and should not call for further specific comment. They will, of course, be provided with staff appropriate to the scope of their work.

Whilst any company setting out to build a new steelworks will require a Board of Directors, a Chief Executive and a Finance Director, it is quite possible to put out to contract the whole of the rest of the functions, and have the plant engineered and built on a turn-key basis. At the other end of the scale, the company may prefer to make its own appointments covering the entire field of activity. There are many gradations between these two extremes of treatment, and the question is which one will be most applicable to Brazil and Brazilian conditions in the short, the medium and the long term. The answer depends, once again, on the number of engineers and managers available to fill the key positions on the chart at the right time.

There are clearly good managers and skilled engineers in Brazil, but the Government is contemplating a scale of expansion in its iron and steel industry in a confined time-scale which is almost without parallel, save perhaps in the Soviet Union and Japan, where the engineering resources are vastly greater. History and experience suggest that the sheer volume of what is proposed may well be beyond the resources of experienced national manpower which exist.

Indeed, the availability of engineers of the right experience has all too often proved the limiting factor in steelworks construction, and in most cases where a project has run late, or exceeded the estimated cost, it is because the engineering was not adequately done before contracts were placed or physical work put in hand. There is nothing so expensive in time and money as changes in plan during manufacture and construction. It follows from this that no work should be ordered until the entire project has been properly thought through to the end. Until the work is well defined, it is not possible to measure it. Without measurement, it is not possible to prepare reliable financial budgets, nor to authorize and control expenditure realistically. Definition means engineering. Time and money spent on engineering before physical work is ordered, is nearly always time and money saved in the end. It should be a prime task of executive management to ensure that this principle is followed.

Insofar as it has been decided that, at the first stage, three large existing Brazilian steelworks are to be expanded, the work will no doubt be handled, engineered and managed by the existing staffs at those plants, with such external aid as their directors consider necessary The same would apply to any further expansion on those sites. It is probable that full local capability in iron and steel engineering already exists within these companies. However, as they are likely to be engaged on this programme for some years, it may be difficult to spare the requisite number of qualified staff without detriment to other projects.

The establishment of an entirely new plant on a greenfield site may require a substantial degree of external assistance, particularly if such a project were to be put in hand concurrently with the expansion of existing plants.

It may be that, in all the circumstances of Brazil's steel expansion plans, it would be wise in any event to place contracts for the main plant units, i.e. iron plant; steel plant; rolling mills and roll shop; maintenance workshops and stores, on the basis of separate turn-key contracts for each perimeter. Where engineering manpower is limited at the centre, it is often better to harness the resources of equipment contractors on the basis of subletting total engineering responsibility, albeit with an appropriate system of supervision and co-ordination. In this way, the central organisation can be kept to a reasonable size.

In practice, it is quite normal for coke ovens and blast furnace plants to be ordered on a turn-key basis, because no other method is really practicable. It is conventional also to contract for a blast furnace with its ancillaries as a unit, though it is a matter of judgement and circumstance whether agglomeration plant should be included in a contract for a total ironmaking plant, or whether it should be treated separately.

It is desirable to contract for a basic oxygen steelplant on a turn-key basis, at least as regards engineering. It is important that the whole plant should be designed and engineered as an integrated whole, and there is much merit in placing the total responsibility with a single engineering enterprise.

Rolling mills comprise a subject of great diversity, but it is unlikely that a company would establish a large rolling mill installation, such as hot and cold strip mills, bar mills, rod mills or structural mills, without seeking external engineering advice. Most of the know-how and experience lies in the hands of the reputable international equipment builders. We consider that there is merit at the present stage of development in placing contracts for rolling mill equipment on a totally engineered and constructed turn-key basis, which includes placing on the mill builder the responsibility for defining and procuring the whole mill complex, including electricals, buildings, cranes, furnaces and all ancillaries.

In all these areas, contracts should be placed on the basis that the maximum opportunity is provided for Brazilian engineers to be associated with the engineering and construction of the plant units at every stage. We make the point that, whatever can be done by Universities and technical colleges in providing engineering education, it is only by hard practical experience that men will learn the business of engineering and constructing iron and steelworks. Once again, the development of 'full local capability' in the implementation of a project, both in its engineering and management aspects, will only be achieved by doing it.

37.3 Civil and structural engineering

Civil works

The major construction projects currently being undertaken, or recently completed, in Brazil leave no doubt that within the country the capability is available to undertake the civil engineering design and construction for the type of projects envisaged.

Difficulties may arise, however, from the sheer volume of what is proposed. The maintenance of a programme of civil engineering design and construction is crucial to the orderly implementation of a steelworks construction project. The projected growth of the Brazilian steel industry within the time scale envisaged will make very heavy demands on national resources for civil engineering design and upon the logistic support for construction, e.g. upon the available production capacity for cement, reinforcement, structural steelwork and some classes of skilled labour.

Doubtless, other industries will have expansion projects running concurrently. The planning of the use of these resources will, therefore, be of great importance and we place the main emphasis on civil engineering design because until at least the main outlines of design are established, it is not possible to measure the physical and material needs. From this standpoint, it may perhaps be desirable to supplement national design resources by assistance from overseas.

The probable requirements of the steel industry for the rate of expansion envisaged, in respect of civil engineering and foundation works, are a continuing annual demand for about 600,000 - 700,000 m^3 of reinforced concrete work, in value about US $100 million per year. This will require 150,000 - 180,000 tonnes of cement and 60,000 - 70,000 tonnes of reinforcement per year.

In the year 1969 five of the major civil engineering companies carried out contracts to the value of approximately US $1,500 million in the industrial and public works field, which would indicate a satisfactory level of ability from the industry as a whole.

A programme of development to increase the output of the cement manufacturing industry has been approved, and this will raise the annual production to 21.5 million tonnes by 1975.

Structural steelwork

Whilst some steelplant buildings can be constructed using reinforced concrete, generally every part of the development programme will require the supply of structural steelwork. The merit of continuing to import heavy steel structures must be analysed, in the light of a growing internal market which is likely to replace some areas of reinforced concrete construction.

The probable continuing requirements of the steel industry programme for major structural steel fabrication are 50,000 - 60,000 tonnes a year. The possible fabrication capacity is presently limited to structural welding plants attached to the works of CSN and Usiminas which are reported to have a combined capacity of approximately 55,000 tonnes per year. This suggests that some expansion will be required if the total demand is to be satisfied. There are no heavy rolled sections made in Brazil at present.

Reinforced concrete, however, is used extensively on small industrial and non-industrial building application; to ensure the continuing economic use of any new steel fabrication facilities, the development programme outside the steel industry must include projects which require structural steelwork, otherwise the capital expenditure and training of engineers and craftsmen cannot be justified.

37.4 Plant and equipment design

All steelmaking countries have at one time or another benefited from developments in plant design which have occurred in other countries. In blast furnaces, for example, the United States steel industry in the first half of the cent y, improved on the European practices from which their technology was originally derived. Within the last decade the Japanese, building on this base, have led the way in developing the blast furnace still further into huge production units which offer great benefits of scale. Most of these developments have been attended by troubles and problems. It is unthinkable to us that Brazil should do other than acquire the most suitable technology available from world sources and apply it to her own context, at least during the present decade.

The same applies in almost all the fields of iron and steelworks plant. For example, the continuous rolling of wide steel strip, hot and cold, began in the United States in the 1920's. The developments since then, both in the United States and elsewhere, have been so vast and the technological advances in design of equipment so great, that Brazil could not hope to catch up by starting from scratch, and will surely wish to have access to world technology, to use it and to improve on it as opportunity offers.

In course of time, Brazilian steelmakers will make their own contribution, but on the short and medium term view the repositories of equipment technology will continue to be the specialist engineering companies who have the experience of what has happened with the growth of new processes, and are in a position to apply it in terms of engineering design. Such companies can be expected, in principle, to enter into licensing arrangements with Brazilian steel and engineering companies, whereby technology can be made available as a basis, when appropriate, for the production of drawings in Brazil for specific contracts. We recommend that this is encouraged, as it is the way in which Brazilian engineers will grow up with a fundamental and up-to-date knowledge of plant and equipment design. The policy will make a modest demand on foreign exchange, but it will be relatively small and it will be much cheaper from every point of view than the alternative, and probably impracticable, policy of setting up Brazilian design institutes, required to produce new designs of major plant and equipment from first principles.

In summary, therefore, we suggest that 'full local capability in plant and equipment design' is not a desirable immediate objective. Brazil, with its current programme, should do what other countries have done and initially seek to acquire the best equipment designs available from world sources without restriction. As time goes on, it will no doubt improve on these designs, both from practical experience and from planned research. In due course, when Brazilian engineers believe that data thus acquired will enable them to design something better, or new, they should of course design and build it, if it is economic so to do. This has been the general pattern of development outside the authoritarian countries.

37.5 Plant and machinery construction

General considerations

Implicit in the objective of developing a major iron and steel producing industry is the associated development of a number of iron and steel consuming industries. These are likely, eventually, to contribute as much as ten times the gross national product generated by the iron and steel industry itself. Clearly, the achievement of the planned increase in iron and steelmaking capacity can only have meaning in the context of concurrent expansion and development of major steel consuming industries; without the latter the iron and steel industry would be still-born. Devoting resources to stimulating the development of these industries must therefore be of first priority; as total resources are limited, the comparative merits of alternative development projects will require detailed examination before decisions are taken.

In the short term - that is to say over the period during which new iron and steelplants, to service the 1980 demand for products, are being built - the iron and steelplant manufacturing industry, as a whole, is likely to be adjudged to have a lower priority in the claim for resources, since more attractive returns will probably be obtained from investment in more intensively consuming industries. The speed with which Brazil is able to develop a full capability in this field will be determined principally by the rate at which the Brazilian economy is able to accommodate growth.

There will be, however, sectors of the steelplant manufacturing industry that it would pay to develop immediately. In particular, those sectors that supply plant to a number of other industries as well have a higher claim for early development. Examples within this category are the electrical equipment industry, which will supply such items as motors and switchgear to a large variety of industrial users, and the mechanical handling plant industry, which again will supply a variety of users with conveyors, cranes and mobile handling equipment. Other sectors that should be expanded at an early stage are those concerned with the regular supplies or replacement items for the steel industry. Examples in this field are refractory bricks and rolls for rolling mills.

As a measure of the total requirements of the steel industry in the near future, it can be stated that the rate of expansion corresponds to the installation of an annual tonnage of plant and machinery of 100,000 - 120,000 tonnes, at an average value, including engineering and design costs, of about $1,000 per tonne.

Heavy plant manufacture

In the medium and heavy plant manufacturing industries, Brazil already has a production capability and it would obviously be in the interests of national development to extend the annual output of these industries. The requirements within Brazil for the very heavy and very sophisticated items of mechanical and electrical equipment are unlikely to be either large in volume or on a regular basis, and it is unlikely that this particular area of manufacture could be economically established at the present time.

A large proportion of the plant and equipment which comprises the various items of iron and steelworks plant is relatively uncomplicated to manufacture and construct, but the present-day plant sizes are such that the manufacturing works need to be equipped, in some cases, to handle, machine and form pieces of equipment which are of very large weight.

The manufacture of blast furnace plant, sinter plant, pelletising plant and, to a large extent, the steelmaking plant, call for a large proportion of facilities of the boiler making type, that is the capacity for bending and forming large plates and joining them with a fair degree of accuracy. In the case of ironmaking plant, the furnace shell is assembled at site from workshop-prepared plant sections, whilst at the steelmaking area ladles are completely assembled before leaving the workshops, and units such as ladle transfer carriages are a combination of welded fabrications for the main body and the machinery for propulsion. Another very large section of the equipment is comprised of steel structures which house some specialised process equipment, and a considerable amount of machined parts and iron and steel castings. The majority of the work in these plant items calls for manufacturing facilities which are within the normal standards of the engineering industry and which are, to a considerable extent, already available in Brazil. The basic oxygen steelmaking vessels, however, are principally large welded fabrications with very heavy component parts. The manufacture of these vessels calls for a higher grade of welding, and requires shop cranage and machine tools of larger capacity. It would not be possible to set up a manufacturing capability only to produce steelmaking vessels, so that to be economical this facility must have a market for other products, such as large pressure vessels.

Soaking pits, reheating furnaces and heat treatment furnaces, to a very large extent, comprise structural steel fabrications, refractory brickwork, and castings, together with some mechanical equipment. Normally, the manufacture of furnaces does not call for any manufacturing facilities which are outside the capabilities of the medium and heavy engineering manufacturers. Electric arc steelmaking furnaces have a large specialised electrical element but the remainder of the equipment follows the general line of furnace construction.

Manufacture of machinery

This includes blast furnace blowers, small turbo-generators, rolling mill equipment and items of machinery in all the other plant perimeters. Most of the machine tools required are conventional, although many mill parts are nowadays designed for machining on heavy duty horizontal milling machines, which are often equipped with [illegible]erical control. There is also need for a range of gear cutting capacity, [illegible] coarse pitch heavy duty gears ranging in size from small double helical pinions up to spur wheels of, say, 5 feet diameter. Nearly all the components can be made in machine shops equipped with 10 or 20 tonne overhead cranes, while most of the machinery units can be assembled in erecting shops equipped with cranes of 50 tonnes lifting capacity.

We consider that Brazil should put herself in a position to furnish most of the equipment within this broad category.

Above these weights is a group of items which is constituted in the main by the rolling mill stands for primary mills and for hot and cold strip mills. There are very few steel foundries in the world capable of making these castings, and these facilities cannot be economically established unless there is a prospect of a complementary demand for very large steel castings in the 100 - 200 tonne range for other capital industries, and this situation cannot be foreseen in Brazil within the coming decade.

Similarly, machine shops capable of machining these large pieces to the accuracy required are highly specialised units. They call for very costly machinery and for highly skilled and experienced operative labour and supervision. The shops themselves, with gantries suitable for cranes capable of lifting 150 or 200 tonnes in weight, are also extremely costly. We do not recommend this type of investment and we think Brazil should continue the policy of importing these very heavy rolling units. Nearly all the leading rolling mill engineering companies will be willing to enter into contracts on the basis that they supply the heavy units themselves and arrange for the manufacture in Brazil of most of the machinery units which are within Brazil's manufacturing capacity.

Most of the overhead cranes for steelworks are essentially similar to those for medium and heavy engineering plants, and need the same manufacturing facilities. From what we have seen of Brazil's mechanical engineering industry (and we must emphasize that this is limited), it appears that Brazil is already virtually self-sufficient in cranes, apart from some of the very specialised ladle cranes and those embodying sophisticated electrical control gear. Brazilian engineering companies are already seeking and securing licence agreements with internationally known rolling mill engineering companies. We have been impressed with the vigour and enterprise being shown in these directions, and we think that if the steel industry's plans are made known in sufficient time, then the indigenous engineering industry will take the necessary steps to supply what it is economic to supply. We do not think any special pressure on the engineering industry to go beyond the natural pace of development is necessary, although CONSIDER will presumably wish to check from time to time that expansion plans are, in fact, being implemented to meet the requirements of Brazil's steel developments.

We must make clear, however, that it has not been possible for us, within the time scale of our study, to make any quantitive assessment of Brazilian heavy engineering manufacturing capacity, nor to relate it to prospective demand. It may be that CONSIDER should put in hand or commission such a study to provide a base from which subsequent monitoring can be carried out. It is worth mentioning in this context that when in 1946 the UK steel industry decided to embark on its large post-war expansion, the British Iron & Steel Federation, which was the industry's central organ, asked the Association representing the equipment manufacturers for specific assurances regarding their members' ability to carry out the major part of the stipulated programme. This resulted in considerable additional investment by the plant makers in their own facilities, which might otherwise have been undertaken too little or too late. CONSIDER may well think that a similar initiative would be timely in Brazil in the near future although, to be effective, it will be necessary to specify with fair accuracy, not only the programme, but also its timing and phasing.

37.6 Roll production

It is obvious that the increases in steel production will engender a corresponding increase in the consumption of mill rolls. There are several distinct types of mill rolls and, at present, most kinds are being made in Brazil, although not in the volume necessary for complete self-sufficiency. Villares is the largest producer of strip mill rolls, making cast steel back-ups, iron and cast steel type work rolls for hot mills, and hardened forged alloy steel work rolls for cold mills. They have a licence agreement with Ohio Steel Foundry and their facilities appear to be excellent, comparing well with international roll making companies. Their capacity can be considerably expanded by marginal investment and they stated their policy as being able to furnish about 60 percent of the market, now and in the future. This will involve increasing their present output of all types of rolls from 350 tonnes/month to 950 tonnes/month by 1975, of which 150 tonnes/month would be in forged rolls. They felt it wise for some import to continue, as competition between suppliers in roll quality and performance is strong and they believe it necessary to retain this spur to the efficiency of their own operation. This, we think, is wise judgement.

CSN also cast part of their own hot strip mill work-roll requirements and also rolls for their structural mill, but they are deficient in machining capacity. They currently enlist the help of Villares in this problem, but it is a matter which may require attention if Villares' expanding production should later absorb the whole of their machining capacity.

The market for the smaller merchant mill rolls, which are mostly cast in special iron and semi-steel, is currently satisfied partly by Villares, partly by smaller foundries in the Sao Paulo area, and partly by imports. We have no information on the actual proportions, but imports appear to be small.

Some figures of roll life for nationally produced rolls were quoted and prima facie some of these were below international experience. However, we do not attach much importance to this, as it is an area where comparisons are notoriously unreliable and misleading, unless all operating conditions are known. We see no reason why Brazilian rolls should not be equal to the best and since Villares have already developed some export trade, it can be assumed their quality is generally satisfactory.

We believe, therefore, that provided the Brazilian steel industry continues to make known its expansion plans in ample time, the present rolls industry can be relied upon to make the necessary private investment, so as to supply the bulk of national requirements. There may be exceptions, however. We do not think it would be economic, for instance, for Brazil to manufacture the back-up rolls for the projected 160 inch plate mills owing to their great weight and the need for heavy and expensive facilities which could not be fully utilized. Also we attach importance to early notification of requirements, so that the rolls industry may know in which direction to expand, e.g. in cast iron, cast steel or forged steel. Scope should be retained, we believe, for reasonable foreign competition as a means of ensuring that the steel industry has rolls available to it which are equal to the best.

37.7 Electrical equipment

The requirements of the expansion programme for the industry will amount to an expenditure on electrical equipment, including motors, switchgear and cabling of US $35-40 million per year.

On the basis of discussions with the Brazilian electrical equipment suppliers, although without any detailed investigation, it is a fair assumption that most of the commonly used transformers, motors and switchgear can be supplied by the existing private industry, which could be expected to expand by marginal investment. Once again, it is necessary for development plans to be published well ahead of actual needs, so as to allow time for the supplying industry to assess requirements in detail and take such steps as may be necessary.

There are, however, some electrics in rolling mill installations in particular which call for special mention. The main drives and control gear for large reversing mills and for continuous mills include some highly sophisticated engineering, especially where exact speed relationships and rapid response to rolling variations are needed. We do not think it wise for Brazilian electrical equipment firms to attempt to manufacture such equipment except under licence from experienced USA or European companies; and it may well be wise, at least in the medium term, to continue to import.

The modern tendency in roller table design is for each roller to be driven by its own motor, involving multiple production of these machines. The variable speed characteristics required from some of these motors are often obtained by employing variable frequency alternating current. We see no reason why these machines should not be made in Brazil and the know-how should be obtainable under licence if, indeed, it does not exist already.

Instrumentation and control equipment

All aspects of iron and steel production require control and instrumentation systems which, in the main, use basic common instruments. An instrument industry could not be justified merely on the demand generated by the iron and steel industry, even with a programme such as is envisaged in Brazil. However, since there will be a general upsurge of industrial development, there will be much more widespread demands for instrumentation and control systems.

In such a climate of industrial expansion, it is to be expected that a vigorous industry will develop in this sector without any particular stimulus from the steel industry. It will be important, however, for the iron and steel industry to keep in close touch with the instrument industry, and to help in setting up special applications sections to deal with the specific requirements of iron and steel mills.

37.8 Conclusions and recommendations

There would appear to be no reason why Brazil should not steadily improve her capability to undertake, with indigenous resources, at least a part of the planning and engineering for the expansion of the steel industry. In particular we recommend the early formation of consulting groups, with effective liaison with international consultants of repute to initiate and undertake feasibility studies and engineering design.

We recommend that special attention should be given to the structural engineering problems associated with heavy steelworks plant, and also that the techniques of project management should be studied and mastered by Brazilian engineers.

We believe that the plant and equipment manufacturing industries which support the steel industry will develop nationally in Brazil, and that it would be unwise to force the pace of development artificially. In this way, Brazil is likely to develop a slightly more broadly-based heavy engineering industry which, in time, will be able to manufacture an increasing range of steelworks plant. We recommended that the initial stage in developing this manufacturing capacity should be based on imported designs built under licence; this will enable the industry to become thoroughly established before embarking on the comparatively more risk-prone stage of design and construction of all-Brazilian plant.

In the case of the ancillary industries such as electrical engineering and instrumentation we recommend that the existing industries should continue to service a wide range of industries rather than concentrate on narrow specialisation in steel plant requirements, although these can increasingly be met.

CHAPTER 38 - RESEARCH AND DEVELOPMENT

One of the most difficult decisions for nations in the process of industrialisation concerns the deployment of resources for long-term rather than immediate benefit. Any investment for the future requires a sacrifice in the present. This difficulty presents itself even more forcibly when the future benefit is uncertain and intangible as with research and development. It is clear, if only from inspection of practice elsewhere in the world, that a large steel industry, for example, will require a fairly substantial level of research and development activity. What is less clear are the amount of resources which should be allocated to it and the overall objectives which should be pursued.

38.1 World practice

As a first step in estimating the level of effort to be devoted to research and development we can indeed look at what is accepted elsewhere. As might be expected, research and development expenditure varies directly with steel output, as shown in Table 38.1. US expenditure is highest, followed by Japanese, while the Netherlands has the lowest expenditure of those countries included in the comparison. Comparison of expenditure per tonne of output however, shows, no relationship with the level of output. It might have been thought that the US would again show the highest per tonne expenditure, but Sweden, with ninth ranking in tonnage produced, spent nearly three times as much per ton as the USA; this is principally a reflection of the emphasis of the Swedish industry on stainless and special steel products. Neither is the proportion of steel industry manpower engaged in research and development related to the industry's output level (Table 38.2). It is apparent that while big national industries spend more in this area than small ones, the extent to which the industry should rely on research and development is mainly a matter of policy. Sweden, for example, has needed to develop a high degree of sophisticated manufacturing technology. Belgium, on the other hand, does not specialise at all and produces mainly ordinary grades of steel. In consequence, Swedish per tonne expenditure on research and development in 1966 was about eight times that of Belgium, $3.15 as against $0.38. The comparable figures for the UK and USA, at $1.30 and $1.10 per tonne, could be taken as a rough norm for long-established industries with a broadly-based product mix.

These figures give an idea of the scale of resources that might be devoted to research and development in the Brazilian steel industry. To match the 1980

TABLE 38.1 - EXPENDITURE ON R & D BY THE STEEL INDUSTRIES OF VARIOUS COUNTRIES

Country	Years	R & D expenditure ('000 $)	Crude steel production ('000tonnes)	Expenditure on R & D/tonne crude steel ($)
Germany	1964	32,750	37,339	0.88
Belgium	1955	742	5,893	0.13
	1966	3,389	8,911	0.38
France	1955	6,100	12,592	0.48
	1966	17,220	19,585	0.88
Italy	1955	720	5,548	0.13
	1966	7,504	13,639	0.55
Netherlands	1966	3,039	3,256	0.93
UK	1955	7,264	20,109	0.36
	1966	32,150	24,705	1.30
Sweden	1966	15,000	4,764	3.15
Canada	1956	400	4,809	0.08
	1966	5,800	9,075	0.64
USA	1957	64,000	102,254	0.63
	1965	131,000	119,262	1.10
Japan	1956	5,497	11,106	0.77
	1965	42,181	41,161	1.02

Source: OECD

TABLE 38.2 - MANPOWER IN R & D IN THE STEEL INDUSTRIES OF OECD COUNTRIES

Country	Year	Scientists	Technicians	Others	Total	Manpower in the steel industry	Manpower in R & D as % of total
Germany	1964	770	...	3750	4340	252,892	1.72
Belgium	1955	32	143	106	281	48,700	0.58
	1966	107	361	213	681	56,713	1,20
France	1955				1320	120,903	1.09
	1965	429	730	685	1844	158,814	1.16
Italy	1955	33	55	139	277	52,597	0.43
	1966	134	122	355	611	69,265	0.88
Netherlands	1966	45	85	230	360	19,038	1.89
UK	1955	567	195	1080	1842	289,449	0.64
	1966	1432	728	3028	5188	288,000	1.80
Sweden	1966	275	350	750	1375	46,200	2.98
Japan	1957	538	1191	1164	2893	214,156	1.35
	1966	2171	3155	2803	8129	310,487	2.62

Source : "Technology in the Iron and Steel Industry"
O.E.C.D. Paris, 1969.

target capacity of 20 million tonnes, between US $15 million and US $25 million a year should be allocated at that stage. Closer definition of the sum will depend on policy decisions as to how innovative the industry should be, the extent to which 'know-how' should be bought from abroad, and the nature of problems arising under local operating conditions. Similar considerations would decide the manpower required. To make a round estimate it is a reasonable assumption that the proportion of the total workforce in research and development might be similar to that in the UK, at about 2 percent. On this basis, with a workforce of about 120,000, producing 20 million tonnes of steel a year, some 2,400 men would be employed in research and development, about half of them professionally, or technically, qualified.

38.2 Research and development objectives

In general research and development in the steel industry has three prime functions: basic research in, for example, metallurgy; improvement of existing products and processes; and adaptation of standard processes, or the development of new ones, to meet local conditions. Broadly speaking, the resources devoted to these categories will be determined respectively by; the fact that the fundamental design of steel processes is unlikely to change for at least the next decade; the decision whether the strategic aim of the industry should be to specialise and innovate or simply to produce ordinary steel grades as an ancillary to domestic user industries; the degree to which the industry is established and integrated with ore and fuel supplies, its workforce and its customers.

The significance of the fixed nature of basic steel manufacturing processes is that to arrive at substitutes for them would require immense research effort and prolonged development to produce anything economically feasible. It would almost certainly not be desirable for Brazil to embark on such a programme by herself. Indeed, so high is the investment threshold for effective research in this area that an advanced industrialised country has to consider very carefully the value of committing any large scale resources to basic process research. It is a fact, however, that some major technical innovations have been made outside the major steelmaking countries: Austria was largely responsible for the BOF process and Mexico (with the USA) for HyL. Similarly, there is one field of basic process research, direct reduction using nuclear energy, discussed later, to which Brazil might in certain circumstances turn her attention.

The development posture of the Brazilian steel industry will, until 1980 at least, be determined by its role within the domestic economy. It will in effect be a primary industry producing what is virtually a raw material for construction, engineering, ship-building and consumer goods manufacture. The investment, manpower and development effort that the steel industry will be able to command will be fully extended by the exigencies of reaching the 20 million tonne basic capacity target together with essential specialities that the rest of the economy will demand. During the next decade at least, crude steel capacity growth will predominate and will not permit orientation of the industry as a whole to high value special products. The function of research and development will be to improve the efficiency of existing processes, to improve output quality and consistency, and also to lay the foundation of a programme whereby the needs of domestic industry can eventually be anticipated with new methods and new products. It is inevitable that in a period of massive growth such as Brazil is currently going through, there will not be a clear boundary between research and development, quality control and trouble-shooting. This certainly seems to have been the case in Japan where in 1967, shortly before the fastest increase in capacity, 56 percent of the research and development budget was applied to improving existing processes and products as against 13 percent to basic research.

The third function merges with the second, namely the adaptation of processes to the local environment. This area is inescapable and essential to the maintenance of the industry at any stage. Processes must be tailored to cope with locally available raw materials, especially Brazil's own coal and iron ores. Ore treatment and blending requirements, for example, can be determined within the industry where the advantages of continuous experience and feedback of experimental results can be exploited. The capacity of supporting industries may present problems which can be solved by modification of steel plant requirements. Methods of work which vary from community to community may throw up manning and control problems requiring consideration of an Operations Research nature. Then, as plant is extended and replaced, good management will need the services of research and development to bring about the necessary adaptation.

Once again it may seem difficult to distinguish research and development from trouble-shooting and quality control functions, and there is indeed some overlap. Research and development, however, is a continuous, programmed activity which will concern itself with longer term technical rather than immediate problems, tending to anticipate situations rather than react to them. It contrasts similarly with quality control, aiming to provide means of achieving and sustaining quality parameters rather than actually maintaining them. Although it must be closely coupled with process management in the sense that communication between the two spheres needs to be open and easy, research and development must be seen as an adjunct to investment decisions for future production rather than present output.

The nature of the objectives outlined as broadly appropriate to the needs of Brazil in the coming decade suggest that the principal emphasis will be on development rather than research. The pace of basic research should not be forced; it is better to allow it to evolve naturally, as and when inventive talent can be devoted to it without undue sacrifice in other directions.

38.3 The organisation of research and development

In many countries, steel industry research and development is organised on two complementary levels: at the plant or the manufacturing company, and at the specialised research institute or university. There is thus a strong tendency for the research and development functions to split according to location. At the plant, attention is devoted to more immediate product or process improvement which, if successful, can provide an effective entrepreneurial advantage to commercial operations. Strategic, long-term research on the other hand is left, in practice, to the very large firms such as are found in the USA, Europe or Japan and to central research institutes and universities. Countries that have set up central research institutes for the steel industry include France (IRSID), the UK (BISRA, now absorbed by BSC), Belgium (CRM), India (NML) and USSR (various institutes). In the USA and Japan the research is largely centred in works laboratories. Research at this level demands great resources of money and manpower, and there is no immediate pay-off. In consequence, it has been common practice to establish a central research body under the aegis of the government, possibly with some kind of levy on those with the potential to benefit from the work. BISRA in the UK was at one time financed from a compulsory levy on steel producers; IRSID in France is paid for from the voluntary subscriptions of corporate members, and there are other similar examples. An important European body is the Research Fund of the ECSC, financed from a levy on all steel produced within the EEC. One of its principal functions is to sponsor research at other institutions; for instance, human factor problems in universities, pollution problems in research associations and technical research in the associations and company departments. The Indian NML is of particular interest to countries embarking on the development of their steel industry, since its successful record of contribution to the furtherance of knowledge has been outstanding.

The present organisation of research and development for the Brazilian steel industry is briefly described in Article 1.3 of Chapter 7. It appears that the main research and development effort is being developed through individual companies. The inherent danger in this is that commercial secrecy may deprive the industry, as a whole, of some improvements devised by a single company in the private sector. This is less likely to happen in the flat-product sector, which is largely State controlled. On the other hand, the rapid growth of the industrial sector of the Brazilian economy envisaged over the next two decades will provide rich entrepreneurial opportunities which are likely to be seized by those companies adapting themselves to market requirements through their research and development activity.

The world of steel industry research and development is very open, and it is rare for important developments to emerge from one laboratory or even one country. So great is the lag between proving a development at laboratory level and putting it into practice on a commercial scale, that there is little to be gained by maintaining a regime of strict secrecy. Again, the cost of major new developments is so large that some measure of co-operation between institutions or even countries becomes quite desirable.

A central co-ordinating and sponsoring body in a situation of relatively scarce resources could do much to prevent wasteful duplication of effort and impose some overall shape and direction on the totality of the country's research. The activities of this body could include the following functions:

(i) Surveying the available qualified manpower and ensuring that it is used to the best national advantage.

(ii) Stimulating and approving new research and development projects which could be carried out under contract by individual companies in their own works facilities.

(iii) Preventing wasteful overlap or duplication of work.

(iv) Recommending to Government where financial assistance is necessary and merited.

(v) Monitoring performance and reviewing results.

(vi) Supervising, and perhaps controlling, the overall policy on importing and adapting foreign technology.

It should not, however, seek to prevent any company from pursuing research independently - the very stimulus of commercial advantage may be the best incentive to vigorous pursuit of research objectives.

The co-operating body should be drawn from representatives of both public and private sectors of the industry, the universities, the research institutes, and the Government.

The construction of large centralised research facilities, serving the industry as a whole, is probably not the right course for Brazil at the present time. Nevertheless, it will be necessary to give some thought, now, to the longer-term pattern of research and development in the industry if the support required by a 20 million tonnes per annum capacity is to be provided.

Organisation of centralised research through a Research Association, such as BISRA used to be, has not always proved to be the most efficient means of achieving technological progress. It is clear, however, that a major industry cannot be supported by minor-key research facilities, and in the field of process development pursuing a line of research through to successful application often requires major expenditure on pilot plant.

It is not within the scope of this report to enter into a detailed discussion of the various ways in which research and development can be administered and financed; the appropriate pattern and scope for Brazil requires further extensive study. However, as an indication of some of the possibilities, we have shown in Figures 38.1 and 38.2 the organisation of research and development in the iron and steel industry in a centralized economy and in the UK; Figure 38.3 shows a typical organization for a research association.

38.4 The educational role

A further important function of a research and development department or institute is education. This has two aspects. The more obvious educational process is transmission of laboratory developments to the process plant, and eventually the complementing of plant-based staff with laboratory personnel experienced in high technology. But, if the institutes work well, there should be a counter-flow of information, experience and even personnel from the

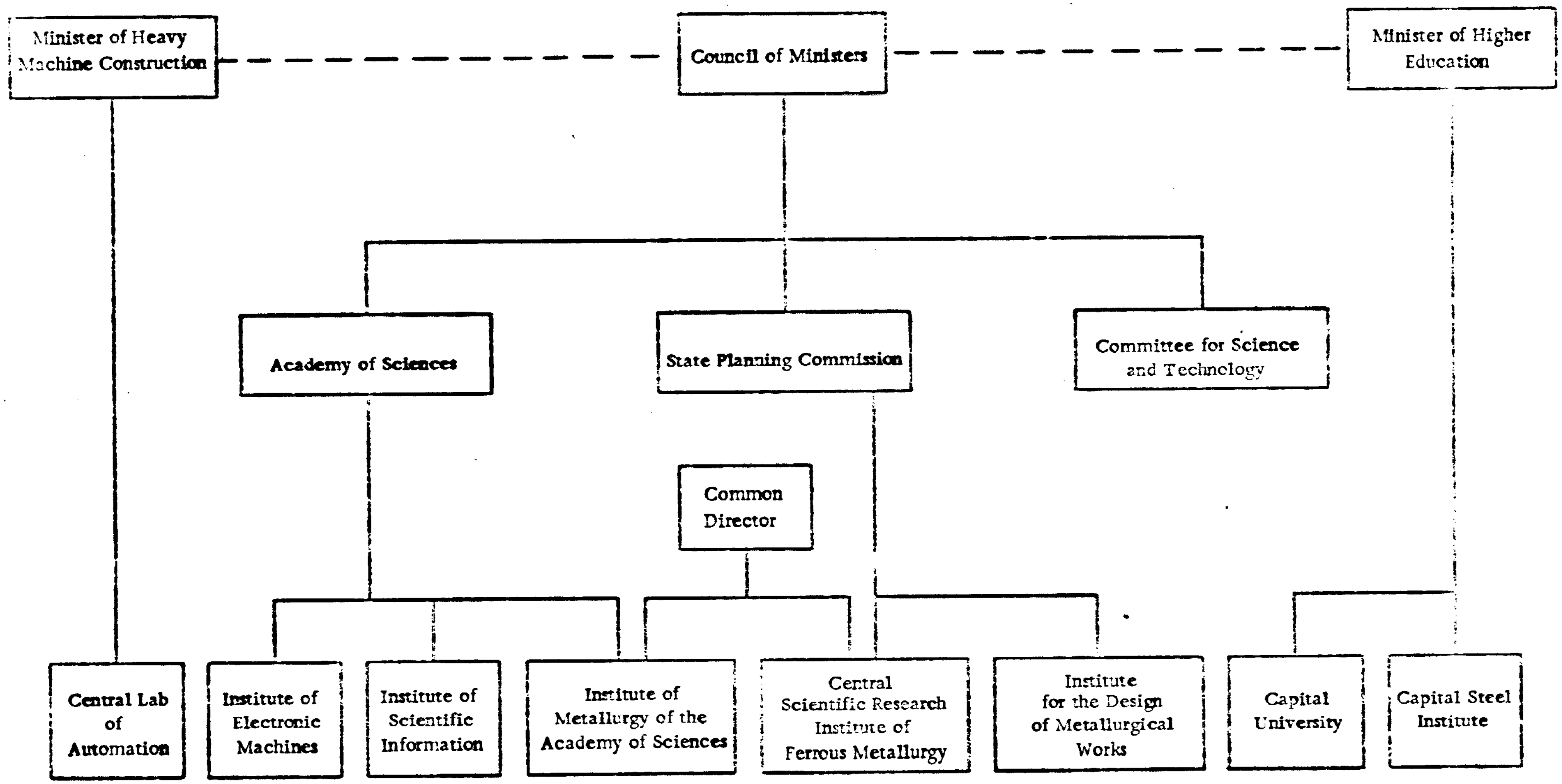

FIGURE 38.1 - TYPICAL ORGANISATION OF IRON AND STEEL RESEARCH IN A CENTRALISED ECONOMY (USSR)

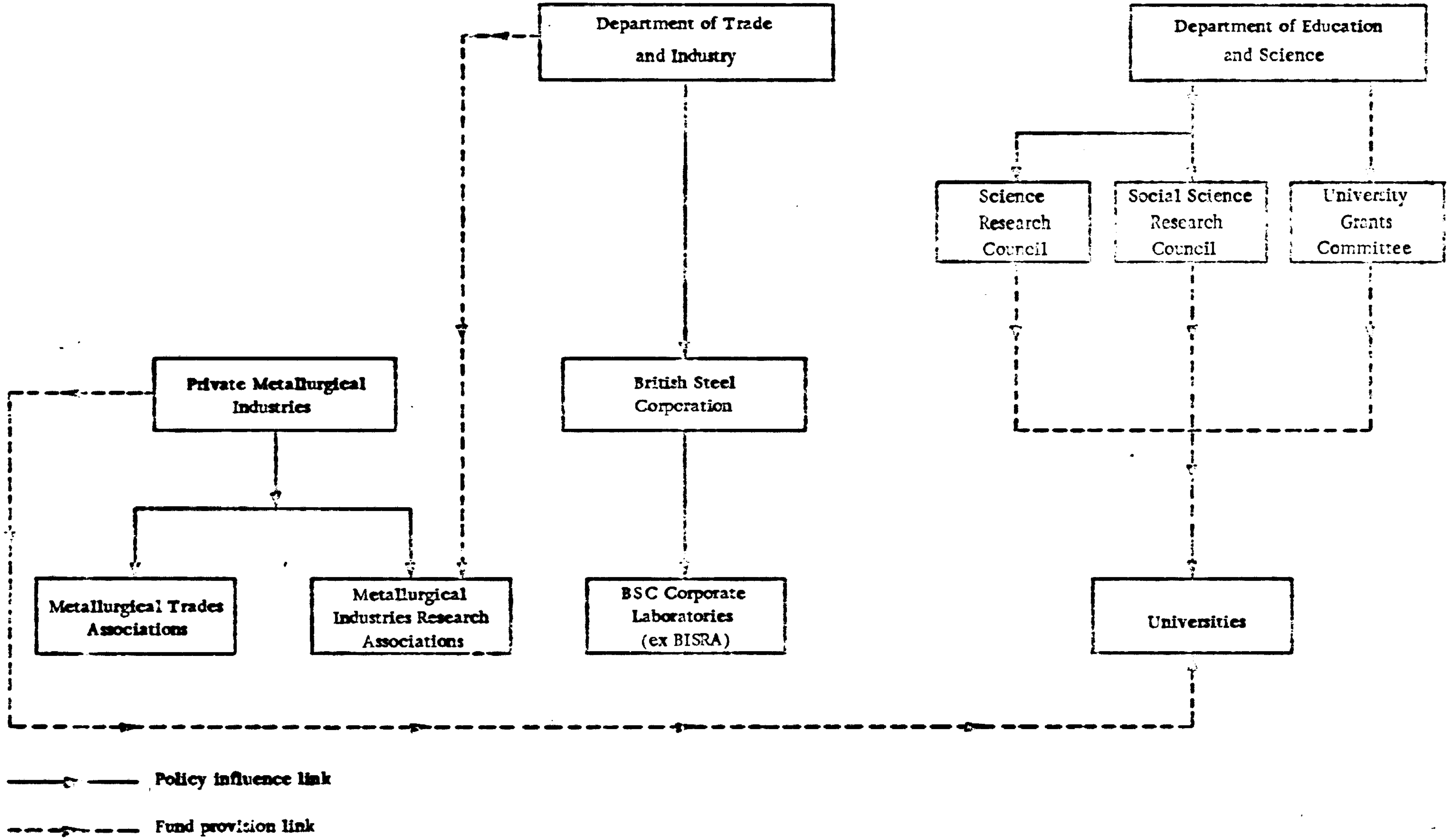

FIGURE 38.2 - ORGANISATION OF IRON AND STEEL RESEARCH IN THE UK

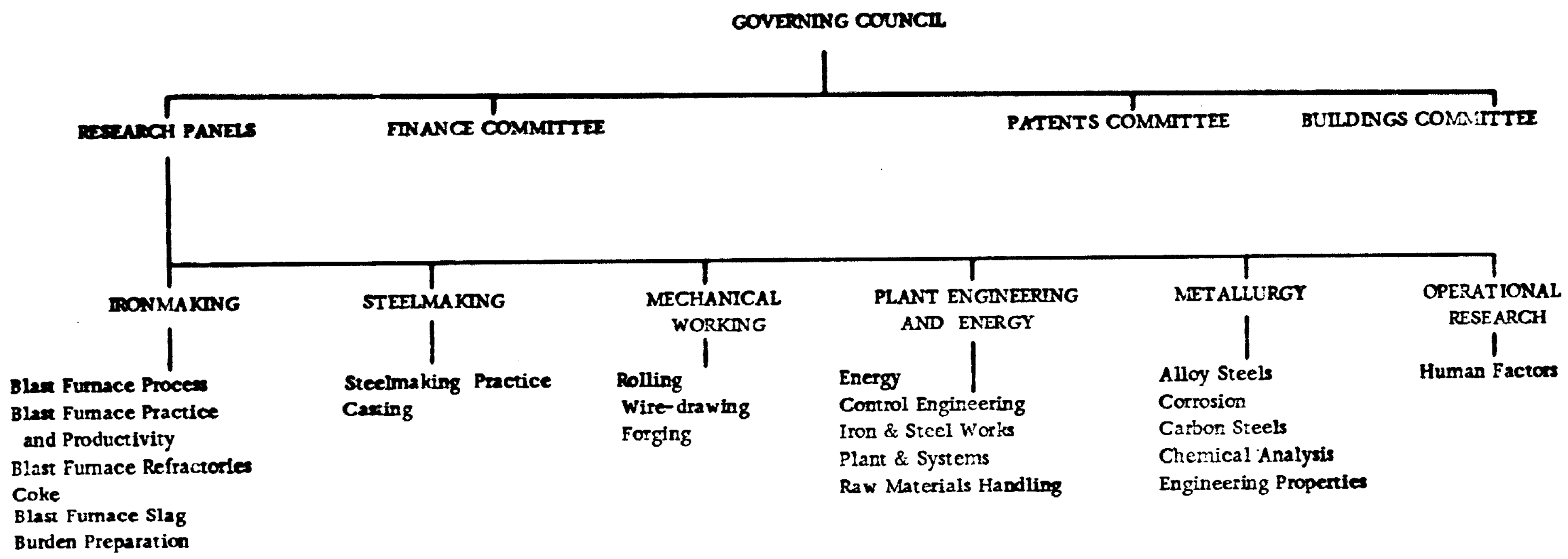

FIGURE 38.3 - ORGANISATION OF AN IRON AND STEEL RESEARCH ASSOCIATION

(BISRA prior to formation of BSC)

plant to the research institute. Only in this way can the laboratory become sensitive to the practicalities and exigencies of the process plant itself. This can be of great importance where long traditions of professional and educational elitism have insulated the highly qualified scientist or engineer from the shop floor.

A steel industry research and development department could also fulfil another educational function. In planning the deployment of resources in an environment of rapid industrial development, such as Brazil's, no single industry can be considered in isolation. The iron and steel industry, which is the key to so much other industrial development, could be instrumental in training professional research and development staff who would eventually pursue their research activities in a wider industrial context.

38.5 Educational requirements

A research and development capability can only be maintained if there is a readily available supply of suitably qualified scientists and technologists. About one quarter of the staff would normally be qualified scientists - in the case of Brazil, say 600. These, typically, will be people with high formal qualifications in metallurgy, physics, chemistry, engineering etc., but could also include social scientists such as economists and psychologists. Not only should the staffs be academically qualified, however; it is desirable that some, at least, have experience of work in other industries, so that research will not be cut off from the needs of the manufacturing user, and will be exposed to the influence of methods and ideas from other fields.

The research scientist will be basically university educated, though with the establishment of research institutes, it is quite possible that his professional formation could be completed there. It is important, however, that all research bodies see part of their job as the continuous education of their own staff and others from elsewhere in the industry.

Increasingly in research and development the scientist can function only as part of a team, especially where research is organised on a large scale. His work can be done only with the assistance of high grade skilled technicians who may well constitute 75 percent of the staff. Training for them will probably fall to technical colleges and vocational training institutions, but research centres themselves, inside and outside the steel companies, must also play an important part. Training is just as important for technicians as for professional scientists, and comparable attention and resources must be devoted to it.

More detailed analysis of educational requirements is presented in Chapter 39.

38.6 General conclusions and recommendations

There are a number of subject areas which warrant detailed attention by the Brazilian steel industry and may yield substantial benefit in the context of its long-term development. Before discussing them, however, two general, but very important, points must be made.

Firstly, Brazil will, in the long-term, derive more benefit from research and development undertaken in other countries than she will from her own practical efforts. This is true of all but the few largest steelmaking nations, and may even be true of those as well. It is essential that a communication network be set up to monitor research and development abroad, and to ensure that this information and the results of internal research and development are channelled to all those parties which may find them useful.

The second point concerns the principle of selectivity and concentration of effort in research and development. The amount of effort devoted to each area, in terms of manpower and facilities, must be sufficient to ensure a good chance of making a significant contribution to the overall economics of the Brazilian steel industry. The threshold effort needed to achieve significant results in some areas is high. These facts mean that the number of topics upon which practical work is undertaken should be carefully restricted. It will be far better to devote effort to monitoring foreign work on a given subject than to devote a weak Brazilian research effort to it. Weak research efforts produce insignificant results and also weaken effort on other topics which receive less attention than they might otherwise.

Readily identifiable areas worthy of detailed study are discussed below. Some work can be undertaken in research laboratories, in or out of the steelworks. Much of the work should, however, take the form of trials on industrial plant. It is likely that the trials would have to be devised, observed and analysed by research staff from outside the works, collaborating with operating and technical staff within the works. A great deal of information can be obtained from such trials provided that they are efficiently organised.

Sintering

The importance of sinter quality has been discussed in this report. With large blast furnaces planned for very high output, strong well-sized sinter is essential. Substantial saving can be achieved by reducing the recirculating content. The economics in blast furnace operation offered by superfluxed sinter and the possible savings in coke breeze which can be achieved by mixed fuel practice on the sinter strand, both warrant industrial trials in Brazil and the very careful monitoring of foreign results. The possibility of alternatives to conventional coke breeze, made from cheaper non-coking coals by carbonising and perhaps briquetting, should also be examined.

Cokemaking

The greatest savings in steelmaking costs in Brazil can be obtained by reducing the effective cost of the coke in the blast furnace. This can best be achieved by reducing the cost of the coal feed which now consists largely of costly imported coking coal. Two avenues of opportunity are open. The first involves coking cheaper coals in conventional slot ovens and the second involves using cheaper non-coking coals to make formed coke.

The first method of decreasing cost involves selective crushing of the coal charge; the more uniform distribution of the various constituents often making it possible to include a substantial proportion of weakly coking or non-coking coal. Trials could be arranged at one of the new coke oven batteries, using a variety of cheap coals.

The second method requires the construction of small scale formed coke plants. Three promising processes have been discussed in Chapter 9 and one or more of these should be tested. Installations can now be purchased from the plant manufacturers. Full scale industrial trials require stockpiling of sufficient formed coke briquettes.

As there is no coke research organisation in Brazil the work would have to be undertaken by the steel industry itself.

Direct reduction of iron ore

The bases for the operation of the important direct reduction processes are established, but at individual locations tests are required on the raw materials to be used. The existence in Brazil of an SL/RN plant and an HyL plant will provide an excellent opportunity to obtain valuable information on both these processes and quite clearly the centres of research and development activity in these processes should be located at the plants.

A method which may be important for the future of the Brazilian steel industry is the Midrex gas reduction process. No plans are laid for an installation in Brazil but information on this process should be accumulated and world developments closely followed. The study programme should involve visits to existing plants whenever this can be arranged.

Developments in the use of nuclear energy for ironmaking may be regarded as too distant for Brazil to wish to become heavily involved at this stage but, with her important uranium ore deposits, a nascent atomic energy research capability, and her coking coal problems, such developments should be closely followed. The possibilities of collaboration with Japanese or with American or European interests could be explored but Brazil would not of course expect to carry out a research programme of this kind herself at this stage in the development of her industry.

Steelmaking

The problems in this field are mainly those of achieving good performance indices with standard processes operating under Brazilian conditions. There have been developments in electric arc steelmaking which Brazil must become fully familiar with, but none of this involves research or trials. One area which is novel is electric arc steelmaking with reduced pellets and no doubt extensive in-works trials will be undertaken on this subject. Similarly it may be thought worthwhile to convert one of the older steelmaking shops for SIP or OBM trials.

Special steels

A great deal can be done to translate to Brazil the expertise of other steelmaking countries in special steelmaking. This will probably entail setting up a small group of specialists to visit all the Brazilian plants and to visit overseas installations and monitor progress in the field.

Casting

Several developments are taking place on continuous casting which may offer advantages. One area which must be studied carefully is the continuous casting of rimming steels and it is essential that all the problems are solved if the long-term plan is to instal no further ingot casting plant. A high degree of success in slab-casting rimming steels is claimed in the USSR and this should be followed up in Brazil.

Product development and substitution

As a primary material producer, the steel industry has little opportunity itself to develop end-products and to introduce steel as a substitute for other materials. It can co-operate with manufacturers of each product in order more successfully to accommodate their needs. There are two end-product areas where research and development by the steel industry itself would be valuable - the use of steel as building and as packaging material. Improvements in structural design involving reinforcing bar or structural steel should be well within the domestic research and development capability. More important, however, would be a rigorous assessment of the opportunities for steel as a packaging material, especially in canning. The most important canning material is tinplate but other coated products will be used. The techniques of differential coating, plastic and lacquer and, in the longer-term, tinfree steel will also require attention.

Maintenance engineering

The importance of effective maintenance in reducing the costs of iron and steelmaking should not be underestimated. Increasing attention is being paid in the world's industry to this subject, now designated tero-technology, and it is likely to justify a central group in Brazil accumulating information and disseminating expertise within the country.

Automation

With so much very modern plant being installed over the next few years Brazil should devote considerable effort to the study of the advantages of automation. The threshold cost of an effective steelworks automation research group and a programme of trials is rather high but the long-term benefits could be very large.

CHAPTER 39 - EDUCATION AND TRAINING FOR THE STEEL INDUSTRY

Establishing industrial capacity in a developing country makes great demands on a whole range of infrastructure, especially social, institutions. Education is one of the most important of these since there is no substitute for a literate and trained or trainable workforce. The higher the level of technology of an industry, the more it will rely on high levels of formal education and training together with what can be termed educational competence, the capability of usefully applying formally acquired skills. There is an immediate difficulty for industrialising countries inasmuch as they require educated and trained workers in advance of major development programmes, and yet have to make do in the short term with an educational apparatus appropriate to a pre-industrial or quasi-industrial society. In consequence, there is competition between industries for available qualified men, and firms themselves will resort to costly and inefficient expedients to make up the lack. The steel industry will not be excepted from these difficulties; indeed since it will require many specialists who can only be found within existing steel companies, its situation will be that much more difficult.

The requirements of a nascent industry for formally qualified staff can be estimated by using as a norm the numbers employed in successfully developed examples of the industry. Similar inferences can be made, though less easily, about the education and training of work staff without formal or academic training. The following articles give a preliminary estimate of the total requirement and an outline of the institutional development that will be necessary to achieve it.

The Brazilian steel industry at present employs about 82,000 people but when compared with the USA and Japan its labour force is higher by a factor of three, per tonne of steel produced. Therefore, although by 1980 steel production is expected to treble, it is unlikely that the industry would require a similar increase in total labour force. However, with the installation of modern plant and equipment and with the attainment of higher performance standards, emphasis will be placed on the requirement for more technical and skilled operatives, rather than unskilled labour. Recruitment of these types of personnel is a long-term process and the industry, with the aid of Government and other national institutions, must lay careful plans to satisfy this demand.

39.1 The requirement for qualified staff

Although the aims of steel industries around the world and their problems are similar, their methods and solutions vary considerably. This is equally true of social institutions such as education and training. Behind the common need for skilled, trained men are differing ideas as to how and where training should be undertaken. One obvious example is the difference of opinion between European universities on the one hand, and US and Japanese on the other, as to their roles in vocational training. On the whole, European universities eschew the purely vocational with the result that their technological education tends to be theoretical, and if it is to be practically applied, requires that graduates complement it with some kind of shop floor apprenticeship. US and Japanese universities provide fully vocational training while incidentally conferring academic status on it.

This difference in the function of universities has two results that concern us here. The first is the problem of resolving what should be a desirable ratio of formally qualified men to others in the steel industry, based on the practice of mature, efficient industries elsewhere in the world. If, for instance, with the approval and co-operation of the industry, universities set up degree courses in steelworks management and similar vocational subjects, it is likely that there will be more graduates in the industry - in fact, the diploma will become a condition of eligibility. Where university courses are less specific, it will be more fortuitous whether graduates enter the steel industry or other industries and it will be more difficult to forecast the number that will be available to the steel industry. It is likely that under this system there will be fewer graduates in the steel industry and more men who have qualified in other ways. This is not to say that, other things being equal, either system is intrinsically preferable; some ramifications of the two situations will be discussed later.

The second point is that there is no easy way of comparing proportions of qualified employees from country to country, since even the nature of qualification is variable. We have had to infer the proportions from breakdowns of work forces according to functional category: managerial and professional, supervisory, skilled and semi-skilled, and unskilled. We have assumed that all managerial and professional staffs would be formally qualified, half of the supervisors, twenty-five percent of the skilled and semi-skilled category, and none of the unskilled. A round total figure of 120,000 has been taken as the number of people who will be employed in the 20 million tonne steel industry. On this basis, with manpower and management deployment in accordance with accepted good practice, the relative numbers and proportions of the workforce estimated in each category are shown in Table 39.1.

39.2 Types of education and training

Managerial/professional staffs are likely to be educated in universities or the equivalent, while supervisory and skilled men will have a technical education. Following the analysis in Table 39.1 above, there will be 2,000 in the first category and some 22,000 in the second two groups. Although

TABLE 39.1 - ESTIMATED MANPOWER DEPLOYMENT IN THE 1980 STEEL INDUSTRY

	Managerial/ Professional	Supervisory	Skilled/ Semi-skilled	Unskilled	Total
Number	2,000	14,000	60,000	44,000	120,000
% of total	1.7	11.7	50.0	36.6	100
Number qualified	2,000	7,000	15,000	0	24,000
Number qualified as % of total	1.7	5.8	12.5	-	20

these figures seem quite large, the requirements do not appear difficult to meet when set against the national plan's projected education provision levels for 1973.

Implications of educational patterns

The organization of Latin American universities owes more to the European than the American model, and reflects educational and social values of the Old World rather than the New. This must be recognised and allowed for when planning for the role educational institutions are to play in industrial development. Universities recruit very largely from sections of the community for whom technological management in industry has historically been unattractive. As a corollary to this, university science and technology courses have in the European manner rarely been vocational. The result has been that university graduates have not been well qualified to enter the operational side of industry, and generally have not done so. Only 2 percent of Brazilian steel industry employees are graduates, as against 12 percent in Japan.

This situation in itself would not be serious for industry, if technologically trained staffs were available from elsewhere in the educational system to fulfil operational management functions. To a great extent such men are available but not for induction into responsible management echelons owing to the close parallelism between the educational system and the social/income structure, with its wide differentials.

The results of this situation for the steel industry are potentially quite serious, especially in view of the current expansion programme. At present too few graduates are attracted into operational management as distinct from the practice within the industry of their professional skills. Universities tend to concentrate on the inculcation of professional technological skills rather than adapting their courses and indeed their educational philosophy to comprehend the exigencies of industrial organisation. Meanwhile management is strongly inhibited from recruiting to its ranks from the numbers of those with vocational training and first hand experience of steel making processes.

University education

Achieving a modest improvement in practice up to best European levels would require that the steel industry roughly triple the number of graduates employed. This would involve increasing the numbers of higher managerial staffs with university technological qualification, but more important than that would be the introduction of graduates to the lower 'supervisory' and 'skilled' employment levels. This is already common in Japan, and is becoming more so in the UK. The result of such a policy would be to improve the quality of staff at this level, but more important in the long run it would pave the way to more closely integrated supervisory and management functions. Management would eventually be leavened with cadres possessing factory floor experience, and in turn communications between the two levels would improve with the disappearance of the social/income rift between them.

The general prescription for Brazil's university education system with respect to the requirements of the steel industry is thus not only that it should increase its output of graduates, important as this aim is. It must also co-operate with the steel industry in designing courses which will more effectively and immediately meet the industry's requirements. The steel industry must meanwhile seek to place graduates in sub-managerial supervisory positions, creating management structures which will facilitate movement of personnel from one level to the other.

Technical education

The expansion of technical education, which planned industrial development will require, must also involve an overall improvement in its quality, so that ultimately there is no sharp break between this and university-based education; above all, there should not be a sharp division of status between the two. It is no accident that Japanese effectiveness in steel production has been accompanied by the breakdown of much of the traditional system of instituationalised status attaching to education and occupation. The graduate blast-furnace foreman is commonplace in Japan, but so is his promotion to plant manager and beyond.

In technical education it is even more necessary that there be constant communication between the shop floor and the training centre. Although formal qualifications demand systematisation of syllabuses, for example, these should be flexible and readily altered to keep ahead of factory requirements. Teaching staff should be allowed frequently to update their own experience of factory processes. Provision could profitably be made for much of the instruction given to come from experienced factory operatives themselves.

Not only should instructors renew their plant experience, but plant workers themselves at all levels should be encouraged to regard education as a continuing complement to their own work. Further training can be presented to operatives as a means of self-improvement and advancement, while to the employer it is a means of making his staff more efficient and effective.

39.3 The organisation of education and training

Education can be regarded as an expensive long-term investment where it is difficult to determine how the benefits accrue. The solution adopted by most societies is to make education the responsibility of the state, so far as most investment is concerned, though some measure of private organisation and funding is permitted. Thus, although the steel industry in many countries is in private hands, the formal education requirements of the industry are met by state institutions. The practical explanation for this arrangement is that while formal education must be made available for the well-being of the industry, individual small enterprises would not or could not provide for themselves. There are further advantages to state organisation. The state is able to standardise and maintain the quality of education, and it can promote fruitful interaction between different branches of the educational system.

The role of the universities here has been outlined already. They provide an academic style of education in which distinct intellectual standards are maintained. However, the distinction between university education and higher level technical training can be expected to become more blurred; the idea of the 'technological university' is established in Brazil, and is bound to become more popular. Universities are usually distinguished by standing slightly apart from the mainstream of industry, and to that extent are autonomous. This is not to say that they can afford to allow themselves to become insulated from industry's requirements.

In vocational training institutions the relationship with industry must be closer, since it is here that operatives will learn the basis of operating and managing actual processes. So close does the relationship become and correspondingly so much more immediate the benefits to the industrial firm, that in the UK at least it has been thought proper to fund much of this training from a levy on the industry. This is a solution which might well commend itself in Brazil, in view of the strong competition for public funds.

Every encouragement should be given by government to firms wishing to institute their own education and training schemes. Some minimal training must be given to otherwise unskilled or semi-skilled workers, but it is possible for larger firms to go further than this. With tax concessions and judicious grants, the government could ensure that a firm's unique ability to provide training close to if not on the factory floor is exploited. In like manner, research organisations inside and outside the firm could be encouraged to offer education and training in their specialities to selected staffs from all over the industry.

Current and planned provision

It is impossible without a detailed analysis of the needs of the whole of industry to decide whether the forecast levels of educational provision in Brazil will be adequate for the steel industry. At planned 1973 levels the annual output of university graduates in technological disciplines will be about 10,000, and of technical trainees of graduate level attainment, about 15,000. The plan for the steel industry of 1980 envisages some 8 percent of employees with this level of educational attainment, that is about 9,000 - 10,000 men. To maintain this level, an annual induction rate of about 1,000 graduates would be required over the industry as a whole, or 4 percent of the technologically qualified output. Since the contribution of the steel industry to Brazil's GNP will also be of the order of 4 percent, we can say that the industry would certainly take no more graduates than the share due to it on this account. The steel industry will, however, provide an essential prime material for manufacturing industries producing no less than a quarter of the total GNP, and should in consequence be allowed some priority in recruitment.

39.4 The transfer of technology*

One of the most important functions of institutions for technological education in an industrialising country is management of the importation of technology. This is broadly achieved in two ways, passively by the assimilation and rebroadcasting of new ideas in foreign publications, actively by the engagement of foreign teachers or the dispatch of teachers or students abroad. These processes all required careful organisation and planning. It is understood that there are plans to set up an organization in Brazil to organize the transfer of technology.

In a country such as Brazil with highly capable elites within the educational system and the steel industry, there is no problem about the assimilation of new technology. Difficulties only arise at the stage of dispersing edited information to those who will make and operate new machinery and modify the old. Those who acquire the first news of new developments typically have little motivation or practical capability to implement them, and a great status and comprehension gap separates them from men, on the shop floor for instance, who could manage the detail of implementation. A concerted drive from within the steel industry and the educational institutions to improve this kind of communication will be essential to the future health of the industry.

Motivational questions are also prominent in the diffusion of new technology by employing foreigners or by sending one's own staff abroad. Both in the case of staff taught by the foreigner and those sent abroad for training, care must be taken that those chosen have sufficient weight within the firm to be listened to in their turn, to put to use what they have learnt. Equally they should not be of so high a status as to be made uncomfortable, and thus unreceptive, by being placed in a learning situation which they may perceive as a potential threat. At the same time, the expatriate teacher must be sensitive enough to learn rapidly how to reach his pupils, for example, by

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*UNIDO Workshop on Creation and Transfer of Metallurgical Knowhow. Jamshedpur - December 1971 (ID/WG110) taking account of their own values and motives. These remarks apply in principle equally to the case of the pupil overseas, though here the home country has little control of the situation. Then, once the initial transfer of technological information has been achieved, the strictures apply as before to its diffusion to people who will realise it as new processes.

A research and development centre can also become the means of introducing ideas and information from abroad to the domestic industry, improving on them or adapting them to local conditions. In the same way, it can publicise domestic development abroad, allowing the home industry to profit from advertisement or even from licensing and development contracts.

It is likely that in terms of the numbers of technologically qualified staff required by the expanding steel industry, the Brazilian educational system should have little difficulty keeping pace. This will be even truer if the steel industry is allowed some priority nationally in the recruitment of suitable personnel. Rather more difficult will be the matter of using the educational system as a means of breaking down status and communication barriers to the dispersion of technological 'know-how', and as a means of cultivating predisposition to implement new ideas.

39.5 Conclusions and recommendations

If the planned pace of development is to be achieved in the Brazilian steel industry, it will be necessary to have effective manpower. Without this the improvements in operating practice will not be attained, and the new works planning will not be properly implemented.

The capability for achieving the desired level of training at all levels of operation and management in the industry already exists in Brazil; it requires mobilising to service the particular requirements of the steel industry.

Central manpower planning will play an important part in the development of all Brazilian industries; we recommend that the steel industry should give a lead by making an immediate detailed study of its management and skilled and semi-skilled labour requirements during the next ten years. The information gained from this study should then form the basis for programmes of education and training to be implemented in the various centres of learning.

CHAPTER 40 - RECOMMENDATIONS FOR ACTION IN PLANNING THE BRAZILIAN IRON AND STEEL INDUSTRY

40.1 The planners

The implications of world technological trends will influence decisions at all levels, from government encouragement of growth in specific sectors to decisions on the modernisation or expansion of individual works.

It is clear that the larger works must embrace, or displace, the smaller units in the fullness of time so it is vital that the overall strategy for the industry is defined in a way that allows the development of each enterprise to be seen in context.

CONSIDER, the agency responsible for undertaking the Brazilian Government's part in this work, will be directly concerned with the recommendations set out in this chapter, but it is also important for the industry itself to participate fully in the planning of its own future.

To ensure that the new equipment to be installed is designed to the latest world standards, we recommend that a central advisory panel be set up to appraise and monitor world-wide plant design trends. This panel, which could be established by either CONSIDER or IBS, could be consulted by those responsible for planning the building of new plants or the expansion of those already in production. Such a panel would also be of assistance in the successful development of the Brazilian iron and steel plant manufacturing industry.

CONSIDER, and the industry, will be wise to minimise the effort required to formulate and specify the techno-econometric models needed to resolve the interactive situations which comprehensive planning generates; this can be done by using specialist planning consultants, thereby leaving the Brazilian planners greater freedom for analysis and evaluation of strategic options.

Once the main task of establishing the overall strategy for the industry has been completed, the planning of individual works will require further effort. This may also be most economically done by using consultants to assist company management over the peak of effort required to prepare the detailed plans.

40.2 Studies of key decision areas

The strategy resulting in a plan for the Brazilian iron and steel industry in 1980 will embrace the production in perhaps 60 different plants each with an average of five or so process centres. In consequence there will be between

300 and 400 decisions to be made on plant capacity and location. These decisions fall into two groups; firstly there are the key decisions needed to shape the industry to meet the future demands placed upon it, in the context of modern technology and the Brazilian environment. These key decisions are closely interrelated and can only be determined by carrying out planning studies to establish the relationships, and to qualify the interactions between them. The second and larger group is more straightforward, comprising logical extensions of the key decisions and decided by technological parameters only. We have identified thirteen major studies which constitute components of the total strategy. These are:

a market/product evaluation for packaging materials.
a detailed survey of pipe and tube products.
a detailed survey of medium and heavy section demand.
an evaluation of different locations for a continuous hot strip mill, and tinplate plant.
a study of scrap availability and utilisation.
a study to determine the steelmaking policy for the non-flat product sector.
a study of feedstock sources for special steelmaking.
a review of mill capacity in the non-flat sector in relation to steel qualities and products required.
a study of the economics of rolling stainless and other special steel sheets.
a study of product standards and quality.
a study to specify performance indices appropriate to the industry.
an evaluation of the technical characteristics of transportation which are of importance to the steel industry.
a study of the availability of fuel and reductants, with special reference to formed coke.

We envisage that the content of each of the sub-studies, and the results required from it, will be in accordance with the following digest:

Market/product evaluation for packaging materials

The competition between the various packaging materials is continuous. For Brazil, developing in all product sectors, it is important to be fully aware of the current advantages which each material has to offer. It is equally important to be aware of the technical characteristics of each market so that the degree to which product substitution is practical, as distinct from economic, is known. We therefore recommend a study of packaging needs, particularly of those industries now using tinplate, to establish what packaging trends may influence their demand for tinplate and also to what extent alternative steel products, such as tinfree steel or lacquered sheet, may be substituted for tinplate.

Market survey of pipe and tube products

The only indication of a pipe or tube market demand given in the Technometal report is for seamless tube. We regard it as essential to establish the pipe and tube market demand in more detail, because of the multiplicity of tube making processes, each suited to a particular range of products. We note the continuing trend of replacement of seamless pipes by welded ones and are, therefore, inclined to regard the market forecast for seamless tubes alone as unreliable. This study must be completed before decisions can be made on provision of pipe and tube making capacity. It will also reflect upon the demand for billets for tube rounds and narrow slabs for skelp.

We consider this study to be an essential input to the decision making on section mill capacity.

Hot strip mill and tinplate plant location study

We have noted in Article 36.1 the key nature of the decisions relating to the location of the next hot strip mill. This study must cover the evaluation of alternative sites (in terms of the iron and steelmaking capacity required to support the mill at full capacity), the range of products to be rolled, the extent to which these are to be further processed on the same site or despatched to other mills and the effect of the new mill on existing hot strip capacity. This study will determine the shape of the flat product sector in 1980; all other decisions about provisions of capacity are subordinate to it.

The demand for additional tinplate production facilities appears to justify the building of a complete new unit comprising cold and temper mills, pickling, annealing and tinning lines. It is not imperative that such a plant be sited at the hot strip mill which supplies it. The study should also cover the various options of extending existing facilities and of building a new unit at locations having such advantages as a pool of labour, a transportation mode or a larger tinplate market.

Scrap availability and utilisation study

This study would be an amplification of previous work to establish the following:

(i) quantities of various qualities of scrap available in each location.
(ii) quantities of various qualities of scrap required for each steelmaking process.
(iii) levels of scrap mobility.

Survey of medium and heavy sections

The Technometal report gives a single tonnage to cover this wide range of products. We have remarked that heavy structural sections are now usually fabricated from universal plate. Ship profiles in the large sizes are also produced in this fashion. Universal beam mills are now the recognised method for rolling medium structurals up to say 550 millimetres and may even be used for rail production.

The tonnage required seems small compared with the general growth of the Brazilian economy and so we consider it important to establish, in this survey, how much demand could be stimulated by the knowledge that, for example, universal sections were available.

The study would have two outputs. The first would be an overall appraisal by region, of the scrap position. The second output would be a forecast of the amount of quality scrap available for special steel production.

Steelmaking policy for non-flat product sector study

In Article 36.2 we have given a preliminary indication of the content of this study. The objective of the steelmaking policy is to make the best use of raw materials. This implies using as much scrap as possible without creating a "shortage".

This study involves the entire industry since the steelmaking practice in the flat product sector must also be studied to establish what calls on outside scrap are to be made by that sector.

The object of the study is to determine the amount of steelmaking capacity that can be scrap-based and broadly where it is to be located.

Study of feedstock sources for special steelmaking

This study builds on the scrap utilisation study and also has to be related to the steelmaking policy study for the non-flat sector. The objective of this study is to determine the amount of quality feedstock available for this sector from the scrap supply and whether alternative supplies must be planned. Alternatives may be:

- the building of a small BOF steelplant for non-common steel using hot metal from a neighbouring large works.
- the building of a small BOF steelplant complete with Elkem smelters.
- the supply of sponge iron for steelmaking using electric arc furnaces.

Reveiw of mill capacity in non-flat sector

This study comprises an inventory of existing finishing mill capacity, classified by product mix, product quality and development potential.

Study of rolling options for special steel sheets

This study should deal with the process economies of alternative options for rolling stainless sheet, grain oriented electric sheet and other special sheets. Options will include hire rolling of hot sheet in the main flat product sector and the building of a CRGO sheet production unit.

Product standards and quality study

The purpose of this study is to review the market requirements for standards, and specification of quality, to ensure that provision is planned for adequate facilities within the industry to meet these requirements. The study will identify the standards and quality levels relevant to product groups, and will indicate opportunities for rationalisation to meet the requirements laid down by different markets.

Specification of performance indices

The evaluation of both existing and proposed plant facilities can only be done satisfactorily if clearly defined indices are used to describe plant performance. To some extent this work can be done in parallel with the setting up of management information systems which we recommended in Chapter 6. However, it should be noted that performance indices for planning purposes are not usually the same as those needed for day to day control of the plant, although they are, of course, derived from the same basic data.

Transportation study

There are three main transport situations facing the planners of the Brazilian steel industry. These are the large scale movement of raw materials and finished products in the "industrial triangle", the support of markets remote from this triangle which may be large enough to justify local works, such as the South and the North East, and the possible large scale transfer of semi-finished products (particularly billets) between works.

Each situation has different handling characteristics both in terms of product packaging and loading equipment. Also some products or materials may require specially designed transporters. An economic evaluation of the alternatives and an assessment of the probable form of transport development are the main outputs of this study.

Fuel and reductant study

It is clear that the industry is going to depend heavily on blast furnace production of hot metal. Thus a study of all the alternative options to using metallurgical coke must be made to establish an overall policy for the industry on reductant consumption. This study will deal with: the technological evaluation of possible coals available to Brazil, both indigenous and imported; the developments in cokemaking and formed coke production; and the economic ranking of the various options.

40.3 Overall strategy for the industry

The strategy for the whole industry embodies the sub-strategies for the three main product sectors; these may be studied as a totality using the sub-studies outlined in the previous article as input data. The relationship between the sub-studies and those of the industry as a whole is shown diagrammatically in Figure 40.1.

The techniques for the evaluation and optimisation of the capacity of each works, and its parts - and, similarly, of the industry as a whole - have been explained in a paper by Mills and Soan.* Representative examples of 'model' works that must be created when planning future capacity are given in Appendix 3.

When a decision is taken to make an overall plan for an enterprise, it is a temptation to try to complete the whole study in minimum time. Although

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* Determination of Optimum Capacity of the fully-integrated Iron and Steel Plant and its Parts - UNIDO Second Inter-regional Symposium on the Iron and Steel Industry - Moscow, 19 September - 6 October 1968.

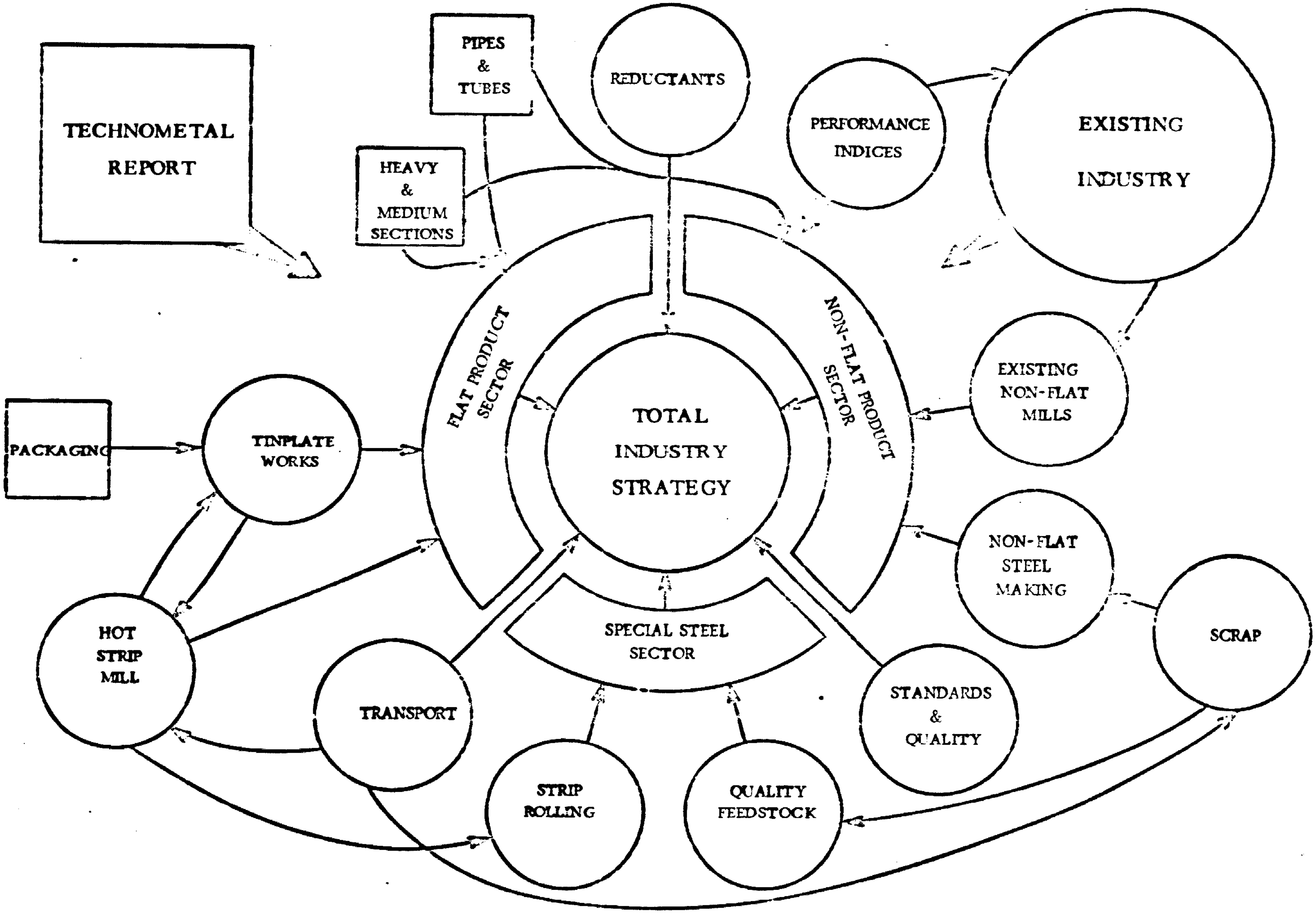

FIGURE 40.1 - TOTAL PLANNING STRATEGY

delay reduces the validity of the data gathered, undue haste is also to be deprecated. The magnitude of the task of planning an entire industry is such that it is not practicable, because of manpower and organisational limitations, to plan it all simultaneously. Under these circumstances it is preferable to prepare quickly a total plan in outline, and then to concentrate detailed study on the more urgent aspects. Of the key decision areas identified in Article 40.2 we consider that the following deserve the highest priority:

the hot strip mill (and tinplate plant) location study;
the scrap availability and utilisation study;
the steelmaking policy for the non-flat product sector study;
the study of feedstock sources for special steels
the fuel and reductant study.

It is also important to complete, at an early stage, the specification of performance indices because this will determine the accuracy of all future planning.

Once established, the strategy must be continually reviewed and revised to take account of technological developments and socio-economic pressures. It must be remembered, however, that while the strategy can be changed very quickly in response to outside influences, the resulting replanning can only take place in stages which are governed by the size and frequency of developments that can be countenanced at individual plants. It is for this reason that at no time can any industry be regarded as truly up-to-date.

APPENDICES

APPENDIX 1 - BASIC PERFORMANCE DATA

A1.1 Definitions of performance criteria

The definitions of performance criteria which have been used in the report are given below:

Blast furnace output index (B.O.I.)

This index is derived from the expression:

$$\frac{P(0.02B + 10)}{72(3.3D - 10)}$$ for furnaces with D more than 6.1 metres

or, $$\frac{P(0.02B + 10)}{19.4D^2}$$ for furnaces with D less than 6.1 metres

Where,

P = Production of hot metal - tonnes per day
B = Burden weight - kilogrammes per tonne of hot metal
D = Furnace hearth diameter - metres.

Note: Burden weight is assumed to consist of all materials charged into the furnace except coke or charcoal.

Corrected coke rate

The actual coke rate for each blast furnace is corrected to 85 percent fixed carbon. Where fuel oil injection is practised, the amount injected at the tuyeres is converted to an equivalent amount of 85 percent fixed carbon coke on a thermal basis, assuming that an 85 percent fixed carbon coke would have a net calorific value of 29 megajoules per kilogramme. The total corrected coke rate is then derived by accumulating the above items as appropriate.

Corrected charcoal rate

The derivation of corrected charcoal rate for blast furnace operation is based on the same principle as that described for the derivation of corrected coke rate except that the fixed carbon content of charcoal is corrected to 76 percent. The equivalent amount of charcoal corresponding to injected fuel oil has been calculated on the basis that a 76 percent fixed carbon content charcoal would have a net calorific value of 29 megajoules per kilogramme.

A1.2 Levels of performance

The performance levels of the various manufacturing facilities shown below are those which are expected to be achieved by the operators of the world's leading iron and steelworks in 1980. Generally they represent the best plant performances currently being achieved. These performance levels have been used in this report in determining process costs. (All plant, except rolling mills, is assumed to operate 8,000 hours per year).

Coke oven

Output rating - 1.0 tonne of coke (all grades) per cubic metre of oven volume per day.

Sinter plant

Output rating - 32 tonnes of usable sinter per square metre of effective grate area per day.

Blast furnace

Output rating - 3 tonnes of hot metal per cubic metre of effective furnace volume per day.

This rating is based on the following practice:

Fe bearing burden	Sized lump ore containing not less than 64 percent Fe and/or self-fluxing sinter or oxide pellets with equivalent Fe content*.
Coke rate (dry basis)	420 Kg per tonne of hot metal
Oil injection rate	60 Kg per tonne of hot metal
Blast temperature	1250°C
Top pressure	2 atmospheres
Oxygen content of blast	24 percent

* Brazilian furnaces have been assumed to operate on 100 percent sinter; international furnaces on 60 percent sinter, 40 percent lump ore.

BOF Steelplants

Furnace Size	Cycle time (annual average) (minutes)	Plant Utilisation (percent)	Approx. number of heats per year
Less than 100 tonnes	33	90	14, 300
More than 200 tonnes	33.5	90	13, 500

Electric arc steelplants

Furnace size	Cycle time * (annual average) (minutes)	Plant Utilisation (percent)	Approx. number of heats per year
Less than 50 tonnes	180	90	2, 600
More than 100 tonnes	240	90	2, 000

Continuous casting machines

Output ratings:**

Billet production (100 mm x 100 mm)	14 tonnes per hour per strand
Bloom production (250 mm x 250 mm)	28 tonnes per hour per strand
Slab production (1500 mm x 250 mm)	120 tonnes per hour per strand

The above ratings are based on the following conditions:

Maximum pouring time	70 minutes
Reset time	30 minutes

1 standby machine to every 3 casting machines.

Rolling mills

Plant availability	7, 000 hours per year
Plant utilisation	90 percent of available hours.

* Based on carbon steel production

** If "continuous continuous" casting is practised - when more than one heat of steel is cast in sequence - the output ratings and material yields will increase significantly.

A1.3 Process yields

The material yields of various process areas currently being achieved by leading iron and steelworks are set out below. These yields have been used in this report when determining the levels of production required and the production costs:-

Process area	Material	Product	Yield-percent
Cokemaking	Coking coal blend	Coke (all grades) Blast furnace coke	74(1) 68(1)
Sintering	Fe in iron ore fines	Blast furnace sinter	100(1)
Blast furnace ironmaking	Fe in iron bearing charge	Hot metal	97.5
Direct reduction	Fe in iron bearing charge	Reduced product (Sponge iron)	98
BOF steelmaking	Metallic charge	Liquid steel	91
EA Steelmaking	Metallic charge	Liquid steel	94
EA Steelmaking	Metallic charge: 80% reduced product(2) 20% scrap	Liquid steel	87
Ingot casting	Liquid steel	Ingots	98
Continuous casting *	Liquid steel	Slabs	95
	Liquid steel	Blooms	96
	Liquid steel	Billets	96
Rolling	Ingots	Slabs	90
	Ingots	Blooms	90
	Slabs	Plates	90
	Slabs	Hot rolled coils	96
	Hot rolled coils	Prepared hot rolled coils	96
	Hot rolled coils	Prepared hot rolled sheets	90
	Hot rolled coils	Cold reduced coils	94
	Cold reduced coils	Prepared cold rolled coils	97
	Cold reduced coils	Prepared cold rolled sheets	93
	Cold reduced coils	Tinplate	97
	Tinplate	Tinned sheets	96
	Cold rolled sheets	Galvanized and terne sheets	103

*See footnote on previous page.

Process area	Material	Product	Yield-percent
Rolling (Cont'd)	Blooms	Billets	95
	Blooms and Billets	Sections	90
	Blooms	Rails	90
	Billets	Bars	95
	Billets	Wire rods	91
	Blooms	Seamless tubes	80
	Billets	Seamless tubes	91

Note:
1. Dry basis.
2. Reduced product of 85% metallisation, where metallisation is defined as the ratio of metallic Fe to total Fe of the product.

APPENDIX 2 - DERIVATION OF COMPREHENSIVE COST AND CAPITAL RECOVERY FACTORS

A2.1 Definition of cost terms

A number of different terms have been used in this report to measure the relative costs of alternative processes. The diagram below indicates which components of the total cost of a manufacturing process are included in each of the terms used.

<table>
<tr><td rowspan="7">Total (or comprehensive) cost</td><td colspan="2"></td><td>Raw materials</td></tr>
<tr><td rowspan="4">Comprehensive conversion cost.</td><td rowspan="3">Conversion or Operating costs</td><td>Consumables</td></tr>
<tr><td>Energy</td></tr>
<tr><td>Manning</td></tr>
<tr><td></td><td>Capital charge</td></tr>
<tr><td colspan="2" rowspan="2"></td><td>General works services
and working capital</td></tr>
<tr><td>TOTAL</td></tr>
</table>

A2.2 Comprehensive cost

The separate consideration of capital and operating costs may not always indicate clearly which of two alternative processes of similar apparent technical feasibility will represent the best investment. If one process has a low annual operating cost with a high capital cost, and the other a high operating cost but requiring little capital, they are difficult to compare unless a single parameter incorporating both types of cost can be established. This can be done by regarding capital as a commodity which is hired for an annual charge, and the addition of this capital charge to the annual operating (conversion) cost creates a comprehensive annual cost which supplies the single parameter necessary to compare the alternative processes. The capital charge must include allowances for:-

a) depreciation (that is, it must take into account the life of the asset);

b) a satisfactory profit margin to cater for the cost of capital (dividends and/or interest payments);

c) the absence of profit during the construction period and the running-in period of the plant.

The capital charge is calculated by applying a capital recovery factor (expressed as a percentage) to the relevant capital expenditure. In algebraic terms, the annual capital charge is given as rC and the comprehensive cost may be expressed as an equation:

$$T = P + rC$$

where T = annual comprehensive cost
P = annual operating cost or conversion cost
C = capital cost
rC = annual charge for capital
r = capital recovery factor

In order to determine the appropriate capital recovery factor, a number of basic assumptions regarding the process, the financial terms, and the fiscal environment need to be made. These include :

i) Phasing of capital cost expenditure.

ii) Life of the project.

iii) Commissioning rates applicable to the project.

iv) Additional operating costs during the commissioning period.

v) The split of capital costs between plant, buildings, etc.

vi) Disposal values of buildings, etc.

vii) Method of raising capital and the required discount rate (gross or net of tax).

viii) Rules governing the treatment of losses for tax purposes.

ix) Rate of taxation.

x) Time lag in collection of taxes.

xi) Investment grants and depreciation allowances.

xii) Time lag in investment grant payments and depreciation allowance set-offs.

xiii) Other fiscal incentives.

Two capital recovery factors were calculated for use in this study, one for the Brazilian financial and fiscal environment, the other for the international environment. The calculated values were :-

Brazil : 16 percent
International : 19 percent

and both values were based on a required rate of return to equity equal to 12 percent per annum in real terms.

The basic assumptions made in regard to the financial parameters, and the detailed calculations of the capital recovery factors, are given below :-

Assumptions

Brazil :

Equity return 12 percent per annum
Gearing: 60 percent loans; 40 percent equity
Loan - interest @ 8 percent, 4 years grace on interest payment, then repaid over 12 years
Depreciation @ 5.56 percent straight line for all capital expenditure (i.e. buildings and plant)
Profit build-up 0.6x, 0.8x, 1.0x where x is the level of desired profit
Additional cost in the early years -20% of capital expenditure
Tax - 30 percent in South-east
Commercial life of project 18 years
No resale value at end of profect life

International :

Equity return 12 percent per annum
Gearing 40 percent loans; 60 percent equity
Loan - interest @ 8 percent capitalised during construction period, debenture type repayable at the end of the project
Investment - on buildings 35 percent, on plant and equipment 65 percent
Tax allowances : Buildings 15 percent initial + 4 percent annual straight
Plant 60 percent first year + 25 percent annual reducing
Corporation tax - 40 percent
Commercial life of project 15 years
No resale value at end of project life.

Calculations of a capital recovery factor

On the basis of the above assumptions, the method of calculation is illustrated below for the Brazilian case:-

Example - Brazil case
Capital expenditure - US $ 1,000
Gearing - Loans 60 percent, equity 40 percent.

Phasing of capital expenditure:

Year	Phasing	Capital Expenditure	Source of funds	
			Loan	Equity
-2	5%	50	30	20
-1	45%	450	270	180
0	40%	400	240	160
1	10%	100	60	40
		$1,000	$600	$400

Fixed capital loan and repayments:

Interest on loan @ 8 percent per annum, moratorium on interest and capital payments for first 4 years of operation, during which period the interest is added to the loan, the amount outstanding is repaid in 12 equal annual instalments.

Year	Loan required during the year	Average loan	Interest @ 8%	Balance end year	Repayments
-2	30	15.0	1.2	31.2	
-1	270	166.2	13.3	314.5	
0	240	434.5	34.8	589.3	
1	60	619.3	49.5	698.8	
2	-	698.8	55.9	754.7	
3		754.7	60.4	815.1	
4		815.1	62.5	877.6	
5		841.1	67.3	804.6	73.0
6		768.1	61.4	731.6	"
7		695.1	55.6	658.6	"
8		622.1	49.8	585.6	"
9		549.1	43.9	512.6	"
10		476.1	38.1	439.6	"
11		403.1	32.2	366.6	"
12		330.1	26.4	293.6	"
13		257.1	20.6	220.6	"
14		184.1	14.7	147.6	"
15		111.1	8.9	74.6	73.0
16		37.3	3.0	-	74.6

Assessment of tax and allowances:

Year	Tax depr.	Tax value of depr.	Loan interest	Tax value of interest	Profit effect	Tax paid	After tax profit
-2			1.2				
-1			13.3	.4			
0			34.8	4.0			
1	55.0		49.5	10.4	.6x-100*		.6x-100
2	55.0	16.5	55.9	14.9	.8x-100*	.18x-30	.62x-70
3	55.0	16.5	60.4	16.8	1.0x	.24x-30	.76x+30
4	55.0	16.5	62.5	18.1	1.0x	.30x	.70x
5	55.0	16.5	67.3	18.8	1.0x	.30x	"
6	55.0	16.5	61.4	20.2	1.0x	.30x	"
7	55.0	16.5	55.6	18.4	1.0x	.30x	"
8	55.0	16.5	49.8	16.7	1.0x	.30x	"
9	55.0	16.5	43.9	14.9	1.0x	.30x	"
10	55.0	16.5	38.1	13.2	1.0x	.30x	"
11	55.0	16.5	32.2	11.4	1.0x	.30x	"
12	55.0	16.5	26.4	9.7	1.0x	.30x	"
13	55.0	16.5	20.6	7.9	1.0x	.30x	"
14	55.0	16.5	14.7	6.2	1.0x	.30x	"
15	55.0	16.5	8.9	4.4	1.0x	.30x	"
16	55.0	16.5	3.0	2.7	1.0x	.30x	"
17	55.0	16.5	-	0.9	1.0x	.30x	"
18	65.0	16.5	-	-	1.0x	.30x	.70x
19	-	16.5	-	-	-	.30x	-.30x

* **Extra costs in initial years.**

Calculation of recovery factor :

Year	Equity Payments	Tax values of depreciation and interest	Net Total Expenditure	After tax profit	Discount factors @ 15%	Present Values of Net expenditure	Present Values of profit
-2	20	-	20.0	-	1.254	25.08	-
-1	180	.4	179.6	-	1.120	201.15	-
0	160	4.0	156.0	-	1.000	156.00	-
1	40	10.4	29.6	.60x-100	.893	26.43	.536x-89.3
2	-	31.3	-31.3	.62x-70	.797	-24.95	.494x-55.8
3	-	33.3	-33.3	.76x+30	.712	-23.71	.541x+21.4
4	-	34.6	-34.6	.70x	.636	-22.01	
5	140.3	35.3	105.0	"	.567	59.54	
6	134.4	36.7	97.7	"	.507	49.53	
7	128.6	34.9	93.7	"	.452	42.35	
8	122.8	33.2	89.6	"		36.20	
9	116.9	31.4	85.5	"	.361	30.87	
10	111.1	29.7	81.4	"	.322	26.21	
11	105.2	27.9	77.3	"	.287	22.19	3.394x
12	99.4	26.2	73.2	"	.257	18.81	
13	93.6	24.4	69.2	"	.229	15.85	
14	87.7	22.7	65.0	"	.203	13.33	
15	81.9	20.9	61.0	"	.183	11.16	
16	77.6	19.2	58.4	"	.163	9.52	
17	-	17.4	-17.4	"	.146	-2.54	
18	-	16.5	-16.5	.70x	.130	-2.15	
19	-	16.5	-16.5	-.30x	.116	-1.91	-.035x
						666.95	4.930x-123.7

Profit (x) required :

$$4.93x - 123.7 = 666.95$$

$$x = \frac{(666.95 + 123.7)}{4.930}$$

$$x = 160.4$$

Recovery factor : $r = 16\%$

A2.3 Working capital

In addition to the capital invested in fixed assets, there is a need to reflect in the costs the financing of working capital needs. Net working capital, in this context, is defined as investment in stocks (raw materials, semi-finished and finished products) and money owed by debtors less money owed to the creditors. Since creditors constitute a "cost free" source of working capital, for the purposes of allowing for additional financing it is necessary only to allow for that proportion of the working capital which needs financing on a permanent basis, that is, net working capital. Further, since value-added taxes are counter-claimed, and since the comprehensive costs generally refer to a works gate situation, it is necessary to construct the net working capital requirements appropriately.

In similar fashion to the fixed capital expenditure, it is possible to calculate a capital recovery factor which converts the investment in the net working capital to an equivalent annual charge. To simplify its use, it is convenient to express the recovery factor as a percentage of the total comprehensive cost (excluding at this stage the working capital charge). The working capital recovery factors used in this study are:-

Brazilian environment	-	2.8 percent
International environment	-	4.2 percent

In deriving the above factors, 20 percent of sales revenue (net of IPI and ICM on steel products*) has been taken as the level of funds required. It was assumed that this was raised on the basis of 80 percent loan, 20 percent equity, interest at 10 percent and an equity return of 12 percent on a discounted basis. On this basis, the "on-cost" to the comprehensive production costs was calculated at 2.3 percent, to which was added a further 0.5 percent to provide for the cost of discounting trade bills since about 5 percent of debtors are handled this way. Similarly, an examination of large international bulk steel producers' accounts revealed the level of the permanent net working capital to be at about 30 percent of revenue, financed by 40 percent loan and 60 percent equity with interest at 8 percent corresponding to overdraft financing, and a 12 percent discounted return to equity. On this basis the allowance for working capital in the international environment was calculated as 4.2 percent of the total comprehensive cost.

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* **Brazilian Federal and State taxes.**

APPENDIX 3 - COSTS OF STEEL FROM SELECTED WORKS CONFIGURATIONS

A3.1 Analysis of the value of world technological trends

Limitations on the availability of national resources sometimes preclude the full exploitation of the latest developments in technology. It is expedient therefore, to quantify the various potential technological contributions to the industry's prosperity when major industrial development programmes are being considered. This permits concentration upon those aspects which provide the greatest economic benefit to the industry and hence to the national economy.

For this purpose we have used, in this report, the total costs of steel and related products as norms against which the impact of currently available world iron and steel technology can be evaluated. The norms have been developed for a number of works configurations - or model works - which take account of both international and specifically Brazilian conditions.

The model works costs have been used for example, as the basis for comparing the costs of different steelmaking routes (Chapter 14) and for considering the effect of transport costs and economies of scale upon the location of works (Chapter 26)

In developing the model works costs we have used the 1980 criteria for performance and operating practice (Appendix 1) and have dealt with capital charges in the manner described in Appendix 2. The quantities of basic materials and energy used in the manufacture of the various products considered in this report are set out in Table A3.1. The costs of the basic materials which have been assumed will be found in Table A3.2. All costs are for the year 1971 and are presented in sufficient detail for alternative values to be substituted by the reader if desired.

With regard to capital cost estimates the following assumptions have been made:

i. All costs are based on 1971 prices.
ii. Brazilian and 'international' plant performance are assumed to be the same.
iii. Model works are costed at 90 percent utilisation.

TABLE A3.1 - MATERIAL AND ENERGY REQUIREMENTS

The quantities of basic materials and energy required for the manufacture of various products, as discussed in this report, are set out below. These requirements apply both to international and Brazilian conditions unless mentioned otherwise.

Process area	Product	Material	Quantity required per tonne product
Cokemaking	Coke (all grades)	Coking coal blend(1)	1350 (1) Kgs.
Sintering	Blast sinter	Iron ore fines	950 Kgs.
		Coke breeze	69 Kgs.
Blast furnace ironmaking:	Hot metal	Sinter	1520 Kgs.
		Coke	420 Kgs.
		Oil	60 Kgs.
Electric smelting:			
Tysland-Hole	Hot metal	Lump iron ore	1500 Kgs.
		Coke	350 Kgs.
		Electricity	2200 kWh
Elkem	Hot metal	Lump iron ore	1500 Kgs.
		High grade coal (imported) (4)	550 Kgs.
		Electricity	1320 kWh
Sponge ironmaking: HyL	Reduced product (2)	Oxide pellets	1360 Kgs.
		Natural gas or, naphtha	660 Nm^3 5 barrels
SL/RN	Reduced product(3)	Oxide pellets	1410 Kgs.
		Brazilian coal, or High grade coal (imported) (4)	1000 Kgs. 750 Kgs.
BOF steelmaking	Liquid steel	Hot metal	791 Kgs.
		Scrap (28 percent)	306 Kgs.
BOF steelmaking (Brazilian conditions)	Liquid steel	Hot metal	880 Kgs.
		Scrap (20 percent)	220 Kgs.

/continued........

Process area	Product	Material	Quantity required per tonne product
Electric arc steelmaking	Liquid steel	Scrap (100 percent)	1063 Kgs.
		Electricity	500 kWh.
		Oxygen	15 Nm^3
Electric arc steelmaking	Liquid steel	Reduced product (HyL)(2)	920 Kgs.
		Scrap (20 percent)	230 Kgs.
		Electricity	750 kWh.
		Oxygen	10 Nm^3
Electric arc steelmaking	Liquid steel	Reduced product (SL/RN)(3)	900 Kgs.
		Scrap (20 percent)	230 Kgs.
		Electricity	725 kWh.
		Oxygen	10 Nm^3
Continuous casting	Slab	Liquid steel	1052 Kgs.
	Bloom	Liquid steel	1052 Kgs.
	Billet	Liquid steel	1042 Kgs.

Notes:
1. Dry basis
2. Metallisation - 85 percent
3. Metallisation - 92 percent
4. Applies only to Brazilian Conditions.

Table A3. 2 Basic cost data

The costs of materials and utilities used in estimating the operating costs are set out below. These costs are typical for the year 1971, the rate of exchange being taken at 5.3 Cr$ = US$ 1.

Item	Unit	Delivered cost at Brazilian works US$	Delivered cost at International works US$
Iron ore (64% Fe)	Tonne		
Lump ore		-	14.5 (40% lump and 60% fines).
Fines		4.0(works near mine)	
Oxide pellets (64% Fe)	Tonne	12.0(works near mine)	17.0
		17.0(works on coast)	-
Scrap(1)	Tonne	30.0	29.0
Coke	Tonne	-	41.0
Coal(2)	Tonne		
Coking coal		28.9 (imported)	25.0
		31.1 (indigenous)	-
Non-coking coal	Tonne	11.3 (indigenous)	20.0(3)
Fuel oil (heavy)	Tonne	20.0	20.5
Natural Gas	GJ	0.25	-(3)
Naphtha	GJ	0.61	-
Electricity	kwh	0.011	0.011(3)
Labour (weighted average)	man year	2,800	4,800

Notes:

(1) A derivation of long term international scrap costs is presented in Chapter 14, Article 14.2.

(2) Contains 10 percent moisture as purchased.

(3) For the cost comparison between direct reduction processes made in Chapter 11, special prices were used, below the international costs given here.

iv. Total freight and insurance costs to Brazilian works is taken as 18 percent of the ex works plant and machinery prices and includes port dues. 'International' works have assumed freight and insurance costs of 25 percent of ex works plant and machinery prices.

v. Costs of erection and commissioning of plant at Brazilian works is assumed to be the same as the costs at European works.

vi. All mechanical and electrical service equipment is assumed to be supplied within Brazil at a cost of 106 percent of identical European equipment.

vii. Costs of civil works are assumed to be the same in Brazil and Europe

viii. Light buildings and structures are assumed to be supplied within Brazil at the same costs as those in Europe. Heavy buildings and structures such as those in BOF plant and casting shops are assumed to be made up of 60 percent Brazilian supply and 40 percent foreign manufacture. The foreign component is costed at 115 percent the equivalent costs in Europe, and the Brazilian component the same as those costs in Europe.

ix. The costs of 'preliminaries' for the works is assumed to be approximately 17 percent higher than in Europe.

x. No contingency has been included for cost escalation but 10 percent has been added to the capital costs (including works services) to allow for effective matching of individual plant items.

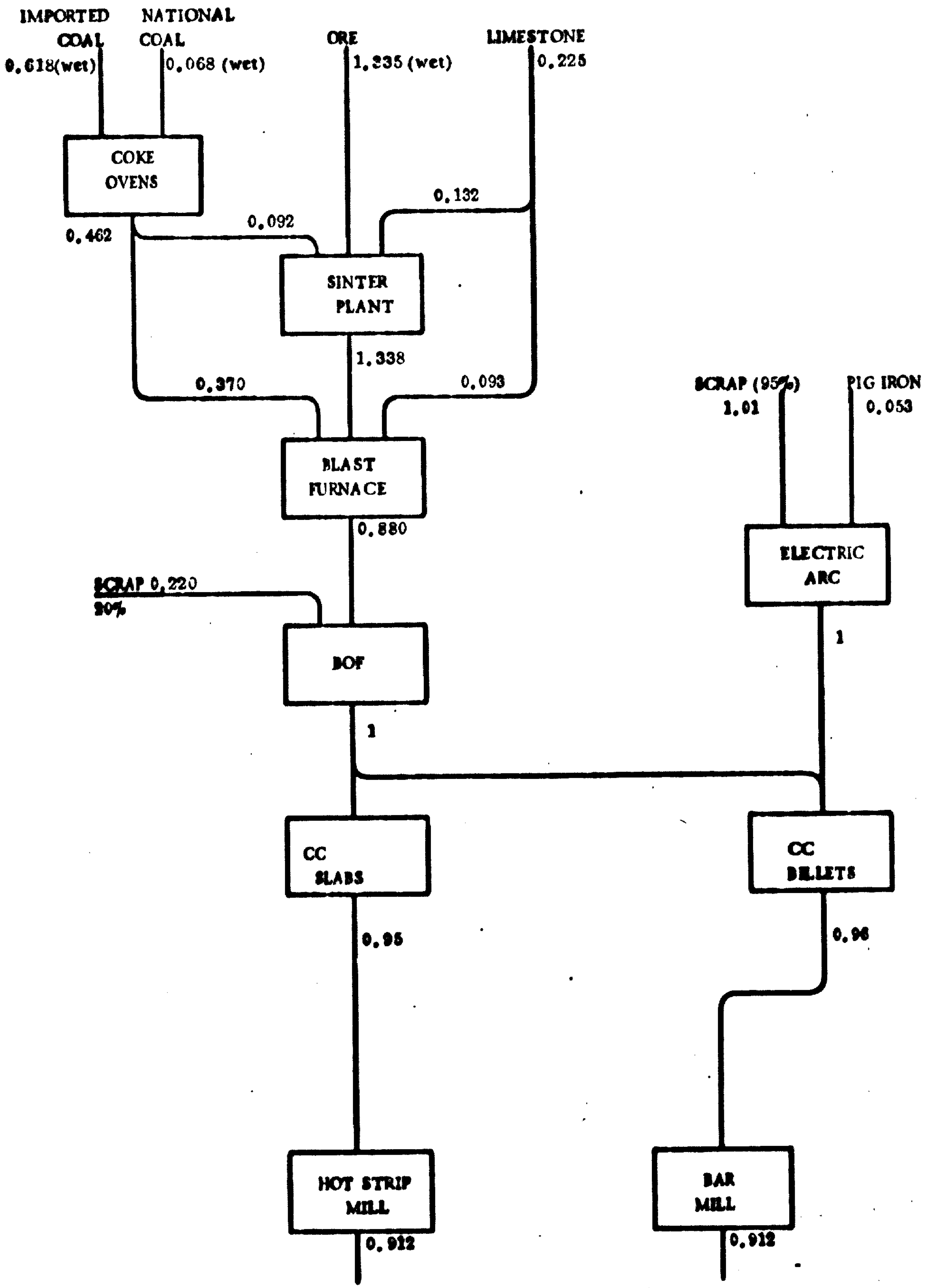
A3.2 Descriptions of model works

The flow sheets upon which the model steelworks have been based are illustrated in Figures A3.1 to A3.3:

Flowsheet 1 (Figure A3.1) indicates the material requirements, in Brazil, for the production of one tonne of liquid steel by the coke oven - sinter plant - blast furnace - BOF route and by the electric arc route; also indicated are the amounts of strip and bar mill products that would be available from continuous casting slab - hot strip mill and continuous casting billet - bar mill routes, respectively.

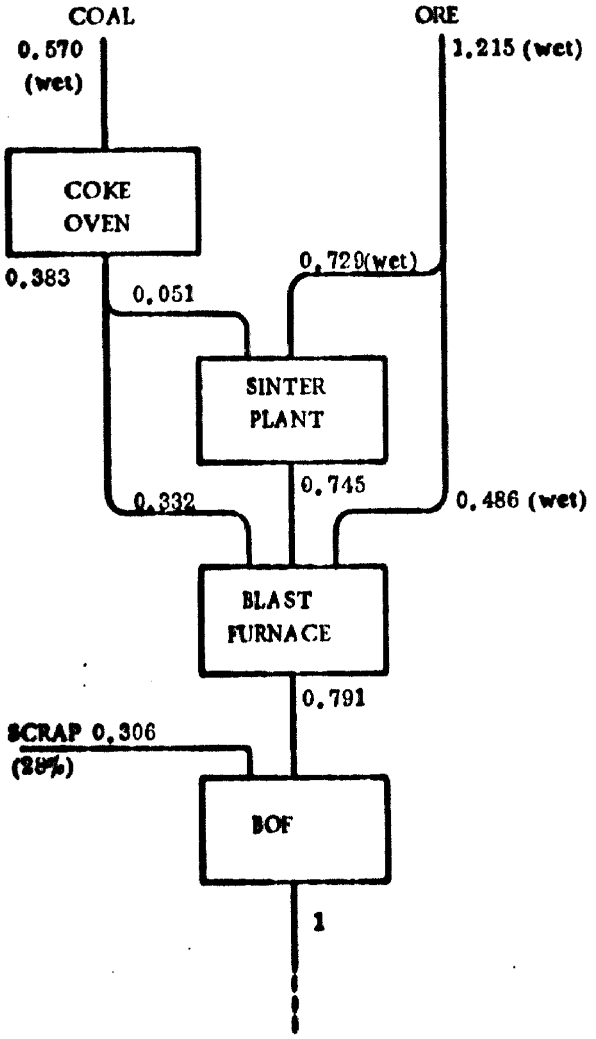
Flowsheet 2 (Figure A3.2) indicates the material requirements, at an international location, for the production of one tonne of liquid steel by the coke oven - sinter plant - blast furnace - BOF route.

Flowsheet 3 (Figure A3.3) indicates the material requirements, in Brazil, for the production of one tonne of liquid steel by the HyL reduction of pellets - electric arc route.



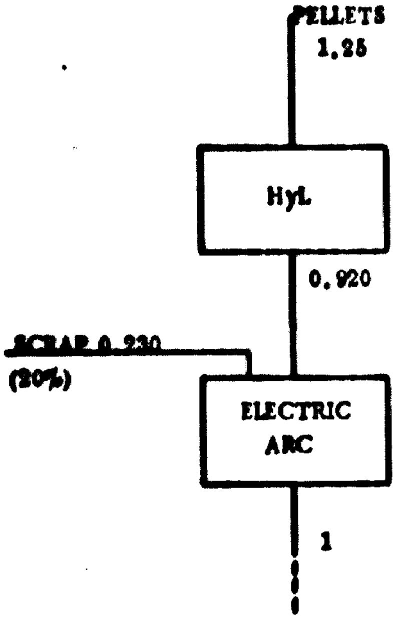
Tonnes per tonne of liquid steel

FIGURE A3.1 - FLOWSHEET 1 FOR MODEL WORKS - BRAZIL



Tonnes per tonne of liquid steel

FIGURE A3.2 - FLOWSHEET 2 FOR MODEL WORKS - INTERNATIONAL



Tonnes per tonne of liquid steel

FIGURE A3.3 - FLOWSHEET 3 FOR MODEL WORKS - BRAZIL

Eight model steelworks have been designed from these basic flowsheets for the purpose of estimating capital, operating and product unit costs. The model works are:

Model works 1.	A one million tonnes per year blast furnace - BOF plant situated at a Brazilian mine site. (Flowsheet 1, Figure A3.1)
Model works 2.	A three million tonnes per year blast furnace - BOF plant situated at a Brazilian mine site, and with continuous billet casting and a rod and bar mill. (Flowsheet 1, Figure A3.1)
Model works 3a.	A five million tonnes per year blast furnace - BOF plant situated at a Brazilian mine site, and producing billets by the continuous bloom casting - billet rolling mill route. (Flowsheet 1 - Figure A3.1)
Model works 3b.	As model works 3a, except that the product is hot rolled coil instead of billets; the production route is continuous slab casting - hot strip mill. (Flowsheet 1, Figure A3.1)
Model works 4.	A five million tonnes per year blast furnace - BOF plant situated at an international coastal site and producing hot rolled coil as in model works 3b (Flowsheet 2, Figure A3.2; and Flowsheet 1, Figure A3.1)
Model works 5.	A half million tonnes per year plant situated at a Brazilian coastal site with a natural gas supply, or at a mine site with naphtha supply. The process route is Hyl reduction of pellets - electric arc steelmaking. (Flowsheet 3, Figure A3.3)
Model works 6.	A half million tonnes per year plant situated at a Brazilian coastal site and based on the SL/RN reduction - electric arc process route. This is not shown on a flowsheet but yields have been assumed to be identical with those given in Flowsheet 3 (Figure A3.3).
Model works 7.	A half million tonnes per year plant situated in Brazil, near a suitable source of scrap, and producing steel by the scrap based electric arc route. (Flowsheet 1, Figure A3.1).

A3.3 Costs of steel produced in the model works

The cost data for the model works are set out in Tables A3.4 to A3.11, and the unit costs of various products are summarised in Table A3.3.

TABLE A3.3 - SUMMARY OF PRODUCTION COSTS FROM MODEL WORKS

(US $ per tonne)

Model Works details				Product							
Ref:	Steelmaking processes and capacity*		Location	hot metal	sponge iron	liquid steel	slabs	blooms	billets	h. r. c.**	rod & bar
1	Blast furnace/BOF	1.0	Brazil mine	56.3	-	70.2	-	-	82.8	-	-
2	" " "	3.0	" "	52.0	-	64.3	-	-	76.9	-	97.8
3	" " "	5.0	" "	50.0	-	61.5	73.5	72.5	81.9	93.8	-
4	" " "	5.0	International coastal	56.3	-	64.4	77.7	-	-	99.3	-
5	HyL/electric arc	0.5	Brazil mine	-	46.1	78.4	-	-	91.6	-	-
	" " "	0.5	Brazil coastal	-	43.5	76.0	-	-	89.1	-	-
6	SL/RN/electric arc	0.5	Brazil coastal	-	50.4	81.4	-	-	94.8	-	-
7	Scrap based electric arc	0.5	Brazil scrap centre	-	-	60.5	-	-	73.1	-	-

* million tonnes of liquid steel

** hot rolled coil

TABLE A 3.4

MODEL WORKS - 1

Location: **Brazil (mine site)**
Potential capacity: **1.0 million tonnes of liquid steel**
Process route: **Blast furnace, BOF,**
Utilization: **90%** **Capital recovery factor: 16.0%**

	Capital Costs	US $ x 10^6	Unit Costs	US $
IRONMAKING	Sinter plant	11.3	Iron ore fines (@$4.0/tonne)	6.2
	Coke ovens	17.6	Coal (@$29.1/tonne*)	22.7
	Blast furnace	31.0	Oil	1.7
	G.W.S. Allocation	21.6	Conversion costs	8.1
			G.W.S. operating , costs	2.9
	Total	81.5	Sub-total	41.6
			Capital charges	17.5
	Annual capital charge	13.0	Working capital	1.5
			Credits	-4.3
			Total per tonne of hot metal	56.3
STEEL-MAKING	Steel plant	22.6	Hot metal (@ $ 56.3/tonne)	49.5
	G.W.S. Allocation	8.1	Scrap (@ $ 30.0/tonne)	6.6
			Conversion costs	6.4
	Total	30.7	G.W.S. operating costs	1.6
			Sub-total	64.1
	Annual capital charge	4.9	Capital charges	5.5
			Working capital	0.6
			Total per tonne of liquid steel	70.2

*based on blend: 10% home coal @ $31.1/tonne, 90% imported @$28.9/tonne

TABLE A 3.5

MODEL WORKS - 2

Location	Brazil (mine site)		
Potential capacity :	3.00 million tonnes of liquid steel		
Process route :	Blast furnace, BOF, billet casting, rod and bar production.		
Utilization :	90%	Capital recovery factor :	16.0%

	Capital Costs	US \$ x 10^6	Unit Costs	US \$
IRONMAKING	Sinter plant	23.7	Iron ore fines (@\$4.0/tonne)	6.2
	Coke ovens	38.2	Coal (@\$29.1/tonne*)	22.7
	Blast furnace	73.6	Oil	1.7
	G.W.S. Allocation	48.8	Conversion costs	7.6
			G.W.S. operating costs	2.8
	Total	184.3		
			Sub-total	41.0
			Capital charges	13.9
	Annual capital charge	29.5	Working capital	1.4
			Credits	- 4.3
			Total per tonne of hot metal	52.0
STEEL-MAKING	Steel plant	45.2	Hot metal (@ \$ 52.0/tonne	45.8
	G.W.S. Allocation	16.3	Scrap (@ \$30.0/tonne)	6.6
			Conversion costs	6.1
	Total	61.5	G.W.S. operating costs	1.5
			Sub-total	60.0
	Annual capital charge	9.8	Capital charges	3.8
			Working capital	0.6
			Total per tonne of liquid steel	64.3
CONTINU-OUS CASTING	Casting plant	66.0	Liquid steel (@ \$64.3/tonne)	66.9
	G.W.S. Allocation	23.6	Conversion costs	4.2
			G.W.S. operating costs	1.2
	Total	89.6		
			Sub-total	72.3
	Annual capital charge	14.3	Capital charges	5.8
			Working capital	0.2
			Credits	-1.4
			Total per tonne of billets	76.9
ROLLING	Mill	20.3	Billets (@ \$76.9/tonne)	80.9
	G.W.S. Allocation	7.3	Conversion costs	6.6
			G.W.S. operating costs	2.0
	Total	27.6		
			Sub-total	89.5
	Annual capital charge	4.4	Capital charges	8.8
			Working capital	0.4
			Credits	-0.9
			Total per tonne of rod and bar	97.8

* based on blend: 10% home coal @ \$ 31.1/tonne, 90% imported @ \$28.9/tonne

TABLE A 3.6

MODEL WORKS - 3a

Location :	Brazil (mine site)
Potential capacity :	5.0 million tonnes of liquid steel
Process route :	Blast furnace, BOF, bloom casting, billet rolling
Utilization :	90% Capital recovery factor : 16.0%

	Capital Costs	US $ x 10^6	Unit Costs	US $
IRONMAKING	Sinter plant	35.2	Iron ore fines(@ $4.0/tonne)	6.2
	Coke ovens	61.7	Coal (@$29.1/tonne*)	22.7
	Blast furnace	113.6	Oil	1.7
	G.W.S. Allocation	75.8	Conversion costs	7.4
			G.W.S. operating costs	2.7
	Total	286.3	Sub-total	40.7
	Annual capital charge	45.8	Capital charges	12.3
			Working capital	1.3
			Credits	-4.3
			Total per tonne of hot metal	50.0
STEEL-MAKING	Steel plant	64.2	Hot metal (@ $ 50.0/tonne)	44.0
	G.W.S. Allocation	23.1	Scrap (@ $ 30.0/tonne)	6.6
			Conversion costs	5.9
			G.W.S. operating costs	1.4
	Total	87.3	Sub-total	57.9
	Annual capital charge	14.0	Capital charges	3.1
			Working capital	0.5
			Total per tonne of liquid steel	61.5
CONTINUOUS CASTING	Casting plant	77.1	Liquid steel (@ $ 61.5 /tonne)	64.5
	G.W.S. Allocation	27.8	Conversion costs	4.1
			G.W.S. operating costs	1.2
	Total	104.9	Sub-total	69.8
	Annual capital charge	16.8	Capital charges	3.9
			Working capital	0.2
			Credits	-1.4
			Total per tonne of blooms	72.5
ROLLING	Mill (2.8 m.t.p.a.)	39.8	Blooms (@ $ 72.5/tonne)	76.1
	G.W.S. Allocation	14.2	Conversion costs	3.0
			G.W.S. operating costs	0.9
	Total	53.7	Sub-total	80.0
	Annual capital charge	8.6	Capital charges	3.4
			Working capital	0.1
			Credits	-1.6
			Total per tonne of billets	81.9

* based on blend: 10% home coal @ $31.1 tonne, 90% imported @$28.9/tonne

TABLE A 3.7

MODEL WORKS - 3b

Location:	Brazil (mine site)
Potential capacity:	5.0 million tonnes of liquid steel
Process route:	Blast furnace, BOF, slab casting, hot rolled coil.
Utilization:	90% Capital recovery factor: 16.0%

	Capital Costs	US $ x 10^6	Unit Costs	US $
IRONMAKING	Sinter plant	35.2	Iron ore fines (@$4.0/tonne)	6.2
	Coke ovens	61.7	Coal (@$29.1/tonne*)	22.7
	Blast furnace	113.6	Oil	1.7
	G.W.S. Allocation	75.8	Conversion costs	7.4
			G.W.S. operating costs	2.7
	Total	286.3	Sub-total	40.7
			Capital charges	12.3
	Annual capital charge	45.8	Working capital	1.3
			Credits	-4.3
			Total per tonne of hot metal	50.0
STEEL-MAKING	Steel plant	64.2	Hot metal (@ $ 50.0/tonne)	44.0
	G.W.S. Allocation	23.1	Scrap (@ $ 30.0/tonne)	6.6
			Conversion costs	5.9
	Total	87.3	G.W.S. operating costs	1.4
			Sub-total	57.9
	Annual capital charge	14.0	Capital charges	3.1
			Working capital	0.5
			Total per tonne of liquid steel	61.5
CONTIN-UOUS CASTING	Casting plant	96.4	Liquid steel (@$ 61.5 tonne)	64.5
	G.W.S. Allocation	34.7	Conversion costs	4.1
			G.W.S. operating costs	1.2
	Total	131.1	Sub-total	69.8
	Annual capital charge	21.0	Capital charges	4.9
			Working capital	0.2
			Credits	-1.4
			Total per tonne of slabs	73.5
ROLLING	Mill	160.2	Slabs (@$ 73.5 tonne)	76.5
	G.W.S. Allocation	57.7	Conversion costs	4.8
			G.W.S. operating costs	1.4
	Total	217.9	Sub-total	82.7
	Annual capital charge	34.9	Capital charges	11.6
			Working capital	0.4
			Credits	-0.9
			Total per tonne of hot rolled coil	93.8

*based on blend: 10% home coal @ $31.1/tonne, 90% imported @ $28.9/tonne

TABLE A 3.8

MODEL WORKS - 4

Location:	International coastal site
Potential capacity:	5.0 million tonnes of liquid steel
Process route:	Blast furnace, BOF, Slab casting, hot rolled coil production
Utilization:	90% Capital recovery factor: 19.2%

	Capital Costs	US \$ x 10^6	Unit Costs	US \$
IRONMAKING	Sinter plant	19.9	Iron ore (@\$14.5/tonne*)	22.7
	Coke ovens	50.1	Coal (@\$18.0/tonne)	12.9
	Blast furnace	101.9	Oil	1.6
	G.W.S. Allocation	61.9	Conversion costs	6.4
			G.W.S. operating , costs	2.3
	Total	233.8	Sub-total	45.9
			Capital charges	12.5
	Annual capital charge	44.9	Working capital	2.2
			Credits	-4.3
			Total per tonne of hot metal	56.3
STEEL-MAKING	Steel plant	58.0	Hot metal (@ \$ 56.3 /tonne)	44.0
	G.W.S. Allocation	20.9	Scrap (@ \$ 29.0 tonne)	8.8
			Conversion costs	5.9
	Total	78.9	G.W.S. operating costs	1.5
			Sub-total	60.2
	Annual capital charge	15.1	Capital charges	3.4
			Working capital	0.8
			Total per tonne of liquid steel	64.4
CONTIN-UOUS CASTING	Casting plant	86.3	Liquid steel (@ \$ 64.4/tonne)	67.8
	G.W.S. Allocation	31.1	Conversion costs	4.4
			G.W.S. operating costs	1.3
	Total	117.4	Sub-total	73.5
	Annual capital charge	22.5	Capital charges	5.2
			Working capital	0.4
			Credits	-1.4
			Total per tonne of slabs	77.7
ROLLING	Mill	142.2	Slabs (@ \$ 77.7/tonne)	80.9
	G.W.S. Allocation	51.2	Conversion costs	4.9
			G.W.S. operating costs	1.5
	Total	193.4	Sub-total	87.3
	Annual capital charge	37.1	Capital charges	12.4
			Working capital	0.5
			Credits	-0.9
			Total per tonne of hot rolled coil	99.3

*based on R.O.M. (40% lump 60% fines)

TABLE A 3.9

MODEL WORKS - 5

Location:	Brazil (coastal site with natural gas)	
Potential capacity:	0.5 million tonnes of liquid steel	
Process route:	Direct reduction (HyL), electric arc.	
Utilization:	90%	Capital recovery factor: 16.0%

	Capital Costs	US $ x 10^6	Unit Costs	US $
IRONMAKING	HyL plant	18.8	Iron ore pellets (@$17.0/tonne)	23.1
	G.W.S. Allocation	6.7	Natural gas (@¢ 2.6/therm)	6.0
			Conversion costs	2.6
			G.W.S. operating costs	0.7
	Total	25.5		
			Sub total	32.4
			Capital charges	10.0
	Annual capital charge	4.1	Working capital	1.1
			Total per tonne of sponge iron	43.5
STEEL-MAKING	Steel plant	12.7	Sponge iron (@ $43.5/tonne	40.0
	G.W.S. allocation	4.6	Scrap (@ $30.0/tonne)	6.9
			Electrical power (@¢ 1.1/kwh)	8.3
	Total	17.3	Conversion costs	11.4
			G.W.S. operating costs	2.2
			Sub total	68.8
	Annual capital charge	2.8	Capital charges	6.3
			Working capital	0.9
			Total per tonne of liquid steel	76.0

Location: **Brazil (mine site with naphtha available)**

	Capital Costs	US $ x 10^6	Unit Costs	US $
IRONMAKING	HyL plant	19.6	Iron ore pellets (@$12.0/tonne)	16.3
	G.W.S. Allocation	7.1	Naphtha (@¢ 6.4/therm)	14.7
			Conversion costs	2.8
			G.W.S. Operating costs	0.8
	Total	26.7		
			Sub total	34.6
	Annual capital charge	4.3	Capital charges	10.4
			Working capital	1.1
			Total per tonne of sponge iron	46.1
STEEL MAKING	Steel plant	costs as above	Sponge iron (@$ 46.1/tonne	42.4
			Other costs as above	36.0
			Total per tonne of liquid steel	78.4

TABLE A 3.10

MODEL WORKS - 6

Location: Brazil (coastal site)
Potential capacity: 0,5 million tonnes of liquid steel
Process route: Direct reduction (SL/RN), electric arc
Utilization 90% Capital recovery factor: 16,0%

IRONMAKING	Capital Costs	US $ x 10^6	Unit Costs	US $
	SL/RN plant	16,1	Iron ore pellets (@ $17/tonne)	24,0
	G.W.S. Allocation	5,8	Coal @ $15,0/tonne)	11,3
			Conversion costs	4,5
			G.W.S. operating costs	1,3
	Total	21,9		
			Sub total	41,1
			Capital charges	8,0
	Annual capital charge	3,5	Working capital	1,3
			Total per tonne of sponge iron	50,4
STEEL-MAKING	Steel plant	12,7	Sponge iron (@ $50,4/tonne)	45,4
	G.W.S. Allocation	4,6	Scrap (@ $30,0/tonne)	6,9
			Electrical power (@ ¢ 1,1/Kwh)	8,3
			Conversion costs	11,4
			G.W.S. operating costs	2,2
		17,3		
			Sub total	74,2
	Annual capital charge	2,8	Capital charges	6,3
			Working capital	0,9
			Total per tonne of liquid steel	81,4

TABLE A 3.11

MODEL WORKS - 7

Location: Brazil (at scrap source)
Potential capacity: 0,5 million tonnes of liquid steel
Process route: Scrap-based electric arc
Utilization: 90% Capital recovery factor: 16,0%

STEEL-MAKING	Steel Plant	14,2	Pig iron (@ $50,0/tonne)	2,7
			Scrap (@ $30,0/tonne)	30,3
	G.W.S. Allocation	5,1	Electrical power (@ ¢ 1,1/Kwh)	6,8
			Conversion costs	10,2
	Total	19,3	G.W.S.	2,1
			Sub-total	52,1
	Annual capital charge	3,1	Capital charges	6,9
			Working capital	1,5
				60,5

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