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THE TRANSFER OF EXTRACTIVE METALLURGICAL TECHNOLOGY TO DEVELOPING COUNTRIES [1]

by

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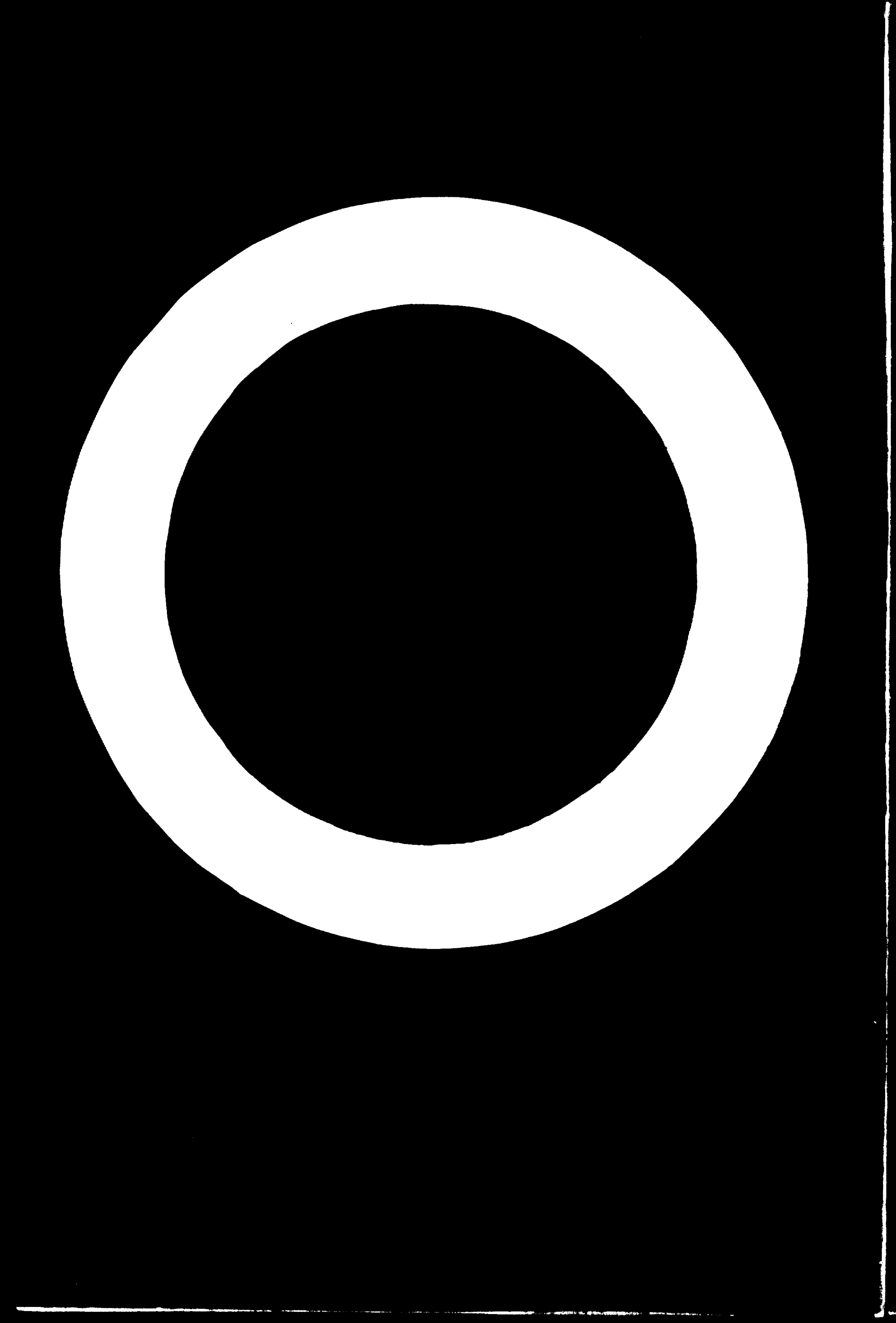


SUMMARY

A. INTRODUCTION

B. TECHNOLOGICAL REQUIREMENTS OF DEVELOPING ECONOMIES

The technology of production

- should not be capital intensive;
- should perhaps substitute available cheap labor for capital;
- level of sophistication required should match the level of education;
- should be economical at a small scale when production matches local demand;
- should not have excessive demands for infrastructure development;
- should avoid compounding the problem of excessive urbanization;
- should be "appropriate" - optimize available resources of capital labor and raw materials.

C. CHARACTERISITCS OF THE METALLURGICAL INDUSTRY

The extractive metallurgical industry is characterised by

- metal consumption is mainly in developed countries;
- already capital intensive;
- process developments in the West have been aimed at reduction in labor input;
- quality requirements are such that usually labor cannot be substituted for capital;
- quality requirements becoming more stringent;
- the structure of ore marketing and metal marketing in the U.S. and Canada is such that the profits are made in mining and fabrication and not in primary metal production.

- extractive metallurgical procedures for the principal metals are based on electrometallurgy and pyrometallurgy, as a result, only large scale operations are profitable;
- the primary metal industry is a high consumer of energy and availability of cheap energy in one form or another can have a major impact on the economics;
- transportation economics important for low cost metals;
- the smallest size of an economic primary metal production unit based on current technology can still be so large as to saturate the internal market and rely on the export market for most of the production;
- secondary metal is an important factor in the market.

D. METALLURGICAL INDUSTRY FOR DEVELOPING COUNTRIES

- two models exist:
  a) Technology Transfer - Adaptation of new western technology with minimal modifications.
  b) Intermediate Technology - Adaptation of old (50-100 years) western technology.
- both are essential but can provide partial solutions because
  a) Technology is not "appropri ·a";
  b) Inappropriate technology tied to financing sources is available
- have to consider tradeoffs of capital vs labor intensity consistent with production of quality product.
- other possible solutions for the future
  New processes already developed or under development which have potential for developing economies because they can operate on a small scale

- Ferrous: low shaft blast furnace for supplying local foundries; mini steel plants.
- Hydrometallurgy: not as size sensitive as pyrometallurgy, e.g., copper, lead, zinc.
- Copper: Momoda blast furnace, Outokumpu flash smelting.

- Development of regional markets and regional research centers for applied (adaptive) research.

E. CONCLUSIONS

For a primary metal industry in a developing country

- desirable to have a good match between production rate and domestic market. Example, Pb-Zn-superphosphate and mini-steel mill in Nigeria. Based on a study of metal import statistics in various countries, the following are possible candidates for local primary metal industry. (Table)
- met.process development is expensive and development of appropriate technology on a local level, though a desirable and idealistic aim perhaps cannot and should not be pursued. A more fruitful approach might be adapting technology developed elsewhere to suit national needs.
- because the old or new technology might not be the most appropriate in all cases, a certain degree of technical sophistication on a local level is desirable so that available technology can be evaluated on the basis of local needs.
- Example - ADL experience in setting up of a regional research center in Brazil.

A. INTRODUCTION

1. Over the past decade, the basic strategy for rapid development of the less developed countries has been based largely on maximum stimulation of economic growth through emphasis on large-scale industries using modern technologies from the West. Behind this emphasis has been the belief that such industry based on modern technology has a very high productivity and can therefore generate a high rate of savings--the prerequisite to "take-off" in economic growth. In the present decade, there appears to be growing uncertainty over the optimism of earlier development strategies. The earlier strategies of crash modernization in general appear to have failed to produce the desired economic growth and are seen as contributing directly to an inability to create full employment, to rapid rural migration and hence to explosive expansion of the urban areas. It can be argued, however, that economic growth has occurred but has been negated by population growth. These larger problems of overall economic strategy mentioned above are relevent to the extractive metallurgical industry because this industry has played a significant part in the crash modernization of the economy of developing countries.

2. The extractive metallurgical industry is a logical candidate for a crash modernization strategy. It is capital intensive, with a good potential for a high payout. Metals are essentially a high valued commodity traded in the world markets. In general, the products of a mining or metallurgical industry based on resources in a developing country can be transported a considerable distance to the markets and the country benefits from this source of foreign exchange. Many of the developing countries have already proven deposits of metals and are currently engaged in some phase of the mining and extraction business. Forward integration into the extraction of primary metals therefore appears to be a way of increasing the possible economic benefits that can be accrued from additional exploitation of an

internal resource. The availability of primary metal in a developing country may be expected to further economic growth through generating satellite industries based on the primary metal.

3. This paper is an attempt to look at the issues involved in transferring extractive metallurgical technology to the developing countries. Our examination will first consider the requirements for technology in developing economies and compare them with the characteristics of the metallurgical industry to see whether the industry as it exists today is responsive to these requirements. We will then review the appropriateness of the available technology to the needs of the developing countries. We will identify the trends in technological development in the West and the prognosis for the future. Finally, we will present a few case histories.

B. THE CONCEPT OF APPROPRIATE TECHNOLOGY

4. In the developed countries, technological progress in extractive metallurgy has been the result of several interacting factors. The industry has operated in a climate of increasing labor rates, growing market demand and more stringent specifications for the quality of the products. As a result, the industry has developed larger and more efficient units to meet the market demand and reduce the labor required per ton of product while increasing the sophistication necessary to operate the process. As examples: one sees the blast furnace increasing in size from 20 feet to 30 feet and now about 40 feet in diameter; width of copper reverberatory furnaces increasing from 20 feet to 40 feet; open hearth capacity from 50-ton/unit to 500-ton/unit; and basic oxygen steelmaking furnaces from 15 tons to several hundred tons. The average sized production units today would have been considered unusually large a generation or two ago.

5. The phrase "western technology" as used in this paper represents the type of technology that has developed from such considerations as discussed above and accordingly is highly capital intensive and distinctly labor saving. The trade-off between labor and capital in western technology is based on conscious attempts to maximize the returns on invested capital. Thus, western technology may often be inappropriate for the conditions of scarce capital and abundant labor and small internal markets found in the developing countries today.

6. We have used the general term "appropriate technology" to describe technology that is relevant to a particular economic environment in a developing country. In general, the appropriate technology in developing countries would be less capital intensive, would allow substitution of readily available labor for capital where this is practical, be operable at a small scale when the production can match the local demand, would require a level of technical sophistication that matches the local level of education, and would be relatively self-sufficient and not put excessive demands for new infrastructure development. In short, "appropriate technology" is one that optimizes the available resources of capital labor and raw materials in a particular economic climate. By optimize, we do not necessarily mean a cash flow return on investment, although this can be an important element if foreign capital is involved.

C. CHARACTERISTICS OF THE EXTRACTIVE METALLURGICAL INDUSTRY

7. For the purpose of this discussion, we have defined extractive metallurgical industry as being that segment of the industry which is involved with the mining and processing of ores up through the production of primary metals but excluding the fabrication and mechanical working aspects. In this paper we will emphasize the processing and metal production aspects rather than the geological, exploration and mining aspects of the industry. The western extractive metallurgical industry is characterized by the following:

(1) Capital Intensity

8. The capital intensity of the industry, as noted above, basically results from technological improvement over the past century in response to increasingly larger markets, increasing labor rates and more stringent product quality specifications. Furthermore, while demand for the metals has increased, the available ore deposits have become lower in grade. More efficient procedures have become vital to reduce the cost of performing the operations which were formerly accomplished by manual labor. These procedures have involved the development of large-scale mining equipment and mining techniques, the introduction of revolutionary new materials handling systems, the development of equipment for large-scale crushing and grinding of the ores, the development of more efficient concentration

methods (such as flotation) and the use of increasingly complex and sophisticated pyrometallurgical and electrometallurgical processes for the production of marketable primary metals.

9. Pyrometallurgy has been the workhorse of the industry and the major industrial metals, with the exception of aluminum, are extracted by pyrometallurgical procedures which traditionally have required significant expenditures of energy for metal recovery. In pyrometallurgy, heat losses from small-capacity units can be prohibitively high especially when the cost of energy is high; hence, the economies in energy consumption obtainable in large-scale operations are important. Thus, the trend towards bigness in the extractive metallurgical industry is one consequence of the available pyrometallurgical technology of the past century.

(2) Labor

10. Technological trends mentioned above are one reason for the capital intensity of western technology. Some additional capital intensity has been added in an attempt to substitute easily available capital for the scarce and relatively high cost labor. Thus the output of metal per unit input of labor has increased steadily over the years. On the other hand, quality labor has not been displaced entirely. In a sense, the adaptation of more complex technology in the metallurgical industry has been cybernetic. It has freed qualified labor from the drudgery and hazards involved in producing metals and has created a demand for highly qualified personnel. Sensing and control devices have not yet been perfected to the stage where they can effectively substitute for the experienced operator. Some examples where experienced labor is required are: the control of a grinding mill by listening to its sound; the control of flotation and other concentration devices by sight and feel; the control of pyrometallurgical operations by visual examination of chilled samples; and the control of such rapid operations such as converting in the ferrous and non-ferrous areas by observation. The necessity for qualified and experienced labor makes extractive metallurgy an art to a large extent, but we should realize that the art is a new one based on man-machine interaction and that the older art that existed before the creation of the machine is essentially lost in western technology.

(3) Raw Materials, Energy, Transportation and Markets

11. The cost of metal production is sensitive to the cost of available raw materials and even more so to the cost of energy: fuel oil, gas, coal and electricity. This is because large amounts of energy are required for metal production by pyrometallurgical and electrometallurgical technology.

12. The markets of primary metals exist mainly in the developed countries and transportation costs from mine to market play a major part in determining the profitability of extractive metallurgical operations, especially for the lower cost metals. Even so, the cost structure for each extractive metallurgical operation can be so variable that, in general, metals should be considered as world commodities; the cost of transportation of the finished product to the market being only one component of the overall cost.

(4) Taxation

13. The structure of the ore marketing and metal marketing in the United States, Canada and in other countries that allow a depletion allowance is such that the profits are made in mining or in fabrication but not in primary metal production. This is because the depletion allowance is a percentage of the value of the first marketable product; for instance, iron ore or pellets in the iron and steel industry and a flotation concentrate in the base metal industry. In vertically integrated companies as found in North America, the depletion allowance can be maximised (and taxes minimized) by maximising the value of these products; hence, the conversion of these products to primary metal becomes a low profit or zero profit operation for integrated producers.

(5) Secondary Metals

14. The recycling of secondary metals in both the ferrous and the non-ferrous industries can supply a considerable portion of the market demand for that particular metal. In several areas, western technology relies on the availability of scrap metal as a part of the feed. In a newly industrialized country, the scrap is not available in the quantities or at the price required by certain processes. For instance, a small, non-integrated steel mill in a developing country based on electric furnace melting of steel scrap might not be economical because of the high cost of imported scrap and might have to be based on prereduced iron pellets.

D. APPROPRIATE EXTRACTIVE METALLURGICAL TECHNOLOGY

15. The previous discussion indicates that the extractive metallurgical technology which is available today is not usually appropriate to the needs of developing economies. Even if modified (and thus more appropriate) technology were available, there can be several non-technological factors that influence the type of metallurgical technology that is transferred to a developing country. For example, inappropriate technology is transferred solely because it is tied to financing sources. In a similar vein, planners from Western or Western trained nations are more familiar with western technology and tend to develop plans preferring these techniques. The practice of international bidding on contracts and the requirement that projects meet international standards also tends to force projects toward the latest capital intensive technology.

16. In many developing countries of the world, the prices for available commodities do not represent their relative scarcities so that the price picture is distorted. This can include high labor rates in a country with abundant unemployed labor and an economic climate that favors capital intensive rather than labor intensive endeavors such as unusually low interest rates, easy availability of foreign exchange, accelerated depreciation and tax holidays. As a result of these factors, the most "appropriate" technology can indeed be the capital intensive technology of the West.

17. In recent years there has been much reference to the terms, "technology transfer" and "intermediate technology." A rigorous definition of either term does not exist but it is generally assumed that "technology transfer" refers to the adaptation of western technology with minimal modifications, whereas "intermediate technology" refers to a conscious attempt to revive and utilize western technology of the mid-nineteenth century and early twentieth century when the per capita income was roughly the same as the average for the developing countries today. "Intermediate technology" can also cover more modern technologies which are less capital intensive and use relatively large amounts of labor.

18. In the extractive metallurgical area, the "intermediate technology" label can cause confusion because of its chronological connotation. For

example, much of the recent technology in extractive metallurgy has been developed outside the U. S., e.g., basic oxygen steelmaking, Imperial Smelting process, continuous casting, the flash smelting process and the Worcra process. However, the older U. S. technology is more capital intensive and is "intermediate" only from the chronological standpoint. This also shows that the term "western technology" although in popular use can no longer be used to indicate the geographical distribution of developed technology.

19. In the remainder of this section we will examine the appropriateness of available extractive metallurgical techniques for developing countries involving the major metals, namely, iron and steel on the ferrous side and copper, lead and zinc on the non-ferrous side. We have excluded the technology of aluminum extraction because it has remained unchanged ever since aluminum became a commercial metal. Alternate technologies in this industry although visible are not espcially pertinent to the needs of developing countries who, in general, have extensive reserves of bauxite.

20. Our approach will be to classify the available technology into three groups:

21. • technology in which it is still possible to substitute labor for capital and produce a marketable metal;

22. • advanced technology which has been developed recently or is under development which makes it economical to produce a primary metal on a small scale in keeping with the local demand; and

23. • advanced large-scale capital intensive technology which can be appropriate for developing countries under special circumstances.

24. We would like to emphasize that this classification is artificial and special situations exist which can reveal new strategies for the development of an appropriate metallurgical industry. Some such special situations will be discussed later.

(1) <u>Industries where Labor can be Substituted for Capital</u>

25. Our examination of the extractive metallurgical technology indicates that there are still a few areas where an acceptable quality product can be

made by substituting large amounts of labor for capital in a small scale operation. Almost invariably, high grade ore or concentrate free from impurities is required. A prominent example of such a process is ore hearth smelting of high grade lead ores. Other examples are the foundry industry, fire refining, and electrorefining of copper and purification (softening), desilverization and dezincing of lead. In certain areas of the world, (e.g., Brazil) a metallurgical raw material (charcoal) can be produced at prices competitive with coke by using unskilled labor. As a case study, we discuss in Appendix A a metallurgical complex for producing lead by ore hearth smelting in Nigeria. Our preliminary examination of the subject indicates that the metallic lead produced could be utilized in Nigeria and could form a nucleus for several satellite industries.

(2) Advanced Technology which can Operate Economically on a Small Scale

26. There have been several developments in the process metallurgy field which make it possible to operate a metallurgical complex on a small scale. The output of such a small plant would be appropriate for the limited local demand. In the ferrous metallurgy area these are: low shaft blast furnaces for supplying local foundries, and mini-steel plants based on melting of scrap or prereduced iron ore in electric furnaces. The steel produced can be continuously cast and rolled to such standard shapes as reinforcing bars for the local construction industry. In Appendix B we describe briefly the factors that are responsible for the increasing popularity of mini-steel plants. In the non-ferrous area, the new developments involve the modification of shaft furnaces in order to accept finely powdered feed (Momoda furnace) or using shaft furnaces in general for economical small-scale operation, application of the flash smelting principle to sulfide concentrates of copper and lead (Outokumpu and others), and direct smelting of sulfides of copper or lead in a converter (ADL process and others). A third area is hydrometallurgy. Several hydrometallurgical processes are in various stages of development for treating sulfide concentrates produced from the ores of non-ferrous metals. These processes would make it possible to operate economically on a small scale producing a high purity product at the same time. At present there are about 15 such processes under various stages of development.

27. Because local conditions can vary widely from country to country, the newer techniques discussed above are not necessarily the most appropriate in all cases. A certain degree of technical sophistication is desirable on the local level so that the available technology can be evaluated on the basis of local needs. The best way of achieving this is by the formation of local centers for industrial development and for applied and adaptive research. Efforts at these centers can be aimed at finding appropriate solutions for local problems. For about two years, ADL has been working in the state of Minas Gerais in Brazil with the Industrial Development Institute (INDI), and organization designed to accelerate the industrial growth of the state. Details have been presented in Appendix C.

(3) Advanced Large-Scale Capital Intensive Technology

28. In numerous portions of the world the demand for a particular metal is not sufficiently large to justify the construction of even a small metallurgical plant in a particular country for domestic markets. The construction and operation of a reasonably sized metallurgical complex can be justified, however, if approached on a regional and multi-national basis. However, there can be several problems in a multi-national project. Some of these are discussed in the context of a West African steel complex based on conventional technology in Appendix D.

29. In certain instances, conventional metallurgical technology can be located in a developing country in order to benefit from a local resource such as low cost energy. The concept of refining blister copper "in transit" is well known in the copper industry. Blister copper is producad by smelters located near the mines and is shipped towards the markets. An electrolytic refinery can be located in a region between the mine and the market which favors low operating costs. The blister copper is thus refined "in transit" to cathode or wirebar, the primary marketable product. Similarly, direct reduction facilities could be located along the major iron ore routes in the world in areas where the fuel costs are low. The additional benefit of iron ore or pellet reduction "in transit" would be a substantial decrease in shipping weight. For example, Australian iron

ore pellets could be metallized "in transit" in Indonesia en route to Japan. The impact of low fuel costs on economics of direct reduction is discussed in Appendix E.

30. The above discussion indicates that there exist three types of technology that can be appropriate under special circumstances. The developing countries in turn can provide incentives for the generation of a more appropriate technology by providing a price and taxation structure that favors labor intensive endeavors. For example, a double or multiple deduction for labor costs, depletion allowances that are proportional to the labor component of the operating costs and others.

APPENDIX A

LEAD SMELTER FOR NIGERIA

1. ADL's work on behalf of the Government of Nigeria throughout the period of the 1960's lead to familiarity with the metallurgical needs and resources of the country. For this reason, we have chosen the example presented below. There are probably several other countries in the world where a similar metallurgical complex would be justified.

2. Deposits of galena and sphalerite (lead and zinc sulfides) are known to exist in Nigeria. They begin near Ishiagu in the East Central State and sweep north to northwest across the Benue River almost to the Jos Plateau. Increasing quantities of silver are known to occur towards the northern limits of the deposits. The deposits are known to have been worked by the Portuguese at a site near Abakaliki in the East Central State as long as 300 years ago. Imports of lead and lead alloys to Nigeria have exceeded 1000 tons per year since about 1962, although lower amounts were imported during the war. Much of the lead use in Nigeria is reportedly for high grade solder (97% Pb and 3% Sn), while the remainder is spread among a multitude of smaller users. There also exists a local lead battery rebuilding industry based on used casings.

3. An operation to produce 1000 to 1500 tons of lead per year would be extremely small by the usual standards employed in the more industrialized nations. On the other hand, it may be possible to justify such an operation if it is based on the ore hearth method of lead smelting. This method has several advantages in this particular instance.

4. • The unit can be started up or shut down on short notice without severe losses of heat or fuel.

5. • The unit size can be small and can be increased in convenient multiples if market volume dictates.

6. • The ore hearth process can produce a soft (pure) lead product directly in a single step.

The process, however, is not suited to all ores and concentrates. The best ores for this method are high grade galena materials that are not too finely divided. The lead content should be in excess of 70% with a silica content of 2% or less. Table A-1 shows the effect lead content in concentrate on lead recovery in ore hearth smelting. Iron and zinc sulfides should not exceed 4% since they combine with galena to give refractory compounds. Silver and gold if present can be recovered subsequently by the Parkes process which is also labor intensive and easily adaptable.

7. The ore hearth consists of a shallow cast iron trough that is hand raked and rabbled. The Newman furnace, a more recent modification, is mechanically rabbled. The charge consists of a mixture of galena, sintered recycle flue dust and coke breeze or charcoal which are spread in a relatively thin layer on the top of the molten lead bath. Lead sulfide is converted to lead and sulfur dioxide. The molten lead is collected in the bath and a gray slag containing silica and lead is raked off. In a small operation the slag would be stockpiled until a more sophisticated processing technique such as blast furnace smelting could be justified by a larger market.

8. For high quality lead raw materials the fuel used is relatively small. While some solid carbonaceous fuel such as charcoal must be added to the charge, natural gas can be substituted if desired to provide the major part of the heat requirement. Very preliminary calculations are presented in Tables A-2 and A-3. Because of the preliminary nature of these calculations, the high rate of return shown in Table A-3 should be interpreted as indicating that a venture of this type would be profitable.

TABLE A-1

EFFECT OF LEAD CONTENT OF FURNACE FEED

	60% Pb Concentrate	72% Pb Concentrate	82% Pb Concentrate
Capacities (tons)			
Ore Treated per 24-hour Day	16	20	28
Pig Lead Produced per 24-hour Day	4.5	9.5	21
Slag Produced per 24-hour Day	4	5	2.5
Fuel Used per 24-hour Day	4	2	1
Recoveries (%)			
As Pig Lead	46.9	66.0	91.5
As Lead in Slag	20.5	15.0	4.2
As Lead in Fume and Dust*	32.0	17.4	4.0

*Ultimately recycled to the feed.

TABLE A-2

PRELIMINARY ESTIMATE OF OPERATING COST OF THE LEAD SMELTER

Process: Ore Hearth Production of Lead from 82% Concentrate
Production: 1,500 Long Tons of Lead per Year
Operation: 250 Days per Year
Investment: $100,000
Recovery: 90% as Pig Lead
Concentrates: Assumed to Cost $80 per Ton after Mining and Milling

Item	Units	$/Unit	Units/Day	$/Day
Raw Materials				
Concentrates	Long Tons	80	8.1	648.00
Charcoal	Million Btu	0.50	0.9	0.45
Limestone	Long Tons	5.00	0.1	0.50
Utilities				
Natural Gas	Million Btu	0.25	9.1	2.27
Power	kwh	.010	1,200	12.00
Direct Labor				
Foreman	Man-day	4.20	4	16.80
Operators	Man-day	2.38	6	14.28
Helpers	Man-day	0.98	12	11.76
Overhead @ 100% Direct Labor				42.84
Maintenance Labor				
Foreman	Man-day	4.20	1	4.20
Mechanics	Man-day	2.38	4	9.52
Helpers	Man-day	0.98	4	3.92
Maintenance Supplies @ 4% Capital Investment				16.00
TOTAL DIRECT COST				782.54

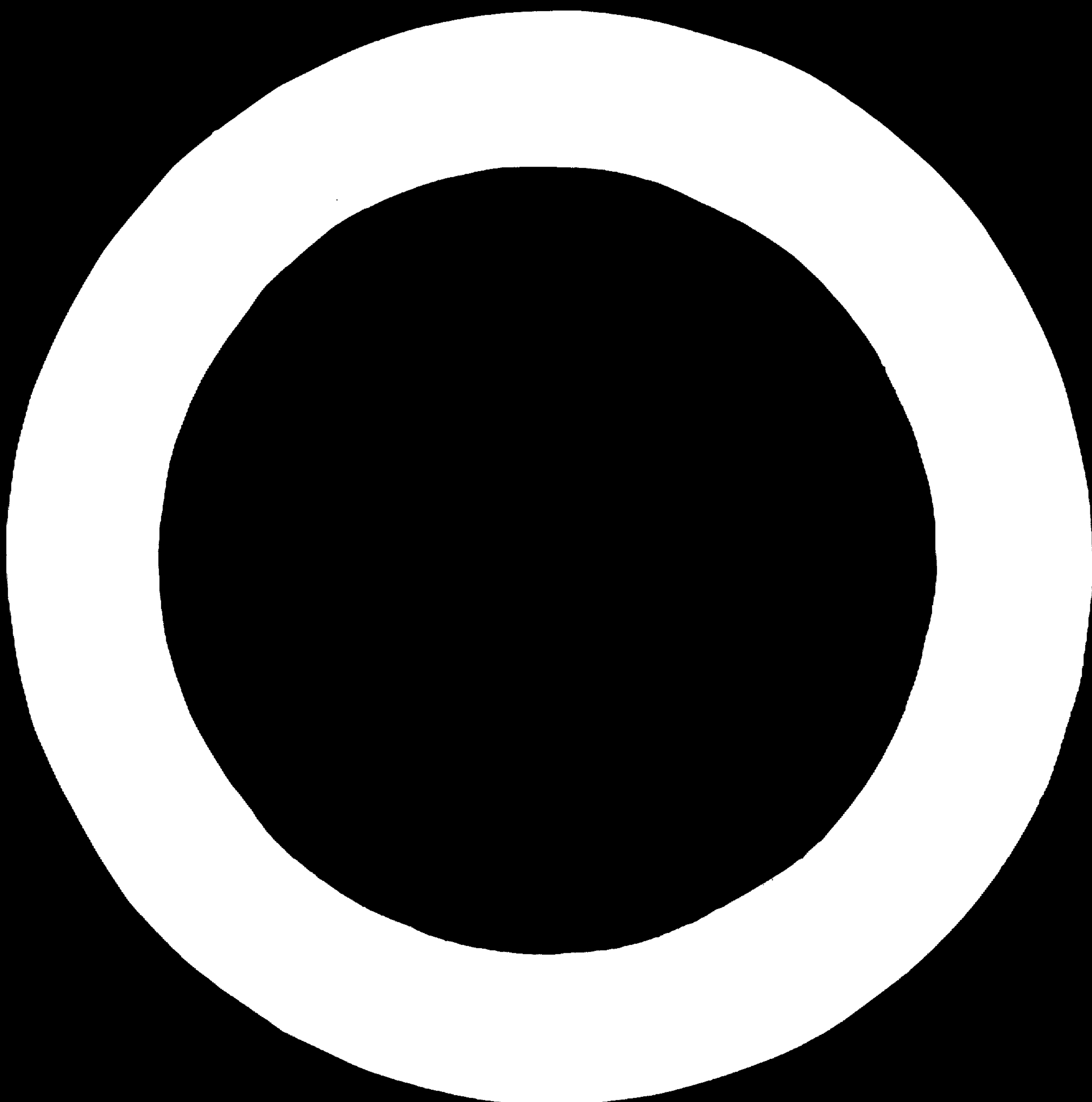
TABLE A-3

PROFITABILITY ESTIMATE

I. Capital Investment - $100,000

II. Working Capital - $10,000

		$/Ton Pb
III.	Sales Income: Pb @ 10¢/lb.	224.00
IV.	Direct Cost	30.42
	Depreciation @ 20% of Capital Investment	13.32
	Taxes and Insurance @ 2% of Capital Investment	1.33
	Sales Cost @ 8% of Sales	21.50
	Interest on Working Capital @ 10%	0.66
	Total Operating Cost	167.23
V.	Gross Profit	56.77
	Income Tax (assumed 50%)	28.38
	Net Profit	28.39
	Add Back Depreciation	13.32
	Cash Flow	41.71
	Return on Investment (Cash Flow/Capital Investment)	62%



APPENDIX B

MINI-STEEL PLANTS

1. Mini-steel plants are small steel plants that primarily serve the local markets. A mini-steel plant produces steel from scrap (non-integrated) or from a primary source of iron (integrated) utilizing mostly electric furnaces for steel making and usually incorporates casting and rolling facilities for the production of simple merchant products for the local market. In the U. S. there exist about 30 plants that are based on the mini-steel plant concept. Majority of these plants had initial capacities under 100,000 tons per year and output of each was mainly reinforcing bars for a nearby market. Mini-steel plants as conceived today are larger and would produce 200,000 to 300,000 tons/year of finished products. Traditional mini-plants in Europe are in Northern Italy and Sweden. Some of the more modern North American facilities utilizing direct reduction are Oregon Steel, Georgetown Steel and the three HyL plants in Mexico.

2. There are several reasons for the development of the mini-steel plants:

3. (1) Location Factors--The mini-steel plants started out in places that were far from the major steel producing centers and where transportation costs were high. In the U. S., the mini-plants serve as an adjunct to the regional service centers of the large steel mills. In general, they fill small orders at comparable prices and with shorter delivery times.

4. Where scrap was available, the mini-steel plants were set up to serve the local market so that although their operating costs were generally higher than those of the major producers, they could take advantage of lower freight, overhead and inventory costs and at times of locally available competitive energy and labor costs.

5. (2) Technological Factors--The major technological factors which have contributed to the growth of the modern mini-steel plants have been continuous casting, direct reduction of iron ores or pellets, and availability of more efficient electric furnaces.

6. (3) Process Economics--In addition to the location advantages that mini-steel plants can have, there have been other developments which make direct reduction-electric furnace steelmaking concept more attractive. The cost of coking coal is increasing and it is expensive to adapt pre-existing coking ovens in order to meet the recent air pollution requirements. In certain areas, low-cost power from large fossil fuel, nuclear, or hydroelectric power stations has become available.

7. (4) Application to Developing Economies--The mini-steel plant concept has numerous advantages to developing economies. In addition to the fact that the technology of mini-plant steelmaking has already been developed, such steel plants are economic in small units which are better suited to smaller markets in the less developed countries. In the developing countries, large quantities of scrap are generally not available, hence, a mini-steel plant would have to be based primarily on directly reduced iron units. Other possible sources of iron units can be pyrite or pyrrhotite cinders from sulfuric acid manufacturing operations or iron oxide produced from other mineral beneficiation operations such as copper ore processing, or the newer technology of upgrading ilmenite to synthetic rutile. A wide variety of energy sources is applicable to direct reduction. For example, steam coal or coke can be used in SL/RN process; reducing gases in the HyL, Armco, Midrex and FIOR processes and electric power in Wiberg and Tysland-Hole processes.

8. The demand for steel in many developing countries is related to the construction industry and the mini-steel plant is ideally suited to produce reinforcing and hot rolled bars. The plant capacity and product mix can be sized at the level appropriate to the market.

APPENDIX C

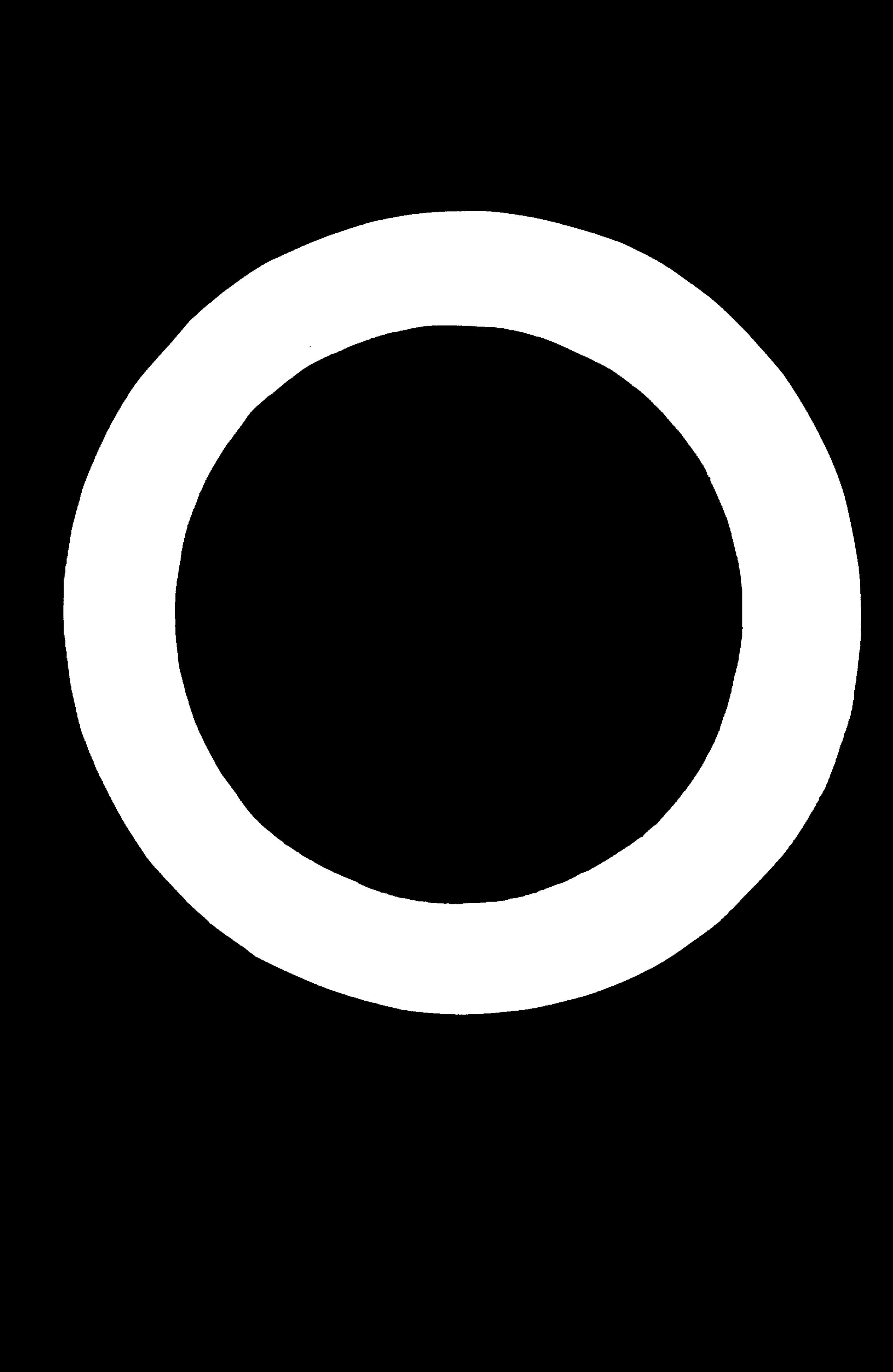
INDUSTRIAL DEVELOPMENT INSTITUTE (INDI), MINAS GERAIS STATE, BRAZIL

1. INDI was created in 1967 by the state electric company and the state development bank to broaden the state's industrial base by attracting private investment. In 1969, Arthur D. Little, Inc. (ADL), with assistance from Brazilian consulting firms began an Action Plan to help INDI in identifying a program for accelerating the industrial development in Minas Gerais.

2. The program of work has included a broad analysis of the resources and investment climate in the state; studies of the most promising industrial sectors to identify specific industrial opportunities; and detailed evaluation of the most promising opportunities.

3. In the beginning, all key personnel in INDI worked with an ADL counterpart and the ADL staff undertook the primary responsibility for pursuing the work and the training of the INDI staff member. Now, after two years, the roles of INDI staff and ADL counterparts are essentially reversed and ADL participation has decreased considerably. The ADL staff is being used increasingly for internal consulting and our formal relationships with INDI under the present assignment are expected to end next year.

4. As a part of this program, ADL has assisted INDI in planning the establishment of a Mineral Technology Center, a research center that will perform experimental work on evolving methods for the development of the state's resources and provide general consulting services to private industry. Recent projects at the center include slurry pipeline transport of iron ores, beneficiation of apatite and others.



APPENDIX D

REGIONAL MANUFACTURE OF IRON AND STEEL BY CONVENTIONAL METHODS-- THE WEST AFRICAN SITUATION

1. A proposal for a blast-furnace mill was put forth in Monrovia in October 1963 by the United Nations Economic Commission for Africa (ECA) as part of its policy of encouraging the establishment of regionally and subregionally oriented industries throughout Africa. The proposal suggested the construction of a conventional blast-furnace steelmaking facility with two blast furnaces on the seacoast to serve a West African coastal and inland market from Senegal to the Congo (Brazzaville) on the coast, and including Mali, Upper Volta, Niger, Chad, and the Central African Republic in the interior. The interior markets would be served by local direct-reduction plants to be constructed, when justified, in addition to the central blast-furnace plant. The capacity of the central plant would be 700,000 tons per year. The rich ore could come from Liberia and/or Gabon. Metallurgical-grade coal would be imported, but Nigerian coal could be incorporated in the mix charged to the coking plant. Three alternative plant locations were suggested: at Buchanan in Liberia; at Tema in Ghana; and at Port Harcourt in Nigeria.

2. Since the Monrovia meeting, there has been some noticeable activity between the West African nations on this question in terms of meetings and more detailed studies on aspects such as alternate plant locations and capacity. Despite such activity, nothing definitive seems to have occurred in West Africa to supply its iron and steel markets from local resources.

3. A direction to resolve these problems in West Africa and thereby establish an industry to serve what is comparatively a small market could be the following:

4. A blast-furnace industry could be created in West Africa if Nigeria, the country in West Africa which has the major market for the steel products were to act unilaterally. Nigeria can build the industry to serve its own markets primarily but with allowances through trade agreements for other

countries to take some product. By this method, the complicated problem of resolving many national interests to a common purpose is avoided. By taking the initiative in such a manner, Nigeria would be able to act freely in connection with the technical and economic matters involved.

5. Then, the blast-furnace segment of the industry could be located on the seacoast in an area accessible to natural gas and rail connections. The Port Harcourt region appears to be an ideal location on the coast offering these advantages. It has a direct rail connection to Nigeria's coal deposits to the north, the potential source of char or coke; natural gas is abundant and available at low cost; fuel oil is available without freight charge from the Port Harcourt refinery; limestone deposits exist nearby in Calabar; port facilities are available; and industrial development already exists. If the export agreements with other countries in West Africa should include processing foreign iron ore, this ore could be landed in the Port Harcourt region, otherwise the iron units from Nigerian sources could reach the blast furnace by river transport.

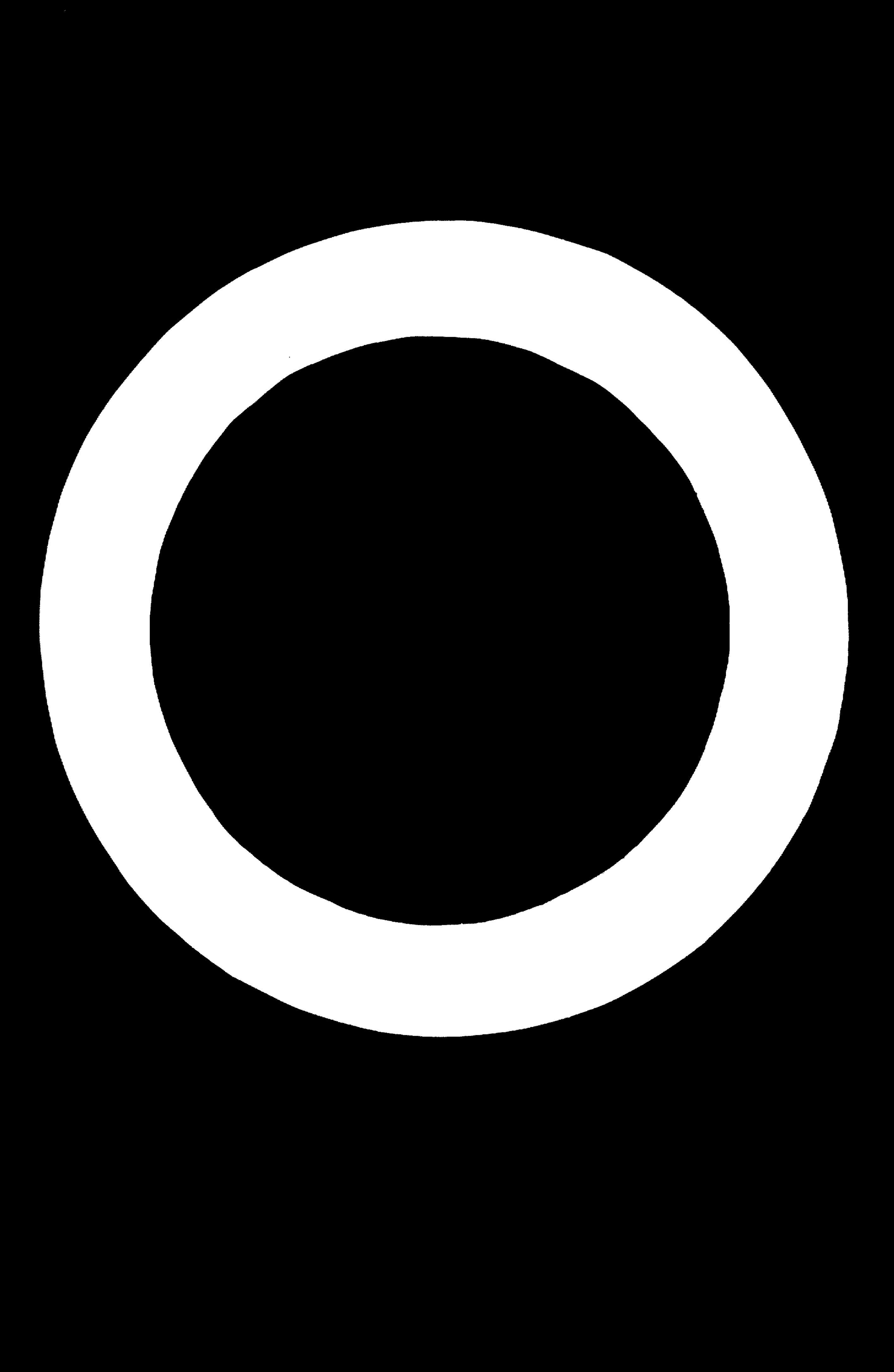
6. The capacity of 700,000 tons per year for hot metal production would be too large for a market based on Nigeria's needs. Therefore, only one of the two blast furnaces should be built initially and it should operate with simple practice. Present day developments in technology permit a simple blast furnace to be constructed as an initial step and capacity to be added at a later date by introducing changes to the operating practice. For example, the initial installation could be designed to use run-of-mine iron ore, to use conventional blast-temperatures, and to make no provision for fuel injection, but the capacity of the cast house and the loading skips would be overdesigned. Later, as demand for production from the blast furnace increases, higher levels of burden preparation could be introduced, blast temperatures could be increased, and oil or gas injection practiced.

7. An example of the improvement in blast-furnace output capacity possible by these methods is in the production statistics for the United States between 1953 and 1962. In 1953 the iron content of the total iron-bearing components in the burden was 50.3 percent, and 18.6% of the iron-bearing components was beneficiated by adjustment of physical form and iron content.

By 1962 these figures rose to 55.5 and 54.4 percent respectively. Coke rates were reduced from 1,812 pounds per ton of iron to 1,380, and the average increase in furnace capacity was from 919 to 1,349 tons per day. This improvement in output arose primarily from burden improvement, but some credit for improvement is due to the introduction or wide-spread use of fuel injection, high top-pressure operation, and higher blast-temperatures. Some of the large 28-foot diameter blast furnaces today are approaching 3,500 tons per day capacity with 60-65 percent iron content and almost 100 percent preparation in the burden, while corresponding coke rates are decreasing toward 1,000 pounds per ton. An equally radical improvement should occur when the use of prereduced agglomerates in the burden is introduced.

8. Local coal resources at first could be used as a blending agent with imported metallurgical coal. Eventually, when the plant is well established with its own trained staff, it could undertake to evaluate some of the new "synthetic" metallurgical coke process.

9. An important feature in such a plan is for exports from a central blast-furnace facility to comprise only steel billets or slabs so that potentially labor-intensive rolling operations can be sited in the individual countries near the markets. Also, when local rolled product markets for specialized shapes are too small to support the local operation, a central facility to serve the aggregate markets can be considered; and the number of such facilities can be allocated among the nations of the region. In a large nation such as Nigeria, such an approach to decentralization might also be considered.



APPENDIX E

IMPACT OF FUEL COST ON DIRECT REDUCTION IN DEVELOPING COUNTRIES

1. When energy costs are low enough to compensate for a freight disadvantage, a large-scale western-type plant can compete successfully in the world market. Consider a direct reduction facility requiring 15 to 20 million Btu per ton of reduced product (90% Fe, 95% metallized). Let us assume that there is a choice in placing the reduction facility in an industrialized country where gas costs are $0.60 per million Btu or in a developing country with large gas supplies available at $0.20 per million Btu. The difference in gas costs is between $6.60 and $8.00 per ton of reduced product and can be used to offset the necessary transportation and handling costs entailed in getting iron ore or oxide pellets to the reduction facility. Of course, this is an oversimplified picture of a direct reduction facility but it does serve to point out an area of new "western technology" that can be quite competitive in some developing countries with the world industry.

2. Should the low cost fuel be available in a developing country that is on one of the world's major iron ore routes, the savings in gas costs (less the incremental handling costs) plus the reduction in shipping weight can increase the attractiveness of a venture of this type.

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