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THE ADAPTATION OF TECHNOLOGY TO SCALE OF PRODUCTION IN CHEMICAL PROCESS INDUSTRIES FOR DEVELOPING COUNTRIES

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Slightly Revised and Reprinted

The Adaptation of technology to scale of production in chemical process industries for developing countries

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Preface

Sources

A certain amount of data were already available. For instance, the FAO has published a set of 17 costed input tables for the manufacture of paper pulp and paper, covering different raw materials by different processes at different scales of production. [1] The United States Forest Service has put out a series of studies on the manufacture of charcoal from various raw materials by various processes. [2] There were several studies by States also on the same subject. Tentative costing sheets are often submitted at United Nations Conferences and Seminars, for instance, those relating to Cement [3], Petrochemicals [4], Basic Chemicals [5], Paper [6], Alcchol [7], etc. Region-wide investigations of and reports on industrial possibilities sometimes contained tentative cost data as, for instance, the Azimov Reports on the Ceara Province of Brazil. The Indian Tariff Commission has published about 200 studies of industry costirg. The USAID Programme has published over many years a series of industry studies and fact sheets which contained outline costing sheets, necessarily of a tentative nature. Some actual estimates submitted by consulting engineers to various countries were forthcoming, and contained cost data of varying degrees of completion and reliability. Thus, there was a fair body of cost data available as a starting base, and many were actually consulted. The data, collected from different sources, were inevitably incoherent and not comparable. The reliability

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[1] FAO - Raw Materials for more Paper - Rome, 1953

[2] Charcoal Production, Marketing and Use - FPL Report No. 2213 of 1961
Cost of Operation for three types of charcoal kilns - 1957

[3] Denmark 1964

[4] Teheran 1964

[5] Bombay 1963

[6] Cairo 1964

[7] Lucknow 1952

of the data could not be taken for granted, and wide divergencies were often noted. Nevertheless, with all these limitations, some kind of cost pattern could be evolved for each of the industries examined.

Approach

There were three directions in which the basic data had to be reworked

(1) Allowing for changes of scale

(2) Allowing for changes of technology

(3) Allowing for changes of parameters

These three adjustments were made to evolve what might be considered to be the best fit for conditions prevailing in developing countries. The change of parameters was the easiest. Extensive statistical information has been published in various countries on common cost elements, such as labour wages, costs of fuels and energy, raw materials, intermediates, consumer products, transport, interest charges, etc. 1/ To a lesser extent, data could be collected for productivity, maintenance cost, depreciation, etc. 2/ Tables of transfer parameters had a fair degree of dependability, probably better than an order of magnitude. A change of scale, leaving all other factors unaltered was the next step. This was far from easy. The exponents suggested and formulas prepared for estimating change of costs on change of scale in the advanced countries were themselves variable over a very wide range, as explained elsewhere in the text (page 40). The possible ranges in developing countries were necessarily much greater. When allowances had to be made for applications of those technological processes which were non-standard in the advanced countries, the cost variations became more a matter of informed approximation than of a mathematically rigid derivation.

1/ E.g. the Statistical Abstracts of various countries and publications by Departments of Labour, Social Services, etc.

2/ E.g. Census of Manufactures, Census of Industries, Labour Gazettes, Journal of Productivity, Asian Productivity Organ, etc.

The most difficult step of all was to visualize and then translate to paper the technology which would best fit the developing countries. Once again, reliance was placed on actual experiences in a limited number of cases, and upon the information disclosed in a large number of publications on chemical technology, from the latest to those reaching back to nearly 100 years ago. [1] Under certain circumstances, some of the processes described in the older literature were found to be quite valid today, if modernised by the incorporation of the latest known materials of construction; methods of transfer of heat, energy and materials; applications of electricity; transport mechanisms and vehicles; machines for size reduction, etc.

The outline flowsheets in the case studies represent the composite result of the design of appropriate technologies in each case. The cost sheets are the summary results of calculations based upon the stated parameters, input tables, etc.

Results

While the results are claimed to achieve only an order of magnitude, the study has established a pattern which, it is hoped, will lead to more fruitful results. The first is to establish the usefulness of examining all possible technological alternatives for the production of a given commodity, even if some of the processes might be old or regarded as unconventional in advanced countries. The second useful conclusion is that, while the economies of scale* are as manifest in the developing countries as in the advanced countries, it is nevertheless possible to make alterations in technology which will to some extent counteract the diseconomies of smaller scale. The third advantage is that the search brings out the possibilities of

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[1] For instance, Kirk and Othmer - Encyclopedia of Chemical Technology (1952 to 1966), Lunge's Sulphuric Acid and Alkali (1889).

* The concept of economy of scale is highly complex, and cannot be discussed here. For the purposes of this paper, it is assumed that "economy" applies to the scarce factor of production which in one case may be capital and in another case labour.

economising on capital investment in the manner likely to be productive of best results. Furthermore, the diversity of industries which are shown to be amenable to this treatment is a fairly strong indication that the principles are of general validity, and might be usefully applied whenever the establishment of a new industry is contemplated. Finally, a start has been made in the examination of a variety of important and popular industries. To that extent it is possible now to work up more detailed and more reliable feasibility studies.

8 April 1965

Slightly Revised 12 October 1966

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Adaptation of technology to scale of production in chemical process industries for developing countries

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Object

One of the important consideration in the manufacture of an industrial product is the technology employed. Several observers have mentioned the paucity of published information on this point.

> "For pre-selection purposes, an approximate description of technological alternatives ... appears entirely satisfactory. At this stage, a wide coverage is essential in order to insure against the risk of overlooking potentially attractive projects. Technical specialists are generally not required for the pre-selection stage, but an effort should be made to include technical information of a critical nature which, if overlooked, might invalidate the conclusions ... even in the absence of such technical specifications, the Data Summaries can be useful ...." 1/

> "The use of data from existing plants for project evaluation runs into many difficulties due to the lack of comparability of conditions of operation and the fact that experience available in one country only covers a limited part of the known technologies and possible sizes of units. Hence,

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1/ Vietorisz - "Pre-investment Data Summary for the Chemical Industry" Paper No IDP/EWG 5 presented to the Expert Working Group on Industrial Development Programming Data, New York, May 1961.

> we feel that an effort should be made to produce standardized date for industrial programming that would make allowance for differences in factors that vary among countries ....
>
> The purpose of this study would be to determine the "normal" (standard) investment and current inputs of production factors required at different scales of output by a given technology and the appropriate organization of production." [1]

The choice is by no means easy or simple, thus --

> "... judgments about relative efficiencies of capital-intensive and labour-intensive industries often involve very complex analysis. Frequently it is not possible, except after most painstaking study, to determine whether a given technology will in practice be labour-saving or capital-saving." [2]

The Economic Commission for Latin America has entered upon a series of investigations in the chemical field. A paper prepared for the ECLA Seminar on Industrial Programming [3] contains a series of costing statements, giving the variation of the investment and production costs with scale of production in eighteen different products of the chemical industries. However, while mentioning that there could be significant differences if modified technologies were followed, these modifications are not given in any detail. A later and much more detailed study [4] went into changes of technology, but these changes were not changes in any essential principle, but only modifications to suit different raw materials. A detailed study by the U.S. Dept. of Labour [5] provided projection indexes for 36 industries, but gave no cost data. The gap in knowledge, therefore still remains, and is sought to be bridged by this study.

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[1] "Formulating Industrial Development Programmes" (Sales No. 61.II.F7) p.136

[2] "How low-income countries can advance their own growth" - Committee for Economic Development, New York, 1966, p. 36.

[3] "Economias se escala en la industria quimica" (ST/ECLA/CONF.11/L.17)

[4] "La industria quimica en American Latina" - United Nations, New York, 64.II.G7 of 1964.

[5] "Technological Trends in 36 major American Industries" - US Dept. of Labour, (Superintendent of Documents, Washington DC, 1964)

Chemical Process Industries

The listing of chemical industries in the International Standard Industrial Classification is on the following lines. [1]

31 Manufacture of Chemicals and Chemical Products

- 311 Basic industrial chemicals
  - acids, alkalis and salts
  - dye intermediates, dyes, colour lakes and toners
  - explosives and fireworks
  - synthetic fibres, resins, plastics, elastomers and rubber,
  - fertilizers
- 312 Vegetable and animal oils and fats
  - crude oil, cake and meal
  - fish and other marine animal oils
  - rendering of inedible animal oils and fats
  - refining and hydrogenation of oils and fats
- 313 Manufacture of paints, varnishes and lacquers
- 319 Manufacture of miscellaneous chemical products such as
  - medicinals and pharmaceuticals
  - perfumes, cosmetics and other toiletries
  - soaps and other washing and cleansing compounds
  - polishes and inks
  - matches and candles
  - insecticides

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[1] Compare Statistical Papers Series M. No. 4 Rev.1 Add.1 (Indexed Edition) -"Indexes to the International Standard Industrial Classification of all Economic Activities" - (United Nations, 1959) Sales No. 59:F.VII:9 (Note: A revised edition is very shortly (1966) to be issued)

The following process industries are at present not classified under "chemical industries":

202	Manufacture of dairy products
207	Sugar factories and refineries
209	Manufacture of miscellaneous food preparations (e.g. starch, yeast, ice)
211	Distilling, rectifying and blending of spirits
213	Breweries and the manufacture of malt
271	Pulp, paper and paperboard
291	Tanneries and leather finishing
300	Manufacture of rubber products
321	Petroleum refineries
329	Miscellaneous products of petroleum and coal (including coal distillation)
331	Structural clay (bricks, tiles, etc.)
332	Glass and glass products
333	Pottery, china and earthenware
334	Cement (hydraulic)
339	Non-metallic mineral products not elsewhere specified (e.g. gypsum plaster, abrasives, etc.)
342	Non-ferrous metal basic industries (including smelting)

All these are normally included within the term "chemical process industries" (CPI) because the industries make considerable use of chemical processes. 1/

For the purposes of this paper, the coverage includes all the industries mentioned in this paragraph. The industries selected for some detailed treatment are the following:

Distillation of coal and wood
Cement
Seawater chemicals

1/ Shreve - "The Chemical Process Industries" (McGraw-Hill, New York, 1959)

Caustic soda
Nitrogenous fertilizers
Sulphuric acid
Petrochemicals
Industrial alcohol
Paper
Man-made fibres (nylon)

Even this treatment has to be elementary, because the angle of approach is to establish generalized principles, not precise technological details, and also due to space limitations.

Definitions

Certain terms will be defined for the purposes of this study.

"Size" in relation to a particular industry is measured by the physical or material output capacity.

"Economic size" means that size which will allow the producing unit to meet all its costs from its own earnings, excluding only arbitrary changes, such as taxes.

"Minimum economic size" is the smallest size which at full rated production will enable the production unit to meet its costs.

"Optimum size" is that size at which the return on further increase in size begins to display a negative gradient. [1]

"Costs" include imputed standard bank rate of interest for all capital, both fixed as well as for operational requirements.

"Economy of scale" means maximising the output of the principal scarce factors.

Variable Factors

The variable factors to be covered in this study are:

(a) Choice of products

(b) Locational factors

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[1] Note that the optimum size may be below the minimum economic size.

(c) Needs of market and end-uses
(d) Considerations of currency exchange
(e) Availabilities of raw materials
(f) Quality standards
(g) Mechanization
(h) Labour problems
(i) Choice of technologies
(j) Scale of operations

Only the last three factors will be analyzed in detail, while the rest will receive qualitative treatment. Several other factors may be involved in an actual practical situation. [1]

Any country investigating the possibilities of expanding industrial production generally follows three lines:

(1) Import substitution
(2) Export promotion
(3) Innovations

Nowadays most manufacturing methods, processes and operations are well known and can be readily hired. There are comparatively few items which have to be placed definitely beyond the reach of even quite small countries.

On the other hand, although it may be technologically possible to manufacture a particular article, it may not be a sound economic proposition at all. The economics of manufacture depend upon a complex network of factors which are always in a state of change. Often it is not possible to say whether a project will or will not definitely be economically sound, and the most that can be said is that it is worth a trial. By and large, due to the permanent secular loss in the value of money, where a particular project is a borderline case under current circumstances, it is usually a good investment from the angle of future worth, taking into consideration the almost certain erosion of the value of money in the future.

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[1] See Rostas - "Comparative Productivity in British and American Industry" - Cambridge University Press, 1948.

Locational factors have much to do with the economics of production. Manufacturing processes concentrate inputs and disperse outputs. Where inputs are heavy and cheap in relation to outputs, like coal and benzene, it is an advantage to be close to raw materials. Where inputs are costly, and the value added is comparatively small (e.g. hydrogenation of oil) or the final products are fragile or perishable, (e.g. manufacture of bread) or of low cost, like pottery or bricks, or hazardous (e.g. sulphuric acid) it is a distinct advantage if a producing unit could be situated close to the consumer market. This advantage may under some situations outweigh other considerations which are normally decisive.

Thus, for instance, the manufacture of alumina from bauxite is in principle extremely simple. The customary Bayer process extracts the alumina content of the bauxite with caustic soda to form sodium aluminate. When the sodium aluminate solution is diluted with more water, it decomposes and gives back the alumina and the caustic soda separately. Despite this apparent simplicity, the industry is actually highly capital-intensive, largely because of the need to recover as much as possible of the expensive caustic soda. But there are several countries in the world, all in the "developing" regions, which have natural lakes of soda ash and sodium sulphate, which can be made to yield up their salts cheaply, and into which the dilute effluents could be returned. If it is possible to dispense with recovery processes and still remain in a competitive position, the entire plant can be very considerably simplified. Technological innovation could play a major role in such cases. However, it takes expertise to recognise and identify such situations.

Market needs have to be carefully investigated. Manufacturing methods and processes have reached a high standard of precision in advanced countries. Sometimes this precision is a functional necessity, as in a clinical thermometer; sometimes it is just a decoration, or an appearance, which is not at all essential. Thus manufacturers of highclass white crockery may go to considerable expenses to produce wares without a single grain of black: if a few black grains could be tolerated, the cost may be reduced appreciably.

It is natural for all countries to aim at the best qualities. However, where the choice is between a somewhat lower (but sufficient) quality and no local production at all, one or the other possibility could be selected. This situation is of frequent occurence in developing countries.

The question of foreign currency is often encountered in feasibility studies. To import consumer goods normally requires payment in some foreign currency. To manufacture locally also requires some payment in foreign currency, either in lump sums or in periodic instalments or both, to pay for capital plant, operational requirements, replacements, service charges, etc. A proper feasibility study would include a full statement of a foreign currency balance sheet. It is not always easy to assess the relative merits of a large lump sum payment at the moment as against the prospect of small annual payments in perpetuity; yet this is often the most important of a feasibility study.

The availability of a given raw material is sometimes the most advantageous factor in the establishment of an industry. Thus, for instance, the copper smelters of Zambia discharge into the air nearly 1 million tons of sulphuric acid (actually in the form of sulphur dioxide). Into Lake Natron in Tanganyika there is an inflow of soda ash estimated at 2 million tons per annum. Nyasaland has a mountain of bauxite (at least 60 million tons already proved) awaiting exploitation. The hydro-electric potential of Ethiopia is of the order of 100 million kilowatts. The list of such potentially valuable natural resources can become very long, and they give ample promise of becoming "core" industries, from which can develop large assemblages of related industries.

Many countries have raw materials which are sadly neglected for one reason or another, and quite often the result is higher costs for a better-known raw material in wider demand, but less readily available. Thus, for instance, it is well-known that in the manufacture of Portland cement, magnesia is a harmful ingredient. Hence, limestones which contain more than about 5 or 6 per cent of magnesia are left out of account in computing resources available for Portland cement manufacture. However, it is also known that when the content of magnesia in cement rises to about 20 per cent, once again the product is an acceptable hydraulic cement, which was once widely used in the USA under the name of "Rosendale cement", and still continues in good demand.[1] For many countries in the world the manufacture of magnesian cements is an excellent way of securing ample supplies of good cement at comparatively low prices.

One more instance must suffice on the question of raw materials. Nylon can be made from several source materials, of which the principal one in the advanced countries is from petroleum refinery products. But there is another suitable raw material, furfural. This material can be readily and easily extracted from all agricultural wastes like shells, husks, cobs, peels, piths, sawdusts, straws, reeds, grasses, bamboos, etc. In developing countries, these materials are available in vast quantities, but are being neglected at present. There are great opportunities for utilizing such raw materials for extraction of furfural, while the residues can be put to other purposes.[2] Even in highly-developed countries, there are vast quantities yet to be properly utilized. Thus it is stated that in the USA -

> "230 to 260 million tons of residues on a dry basis are produced each year. Probably half of the tonnage is available for industrial utilization ...."[3]

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[1] Martin - "Industrial Chemistry" - London, Crosby Lockwood & Sons, 1925, Vol. II, p. 86.

[2] Dunlop - "Furfural from Agricultural Sources" - Royal Institute of Chemistry, London, Monograph No. 4 of 1956. See also article "Adipic looks to Nylon 6/6" in the "Oil, Paint and Drug Reporter" dated 25 December 1961.

[3] Arenovsky, Schniepp and Lathrop - "Using Residues to conserve resources" - US Department of Agriculture, Yearbook of Agriculture, 1950-51, p. 829.

This is only for the USA. The rest of the world must be producing a twenty times as much. Thus, one of the fourteen States of India was reported as producing 769* million tons of agricultural wastes per year.[1] The development of a technology utilising these residues properly will certainly have the effect of reducing costs for countries which do not have adequate resources of the more conventional materials.

Incidentally, furfural is the source of a valuable group of plastics, and this could be valuable economic support for an industry producing furfural. Often it is a combination of such opportunities which results in an industry which is truly profitable under competitive conditions.

One of the objects of technological progress is to improve the quality of a product, and often this can be achieved only at increased cost. Some customers may gladly pay the increased cost for the sake of the more valuable quality improvements, but there are many who are compelled to pay the higher cost, but have little use for the higher quality. Take, for instance, building cement. The chief ingredients of hydraulic cement are the silicates of calcium. The Romans used to make an excellent cement, and the ruins which are still standing (many structures in excellent condition) after nearly 2500 years of exposure to the elements, indicate its suitability for building construction. Such Roman cement can be used for normal houses and similar structures. One of the longest river dams in the world was built in India of similar material as a demonstration,[2] and another huge irrigation dam in India was recently completed of the same material.[3] Roman cement is quite easy and cheap to manufacture, yet few nowadays make it. The better-known Portland cement has all but ousted Roman cement, to the extent that the Government of India had even issued a warning against the use of "hydraulic lime'. Portland cement is more difficult to make, and costlier than "hydraulic lime". True, it is also stronger, but for some ordinary purposes the

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* Probably a misprint for 76.9

[1] Bhatnagar "Industrial Utilisation of Agricultural Waste Products', ('Indian Pulp and Paper', 1962, No. 9)

[2] The Hirakud Dam on the River Mahanadi

[3] The Linganatti Dam on the River Sharavati

additional strength is not used at all, and the potential strength of Portland cement is generally diluted down to a level which could be reached by "hydraulic lime" at much lower cost.[*]

Another instance should suffice. Magnesium sulphate (epsom salt) is manufactured either from mineral magnesite or from seawater residues of salt factories. In one country[**], the standard specifications permitted a small trace of sodium chloride, to allow for the latter. Suddenly the specification was altered to leave no margin for any sodium chloride. This shut out all products from seawater residues, and the effect was to confer a monopoly on the manufacturers from magnesite. The major uses of magnesium sulphate in medicine are as aperient and as desiccative, in which the trace of common salt has no ill effects. There are many other instances which could be quoted to illustrate the influence of end-uses upon the costs of production; but these two must suffice for the present. The point is that it may be a useful exercise to investigate what qualities the consumers really need of a given product, to see how these qualities could be produced at most economical rates.

Mechanisation and Labour

There is a school of thought which asserts that because of shortage of operational skills in developing countries the situation calls for the establishment of the most mechanised and automated processes, in the form of "package plants", where most of the skill has been built into the machinery, leaving very little for operators to do, except make observations, take some routine action in accordance with a pre-arranged schedule, and send for somebody when something goes wrong. Such a processing certainly results in a very high per capita productivity: whether it is the best in the given circumstances has to be evaluated in the circumstances of each individual case.

On the other hand some specialists declare that there are many activities in the world which can be done effectively by manual means and manual equipment. They point to the successful and competitive position

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[*] A paper on Pozzolana Cements will be published by the UN Centre for Industrial Development early in 1967.

[**] Ceylon

of quite sophisticated products of Japanese and Chinese manual industry, like aeroplanes, submarines and transistor radios.

It is clear, therefore, that on this point there is room for a wide diversity of opinions between extremes.

In developing countries the occupations of the available labour force are predominantly agricultural and fishing. The early stages of industrialisation are generally concerned with providing the basic needs of life, such as preservation of foods, building materials and clothing. Unless there are extraneous influences, the level is that of traditional crafts. A good deal of manual dexterity gets built up, and concurrently a remarkable memory and aptitude for pattern and colour. The system lends itself to the perpetuation of tribal and caste distinctions, often in the form of privilege or monopoly. Such industry hardly conduces to modernisation, and the system has no propensity to progress. It needs the impact of external forces to start modern industrial techniques and products.

Human intelligence and ability are needed at all levels of industrial production, from design and feasibility studies, engineering and financial management down to the humblest manual operators. Perspective planning which provides for industrial growth must also provide for the needed skills to grow conterminously; else it may be necessary to import such skills, and thus burden the projects with costs of expatriate personnel. Knowledge and skills can be acquired both from instruction and teaching as well as by actual practical work and experience. Both methods have their use, and it is likely that the best is a suitable combination.

In one respect, at least, developing countries are at an advantage in setting up new industries, because they will not have the problem of deciding what to do with the old and perhaps out-moded industries already in existence. It is often asserted that the phenomenal post-war productivity of the German and Japanese industries was at least partly because of almost complete destruction of existing industry, which resulted in a rapid modernisation of post-war factories which could have been achieved in no other way. Hence such countries would have the greatest flexibility in planning out their industrial future. One of the major sources of strength in the industrial structure of the advanced countries is the considerable reservoir of experience and knowledge which the operatives have acquired by actually working in the industries for many years. This kind of practical knowledge can prove to be equally useful to developing countries, and to some extent would relieve the teaching institutions of part of their burden. A plan for industrialization, and a decision on the actual design of a specified industry would have this aspect as a factor for consideration. In some infant industries, which are in the nature of pilot plants for large units to follow immediately, it might be better to get started straightaway on the latest and most sophisticated techniques. In some other industries, whose future is uncertain, the initial start could well be made on a smaller scale, involving less immediate commitments.

Labour wages have an important influence upon the cost of industrial products, and the effect is more and more pronounced in the less developed countries, where mechanisation has not progressed very far. Many countries have legislation on minimum wages in industrial occupations. The actual rate may vary between 1.70 per hour in the USA to as low as 3 cents per hour in some developing countries. The spread of 50 or 60 to 1 is not always reflected in the productivity per capita, especially when the capital investment on machinery is also taken into account, and where highly skilled operations are concerned. A telephone mechanic whose wages are 12 cents per hour in a developing country may be doing work comparable to that in the USA valued at 5 per hour. That this situation has far-reaching effects can be seen in many places. Thus, for instance, the USA grows cotton, spins yarn, manufactures textiles, and cuts cloth into squares to manufacture handkerchiefs. All these steps are highly mechanised. However, the hemming of the individual squares of cloth is so costly in the USA that it is more profitable to have the cut material shipped to the Philippines for hemming and return. Many instances of this type could be cited. Naturally, developing countries will benefit by participating in the manufacturing sequence at any level, and in any manner. An interesting application of this principle will be found in a later section.[1]

Industrial technology had its real start less than 200 years ago. Only a small base was available - coal, coke and distillation products; cast iron and wrought iron, copper, brass, and cupreous alloys; lead, zinc mercury, etc. But there was no steel or aluminium or cement or rubber or petroleum or natural gas or electricity or oil engines or plastics, etc. Hence technology was comparatively simple, and depended a great deal on the subjective judgements of individuals. Such a technology was very instructive for workers, and allowed them to see what was taking place, and make adjustments accordingly. Such a system had much value, and still has much value in developing countries. Progress in the advanced countries has tended to eliminate the human element as much as possible, and to exercise more and more controls through instrumentation and calculating machines. Thus, for instance, in a recent alumina plant, machinery excavates bauxite, conveyor belts take the bauxite into the factory and there the required chemicals are added, the alumina is dissolved out, and eventually pure alumina precipitated, all under the sole control of one operator seated at a central control console, just keeping watch over pointers and lights. There is even a nitrogen plant which runs completely untended.[2] It may be possible to train workers fairly quickly how to operate such control mechanisms, but this would teach them nothing about the process itself nor, of course, is there any possibility of introducing improvements, except those disclosed by the instruments. For this reason alone, there is something to be said for a developing country following the historical pattern of industrial development, but telescoping the 200 years into a much shorter period.

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[1] Page 54

[2] *Chemical Week*, 3 April 1965, p. 53

History of Industrial Development

In the chemical process industries, the present-day advanced countries started mainly in the following:

Iron, cast and wrought
Coal distillation, ammonia
Salt, soda sulphate
Soda ash, caustic soda
Sulphuric acid, sulphur
Nitric acid
Chlorine, bleaching agents
Copper, lead, zinc
Lime, cement
Bricks, tiles, pottery
Glass
Textiles
Oils, fats, soaps
Leather, gelatine, glue
Alcohol; potable, medicinal, industrial
Oxygen, nitrogen
Fuel gases
Phosphorus, phosphates
Dyes, pigments

It is on this comparatively small base that the present-day industry complexes exist. The evolution of the modern industries has gone on steadily for 200 years or more. However, it is not necessary nowadays for a country newly developing one of these long-standing industries to take the same length of time. Probably 90 per cent of past progress could be mastered in 10 or 15 years, and the country will then be in a position to enter the latest stage of development. Such an orderly step-wise programme may under some circumstances be more advantageous than to enter straightaway into the latest processes, without knowledge or experience of what had taken place before. By way of analogy it might be mentioned that several countries start training their naval cadets on sailing ships.

In the early days of the Industrial Revolution, when new industries were being evolved, naturally they were started on a comparatively small scale. Iron, for instance, might have been produced on the scale of, say, 30 tons per day, and cement at 10 tons per day. However, even on the technologies known in those days, the scale of production increased rapidly, by units increasing either in size or in number or perhaps in both. So that, at the present, there is experience available in a full range of technological variants, as well as in sizes. An older technology need not necessarily have been on a smaller scale than practiced today. Sometimes progress consisted in being able to promote reactions on a smaller scale than prevalent until then. One instance is the manufacture of steel in the electric furnace, nowadays being done successfully on the scale of 1 to 2 tons per heat, or 7 or 8 tons per day. Another case is the fluid-bed catalytic oxidation of naphthalene to phthalic anhydride. As an instance of how local conditions influence choice of processes may be cited the case of an urea plant in Taiwan. There was plenty of coal available, and the question was the best way of securing coke in large quantity. At first sight it would appear that the most economic method would be to establish a large battery of modern by-product coke-ovens. But the report reveals that it was considered better to secure the coke from the hundreds of existing small beehive ovens.[1] It may be mentioned incidentally that India, too, finds the small beehive coke oven quite economically competitive with the large centralized by-product coke-oven battery, and beehive coke production has shown large increases in recent years.[2]

A word has to be said about those technologies which are well known, but so rarely practised that they do not readily occur to mind. One example is the Serpek process for the manufacture of refined alumina from excessively siliceous bauxites, with the simultaneous manufacture of ammonia. This process is still of considerable value in certain circumstances, and a suggestion is made in the Appendix dealing with nitrogenous fertilizers (p. 126). Another example is the manufacture of "vulcanized fibre" from

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[1] "The manufacture of Urea in Taiwan" - Paper No. 42 presented at the ECAFE Conference on the Development of the Fertilizer Industry in Asia and the Far East - Bombay, 1963.

[2] Government of India, Planning Commission - "Programmes of Industrial Development", p. 384, (Manager of Publications, Delhi, 1962).

paper by the use of zinc chlorida. The recovery of sulphuric fumes from smelter gases (compelled by recent air-pollution laws) was found to be best accomplished by a revival of the ancient Hargreaves process, of course, suitably modified to suit modern conditions. These technologies were very valuable in their time in the advanced countries, and can be even more valuable for those countries which have yet to establish an advanced complex of chemical industries.

There are some industries in which suitable technologies have yet to be developed. A small practical example will be illuminating. Sodium silicate is normally manufactured by strongly heating a mixture of soda ash and sand in a glass-making type of furnace. The equipment is expensive, very high temperatures have to be reached, and the technique is quite critical. But very much simpler technologies are available. Rice straw has a large content of silica, varying from 12% to as much as 18%, and rice hulls may contain 35% silica. This straw is of low value for cattle fodder or paper or manurial purposes, and much of it is burnt on the fields. It is found that by simply steeping the straw in caustic soda of a certain composition, the silica is dissolved out, forming sodium silicate. The residue becomes a superior paper-pulping material. The steeping process has thus achieved a double result. The technique is simple, flexible, non-critical, and capable of application at any level of production. It can be done in the rural countryside - indeed, in the very rice fields.

Another small example would be the fabrication of ball mills of wood, and the use of stone pebbles instead of chilled steel or porcelain balls for the grinding. It is not that a timber structure will be a great deal cheaper than a ball mill made of steel (although even a small saving is not to be despised in competitive industry) but that the materials and labour will all be of indigenous origin, and the experience will create a sense of fulfilment in the workers seldom attainable in any other way.

Instances like this are many. As will be noticed, there is normally no incentive for anyone to invent or revive such techniques, and the general tendency is towards discouraging these ideas, due to lack of reliable places where such ideas could be investigated, even if someone in authority were to want an investigation made. Fortunately, Research Institutes are now coming up to handle just these research problems, and are increasingly urged to find local solutions to local problems and situations.

An older technology does not, of course, imply a backward technology, or even an obsolete technology - it may mean simply a forgotten technology. The techniques and compositions of manufacturing mediaeval stained glass have been completely lost. Another instance -

> "During the siege of Prague in 1621, Swedish soldiere captured an instrument said to be capable of burning a hole through metal, and to be used in the refining of gold ... its carefully-polished 4-ft. diameter mirror as capable of capturing the sun's rays as when it was first built. Even now, the secret of its precise manufacture over 300 years ago is unknown." 1/

There are many other such products the technique of manufacturing which has been lost, and the revival of which could make the product fully competitive with the products of advanced technology today. A recent study by a firm of chemical engineering consultants states as follows -

> "The Engineers have seen chemical processing equipment in Turkey that was very primitive but highly effective in that it was turning out a superior product both in appearance and quality.
>
> The Engineers do not advocate "tub and bucket" type plants, but they do believe that there is too much tendency to plan for the 'super deluxe' model, when a standard piece of equipment would serve equally well and cost less ...." 2/

1/ Glaser and Richardson - "Thermal Imaging" - International Science and Technology, No. 34, p. 32.

2/ Ford, Bacon and Davis - "Pre-investment Survey of the chemical industry of Turkey" - USAID Washington, D.C., No. 2/14/00324 of 1962, p. 10.

There is much to be said for a careful and thorough re-appraisal of many technologies which exist around the world in the developing countries, some of which could certainly compete with the latest modern technologies of the advanced countries. Unfortunately, these old-established technologies are dying out, because they call for a great deal of management. This is quite natural, but the fact should be recognized, and allowance made for it in appraising the various alternatives facing a country in its programme of industrial development.

Management decisions

According to an elementary form of Project Analysis Model[1] assuming that there is a known demand for a particular product, and given that the demand will increase in a stated way in course of time, the normal method of satisfying this demand by local manufacture would be to install a plant with a certain amount of surplus capacity. At the start of the operating period, the surplus capacity will be wholly unutilized. With increase in demand the utilisation of capacity increases. There comes a time when the normal comfortable capacity of the plant is reached. As the demand still rises, the management strives to increase output to keep pace with demand by increasing working hours, organizing overtime, instituting productivity studies, rationalising the processes and operations, cutting down wastes, introducing technical improvement, and all the other techniques known to management.[2] Increasingly, however, there would be a wider and wider gap

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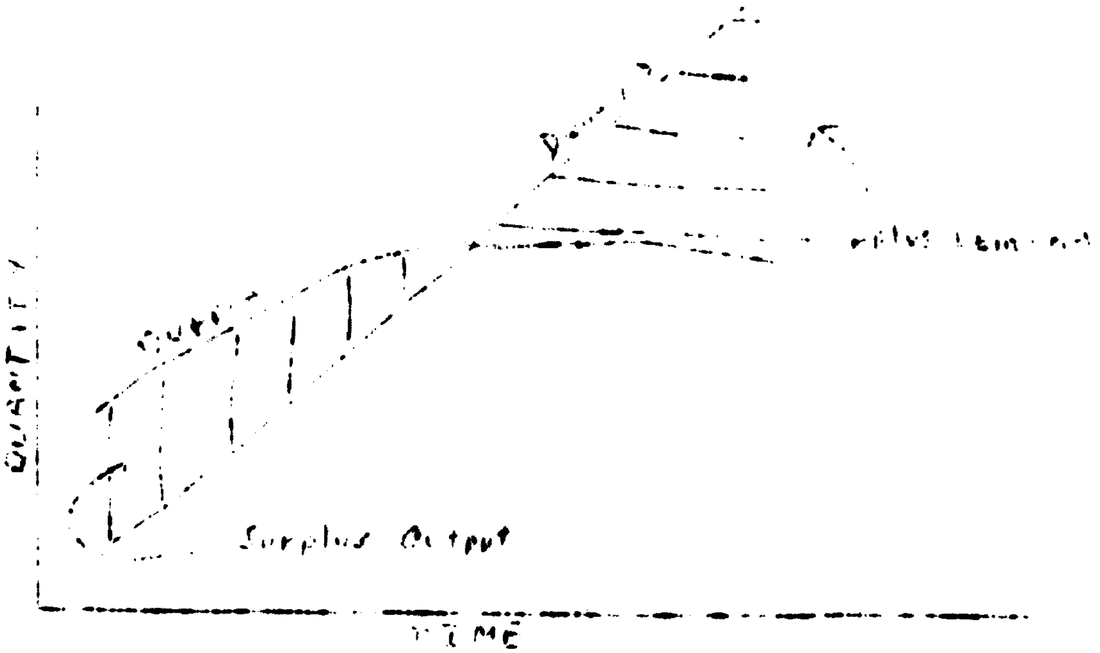
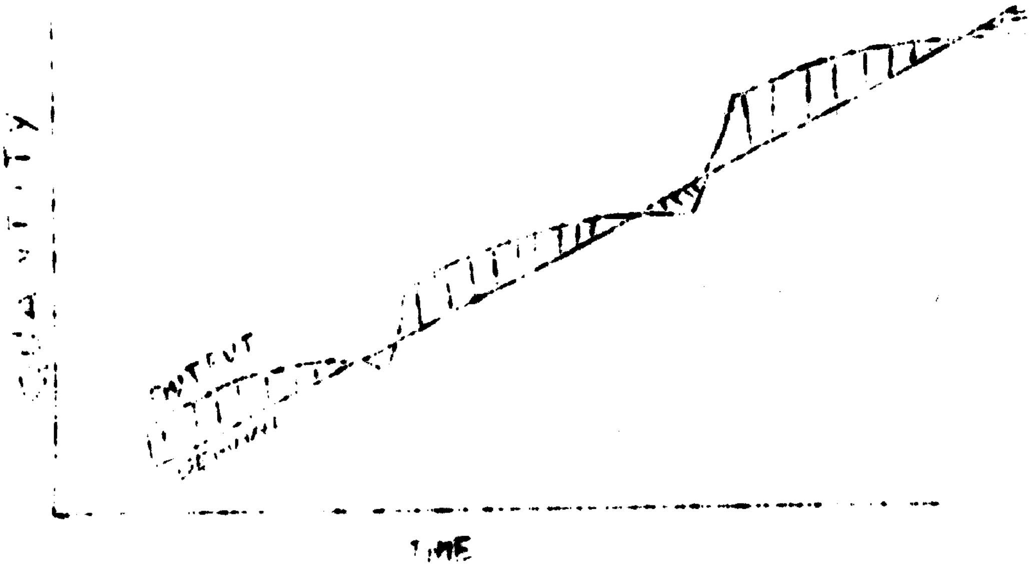
[1] "Determining the Proper Size of Manufacturing Projects" The Engineering Economist, 1963, Vol. 9, No. 1, page 4.

[2] Thus, for instance, from 1920 to 1940, the labour productivity in the US cement manufacturing industry increased by 150% without any major change in basic manufacturing technique - see Frazer and Epstein - "Productivity in the Portland Cement Industry" Monthly Labour Review, 1941, p. 862.

between supply and demand. The whole can be graphically represented as follows.



However, the plant cannot yield more than a certain maximum, however hard it is pushed; and if increased output is needed, new increased capacity must be installed. When an attempt is made to keep satisfying the demand at all times, the graph will be almost the same as the first part of the foregoing graph, repeating itself over and over again, in the following manner:



Whether the additional plants should be put in with considerable surplus capacity at the outset, (thus giving ample time to plan for future expansions) or whether new plants should be delayed as long as possible (thus allowing some scarcities to develop) has to be a point for management policy decisions. In the former case, some capital will be idle for some time, and there maybe operational losses; in the latter case, possible profit opportunities will be missed. Thus, for instance,

> "Some of the chemical plants in the newly-developed countries are operating at high cost mainly on account of the difficulty in finding outlets for their by-products. Several typical examples are found in countries of this region where electrolytic caustic soda plants have been erected without the support of the secondary industries in the utilization of chlorine; hence the production cost of caustic soda has reached twice or three times as much as the landed cost of imported products." 1/

The foregoing model illustrates one of the practical aspects of the influence of scale on the economies of chemical production. In order to make a management decision it is necessary to know the elements which enter into the cost of the manufactured product. It is impossible to prepare a general formula which will yield dependable cost figures under all different manufacturing conditions. Each case has to be studied on its own merits, and the results may vary quite widely, depending on the conditions which actually prevail, as well as the ensemble suggested to effect production. Indeed, it is these variations which create the difference between economic profitability and losses. According to a recent United Nations study, -

> "The study of the performance of factors of production and the impact of prices upon the choice of the most appropriate technology requires extensive knowledge of local conditions and can be carried out only in a given under-developed country or region in the context of actual and anticipated conditions."2/

1/ Economic Commission of Asia and the Far East - Seminar on the Development of Basic Chemical and Allied Industries, Bangkok, 1962, Paper 12 - "Techniques of Programming development of basic chemical industries" (ECAFE, Bangkok, 1962).

2/ Report of the Meeting of the Expert Working Group on Industrial Development Programming Data, Misc. Paper No. 3 of Feb. 1962, p.6.

A later analysis explained the position a little further thus -

> "... a great deal of research is needed to reveal technological alternatives, and determine an appropriate technologically-acceptable 'factor-mix' in specific industrial operations - a relatively little explored field of study ...."[1]

The results of such research are illustrated in the case of one of the biggest producers of chlorine and chlorinated products in the world. They claimed that after some "research in reverse", they decided to establish a small DDT plant to produce only about 6 to 7 daily tons, although this was stated by their own consultants to be five times smaller than the minimum economic size.[2]

It is also of some importance that management (in the case of Governments, the administrators and accountants) keep themselves reasonably well informed about at least the general principles of technology and industrialization. The professional expert, quite naturally, and in perfect good faith, attaches great importance to his own speciality.[3]

Elements of cost

Developing countries would generally start with comparatively small demand for sophisticated products, even where several countries come together for regional or sub-regional co-ordination and harmonization. On the other hand, every productive institution must provide for growth - sometimes for quite rapid growth. Indeed, it is this rate of growth which is the most

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[1] "Adaptation of Processes, Equipment and Products" - Bulletin on Industrialization and Productivity, No. 6, p. 7 (United Nations Sales No.: 64.II.B.1).

[2] "Business Week" 24 December 1960, p. 57.

[3] Thus, for instance, in an article "Choice of Capital Intensity in Industrial Planning", the author says that - '...capital-intensive processes are often identified with "industrialization" and have a prestige appeal. Engineers often have a psychological bias in favour of such techniques because of their educational background and their conscious or unconscious identification of the latest available techniques with "progress" '. - Bulletin of Industrialization and Productivity, No. 7, p. 31 (United Nations Sales No.: 64.II.B.1).

satisfactory criterion of the success or otherwise of the original unit. It becomes important, therefore, to know at what scale of output it is possible to start, what would be appropriate technology, how much expansion capacity must be built into the first plant, how much (both in size and technology) must be left for future decision, and such considerations. This paper is intended to provide some leads.

That this is a matter of considerable importance for the developing countries cannot be overstressed.

> "...one reason why America is the home of mass production and the giant firm is that labour has always been relatively scarce and expensive there. They therefore try to maximise output per man by giving him a lot of capital equipment to work with. Conversely, in some of the underdeveloped countries, where there is a plentiful supply of cheap labour but capital is scarce and expensive, mechanisation and large-scale production offer few immediate advantages over the more crude and old-fashioned methods..."1/

Although no single formula can yield coefficients applicable under all different circumstances, it is quite possible to suggest the headings under which costs can and should be forecast. A fairly simple classification is the following:2/

1/ Speight - "Economics and Industrial Efficiency" - London, Macmillan, 1962, p. 48

2/ After Peters - "Plant Design and Economics for Chemical Engineers", (McGraw Hill, 1958), p. 13

Manufacturing Costs

- Raw materials
- Operating labor
- Operating supervision
- Maintenance and repairs
- Operating supplies
- Power and Utilities
  - Steam
  - Electricity
  - Fuel
  - Refrigeration
  - Water
- Royalties (if not on lump-sum basis.)

[illegible] Costs

- Rent
- Insurance
- Taxes (property)
- Depreciation

Fixed [illegible]

- Medical
- Safety and protection
- General plant overhead
- Packaging
- Recreation
- Salvage
- Control laboratories
- Plant superintendence
- Storage facilities

[illegible]

OVERALL EXPENSES

Executive salaries
Clerical wages
Office supplies
Communications

Administrative Expenses

Sales offices
Salesmen's expenses
Shipping
Advertising

Selling Expenses

Research and development
Financing (interest)

Total income minus total cost equals gross earnings

Gross earnings minus taxes equals net profit

The Transport factor

These are the costs to the manufacturer. The costs to the consumer will be the ex-factory purchase price, plus various additional costs, of which the chief element will be the transport factor.[1] The usual approach to product costs generally leaves this factor out of account. There are reasons for this omission. First, is the difficulty of knowing what the effect of transport will be, and nature of the costs involved. Secondly, is a tacit assumption that the point is not of great importance, because the effect of excessively long haulage and corresponding costs, would be to act as an incentive to erect another factory, and that there is, therefore, a self-regulatory mechanism in operation. This argument was permissible in a perfectly free economy, but does not operate in the developing countries, where laissez-faire has long since been replaced by restrictions and controls on the construction of new factories, and a whole code of legislation. It is no longer safe to assume that if economies dictate the establishment of a second manufacturing unit, the unit will ipso facto come up. It is, therefore, of importance that the view point of the ultimate user of the product should be given due weightage by the authorities charged with the duty of planning and administering the controls.

In order to give an illustration at this stage it will be necessary to anticipate certain findings. Let us assume that a factory is producing and marketing 200,000 tons of cement per year, and that there is an additional market for a further [illegible],000 tons. The

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[1] "The cost of transporting both inputs and outputs becomes an important factor in determining the level of capacity.... By virtue of this location problem, plants may be operated at well below the optimum scale and yet have a competitive advantage over large plants which are further away from the market...." (See "Plant Size and Economy of Scale" - United Nations No. E/C.5/44, para 38).

question which will often confront Government officials in countries where there is some regulation of industries is whether the capacity of the existing cement factory should be increased to meet the needs of the additional market or whether a new factory should be erected to divide the markets. To take a hypothetical instance, the factory producing 200,000 tons a year may be producing cement at, say, $12 per ton, and purchasers may be incurring a transport cost spread of $1 to $3 (average $2) per ton. The total costs incurred overall by the purchasers would then be $13 to $15 (average $14) per ton. If the capacity of the existing factory is raised to 400,000 tons per year, let us assume that the cost of production drops to $11 per ton. If the whole of the additional output is absorbed by consumers within the same area, there will be a net benefit of $1 per ton, i.e. $400,000 in all, for the output of a single factory compared to the products of two factories. But if, as often happens, the existing market is saturated, and the additional production has to find new markets, starting from the periphery of the existing market, the situation becomes different. The transport cost for the additional 200,000 tons may now be, say, $3 to $5 (average $4). Since the enlarged market begins where the previous market left off, and extends further and further, the factory cost of the cement will average about 10% less, but there will be more burden of costs on consumers by $400,000, the closest paying $12 per ton (i.e. less than the previous lowest) and the most distant $16 per ton (which is higher than the previous highest). The total average will then increase from $12 to $13 per ton. If there are two factories, each producing 200,000 tons per year, and serving their own limited markets, the overall average costs to consumers will remain unaltered and the country's transport system would be put to a lesser strain. For higher outputs, the cost of the cement to the consumer from a single large plant has to be weighed against operational economies of scale. 1/

Another example was brought out at the Conference on the Development of the Fertilizer Industry, conducted by the Economic Commission for Asia and the Far East in Bombay, during November/December, 1963. In one of the papers 2/ it was pointed out that

> "An idea which seems to be gaining much ground in the USA is the building of small compact ammonia plants in the open countryside.....It is now an economic proposition to produce ammonia in plants costing some $3 millions, whose productive capacity totals 20,000 tons per year.
>
> These plants...produce at a lower price than the larger units of, say, 100,000 tons of ammonia per year, if the higher cost of transport to the fields that these larger factories entail is taken into account....about 60 small plants of the type mentioned here are shortly to be erected in the farmlands of the USA...."

In connexion with this same plant, it was elsewhere stated that -

> "While the average plant for ammonia production has a capacity of from 250 to 300 tons per day, a recently developed "packaged" plant has a capacity of only 60 tons per day....The production cost of liquid anhydrous ammonia in this plant has been estimated at about $36 per short ton compared with $32 per short ton for a plant with a capacity of 300 tons per day. 3/

1/ An example of how management would decide when confronted with these alternatives (which is the conventional approach in such matters) will be found in Happel's "Chemical Process Economics" (Wiley, 1958) on page 21, Example 1.7.

2/ Paper No. 91 - "A Plan to Set Up in Developing Countries Standard Package Anhydrous Ammonia Plants..." (to be published shortly).

3/ Bulletin on Industrialization and Productivity, No. 7, p. 32 (United Nations Sales No.: 64.II.B.1).

That the [illegible] factor is going to have a powerful influence upon the economics of large plants is obvious, and has received attention. Thus, at the United Nations' Petrochemical Conference held in Teheran in November/December, 1964, one of the consultants, the Institut Française du Pétrole, stated that -

> "Against the economics resulting from the concentration of large ammonia capacity in a single plant... the product distribution costs of large plants are likely to be proportionately higher than those of smaller capacity plants.
>
> Efficient plants with captive markets within an economic radius are therefore likely to withstand the competition from the new giants...."1/

This same point was elaborated in another paper at the same Conference,2/ in which were estimated the costs of manufacturing ammonia by the identical process, using the same raw materials, but at five different levels of production. According to the calculations therein, the cost of ammonia ex-factory would be $23.60 per ton for production at the rate of 400 tpd, which would increase to $42.20 (i.e. 80% more) at the level of 60 tpd. Nevertheless, as was pointed out -

> "In spite of the very attractive economics for the production of ammonia in large single-train units, the small-size ammonia plants (60 to 100 tpd) are still being built in the United States. The main justification for such small units lies in the fact that such small units serve to meet local needs which otherwise can only be met by paying expensive transportation costs." 3/

1/ The Petrochemical Industries - Section II - Conference Paper 86, p. 46. (in print by United Nations)

2/ Strelsoff - Economics of Ammonia production in the developing countries - Conference Paper 3.

3/ Ibid - p. 22

> "... while ammonia might be purchased on the European market for roughly \$40 per ton, the transportation charges could easily bring the total cost to the farmer in some distant country to as high as \$400 per ton...." 1/

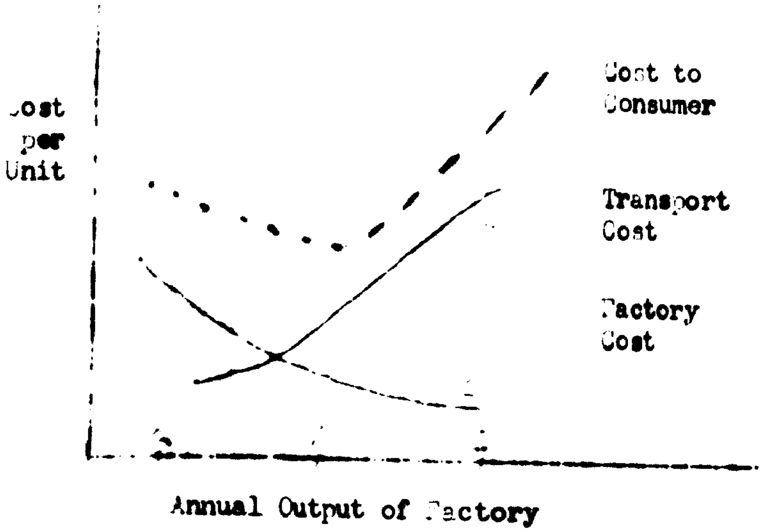
The foregoing is a simplification of a very complex problem, on which a great deal has been said and written. Although the principle looks elementary, there are many instances in the recent industrial history of the developing countries where it has been overlooked, with consequent losses and wastages to the country concerned. The important lesson of it is that it is impossible to predict from *a priori* principles what the final result and effect of changing the scale of production upwards or downwards would be. Depending upon the circumstances of each case and the angle from which it is viewed, the result may be a net gain or a net loss or no change. It is, therefore, necessary to evaluate each case individually. A highly-specialized study in the Netherlands is analysed by Boon, who remarks that -

> "...at high interest rates and low wages, with relatively low output, a process of low capital intensity is likely to be economic.... If these conclusions were to prove to be true for industries other than wood-working, they would be of great significance to ...under-developed countries." 2/

1/ Reed and Sloan - Nitrogenous Chemicals as a Petrochemicals Operation - Ibid - Paper No. 37, p. 1.

2/ Boon - "Choice of Industrial Technology: the case of Woodworking" - *Bulletin on Industrialization and Productivity*, No. 3, P. 25 (United Nations Sales No.: 60.II.B.1).

The following graphical representation, although an over-simplification, brings out the point that is being made -



A is the point of smallest rate of output. Naturally it produces articles at high cost. As the rate of production increases, the unit cost of production goes down. The point A is also the point of lowest cost of transport, because the area of service by the factory, is ex hypothesi, very close. As the rate of output increases, the cost of transport of the products keeps on increasing, because the products have to travel further and further away to find buyers. If the rate at which the production cost dwindles and the rate at which the transport cost increases are not the same (they seldom are) then the final overall cost of the product to the user, which is the sum of these two component costs, will vary with the rate of production. The overall cost can steadily fall, it can steadily rise, or it can first fall and then rise (the graph gives an example of this last) or vary in several other ways.
On the graph shown, point C is the point of maximum factory production (at minimum cost), but also at maximum cost to consumer. B is the point of minimum cost to the consumer, and represents an intermediate scale of production neither too small nor too large.

A factory is a part of society, and has manifold social relationships with other elements of the society in which it exists. Housing, transport, recreation, welfare and job security of workers, creation of employment opportunities, dispersal of benefits and risks, and many other considerations exist. None of them can be taken into account in this paper, which limits itself to technological and economic features only. However, there are various points in this paper from which separate discussions on these considerations may be started.

Variations of technology

This study concerns itself with industries. Each industry may cover several products, and there may be several technological routes to the same end-product. Thus, for instance, caustic soda may be produced by electrolysis or by causticization or by other processes of negligible importance. Electrolysis may use the diaphragm cell or the mercury cell, and may start with sodium chloride or with sodium sulphate or other salts. Causticization may use soda ash or sodium sulphate. Soda ash can be of natural origin, or manufactured by the Leblanc process, or by the Solvay process, or itself by an electrolytic process. Soda sulphate can be produced from natural brines, or from industrial waste liquors, or from furnace gases, or from gypsum, magnesite and common salt. It can readily be realized that a diversity of technologies thus presents itself.[1] It would not be necessary - not even possible - to cover all the technologies in even a few selected industries in this paper. The best that can be done is to choose from the known technologies a few of those which will definitely illustrate the influence of scale. The need for this has often been stressed, as for example -

"In the particular example of individual development

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[1] A diagram of some of the possibilities in this particular case could be found in T.P. Hou's "Manufacture of Soda" (New York, Reinhold, 1942, p. 28)

> projects proposed for financing by financing institutions or development agencies, the original proposals often embody a given choice of technological processes, and do not always provide for the range of possible related alternative processes. When evaluating such projects, it is necessary to consider whether the projects in hand incorporate the most advantageous technologies and whether attractive variants have not been overlooked." 1/

Of the well-known technologies, some are by now obsolescent in the advanced countries, largely because the high cost of labour nowadays makes these processes uneconomic, or because some much more productive process was discovered. As an example of the excessive labour requirements may be quoted the Leblanc soda process, which was predominant in the field for almost one century, struggled with its successor (the Solvay process) for another half century, and is now to all intents and purposes obsolete in the world.2/ An example of the discovery of much better techniques is the Brin's oxygen process, using the oxides of barium as intermediates in a cycle of operations. It was very successful in its time, but was rapidly and completely displaced as soon as the technology of refrigeration was sufficiently developed and it became possible to manufacture oxygen by the fractional evaporation of liquid air. It is pertinent to remember, however, that these older techniques (some of which were very good) may still have a useful and profitable place in those economies where labour costs are much lower than in the advanced countries, relative to the cost of machines and energy. To take an instance, the manufacture of charcoal from wood was subjected to careful analysis in the USA, both on the question of technology and

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1/ Misc. Paper No. 3 "Report of the Meeting of the Expert Working Group on Industrial Development Programming Data" - United Nations, February 1962.

2/ The last identifiable Leblanc plant (in Iran) was reported abandoned in 1942.

scale of operation. At a wage cost of 1.25 per hour, the advantage was decidedly with the largest and most mechanised plant, but at the wage level of 50 cents per hour, there was found to be comparatively little difference between the 2-1/2-cord kiln, the 7-cord kiln, and the 30-cord battery. 1/ A study by Donald Othmer 2/ indicates that it is still economical to carbonise bagasse for the U.S. market.

A bonus in these older industries is that the practice provides the workers with an experience and an intimate knowledge of the chemical industries generally which is attainable in no other way, and which has its value throughout the whole of industry. Lack of elementary knowledge is one of the most crucial factors in a developing country.

> "Significant savings would result, were the manager to have knowledge of all applicable technologies and equipment. The very wide range of technologies available makes this difficult. Many small industry managers with great ingenuity have designed and fabricated mechanical equipment. The small factories of Asia are filled with machine tools, oil expellers, power looms, etc., all custom made . . . ." 3/

For the purposes of this paper, out of the wide diversity of possible technological processes, it is proposed to select only three for analysis for each of the ten products.

The scale of manufacture of most industrial products can start theoretically from a very small point - little better than a cottage craft - and can extend up to millions of tons per year. Neither

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1/ Martin and Hicks - "The Economics of using low-quality hardwoods for producing charcoal in Tennessee" University of Tennessee, Agricultural Experiment Station Bulletin No. 375, of 1964, page 23.

2/ Unpublished

3/ Stepanek -"Managers for Small Industry" (Glencoe, Illinois Free Press, 1960) page 73.

extreme is of any applicability in this paper. In between there is a wide range of possibilities. Sometimes, clearly demarcated levels of production occur, but generally there is a continuous gradation from the small to the large. It is proposed to cover this range by taking cuts at three points, one in about the middle range, and one each at a considerable distance to either side of this median.

Accordingly, in the examples chosen for analysis, there will be 9 sets of figures under each cost heading. For the purposes of this paper the headings will be as follows:

(1) Capital costs (including both fixed capital as well as operating capital).

(2) Direct production costs and other *pro rata* charges like some selling expenses.

(3) Fixed charges like plant overhead, administrative expenses, some selling expenses, cost of financing, etc. which are not *pro rata*, but not including cost of research and development.

(4) Cost per unit of production.

The field of costs is hedged with many difficulties, and it is an impossible task to quote figures in the abstract with any accuracy. Published figures are sometimes misleading.[1] The lack of specific guidelines also creates difficulties. For instance, an international expert group reported that -

> "One of the main weaknesses of present planning procedures is the limited data available to evaluate individual projects. For a limited portion of industry, private investors and government agencies employ engineers to design specific projects, which can then serve as a basis for evaluating the desirability of a given type of investment. These completed projects

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[1] See, for instance, Havemann - "Direct Iron Ore Reduction for Asia" in the Proceedings of a Symposium on the Iron and Steel Industry in India, published by the National Metallurgical Laboratory, Jamshedpur, India, 1962.

> do not exist for many sectors in which production might be desirable, and in the absence of standards for their preparation they are often excessively optimistic in their estimates of production costs." 1/

Of course, it is possible to quote more dependable figures from the consultants' project reports which are available in many countries, and indeed further study may be contemplated in this field. Even here, however, it must be remembered that the figures quoted by different firms for the same item may be different, and one of the major difficulties of evaluating competitive quotations is to ascertain why there should be such a great difference. 2/ Even if all the quoted figures are seen to form a close cluster around median figures, they are applicable only to the peculiarities of that particular locality under the given conditions and for a strictly limited time period. Even a small variation in any of these pre-conditions may cause quite a wide swing of the prices. 3/ Due to these prevailing conditions the most that can be attempted in this paper is to quote orders of magnitude, as a first approximation. For want of time the results have not been checked against figures quoted in any actual project reports, but this may be done in due course, and the amendments found necessary will be incorporated in a revised edition of this paper, for which there is felt need.*

1/ "Formulating Industrial Development Programmes" - United Nations Publication, Sales No.: 61.II.B.7, of 1961, page 136.

2/ According to Happel "Chemical Process Economics" (Wiley 1958), page 106, 'Prices are fixed by supply and demand rather than arbitrary percentages ..., so that equipment companies with a considerable backlog of orders may be able to enjoy greater profits.'

3/ Thus, the expert group mentioned above, continues to say that "...the study of the performance of factors of production and of the impact of prices upon the choice of the most appropriate technology requires extensive knowledge of local conditions and can be carried out for a given country or region only in the context of actual and anticipated conditions."

* Unfortunately, it has not yet been found possible to undertake the detailed revision as of October 1966.

For the present it is hoped that the orders of magnitude quoted will not be far wrong. Variables in developing economy are, naturally, more uncertain than in the advanced countries, and this has a definite effect. Thus,

> "In considering the development of the petrochemical industry in the developing countries, it is important to examine the differences which could arise from the fact that the plant is being constructed and operated in an industrial atmosphere quite different from that found in the more developed countries. These differences arise for many reasons, including the general lack of skilled labour, the lack of adequate supervisory talent, the existence of Government regulations imposing heavy burdens of licensing and controls, problems associated with the limited availability of foreign exchange and extended delays in plant construction." [1]

Anyone with actual experience of industries being established in developing countries would immediately recognise these factors as present in far too many instances.

A common rule of thumb in the chemical process industries states that if the cost of a given piece of equipment is known at one capacity, the cost of a unit x times as large may be put as $x^{0.6}$ times the known price. Thus if a pump costs $100, the cost of a pump with four times larger capacity would be $\$100 \times 4^{0.6}$, which is about $229. The figure of 0.6 as the exponential factor is not applicable universally, and the possible variation extends from 0.48 to 1.02 for complete plants. [2]

When the whole fixed-capital cost of the plant is taken into consideration (i.e., purchase price, installation costs, housing, auxiliary services, etc.), it would be preferable to take an exponent of 0.7, but here, too, there is a rather wide range. For instance, the exponent for the manufacture of styrene is 0.53, while

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[1] Picciotto and Sweeney - "Ammonia Manufacture from petroleum feedstocks" United Nations Petrochemcials Conference, Teheran, 1964, Paper No. 93, p. 33

[2] Chilton - "Cost Engineering" - (McGraw-Hill, 1963), p. 282

[illegible] 1.0.[1] This is a large range, and [illegible] theoretical computations of the variation of capital costs with [illegible] production must always be taken with considerable reserve. The limitations of this "six-tenths rule" must be recognized. It is applicable only to a variation of scale, keeping all the other factors constant. This is rarely the case in actual factory design. Thus, if one plant is made much bigger than another, it is likely that a different technology or higher standards will have to be adopted, which will cost more pro rata in capital but require less labour pro rata. In such case, the exponent would be greater than if the technological factor remained unaltered. It is this which sometimes makes it possible for a factory at a small scale of operation to be more competitive than a bigger plant in the final cost of the product, especially in cost to the consumer.

Even when the simplest case of all is considered (i.e. all process variables constant except size), there is sometimes not much difference in product cost with size of plant. The following is an example.[2]

TABLE 11

Manufacture of hydrogen by electrolysis

(Cost in dollars per 1000 standard cubic feet)

Capacity (M scfd)	100	500	1000
Raw material	0	0	0
Labour	0	0	0
Power	1.82	1.82	1.82
Other Variables	0.54	0.32	0.22
Depreciation	0.93	0.89	0.86
Other fixed charges	0.45	0.43	0.41
TOTAL COST	3.74	3.46	3.31

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[1] Aries and Newton - "Chemical Engineering Cost Estimation" - (McGraw-Hill, 1955), p.6. The figure higher than 1.00 is very significant.

[2] Harper - "Chemical Engineering Practice" - (Reinhold, 1956), p. 54.

It will be noticed that even with one plant ten times bigger than another, the cost of production is not greatly reduced. If the consumer market is diffused, and the extra production has always to find sales starting from the periphery and working outwards, the additional cost of distribution might well counteract the small reduction in cost of production of the large plant.

Another factor which plays an important part is the size of the individual machines which are used in a particular factory.

> "Where a machine is operated by a single person, whether it be a sewing machine or a capstan lathe, the minimum factory-size at which the numbers of machines and their outputs can be balanced may be quite small, smaller in fact than a firm might require for other reasons.
> ...Where a conveyor belt system of manufacture is introduced, with less flexibility as the price for the higher output potential, a rather larger size may be advantageous."[1]

The availability of second-hand and reconditioned plant and equipment in good condition and at reasonable rates, which is a characteristic feature of modern industry management,[2] introduces an altogether different dimension into the picture. To start with, these plants are generally more labour-intensive than the latest plants - the reason why most of them were discarded. Secondly, they do not require as long a period of amortisation as new plants, and therefore offer much more opportunity for innovation and improvisation. Thirdly, they are generally of smaller size than the latest plants, and thus more manageable. Finally, they are available at

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[1] Luttrell - 'Factory Location and Industrial Movement' - London National Institute of Economic and Social Research, 1962, Vol.1, p.162

[2] "Second-hand Machines and Economic Development" Publication No.15/58 of the Netherlands Economic Institute, Rotterdam, 1958.

very reasonable prices, sometimes for not much more than the costs of dismantling and removal, plus brokerage. Costs with this kind of plant can bear no comparison with conventional costing of new plant, and the eventual results are quite unpredictable. The United Nations has made a special study of this source of plant and equipment.[1]

Theoretical costing figures are useful only within limits, because there are other factors which can have greater influence. A couple of instances may serve to prove the point. A certain firm tendered for the supply of an atomic energy power station within the country. The same firm tendered for the supply of the same plant at the same time for installation in a foreign country, but the price quoted was more than twice the previous quotation. In this case, clearly, theoretical figures of how costs would have varied with mere size of plant would have lacked meaning.

In another similar transaction, three firms submitted independent bids for the supply of large electrical equipment, and it was assumed that the three bids were competitive. It turned out, however, that the three firms were acting in collusion with each other, and in a series of lawsuits the successful contractor was forced to pay damages of $42 million.[2] Theoretical cost figures in the face of this kind of "managed" prices would not be of value.

A third case is still more dramatic. The bridge with the longest span in the world (the Verrazano Narrows Bridge) has been constructed in

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[1] "Report of Expert Group on second-hand equipment for developing countries" (United Nations, 1965, Sales No. 66:II.B.9)

[2] "Electrical World" - 15 June 1964, page 87. See also "Time" of 3 January 1964, page 74.

New York at a cost of about $325 million. In the United Kingdom, an almost identical bridge has just been completed for less than 80 million.1/ The reasons for this great discrepancy are being investigated, but once again, theoretical calculations of costs in relation to size would have had no practical meaning.

A good example of the savings which are possible by the better application of available resources is described in the technical press. A plastics manufacturing firm employed its own staff to engineer an additional factory, and it is said that -

> "The result of such an approach..was built for 20% less than a duplicate plant engineered by standard methods,...and 40% less than most outside engineering firms would charge. And it will hit full capacity within three months of startup" 2/

While such an approach is not always applicable, nor always productive of similar happy results, undeniably there could be great savings attendant upon the exercise of intelligence upon design details. When it is recalled how often a management decision between alternative designs swings upon a few percent estimated difference in fixed capital investment, it can be realised how important it is to select the right approach, and adopt a design and procedure exactly suited to the needs of a given situation.

Each of the selected industries treated in this paper has a short introductory preface on the technology, just sufficient to

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1/ "Engineering News Record", 28 May, 1964, p.88, and 2 July 1964 p.10.

2/ "Small-Plant Savings" - Chemical Week, 18 July 1964, p.97

bring out the highlights. A flowsheet follows for each. Due to limitations of space and other considerations, these flowsheets have been held to the bare minimum, just as an elementary pictorial representation of the technological note. The cost sheets are also limited to one page for each industry, to avoid encumbering this paper. Indeed, many pages would be required for the proper costing of a single one of the ninety alternatives which are illustrated. In the final result, the material, although not exactly at an elementary level, cannot hope to compare with the detailed treatises and costing statements to which reference must be made for more accurate and dependable conclusions.

Previous Studies:

This particular theme received some attention in a United Nations study, made in 1959, covering the nitrogenous fertilizers and glass containers industries.

> "On the assumption that the same technology is used in both industrialized and non-industrialized countries, the structure of costs of production in relation to capacity is studied for the former and transposed to the latter... In the next step, the initial assumption of identical techniques pf production...may be introduced, and the results obtained in the first instance are correspondingly re-appraised....."[1]

The results, however, are described only in general terms, and the actual variations of costs of production are not given. A later

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[1] "Problems of Size of Plant in Industry in Underdeveloped Countrie Bulletin of Industrialization and Productivity, No. 2, p. 7 (Sales No.: 59.II.B.1).

study on the identical subject[1] yields results which appear to differ substantially from these conclusions, but this only goes to show how difficult it is to compare one with another in this field, and how careful one must be in drawing analogies.

General Assumptions:

It is obvious that costs would vary very much from place to place so much that it is impossible to quote figures which would be applicable to all countries under all conditions. It is not safe to proceed on generalizations, for instance that the cost of energy must necessarily be greater in the developing countries. Some of these developing countries have an abundance of cheap natural gas, petroleum products, coal and electricity. Even as regards labour, the relative wage levels are such that a skilled worker in a developing country may do equally good work for one-fifth of the wage drawn by his counterpart in an advanced country. As an illustration, in a recent study of the glass container industry in Central America, it was remarked that -

> "Manufacturing costs in Central America would thus be 17 percent lower than in the United States, mainly as a result of the difference in manpower costs."[2]

The shipbuilding industry in the USA is at a severe competitive disadvantage in world markets for this reason and several large shipyards have been forced to close down.[3] Raw materials are, of course, generally cheaper in the developing countries - sometimes very much cheaper. Thus,

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[1] "Possibilities of Integrated Industrial Development in Central America" United Nations, 1964 (Sales No.: 63.II.C.10).

[2] Ibid.

[3] A spectacular example being the Brooklyn Naval Shipyard, with a labour force of over 20,000, finally closed down in 1966.

for instance, straw for strawboard manufacture was costed at $15 per ton in 1952 (the cost today on an equivalent basis would probably be $20 per ton)[1] but it is the common experience that in many countries straw is available at almost no cost. The straw has already passed through the harvesting, transport and threshing stages, and only handling and further transport are involved. Often $5 is more than adequate to ensure a smooth regular flow of the quantities required. This variation introduces a substantial difference in the final cost figures of the strawboard, and allows the use of simpler techniques with no increase in cost of final product. Similarly,

> "Corn cobs had been favourably considered as a raw material for industrial use,... but it was concluded that it was impossible to collect them at low enough cost....
> A survey by the Northern Regional Laboratory in 1941 laid a sound basis for the industrial use that has followed.
> ...cobs have a negative value on the farm. They must be removed from the barn-lot where the shelling takes place, because they are both a fire hazard and a nuisance. Commercial shellers have been glad to arrange for cob suppliers to provide trucks at farm shelling operations, so that the cobs may be loaded directly into them and hauled away. While neither the farmer nor the sheller receives money for the cobs, this service proved valuable to them."[2]

The difference of cost is of substantial value. Nowadays there are excellent processes for converting sawdust into paper, and this may create some changes in the economies of paper making in developing countries. Some sugar factories burn off their bagasse and prefer to use fuel oil in their furnaces.[3]

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[1] "Raw Materials for More Paper" - FAO publication No. 6 of 1953, p. 73.

[2] Lathrop - "Industrial Utilization of Corn Crop Residues" - Northern Regional Research Laboratory, Peoria, Illinois, publication OP-5485, p. 5.

[3] e.g. in Trinidad

Sometimes the cost of raw materials has an influence greater than economy of scale.

> "Cost variations due to varying raw materials costs can be illustrated by examining the range of prices of natural gas throughout the world. These may run from 5 cents per million Btu's in petroleum producing countries to 60 cents per million Btu's in less favoured areas. On the basis of a requirement of 31 million Btu's per ton of ammonia, raw materials costs would run from $1.55...to 18.60 per ton of ammonia."1/

The authors had previously quoted a theoretically possible saving of $6.62 by increasing the capacity of production from 70,000 tons to 350,000 tons per annum. This possible saving is completely overshadowed by differences due to costs of raw materials.

However, since this paper concerns itself with cost figures, some basic norms are followed, and the following averages are assumed for the purposes of this paper, (remembering that the figures are to apply in the developing countries and are exclusive of excise duties or sales taxes).

1/ Picciotto and Sweeney - "Ammonia manufacture from petroleum feedstocks" - United Nations Conference on Petrochemicals, Teheran, 1964. Paper No. 93, page 30.

TABLE III

Item	Unit	Median cost US $ per unit
Materials		
Coal	billion Btu	200
Coke	" "	700
Fuel oil	" "	300
Natural gas	" "	350
Firewood fuel	" "	250
Electric power	kilowatt-year	60
Steam - 400 psi	million lbs.	600
Water	million gallons	40
Refrigeration (34°F)	kiloton-days	500
Cement	ton	10
Building bricks	1000	10
Roofing sheets	1000 sq. ft.	60
Reinforcing bars	ton	70
		Annual Payments $
Personnel		
Management		
Top		6000
Middle		2400
General Service		800
Supervisory		
Grade I		1600
Grade II		1200
Grade III		800
Operating		
Skilled		1000
Semi-skilled		500
Labour		350

A few more generalised parameters are mentioned here for the sake of interest, although their limitations must be clearly recognised.

TABLE IV

Capital requirements for Chemical Process Industries

A - Fixed Capital, in per annual ton capacity
B - Output/Capital ratio

Product	A	B	Product	A	B
Acetaldehyde	54	4.2	Furfural	310	0.7
Acetic Acid (alcohol)	270	0.7	Glycerin, synthetic	620	1.0
" (acetaldehyde)	50	3.8	Hydrochloric acid	170	0.4
" anhydride	200	1.4	Hydrofluoric acid	210	2.0
Acetylene (carbide)	230	1.1	Lime	6	1.8
Ammonia (synthetic)	250	0.4	Methanol, synthetic	270	0.4
Alumina	100	0.8	Nitric acid "	170	1.3
Aniline	320	1.2	Paper from pulp	150	0.8
Butadiene	1200	0.2	Pentaerythritol	480	1.4
Butanol (synthetic)	580	0.6	Phenol, synthetic	450	0.8
Carbide of calcium	87	1.6	Phosphoric (Dorr)	61	2.0
Cement, portland	21	1.0	" (furnace)	180	0.7
Alcohol from grain	160	1.0	Soda ash	70	0.4
" from molasses	85	1.8	Styrene	600	0.6
Formalin (methanol)	18	4.2	Sulfuric (pyrites)	40	0.6
" (petro-chemical)	170	0.5	" (sulfur)	19	1.2

Source - Peters "Plant Design and Economics",-
(McGraw-Hill/1958) New York

TABLE V

Probable Service life for properties in the Chemical Process Industries

Item	Years life	Item	Years life
Acids	15	Paints and Varnishes	20
Alkalis	22	Pharmaceuticals	20
Aniline dyes	20	Rubber products	17
Brewery products	20	Soap	20
Cement	20	Factory Buildings	50
Glass	15	Office buildings	67

Source - Peters, op. cit.

TABLE VI

Elements of Production Cost

Process	Labour man-hours	Power kwh	Steam tons	Water 1000 gals
Acetic acid from carbide	29	420	3.1	86
Alumina from bauxite	3.7	180	7.0	6.4
Aluminum	16	18,000	?	?
" sulfate	1.5	30	3.4	1
Calcium carbide	3	3,400	?	32
Cement, portland	2.1	100	?	0.8
Alcohol from molasses	3.1	34	6.1	16
Oxygen, liquid, small-scale	48	1,860	?	42
" gas 95%, tonnage	0.2	440	2.2	26
Soda ash, Solvay	3.5	96	2	16
" , caustic, electrolytic	9.5	1,500	?	?
" , caustic, from lime-soda	0.9	88	1.4	2.2

Source - Peters - op. cit.

Before going on to the details of specific industries, it would be instructive to consider a theoretical case. Aries and Newton have given an excellent example.[1] For the details of the calculation, the original work should be consulted, but the results are briefly as follows -

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[1] "Chemical Engineering Cost Estimation" - (McGraw Hill, 1955) p. 249

TABLE VII

Variation of costs with size of plant

	Plant size (Tons per year)			
	100	250	500	1000
Capital cost ($1000)				
Cost of those items which increase by number	100	250	500	1000
Cost of those items which increase by size (6-10ths rule)	152	263	400	605
Total capital cost	252	513	900	1605
Per ton per year $	2,520	2,052	1,800	1,605
Manufacturing costs (cents per pound)				
Raw materials	20	20	20	20
Fixed expenses in units varying with number	8	8	8	8
Fixed expenses in units varying with size	7.5	5.2	4	3
Labour, etc. in units varying with number	16	16	16	16
Labour, etc. in units varying with size	7.1	3.6	2.1	1.3
Total (US cents per pound)	58.6	52.8	50.1	48.3

It would be an interesting exercise to work backwards from the set of figures in the last column, and by a suitable change of technology try to keep the labour figures and the fixed expenses more or less the same, if it were possible. In some industries, at least, this is possible, to within acceptable margins of error. At the United Nations Conference on the Application of Science and Technology for the Benefit of the Less Developed Areas in 1963, it was recommended that -

> "The attention of engineers, scientist and technicians should be drawn to the possibility of selecting capital-saving techniques in the core operations of the technologically inflexible industries... . There exists great scope for research in designing equipment and developing processes to reduce the scale of operations with a minimum increase in operating costs... ."[1]

Left to themselves, the engineers and designers are likely to follow the conventional line.

> "Industrial advisers to under-developed countries...a general pattern emerging from their recommendations shows a steady resort to mechanization...this recommendation is in keeping with their experience. They are far less concerned with the social problems surrounding unemployment. However, as a rule, modifications are possible, and, while techniques may be up to date, the size, degree of capitalization and specialization in a wide range of industries will not for some time match those in developed countries... ."[2]

A practical application of the exponential formula will be found in the Report of the Fertilizer Production Committee of the Government of India. The Committee published figures of the cost of production of various products at various levels of output. The summarized results are as follows:[3]

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[1] Quoted from an article in Bulletin on Industrialization and Productivit No. 7, p. 32 (United Nations, 1964). Some remarkable examples are described.

[2] Mountjoy - "Industrialization and Underdeveloped Countries" - London, Hutchinson, 1963, p. 152.

[3] Ministry of Production, No. 41, 1956, Vol. I, p. 183-184 (figures summarized).

TABLE VIII

Level of production Tons nitrogen per annum	Production Cost per ton of nitrogen			
	Ammonia	Amm. nitrate	Amm. sulphate	Sulphate-nitrate
10,000	145	157	138	124
20,000	126	133	119	114
30,000	114	119	108	109
40,000	107	110	105	105
50,000	103	105	103	102
60,000	102	102	101	101
70,000	100	100	100	100

The deductions to be made from these figures are interesting but are beyond the scope of this paper. It will be seen, however, that the exponent varies quite considerably, taking all at the same index base of 100 at the same output of 70,000 tons per annum.

Industrial Complexes and Estates

The analyses carried out in the annexes are confined only to technology and size of plant. In the determination of economic size and optimum size, however, many other factors have to be taken into account. First and foremost is whether the contemplated plant is to stand entirely on its own, or whether it could be integrated into another already in existence. The independent plant has to provide for everything itself, and has to find all the capital, maintenance, repair and replacement costs in full. The volume of production must be large enough to carry this burden. Where an organization already exists, and has already assumed all the burdens of overhead costs, the addition of another unit will benefit both, because generally the total overhead will thereafter be less, per unit of production. In effect, the additional unit will have the advantages of bigger scale working, without having to pay for it in full. Under these conditions, where the unit under discussion will be concerned only with direct manufacturing costs, while almost all the overhead items are provided by the (presumably larger) parent organization, the cost of the finished product could be quite competitive with the product of large scale industry. It is on these principles that that many plants which require small quantities of chemicals (e.g. sulphuric acid, nitric acid, phosphoric acid, caustic soda, potassium chlorate) are able to manufacture these products in small captive units on a competitive footing. Thus,

> "We have designed, built and operated plants of smaller capacities...which constitute a part of a larger industrial complex where their residue gases are being fed to other sections of the factory. Such special design gives under favourable conditions economically satisfactory results"1/

The principle can be extended in three directions. In the first, a cluster of small units can associate themselves to form a complex of vertically integrated industries which, in the aggregate, can compare with a large monolithic factory. Thus, a small producer of crude oil might derive advantages from refining his crude in his own plant, which could not work competitively entirely on its own, if it had to depend on "foreign" crude. In a later stage, the producer might utilize some of the refinery products to manufacture, say, ammonia, sulphuric acid and ammonium sulphate. After some time he might decide to convert a part of the ammonia into nitric acid and ammonium nitrate. With excess nitric acid he might decide to go in for nitrobenzene, aniline, explosives, dyes, etc. As the complex acquires more and more diversifications, each succeeding unit can be of smaller and smaller

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1/ Konstanty Laidler - "Petrochemical and Carbochemical processes in Poland within the period of 1955-1967" - United Nations Petrochemicals Conference, Teheran, 1964, paper No. 30, p.11. (1965-1967 projected) size, and still remain economic. Thus, a moderate-sized firm states in its catalogue:

> "Sales are in excess of $70 millions a year... .
> The company manufactures nearly 1000 different
> chemical products... ."

It is obvious that with an average of $70,000 per product it would not be economic to run independent plants. The reason why this company is making large profits is because all the small producing units are bound into one complex matrix, which in the aggregate is of large size. Another example is the manufacture of petrochemicals in a small plant of an oil company in Jackson, Texas.

> "In this age of automation, and of huge production units...
> it may seem strange that a small plant in a small company
> manages to survive at all. Nevertheless, some are doing
> very well... .
>
> ...With low overhead, stable labor costs and relatively
> small capital investment, it can often make a pound of
> product for less than a large company, and sell it a
> pound at a time, with personal service, at a profit.
> Carload lots are, of course, a different matter... ."1/

The difference between carload lots and pound quantities in an advanced country might be translatable into domestic product compared with the same article of foreign origin in a developing country.

Let another instance is Danish furniture, almost all made in smallish workshops, but commanding a bulk market around the world, due to advantages of design.2/

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* Name withhold

1/ Brennan - "The future of the Small Company" - Chemical Engineering, 12 October 1964.

2/ Kralj - "Report on Mass Production of Furniture in Israel", Bureau of Technical Assistance Operations, United Nations, New York - 1966, p. 4.

The principle is carried yet further in Japanese industry, which long ago realized how advantageous it was for a small plant to be provided with the overhead facilities of large organizations, so that it could devote all its small-level extrepreneurship to technological matters, management and productivity. The Japanese authorities, therefore, embarked upon a deliberate and calculated programme of integrating large industry and small industry together in alternate stages. To take an instance, in the manufacture of chinaware, there may be the following clearly-defined stages -

A. Quarry infrastructure (roads) and preparation, etc.
B. Winning clays, feldspar, etc.
A. Refining crude minerals
B. Preparing the raw materials
A. Manufacturing the green clay mix
B. Manufacture of shaped products and air-drying
B. Applying under-glaze decoration
A. Biscuit firing
B. Glazing and over-glaze decoration (if any)
A. Glost firing
B. Sorting and grading
A. Packing and despatch

(A. Large-scale production
B. Small-scale production)

The small-scale operators work in a kind of symbiotic relationship with the large-scale operators. The B's are generally different, because each small worker tends to specialise on one line, but the A's may either be different, or a single large factory may be able to assist all the small-scale operations. It is a highly efficient system, largely because of Japan's national discipline and business acumen.[1]

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[1] See also Toyoroki Ando "Inter-relations between large and small industrial enterprises in Japan" - *Bulletin on Industrialization and Productivity*, No. 2, p. 26 (United Nations Sales No. 59.II.B.1).

A further development in this direction is the creation of "industrial estates" i.e. where common facilities and services are centralized and distributed to many small units on a fee basis.[1] These common facilities, utilities and services may include:

- Electricity, gas, mechanical power
- Water, sewerage, drainage
- Transport, storage and communications
- Laboratory services
- Personnel recruitment, management and training
- Accounting, auditing, banking and legal assistance
- Technical consultancy advice
- Maintenance and repair of machinery and equipment
- Storage and supply of spare parts, raw materials, etc.
- Marketing of finished products
- Housing, hotels, canteens, cafetarias
- Medical wants, health insurance, preventive medicine
- Accident insurance.

This list is not exhaustive, but goes to show that there are many functions which can be handled by a central body. The management of such industrial estates could be either by the State or by a co-operative or purely by some private profit-making effort. Such a development was foreseen in a United Nations study which mentioned that -

> "These processes (that is, ancillary processes like storage and inventory handling, transport within the plant, loading and unloading, maintenance and repair, laboratory services, etc.) may often be subject to considerable technological flexibility as regards factor substitution which is of particular importance to less developed countries... .
>
> In the initial stage of the projects, such matters will have to be handled on a tentative and experimental basis, until sufficient information has been accumulated to permit a systematic approach."[2]

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[1] A. Molinari "Some Controversial Questions Concerning Industrial Estates" published in "Industrial Estates in Asia and the Far East", p. 415 (United Nations Sales No.: 62.II.B.5).

[2] Report of the Meeting of the Expert Working Group on Industrial Development Programming Data, Miscellaneous Paper No. 3 of February, 1962, p. 8. See also in this connexion Bredo - "Industrial Estates" - (Glencoe, Illinois, 1960), p. 64.

One of the effects of an industrial estate is to allow the small industry to reduce its administrative and managements overheads to the same level as prevalent in large- scale industry.

> "Most of the economies of scale derived from the facilities of economic overheads are independent and irrespective of the size of the plant and can be provided to small plants by surrounding them with appropriate agencies which can take over the functions of economic overheads and perform them as common services to small production units.... .
>
> Technological research institutes can undertake the tasks of improving the production and design of products and developing new processes and products."1/

The subject was recently discussed in an African context.2/

Action on the part of governments also sometimes yields the same effects as economies of scale. Preferential purchases of requirements from small industrial producers reduces the sales costs to perhaps below what it would cost a large producer. Lower wage rates are sometimes permitted to be paid in small industries, and sometimes there is exemption from other requirements, such as contribution to a national employees' provident fund, workman's compensation insurance, overtime escalation, etc., which costs have to be met in full by large industry. Thus, the simple mathematical relationships which are so often constructed to demonstrate the differences between large industry and small are often distorted out of all recognition by these everyday actions on the part of governmental authorities. The net result is unpredictable, and it may become more profitable to work on small scale than on large. Indeed, a school of thought asserts that there is now so much solicitude for the small industrialist, and so many subventions to small industry, that it acts as a deterrent to the establishment of industrial establishments on a large scale.

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1 "Plant size and economies of scale" - Paper presented to the Committee for Industrial Development, Fourth Session, Document E/C.5/41, para. 8.

2/ United Nations Document E/C.5/70.

Only one more distortion of the simple mathematical model will be mentioned, and that is the private middleman or managing agent, the person who provides all the raw materials and services, and agrees to buy all the finished products at guaranteed prices. This kind of operator is very common in some countries, especially in the traditional crafts and occupations, like the manufacture of textiles, cooked foods, matches, salt, cigars, and a host of other such articles. The middleman factotum, in effect, is the nexus between all the producers and their means of production, and his services are tantamount to a multiplication of the size of the individual producing unit, at any rate, in respect of certain services. A good comparison of the relative advantages and disadvantages of large-scale industry vis-a-vis the small industry was recently published.[1]

Foreign Exchange

Balance of payments difficulties between nations have always existed, but is now common talk among the entire public. The "free" or "floating" (sometimes labelled "black-market") exchange rate of a country's currency is often taken as a truer indication of the state of the country's internal economy than the official rate. Although official transactions are nominally carried on at the official rate, this is really a bookkeeping device, because in some indirect manner the transactions finally do get adjusted at the "floating" rate. Currency controls have not stopped the marginal transactions which determine the free rate of exchange. Every import tends to widen the gap between the official rate and the floating rate of exchange. Thus, in the costing of an indigenous product vis-a-vis an import, there is no point in costing the local product at the official rate for indigenous currency, while the foreign article must be paid for in foreign exchange. Both must be reduced to the same datum and costed, either in foreign currency or in indigenous currency, at the free market exchange rate. It will surprise many to find the wide variety of products which can thereby be manufactured within a country at "economic cost". Professor Jan Tinbergen, discussing

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[1] Staley and Morse - "Modern Small Industry for Developing Countries" - McGraw Hill, New York, 1965.

this problem, remarks that -

> "A better insight into the real consequences for the economy as a whole of certain investments will, therefore, be gained if, instead of market prices, accounting prices are applied, implying, inter alia, that labor costs are assumed to be considerably lower than market wages indicate. This may lead to the execution of projects not attractive to the private investor, but attractive according to the accounting price."1/

Levels of Sophistication

Mechanization and automation are two separate sciences, but both have the effect of replacing human beings. As a rough definition it might be said that mechanization replaces strength, while automation replaces intelligence. The extent to which these trends can be given scope naturally depends upon the relative cost of machines versus men. A machine has to bear capital cost, and charges for maintenance, repair, fuel, lubrication, waste heat disposal, etc. A man has to be paid wages, bonus, social security, allowances, incentives and many other contributions in cash or kind or services. He has to be provided with sanitary facilities, medical care, refectories, recreation, meeting hall, etc. which are not required for machines. One set of obligations and responsibilities have to be weighed against another in determining their respective worth. There are great differences between one country and another. An American firm might be willing to invest $200,000 in capital equipment, to eliminate the need of one man, whereas at the other end of the scale, in some countries it is not worth investing $200 on machinery or equipment to replace a human being. The final criterion would normally be the effect on prices of the manufactured goods. In this field, the movement has naturally been guided by the developments taking place in advanced countries, where large plants are completely controlled from centralized points. Thus, a steel plant with an output of one million tons per annum can be worked with just 28 persons per shift. Such highly automated factories would be out of place in countries where wage levels are much lower: yet there is comparatively less expertise available in devising simple technologies to sui

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1/ Tinbergen - "The Design of Development" - Netherlands Economic University, 1956, p. 47.

these developing countries. In the result, neither does the advanced technology (which requires strong and extensive supporting structure) work well, nor do the developing countries have an equally productive and useful alternative to take its place. There is a gap here which has to be filled. Fortunately, many countries have now realized the existence of this gap, and are anxious to create a trend of intermediate technology (also termed "appropriate technology") to fill it.

> " he present consumption of corrugated roofing sheets... would not be sufficient to justify mechanized manufacture of asbestos-cement products (which can also be made almost entirely by hand, incidentally). However, corrugated sheets sell at quite high prices, primarily as a result of high freight costs. Consequently, it is conceivable that a mechanized asbestos-cement industry can be developed even for the present small market."1/

Bigness is occasionally associated with progress and advance, though should not necessarily be inter-linked.

> "Leaders of under-developed countries concerned with promoting industrial growth would be well advised to study Switzerland. This highly industrialized country has one of the highest living levels in the world. But its industries are decentralized to a remarkable degree. There are no big industrial agglomerations as in Britain or Germany; the large cities are commercial rather than industrial. There are hardly any slums. About every tenth factory worker owns and cultivates a small farm. There is a very even distribution of wealth. The country has no important sources of coal or iron, or other raw materials sometimes thought to be essential in an industrial country. It has no basic heavy industry, not even a single blast furnace. Its manufacturing is diversified and carried on mainly in small plants."2/

1/ Tenenbaum - "Industry in British Guiana" - Continental Allied Co., Washington, D.C., 1962, p. 59.

2/ Eugene Staley - "The Future of Under-developed Countries" - New York, Harper, 2nd edition, 1961, p. 306.

Even in the iron and steel industries, popularly regarded as economic only on a very large scale, a leading expert has this to say -

> "In a few quarters, the economies of iron production in small scale plants have been looked askance... the indigenous fabrication of a small iron blast furnace... can be undertaken much more readily... than... a heavy integrated iron and steel plant... ."1/

Accuracy of estimates

There is such a thing as excessive refinement in cost estimating. Some estimators have a practice of calculating to six or seven significant figures, when the normal variations of extraneous conditions could cause a swing in the very first or the second significant figure, thus rendering the rest of the figures of no significance. Instances are numerous in the developing countries, but only two will be cited. The first is an urea plant in Taiwan. According to the report 2/

> "It was expected that about US $10 millions per year of foreign exchange could be saved when the TFC Plant No. 6 is placed in regular operation. Today, as a result of lower fertilizer prices in the international market, the annual saving of only 5 to 6 million dollars of foreign exchange has been realized...."

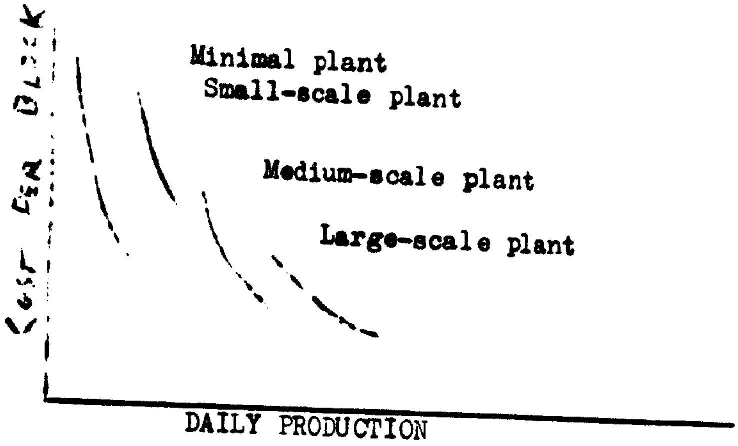
Thus, even before the plant had been completed, the basic assumptions upon which the policy decisions had been made had radically altered. In an instance in the USA, the successful tenderer bid 40% below the consultant's estimate.3/ There is little point, therefore, in calculating estimates to beyond the first significant figure, and estimates may even be treated as orders of magnitude with no loss of dependability.

1/ Nijhawan - "Dissertation on the occasion of the presentation of the Bhatnagar Memorial Award" - National Metallurgical Laboratory, Jamshedpur, India, 1966.

2/ "The manufacture of Urea in Taiwan" - Paper No. 42 presented to the ECAFE Conference on the Development of the Fertilizer Industry in Asia and the Far East - Bombay, 1963.

3/ "Engineering News Record", (October 29, 1964) p. 16.

The second example is a training manual prepared by the Economic Commission for Latin America, in collaboration with the United Nations Technical Assistance Administration. The example takes cost estimates (prepared for the United States' Department of Trade and Agriculture) for a cement-block factory and indicates the results in for form of graphs, as follows:[1]



It is seen that there is a considerable degree of overlap, and that the cost per unit can swing to a wide extent. The output of a small plant working at high capacity can be sensibly <u>less</u> than in a large plant working below capacity. This may sound almost like a truism, but it is surprising how often the losses on a large plant working below full capacity are overlooked in comparison with the small plant. This instance (and others of a like nature) show that excessive dependence upon cost estimate projections is not a completely safe basis for management decisions. Of course, such projections must be made, and must be as accurate as the available data permit, but other factors, not assessable in value terms, must also be given due weightage. One such consideration is the intangible benefits of starting operations on a comparatively modest scale, and through comparatively simple technology.

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[1] UN "Manual on Economic Development Projects" - (Sales No.: 58.II.G.5) New York, p. 159.

However careful, detached, and objective an investigation may be, it is in the nature of things that there is a wide range of possibilities, and it would be unrealistic to quote a single matrix of figures as the only applicable results.

> "Because the product mix may have a marked effect on cost, a given value of output may be associated with several different cost levels.... For this reason, the simple relationships drawn in break-even charts no less than in the textbook cost curves, can be very misleading."1/

The developing countries are coming to realize the value of such alternative technologies.

> "The Committee came to the following conclusions:
>
> (iii) That the decentralized expansion of the industry through small localised units would present a more effective solution for the landlocked areas of the region....
>
> (vii) That there is need for promoting technical research to develop plant units that could best be adapted to the specific needs and problems of the region. It was realised that through independent study and research, economies could be realised and wasteful expenditures avoided, both in fixed investments and in operating costs....
>
> Requests the Executive Secretary of ECA
>
> ...
> (b) To undertake appropriate studies in Mauritania on the possibility of the utilization of gypsum reserves for the cement industry of the sub-region...."2/

1/ Bruce Williams - "Notes on Cost and Capacity" - Manchester School of Economic and Social Studies, Vol. XXIX (1961) p. 289.

2/ "Report on the Conference on Industrial Coordination in West Africa", E/CN.14/324, Annex VIII.

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Case Study

Distillation and Gasification of Wood and Coal

1. Wood: Mature trees in the living state may contain 20 to 50% of moisture. When trees are felled and the wood is air-dried, the moisture content may come down to anything between 10 and 20%. Its gross calorific value would lie between 13 and 15 million B.t.u. per ton (2240 lbs.). The net value may be 1 to 3% less, depending upon its moisture content. If the wood is a conifer, its calorific value would be rated 3 to 10% higher, because of its content of resins and gums.

2. When wood is heated in the atsence of air, decomposition takes place, yielding a charcoal residue, and various compounds in liquid and gaseous form. If the object is to get a lot of gas, the pyrolysis (decomposition by heat) is effected at high temperature (1000 - 1200°C) whereas if the producer wants more charcoal and liquids the process is conducted at lower temperature (300 to 350°C).

3. Possible yields are as follows per ton of dry wood,

	lbs
Gas	675 to 1,800
Tar	70 to 250
Oils	50 to 300
Liquor	600 to 700
Charcoal	400 to 800

Specific products found in the products of the distillation are

- Carbon dioxide
- Carbon monoxide
- Hydrogen
- Methane
- Ethylene
- Methyl alcohol
- Acetic acid
- Acetone
- Methyl acetate
- Phenols

and a variety of other products of lesser value.

4. Pyrolysis of wood to charcoal has been known from prehistoric times and is still being practices on quite an extensive scale, both in developing countries as well as the advanced countries. It is still an industry of considerable importance, especially in areas and among people who do not have a wide range of industrial opportunities available to them.

5.1 The earliest means of wood carbonisation was to pile up wood on the ground, set fire to it, and after the burning had proceeded to a certain extent, to quench the fire with water or wet earth. This could be done on any scale, and this range of scale (without variation of technology) is to be seen even to this day, from a few pounds per day to many tons. To quote from a recent recent report -

> "The simplest treatment of wood is to coke it in the partial absence of air, or to distil it in the complete absence of air so as to drive off volatile substances and leave a more or less pure carbon called charcoal. This is already being done on a significant scale in British Guiana. A crude charcoal is produced by piling up wood in the forest, covering it with earth, igniting the wood, and allowing it to smoulder for some months. Around 5000 tons of crude charcoal, containing a relatively large share of the original volatile substances, are exported to the UK and Canada and to Barbados"1/

A modification was to conduct the pyrolysis in pits. This increased the labour of handling raw materials and finished products, but also conserved heat and reduced losses of charcoal: whether it was profitable to do so depended upon the circumstances of the case. Where wood comes very cheap, as for instance in clearing of forests for land cultivation, there is not much profit in employing scarce and costly labour to increase efficiencies merely to squeese out a few per cent more of charcoal.

1/ Tenenbaum - "Industry for British Guiana" - Continental Allied Co., Washington, D. C., 1962, p. 56.

5.2 Another modification was to cover the wood with wet turf or sods, leaving a few holes here and there for applying and damping down the fire. An excellent degree of control was thereby achieved, again at the expense of considerable labour in covering the whole surface to be almost airtight, and in managing the burn. The next improvement was to conduct the pyrolysis within enclosures or kilns of durable materials like bricks and mortar or steel, assembled each time or of permanent construction. These kilns were designed and operated almost exactly on the lines of the kilns used for firing earthenware, and the same variety and ingenuity of kiln design penetrated the charcoal industry. They are now highly specialised.

6.1 Thus, five technological process groups prevail in the wood distillation industry.

1) Crude open-air process, yielding only about 10-15% of charcoal, of uneven quality.
2) Batchwise pyrolysis in scientifically designed kilns without recovery of any by-products.
3) Batchwise by-product kilns in which arrangements have been made for recovery of by-products.
4) Continuous by-product recovery carbonisation process, in which the raw wood is stacked in buggies moving on rails.
5) Continuous by-product recovery carbonisation in buggies which remain static in the kilns while the initiating heat travels.

There are, of course, many variations, which can be adopted or introduced in each of the foregoing.

6.2 The primary distillation of wood would leave charcoal as the residue, and all the other components are volatalized off. Where by-product recovery is practiced, this would involve separate processing stages.

6.3 Charcoal, for the most part, is sold as such. However, it is quite possible to gasify the charcoal by the use of air or steam or hydrogen or carbon dioxide or mixtures of these and other gases, and this can be done either in the same kilns in which the wood is carbonised (indeed it can be done simultaneously) or in separate gasifiers. The subject is of particular importance, because of the spectacular advances made by petroleum chemistry in manufacturing chemical products from gasified petroleum. These techniques are in many cases adaptable to the gases from the gasification of charcoal as well.

6.4 Coal has been mentioned in the heading of this analysis only to indicate that the same technological principles are applicable to it as to wood distillation. Even the kilns are interchangeable.[1] However, it is of much greater importance and complexity. So much work has been done on coal distillation and the availability of data has reached such proportions that it would not be fair to the industry to discuss it sketchily, which is all that is possible in this paper.[2]

6.5 There are three main sources of raw materials for the world's chemical process industries involving carbon compounds, and they are

Coal
Oil
Agricultural products

For centuries coal had been undisputedly supreme, and agricultural products (chiefly fermentation of cereals and yams) were a subsidiary source. Today petroleum is undisputed leader, and over 70% of the world's organic manufactured products are from this source. The influence of petrochemicals has been so great that it is now possible that its real value has become somewhat over-rated. Actually, coke gasification can give a gas as full of synthesising possibilities as natural gas, and liquefaction of coal can

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[1] See "Charcoal Production, marketing & use" - (U.S. Dept. of Agriculture, Forest Service, FPL Report No. 2213) p. 11.

[2] See Jones - "Coal as a Raw Material" - (Royal Institute of Chemistry, London) Monograph No. 3 of 1956.

yield a liquid as valuable in the process industries as naphtha.1/

> "...solid carbonaceous material (are) converted into synthesis gas by use of the classical water-gas reaction....
>
> In 1948, roughly 50% of the nitrogen production of the world derived its hydrogen from water-gas, but by 1955 this was reduced to approximately 13%....
>
> Depending upon the availability of raw materials, this system still has a place in modern ammonia manufacture, even though the investment required is much higher and in general the manufacturing costs are much higher... the cost of such a plant would be almost twice the cost of an equal size steam-hydrocarbon reforming plant and the total manufacturing cost would be something over 1 1/2 times...."2/

This statement is, of course, subject to qualifications. It is quite possible to adapt technology to reduce the initial capital investment, and it is also necessary to take the extra value of foreign exchange into account. Furthermore, the hydrogen plant can manufacture hydrogen for a variety of purposes, some of which may be more profitable than ammonia, and thus reduce the eventual cost of hydrogen. Summing up, it is worth investigating solid fuels if they are readily and cheaply available to the country.

> "Petroleum-based naphthalene, heavily dependent on fluid-bed phthalic anhydride for survival in a murderous tug-of-war with coaltar naphthalene and ortho-xylene, may be dealt a death-blow within months....
>
> Petroleum naphthalene is judged uneconomic at present in competition with coaltar naphthalene....
>
> One petronaphthalene plant is believed shut down, and another has switched to making other products as a result of the keen competition...."3/

1/ See Jimeson - "utilizing solvent-refined coal in power plants" - Chemical Engineering Progress, 1966, Vol. 62, No. 10, p. 53

2/ Reed and Sloan - "Nitrogenous Fertilizers as a Petrochemical Operation" - Petrochemicals Conference, Teheran, 1964, Paper 37, p. 9

3/ <u>Oil, Paint and Drug Reporter</u> - 28 December 1964, p. 1.

6. It can be readily appreciated that all the possible variable elements can be combined in many different ways so that a number of combinations can be devised. Only three possibilities are taken up for illustration here. They are -

A. Carbonisation of wood (or coal) in open air by purely manual means with charcoal (or coke) as the sole product.

B. Batchwise intermittent pyrolysis of wood (or coal) in properly designed masonry kilns, with charcoal (or coke) as the sole product.

C. Continuous pyrolysis of wood (or coal) in buggies stacked within masonry tunnel, with moving heat, with the object of recovering charcoal (or coke) and by-products.

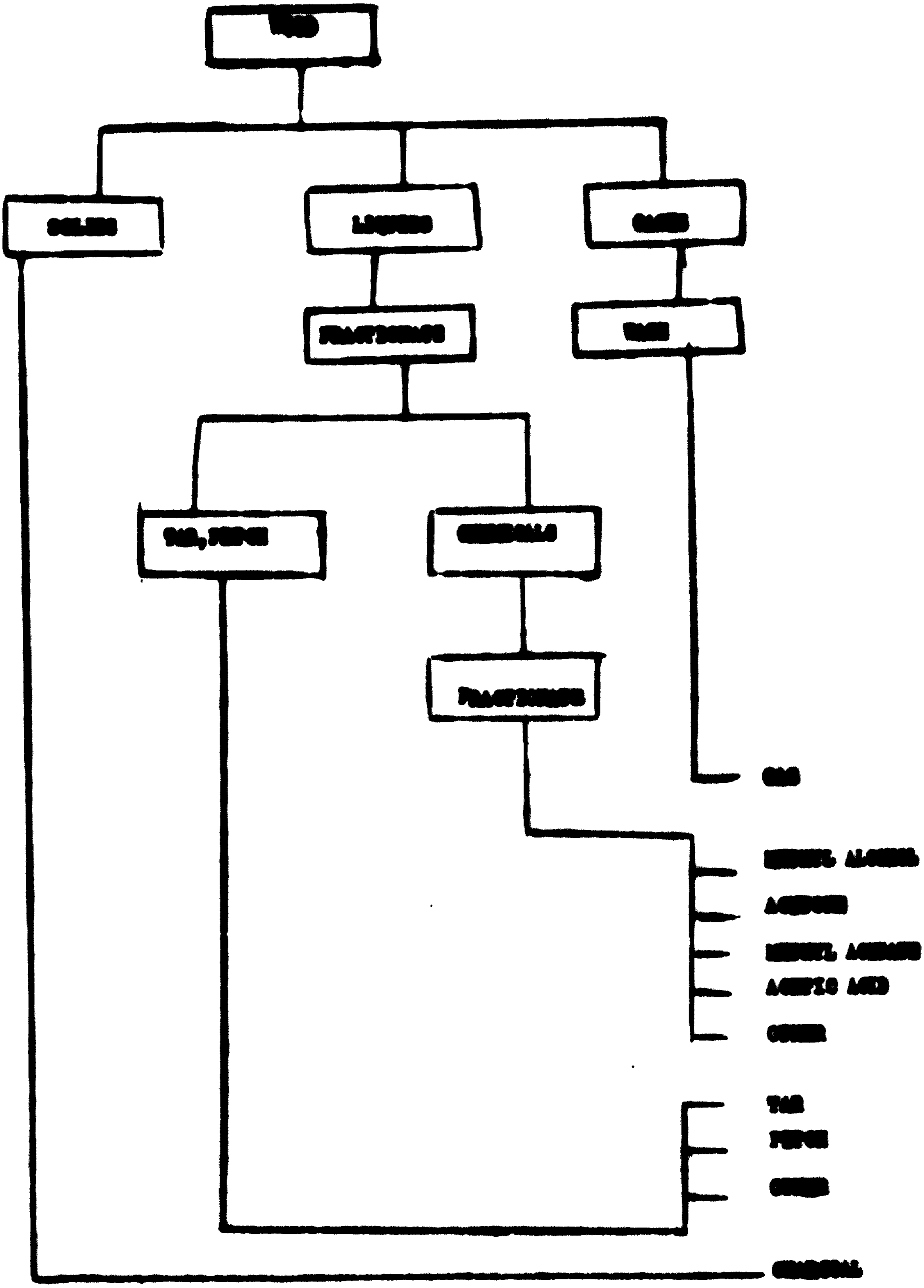
The costing will be done on the charcoal (or coke). If by-products are recovered, credit will be allowed at standard rates, to avoid having to impute a pricing structure for a variety of products. It is assumed that the work is done as a sideline of a managed forest or plantation, in which wood is available regularly and continuously at low costs. Thus for instance, a rubber estate of 10,000 acres in extent, with a replanting cycle of 20 years, and 250 working days per year, could yield about 100 tons of wood per working day. This wood will be valued on the estate at hardly 20 cents (US) per ton - often it will be available free of cost, although, of course, no commercial project will be based upon the availability of the principal raw material free of cost.

7. In this case, the scale of operations would be roughly as follows:

	Tons firewood per day
Small (individual independent operator)	5
Medium (individual co-operative operator)	50
Large (salaried workers)	500

8. The following is an attempt to classify the costs for each type of selected technology at each of the selected operational levels. It will be immediately apparent that this is a process which is cheaper to operate on a small scale by comparatively simple technology. The cost to the end-user is, of course, a different matter.

WOOD PYROLYSIS - FLOWSHEET



Tentative Costing Statements
Pyrolysis of Wood

Item / Process	A			B			C		
Scale	S	M	L	S	M	L	S*	M	L
Capital ($ 1000)									
Fixed	1	4	20	2	6	30	*	15	80
Operating	1	3	15	1	3	12	*	5	20
Sub-total	2	7	35	3	9	42	*	20	100
Manufacture ($/ton)									
Materials	2	3	4	1	2	3	*	2	3
Utilities	-	1	1	-	1	1	*	2	2
Wages	3	4	5	3	3	3	*	4	4
Supervision	-	1	1	-	1	1	*	1	1
Fixed charges	-	1	1	-	1	1	*	3	3
Plant overhead	-	1	1	-	1	1	*	2	2
Sub-total	5	11	13	4	9	10	*	14	15
General ($/ton)									
Administration	-	1	1	-	1	1	*	1	1
Packing	-	-	-	-	-	-	*	-	-
Sales	-	1	1	-	1	1	*	1	1
Other	1	1	1	1	1	1		2	2
Sub-total	1	3	3	1	3	3	*	4	4
Overall cost	6	14	16	5	12	13	*	18	19
Credits	-	-	-	-	-	-	*	5	8
Cost per ton ** Charcoal $	6	14	16	5	12	13	*	13	11

* **Technology inapplicable at this scale.**

** Co-products costed at same sales price in all the analyses.

Note: **Costing is difficult because so many of the items are in the region of $1, and distinctions are hard to make.**

Wood distillation

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The Cement Industry

Case Study

1. Cements are of different kinds. It is proposed to limit consideration in this paper only to the inorganic cementitious materials having strength of the same order as Portland cement. This group would include

Portland cement
Aluminous cement
Magnesia cements
Iron oxide cements
Plaster cements
Soluble silicates
Other miscellaneous cements

All these have a place, a function and a value in the world of today. Some countries have realised the value of such cements in a growing economy. India, for instance is encouraging the manufacture of puzzolan and slag cements.[1]

2.1 Portland Cement

This is a cement which was evolved over the past 150 years and is today the most commonly used of all cementitious materials. It is composed of silicates and aluminates of calcium, with small quantities of iron oxides and other less important ingredients. It is manufactured by intimately mixing a source of lime (limestone, chalk, marl, gypsum) with clay and (if need be) with sand and iron ore, and calcining the mixture to incipient fusion at a high temperature. The product is rapidly cooled and finely ground. During the grinding it is usually treated with gypsum or steam to extend the setting period, which would otherwise be too short for practical building construction.

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[1] A reference to the Indian Journal of Industry and Trade for July 1964, turns up two items, one on page 1235 announcing the manufacture of nearly one million tons of slag cement per annum and the other, on page 1299, mentioning the license issued during that month for the manufacture of 120,000 tons per annum of puszolana cement.

A paper by Chopra on Pozzolan Cements is expected to be published early in 1967 by the UN Centre for Industrial Development.

2.2 The composition and structure of the cement has to conform to several standards which have been laid down, and hence the raw materials have all to conform to certain limits of non-functional ingredients. Many limestones and other calcareous raw materials fail to pass these limit tests, and have to be left out of account in calculating availability of raw materials for a cement industry.

2.3 The real commercial production of what is today considered to be portland cement was started by Joseph Aspdin in the 1820's. By the 1850's it had become popular, and the modern era of portland cement began. As of today, nearly 400 million tons are being made annually in the world [1], and even then the demands are not being met in full in several countries.

2.4 The technology of portland cement manufacture involves -

(1) preparation of raw materials
(2) manufacture of clinker or sinter
(3) grinding.

For preparing the raw materials there are two main processes, wet and dry, with variants in each.

2.5 Clinkering is the heating of the well-mixed materials to the point of incipient fusion. This can be done by holding the mass at about 1350°C for a prolonged period, or by heating it up briefly (say 15 or 20 minutes) to 1450°C. There are two principal processes for accomplishing the desired object.

(1) In one process, the mass of material keeps moving, while the heating zones are stationary. These processes include the rotary kiln, the vertical static kiln and the horizontal tunnel kiln with cars.

(2) The alternative is to keep the mass stationary but move the fire. The best known method is the continuous Hoffmann tunnel ring kiln, without cars.

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[1] See any Minerals Yearbook, (published annually by U. S. Government, Supt. of Documents, Washington, D. C.) Vol. I - Chapter on Cement.

All these methods have their advantages and disadvantages, too numerous to mention here.

2.6 The fuel originally used in cement manufacture was charcoal, but as sources of charcoal dwindled, the industry became more and more dependent upon coal and coke. The ash residues of these fuels were not very harmful indeed, they sometimes permitted a higher proportion of clay to be used, with corresponding greater output of cement. In course of time, the inconvenience of using coal forced a switch-over to fuel oil, and this is the most popular fuel in the industry today. Coal, however, is still widely used, and under suitable conditions charcoal is still favoured. There is a large cement factory in Tororo, Uganda, using wood charcoal as fuel, and in a recent project for Brazil, the recommended fuel is wood charcoal. [1] Developing countries could thus still consider wood charcoal as a positive possibility.

2.7 Once the raw meal has been sintered, the product is ground fine. Any regular size-reduction device can be used, but at present the industry has standardized on the ball mill, rod mill and tube mill. Under certain conditions, the stamp mill and the hammer mill have their place, especially for the softer clinkers of the static process. Neat cement sets very rapidly, and during the grinding it is customary to add gypsum or steam in pre-determined amounts to draw out the setting period to a practical desirable extent. In some cases it transpires that steam is cheaper than gypsum.

3.1 The alumina (or aluminous) cement are those in which there is a preponderance of alumina over all other ingredients, chief of which are lime, silica and iron oxides. The alumina cements are generally manufactured by completely fusing a mixture of bauxite (or laterite), limestone (or chalk), clay and sand. The melting can be accomplished in a reverberatory furnace or in a rotary kiln or in a continuous tunnel kiln. Any source of energy can

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[1] Brazil Project Feasibility Studies and Preliminary Designs - University of Brazil, Ceara, Report No. 63-58, 1963

be used - gas, coal, coke, oil, electricity, etc. Firewood can be used to provide 70 - 80% of the heat requirements.

3.2 When the mixture is melted, it is cast into pigs or quenched into granules, and ground up to a powder, which need not be quite as fine as with portland cement.

3.3 If the raw materials (for alumina cement) are ground very fine and mixed very well, it is possible to convert the mixture into a cement by prolonged heating at a temperature which is just short of melting but sufficiently high for incipient fusion. 1/ This process simplifies manufacture considerably, and reduces cost substantially. The product is much softer than if the mixture had gone through the melting stage, and is therefore easier and cheaper to grind.

3.4 The high-alumina cements possess certain properties in exceptional degree. They set more slowly than normal portland cement, thus allowing more time for the mason to lay his mortar. However, once setting is over, hardening takes place very rapidly, and for most practical purposes the structure can be put to use within 24 hours. Aluminous cement mortar is stronger than portland cement mortar, and is more resistant to seawater and heat. Difficulties are that it requires more care on the part of the mason, and that it should not be laid in hot climate, unless special precautions are taken.

3.5 This product is widely used in advanced countries, but not in developing countries. Since the raw materials are so readily, plentifully and cheaply available, and as the manufacture is so simple, the process should be of interest to developing countries as well.

1/ Smith Bracewell, "Bauxite, Alumina and Aluminum" - (London, HMSO, 1962, No. 88/2204, p. 29

4.1 Magnesia cements are of two main types. One type is the ordinary portland cement loaded with a high proportion of magnesia. In ordinary portland cement, magnesia is usually regarded as deleterious, because it expands on hydration. Cements which contain more than about 4 or 5% of magnesia are subject to slow deterioration over the years and may be completely disrupted in 20 or 30 years' time. But as the content of magnesia in a cement increases, the character of the cement changes, and at a certain stage the magnesia becomes a beneficial ingredient. At a point of about 20% magnesia, the cement is quite satisfactory for most purposes. This cement, called Rosendale cement, was in great demand in the USA before the day of the portland cement rotary kiln.

4.2 Today magnesia is known to be a harmful ingredient in ordinary portland cement, and every Standard Specification throughout the world strictly limits the proportion of magnesia in portland cement. But reversal of the harmful characteristic is not generally taken into account. In the result, many possible sources of limestone are neglected, disregarded or barred because of supposedly excessive content of magnesia. The manufacture of magnesian cements would render useful billions of tons of otherwise valueless limestone around the world.

4.3 The other type of magnesia cement is that produced by the combination of a lightly-calcined magnesium oxide with magnesium chloride or magnesium sulphate. The resultant is a magnesium oxychloride (called Sorel cement) or oxysulphate. It is stated that this cement is one of the strongest cements known 1/, with several times the binding power of portland cement. The use of magnesium oxysulphate in the manufacture of asbestos-cement sheets is increasing. 2/

1/ Martin-Industrial Chemistry, Crosby Lockwood, London, 1935, Vol. II, part 2, page 137

2/ Oil, Paint & Drug Reporter, 19 October 1964, p. 31

4.4 Countries in tropical regions with access to the sea will find this cement of particular interest, because magnesia, magnesium chloride and sulphate can be readily and cheaply manufactured from seawater. In combination with processes for recovering fresh water from seawater and recovery of salt by solar evaporation, the manufacture of oxychloride cements possesses especial attractions. The technology is quite simple. The residue of solar salt manufactories (called bittern) is treated with calcium chloride (to convert magnesium sulphate to magnesium chloride) and then one part is treated with lime to precipitate the magnesia. The remaining part yields magnesium chloride. In one of several alternative processes, seawater direct from the sea is purified and treated with lime to precipitate magnesia, which is washed, filtered, dried and lightly calcined. Millions of tons are used in the USA, Germany, France and other countries as oxychloride cements for industrial and domestic flooring, artificial marble, grindstones, statuary and other building purposes, but its use in developing countries has yet to grow, largely because it is not well known.

5.1 Iron oxide cement. This is a portland-type cement containing a high proportion of iron oxide. It is manufactured by using low-grade iron ore in place of clay in the usual portland cement process. The cement is very dense, and is much slower in setting than portland cement, and is hence of special value for several uses. It is widely used in Germany.

5.2 Many limestones in developing countries are ignored or neglected on the ground that the iron content is excessive. The manufacture of iron cement will enable these limestones to be put to profitable use.

5.3 There is also another high-iron cement manufactured by grinding up blast furnace slag with a small quantity of cement or lime. The slag by itself has poor cementitious properties, but the mixture makes an excellent cement. The technique is of special value to developing countries which have (or intend to establish) an iron smelting industry and do not have much use for the slag. Under such conditions, a cheap cement can be manufactured, which would be a substitute for portland cement for many purposes.

6.1 When gypsum (calcium sulphate dihydrate) is lightly heated, it loses 75% of its water of crystallization, and the resultant product, called plaster of paris, possesses cementitious properties. It is widely used as a mortar, as surfacing plaster, for taking casts, and to make moulds. However, it is not ordinary plaster of paris which commands chief interest as cement, but dead-burned gypsum.

6.2 When gypsum is burnt to red heat and subjected to various treatments with alum or borax or soda sulphate or carbonate, various kinds of hard and durable cements are formed, many of which used to be marketed under different proprietory brand names. These products ought to command considerable interest for countries which have large deposits of gypsum.

7.1 Of the soluble silicates, the most important are sodium and potassium, the former being preponderant. These soluble silicates can have a very wide range of composition, and hence a wide range of properties. Some silicates harden to simulate glass. There are more than 50 standard identifiable silicates of sodium alone. 1/ The soluble silicates are excellent cements for plywood, paper, cardboard, metals, coal, etc. They can be used quite well in masonry, and in fact are used in the linings of brick, tile and ceramic kilns. Normally they cannot compete in price with portland cement, but if the latter is too costly (a frequent experience in some developing countries) and if soda ash is cheaply available,* the manufacture of the soluble silicates for some cement uses may be a commercial success.

7.2 Chemically the conventional manufacture of sodium silicate involves the heating of sand with soda ash or caustic soda or a mixture of the two. Several processes are known.

(1) Sand may be treated with caustic soda and put under steam pressure. This process is especially valuable for extracting silica from the ash of agricultural residues, like rice husks.

(2) A mixture of sand and soda may be fused on a fixed-bed reverberatory furnace or tilting-bed open-hearth, or in tanks.

1/ Martin - Industrial Chemistry, (Crosby Lockwood, London, 1935), Vol. 2, part 2, page 142

*/ As in several African countries possessing soda lakes.

(3) The mixture may be fired in refractory containers in a brick or glass furnace.

(4) The fusion may be done in a small rotary kiln.

(5) Other methods are known but not extensively practiced.

8. Many other cements are known. Sulphur is an excellent cement for some needs. Metal solders can be regarded as cements in a sense. Glass is a valuable cement for certain purposes. Pottery glazes (of which there are large numbers) have strong cementing properties. This is not the place to examine these and other miscellaneous cements in any detail.

9.1 As can now be realized, there are many possibilities and combinations. For the purposes of this paper only one industry can be considered. It is convenient to consider the portland cement industry, because it is well documented. The following technologies will be considered.

A. Brickyard process, using limestone, separately burned to quicklime in a vertical kiln with coal, then slaked and mixed with clay slip, the mixture moulded into bricks, sun-dried, and finally fired in Hoffman continuous tunnel kiln, using firewood for main heat and fuel oil for topping heat. Grinding with 3% gypsum.

B. Wet process mixing of ground limestone and clay, followed by sun-drying and firing in continuous vertical shaft kiln with coal as fuel. Grinding with 3% gypsum.

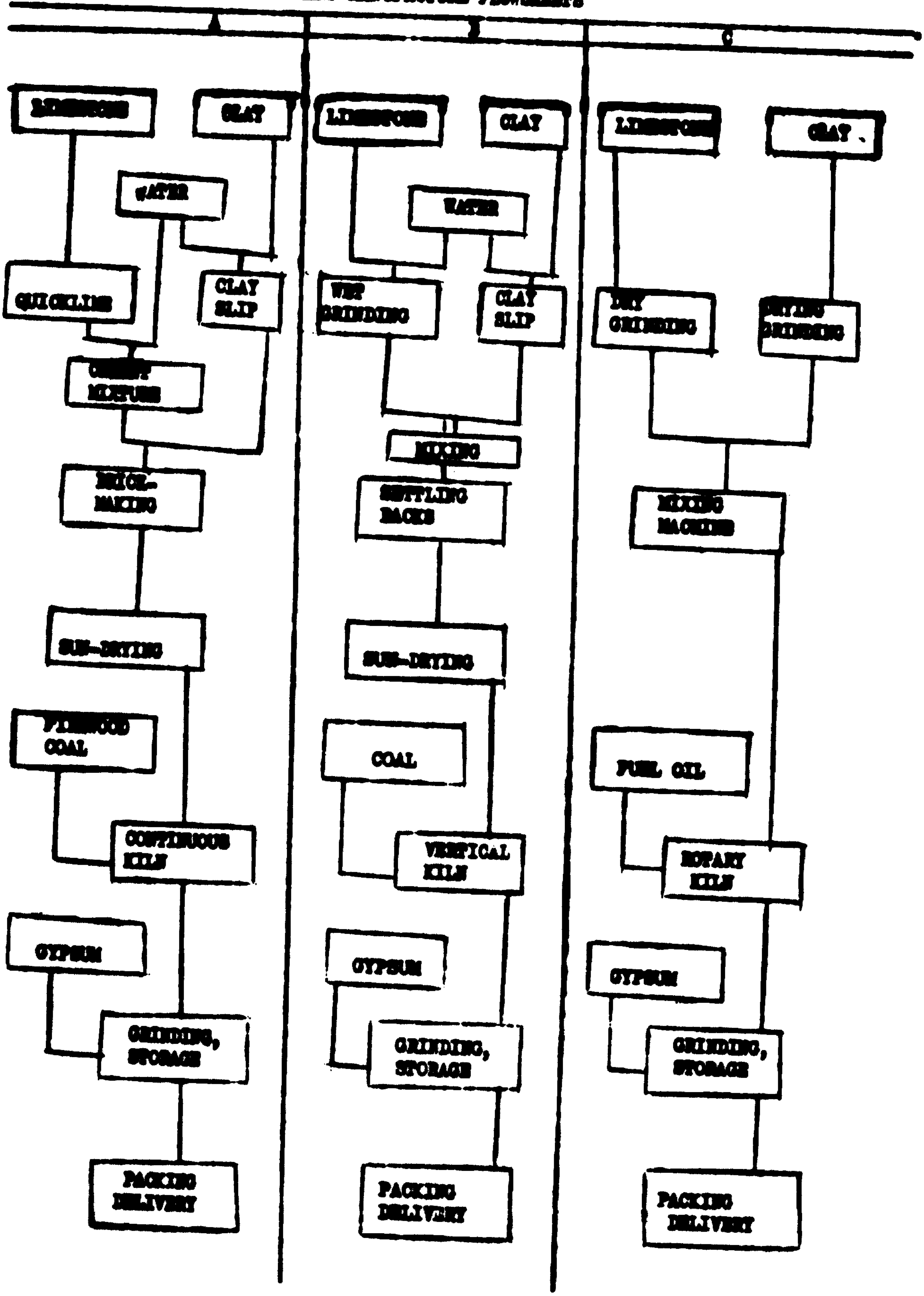
C. Dry process, starting with limestone and clay and firing in rotary kiln with fuel oil. Grinding with 4% steam.

4.2 Each technology will be examined on the scale of -

6 tons per day
60 tons per day
600 tons per day

of finished cement.

CEMENT MANUFACTURE FLOWSHEETS



CEMENT TENTATIVE COSTING STATEMENTS

Item / Process	A			B			C		
Scale	S *	M	L	S	M	L	*S	M	L
Capital ($1000)									
Fixed	-	800	6200	50	850	6500	-	900	6800
Operating	-	30	300	2	40	400	-	45	500
Sub-total	-	830	6500	52	890	6900	-	945	7300
Manufacture $/ton									
Materials	-	2.5	2.5	2.5	2.5	2.5	-	2.5	2.5
Utilities	-	3.8	3.4	3.2	3.6	3.2	-	4.6	4.1
Wages	-	2.2	2.0	3.2	1.9	1.6	-	1.8	1.3
Supervision	-	0.3	0.3	0.2	0.3	0.3	-	0.3	0.3
Fixed charges	-	1.2	1.0	1.2	1.4	1.2	-	1.6	1.4
Plant overhead	-	0.6	0.7	0.6	0.7	0.5	-	0.8	0.6
Sub-total	-	10.6	9.9	10.9	10.4	9.5	-	11.8	10.2
General $/ton									
Administration	-	0.8	0.6	0.4	0.8	0.6	-	0.8	0.6
Packing	-	0.5	0.5	0.4	0.5	0.5	-	0.5	0.5
Sales	-	0.3	0.4	0.2	0.3	0.4	-	0.3	0.4
Other	-	1.6	1.4	2.3	1.6	1.4	-	1.6	1.4
Sub-total	-	2.9	2.9	3.3	3.2	2.9	-	3.1	2.9
Overall $ per ton	-	13.5	12.8	14.2	13.6	12.4	-	14.9	13.1

* Technology not practicable.

Cement Industry

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(Note: A paper by Nadal on "Small-scale Portland Cement Plants" is expected to be published by the Centre for Industrial Development in early 1967)

Seawater Chemicals

Case Study

1. The sea contains every element occurring in the earth, and even the man-made radio-active elements. The various salts in seawater can be grouped in many ways. One grouping is quoted as follows:[1]

	Parts per million
Sodium chloride	27,319
Magnesium chloride	4,176
Magnesium sulphate	1,668
Magnesium bromide	76
Calcium sulphate	1,268
Calcium bicarbonate	178
Potassium sulphate	869
Boron trioxide	29
Silica	8
Iron and alumina	22
Total	35,613 = about 3 1/

2.1 From time immemorial the extraction of salt from seawater (brine) has been practised. In hot, dry countries, nature often produced salt in landlocked embayments subjected to spring tides. When naturally-formed salt was not so easily available, human effort supplemented nature in enclosing shallow low-lying saline marshes subject to inundation by the sea, and exposed to sun and wind. This process was called solar evaporation, and the factory where it was practiced was called a solar salt factory. In some cases, where salt possessed high value, seawater was boiled down in pots. All these methods are still in vogue around the world. In cold climates the practice was to start large fires of wood and quench the fires

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[1] Chesny - *Industrial and Engineering Chemistry*, 1936, Vol. 28, page 383

wood and quench the fires with seawater and this was the practice in England until quite recently.[1] None of these practices was directed to the extraction of material other than common salt, sodium chloride. Some quantity of the other salts adventitiously accompanied the common salt, but was always regarded as unwanted.

2.2 Development of the marine salts industry followed two courses -

(1) The manufacture of common salt by solar evaporation was systematized, stabilized and mechanised, so as to be as independent as possible of the vagaries of the ocean and climatic conditions.

(2) Attention was directed towards utilization of the other components of seawater. The scheme to extract gold from seawater, which culminated in the notorious South Sea Bubble, was a case in point.

3.1 The improvements in the common salt industry by solar evaporation generally followed a set pattern.

(1) Peripheral dikes and levees of earth were constructed around the whole area, with the twin objects of keeping the seawater in and fresh water out. This fresh water, resulting from rains and floods from the surrounding countryside, could have had disastrous consequences.

(2) The saltern (or solar salt factory) was divided into six or eight zones, the seawater in each zone going through a more or less well-defined stage.

(3) Seawater was procured by positive pumping instead of by ocean tides.

(4) Seawater concentrates were stored up, to even out the diurnal, seasonal, annual and secular variations in production due to variations in conditions of sund and wind.

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[1] Mellor - Comprehensive Treatise on Inorgenic & Theoretical Chemistry, Vol. 2, p. 522.

(5) Control became increasingly stricter on the quality of the salt produced.

(6) Harvesting, transport, washing, storage and issue were mechanised.

3.2 It might be noted that over one-third of the world's production of salt is manufactured by solar evaporation [1] and that it must nowadays total over 35 million tons per annum.

3.3 The extraction of other salts from seawater was practiced in France nearly 200 years ago. The Salines du Midi of the French Riviera used to conserve the final bitter residues (called bitters or bitterns) of their solar salt factories, and expose these bitterns to wintry conditions. Thereby, with the aid of manipulated physico-chemical transformations, salts of magnesium and of potash were formed. Magnesium compounds are in great demand around the world for refractory, insulation, cementitious, medicinal, chemical and other purposes. Despite the manufacture of about 5 millions tons of magnesia from the sea, it was still found necessary to mine between 9 and 10 million tons of magnesite mineral. [2] Mineral sources are wasting assets, and are becoming scarcer and more costly, whereas the sea is an inexhaustible source, and technology is making seawater magnesia cheaper and cheaper. There is room for very large expansions in the production of magnesium products from seawater. This will be a very suitable industry for developing countries.

3.4 The recovery of potash from seawater excited much interest among scientists around the world, and many processes were devised. Only two of them have withstood the processes of time. In Norway, an organic compound

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[1] Kaufmann - Sodium Chloride - (Reinhold, New York, 1960), p. 96

[2] "Oil, Paint & Drug Reporter", 19 October 1964, p. 5

is used to precipitate a potassium salt direct from seawater, while in several countries a potash salt is crystallized out of the bitterns on prolonged exposure to solar evaporation. To date these are the standard available processes, although there are several variants.

3.5 Bromine has been recovered from seawater bitterns for the past 30 years or so, and is now quite standard practice, wherever a market can be found for it.

3.6 One product of seawater which has hitherto been very little used is fresh water. Recently there has been a surge of interest in the production of fresh water from the sea, and this is an activity that can radically alter the economics of salt production in places of densely-populated communities, which are prepared to absorb the freshwater, and also take off some of the common salt produced, at attractive prices. 1/

4.1 Three technologies will be taken up for discussion from a wide variety of possible combinations.

A. Recovery of solar salt by purely manual operations, with no mechanisation whatever. Induction of seawater by tidal action.

B. Manufacture of solar salt by mechanising the processes of pumping seawater and transporting and storage of salt. No other product.

C. Fully mechanised manufacture, collection, transport, and storage of salt, and manufacture of magnesia, chalk, bromine, soda sulphate, potash, and magnesium chloride.

4.2 Each technology will be studied at three levels of manufacture, viz.

1) Small - 3,000 tons
2) Medium - 30,000 tons
3) Large - 300,000 tons

1/ Article "Profit from chemicals in brine could lower cost of desalting seawater" in <u>Chemical Engineering</u>, June 1964, p. 88

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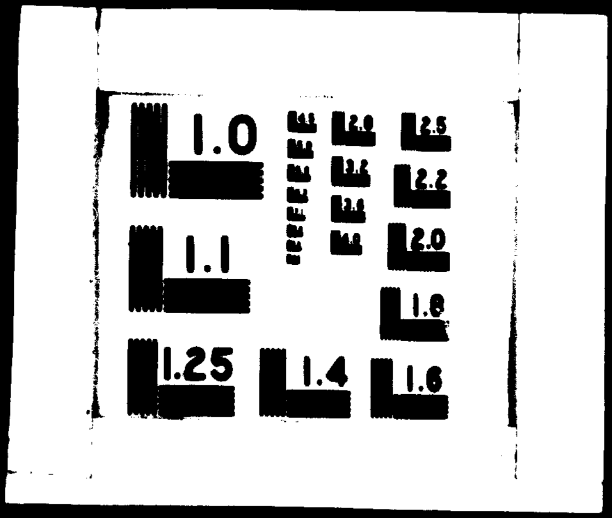
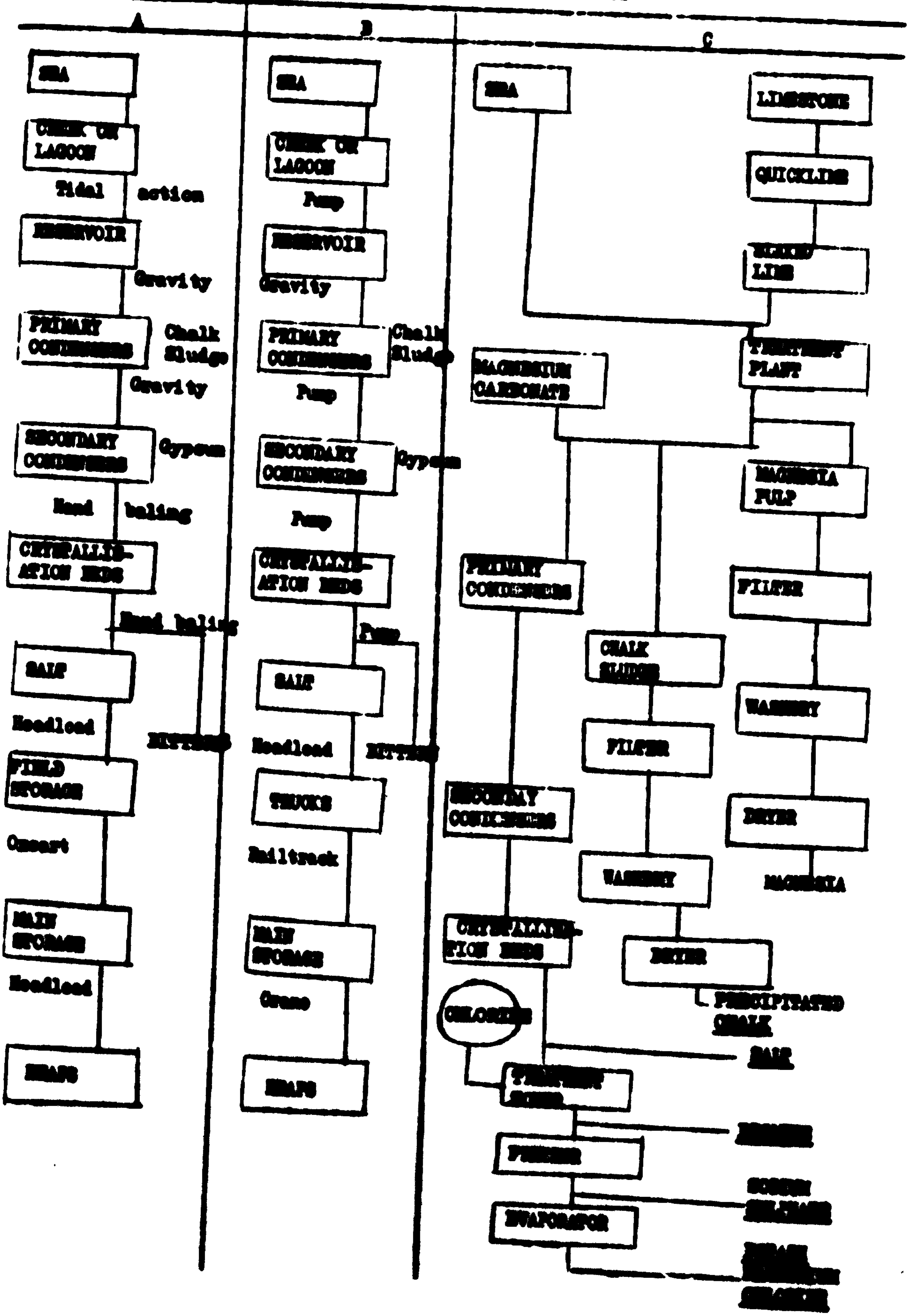


of common salt per year, and (where applicable) the equivalent of other products.

4.3 Costing is done on the common salt produced, giving credit at standard rates for co-products or by-products.

SEAWATER INDUSTRIES - FLOWSHEETS



Tentative Costing Statement

Seawater Chemicals
(Costing for common salt only*)

Item / Process	A			B			C		
Scale	S	M	L	S	M	L	S**	M	L
Capital ($ 1000)									
Fixed	20	120	500	30	250	700	-	400	1200
Operating	5	70	500	7	150	700	-	200	1200
Sub-total	25	190	1000	37	400	1400	-	600	2400
Manufacturing ($/ton)									
Materials	0.2	0.3	0.3	0.4	0.3	0.2	-	0.4	0.3
Utilities	-	-	-	0.2	0.2	0.2	-	0.6	0.6
Wages	1.0	1.1	1.2	0.6	0.5	0.5	-	0.8	0.8
Supervision	0.1	0.2	0.3	0.2	0.2	0.2	-	0.4	0.4
Fixed charges	1.0	1.2	1.3	1.2	1.2	1.0	-	2.0	1.8
Plant overhead	0.2	0.2	0.2	0.2	0.2	0.2	-	0.4	0.4
Sub-total	2.5	3.0	3.3	2.8	2.6	2.3	-	4.6	4.3
General ($/ton)									
Administration	1.0	0.6	0.3	1.2	0.7	0.4	-	0.9	0.6
Packing	0.2	0.2	0.2	0.2	0.2	0.2	-	0.2	0.2
Sales	0.5	0.4	0.3	0.4	0.3	0.2	-	0.3	0.2
Other	0.3	0.2	0.2	0.3	0.2	0.2	-	0.3	0.3
Sub-total	2.0	1.4	1.0	2.1	1.4	1.0	-	1.7	1.3
Overall cost $ per ton	4.5	4.4	4.3	4.9	4.0	3.3	-	6.3	2.6
Credits	-	-	-	-	-	-	-	2.6	2.6
Final cost per ton $	4.5	4.4	4.3	4.9	4.0	3.3	-	3.7	3.0

* Assuming other products are sold at cost

** Inapplicable

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Caustic Soda

Case Study

1. This is one of the earliest chemicals to be recognized and used as a true chemical. It is used today in quantities running into several million tons. It has hundreds of uses, in almost every field of human activity. Today it is one of the basic chemicals, which every country is keen to produce within national boundaries, because of its critical importance in many strategic fields.

2.1 There are two chief routes to the manufacture of caustic soda:

1) indirectly, through soda ash or soda sulphate.
2) Directly, by electrolysis.

2.2 The indirect process, in practice, always uses soda ash as the starting material, and there is no known commercial practice of causticising sodium sulphate. A major paper-making process, the sulphate (or Kraft) process certainly uses sodium sulphate as a source of caustic soda, but the caustic soda is not separately recovered, and is entirely consumed within the chemical cycle which is followed in this industry. The use of sodium sulphate as a direct source of sodium hydroxide is mentioned here only because there are several developing countries which have lakes containing sodium sulphate, and chemical and other factories are being established in those countries which may yield sodium sulphate as a by-product (e.g. rayon). Under these circumstances, it is quite possible that sodium sulphate could be profitably causticised into caustic soda. However, the technology of using sodium sulphate in this manner is not so greatly different in principle from the process based upon soda ash as to merit separate consideration of its own. Hence, there will be no further reference to sodium sulphate technology, but the possibility must definitely be borne in mind, in dealing with chemical industries for developing countries.

3.1 Soda ash itself used to be manufactured by three chief processes

(1) The Leblanc process, devised in 1779, which was the only commercial process for close upon one century.

(2) The Solvay ammonia-soda process.

(3) Direct electrolysis.

There were variants of these main processes, and several other minor processes, but none meriting any separate mention in this paper.

3.2 The Leblanc process consists of roasting a mixture of sodium sulphate, limestone and coal, and dumping the melt (called black-ash) into water. The sodium carbonate formed in the reaction is dissolved out, and the solution is purified and concentrated, when it produces soda ash. Obviously it is not necessary to produce solid soda ash if the object be the manufacture of caustic soda, because the leach liquor from the blackash tanks could be causticised directly.

3.3 The Leblanc Process was almost entirely manually operated and controlled. It demanded great stamina and exertions on the part of the workers, who were exposed to bad working conditions of great heat and humidity all the time. The wastes discharged from the factory produced foul odours, which hung permanently over the factory like a miasma. So it is not surprising that when a new process was invented which was free from all these objectionable features it was welcomed by everyone, and in due course the new process almost completely supplanted the Leblanc process.

3.4 However, it must be recognized of what great value the Leblanc process was during the period it held sway. The process was simple, and a fairly wide variation of working conditions could be tolerated. Comparatively little was required by way of capital equipment, and a considerable amount of local improvisation was possible. Output could be adjusted to needs without too much strain or loss. Most valuable of all at that time was the fact that the workers participated directly in the manufacturing operations. Not only did they achieve a sense of fulfilment, but the industry was an excellent training ground, providing basic education in practical chemical technology. The Leblanc process was mechanised and improved, in a valiant effort to keep up with the Solvay process, but was eventually forced out of existence. However, considering its history and areas of usefulness, there is no doubt that some of the developing countries could find use for this Leblanc process for small quantities of soda ash and caustic soda, where electricity is scarce, costly and undependable, but where coal and soda sulphate are cheap and plentiful.

4.1 The Solvay Ammonia-Soda process consists of reacting ammonia and carbon dioxide together to form ammonium bicarbonate. This is reacted with sodium chloride to yield sodium bicarbonate and ammonium chloride. The sodium bicarbonate is calcined to yield sodium carbonate. The ammonia value in the ammonium chloride is recovered with the aid of lime, and recirculated. The waste end-product thus is calcium chloride.

4.2 The process sounds simple, and indeed is simple, but successful operation depends on a very careful balance of temperatures, pressures, rates of flow, etc. in all parts of the system, and maximum prevention of the losses which are apt to occur. But when the design, erection and start-up are all just right, the plant goes smoothly into full operation without rebelliousness. Nowadays, these accurate adjustments are so common throughout the industries of advanced countries, and can be so easily effected by automatic mechanisms, that it is not readily appreciated how difficult it still is for developing countries. For instance, there was a Solvay plant in India over which the technicians struggled for a dozen years to reach just the right working conditions.

4.3 There were naturally many variants of the main ammonia-soda process, and many of them proved useful under given conditions. One rather fundamental innovation was the recovery of ammonia values as the ammonium chloride itself, for use as fertilizer. This saved one important and costly operation, although it did involve the continuous supply of ammonia. This combination process is specially useful when countries need to manufacture both soda as well as nitrogenous fertilizers. The process is of special value, because the use of sodium sulphate in the initial stage (in place of sodium chloride) results in the manufacture of ammonium sulphate, which is a more acceptable fertilizer than ammonium chloride.

4.4 One of the objections to an ammonia soda plant in a developing country was the quite large scale of operations. The minimum was often stated to be 60,000 tons per annum. On this point, the following quotation is relevant -

> "It is not generally realised that soda-ash can be produced economically by the ammonia-soda process on an extremely small scale, and plants are now available to produce as little as ten tons of soda ash per day, ..." 1/

4.5 Another objection to the Solvay process was that the soda which was produced was very light, and when used in furnaces got blown off by the draft. This defect has not yet been overcome, and if dense soda ash is required from Solvay soda, the latter is dissolved and re-crystallised. In some developing countries this expense can be reduced considerably by solar evaporation techniques.

4.6 The third standard method of manufacturing soda ash is by direct electrolysis of a solution of sodium chloride, while carbon dioxide is bubbled through. There are several advantages in such a process, and while it is by no means common, it does have its usefulness, and special cells have been devised for the purpose.

4.7 The causticisation of soda ash with lime is quite simple in theory, and the practise is in existence all round the world, and operated by ordinary workers, who do not need to possess special skills. In most of the causticisation plants, the resultant caustic soda is used up within the factory itself (e.g. for making soap or paper or alumina) and sometimes it is used without even troubling to separate off the sludge of calcium carbonate.

1/ Martin - Industrial Chemistry, (Crosby Lockwood, London, 1935), Inorganic, Vol. I, p.

If it is required to manufacture solid caustic soda from the causticised soda ash, it becomes necessary to filter off the calcium carbonate and boil down the caustic lye. The boiling is most conveniently effected in indirectly heated vacuum pans (e.g. with Dowtherm.)

5.1 For caustic soda produced by electrolysis, the raw material is almost always sodium chloride. There are two main electrolytic processes, namely -

(1) the diaphragm process

(2) the mercury-amalgam process.

Other processes have been introduced, and some are still in operation, but they are of minor importance.

5.2 The diaphragm process is so called because a diaphragm (generally of asbestos) keeps the liquor around the two electrodes separate from each other while permitting ions carrying electric current to pass. Were the liquors allowed to mix, they would react, and destroy at least a part of the caustic soda. (Indeed, one way of manufacturing such a reaction product, sodium chlorate, is to electrolyse sodium chloride in a cell with no diaphragm). The lye which is produced in a diaphragm cell may contain up to about 12% caustic soda and about 12% of sodium chloride. It is concentrated in vacuum evaporators to 50%[*] caustic liquid, when most of the salt separates out. This 50%[*] caustic can be sold as such, but if solid caustic is needed, it can be boiled down to 75%[*] concentration in a special type of vacuum evaporator heated with Dowtherm vapour. Further concentration, if needed, cannot be conveniently done in vacuum pans, and must be done in iron pots, heated by direct fire. The sodium chloride is washed and re-used, or sold to outsiders for table salt, or transferred within the factory to a mercury amalgam cell section.

5.3 In the mercury amalgam caustic cell, mercury is used as the cathode of the electrolytic cell. The sodium which is produced by the electric current, and which is discharged at the cathode, immediately dissolves in the mercury

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[*] One confusing feature about trade in caustic soda is that it is sometimes measured on its content of sodium hydroxide (Na OH) and sometimes of sodium monoxide Na_2O.

to form an amalgam. This amalgam is transferred (generally in a continuous stream) to another section, adjacent to the electrolytic cell, and is there deceomposed by fresh water to yield caustic soda and hydrogen, while the mercury is regenerated and sent back into circulation.

5.4 In the diaphragm process, the salt has to be carefully freed of impurities, and this can be quite costly. The resultant lye from the cells is comparatively weak (10 - 15%, with average of 12%) and usually has to be concentrated. The lye contains an equal quantity of common salt, and this has to be removed for most purposes. In fact, the diaphragm cell is seldom used if rayon-grade caustic is required. Current densities cannot be increased much more than about 40,000 amperes, and the resultant current efficiency is not too good. On the other hand, the cells and the operation are cheap.

5.5 The advantages of a mercury cell are that it yields up to 50 or 60% caustic soda directly, and that the caustic is exceptionally free of sodium chloride. Such chloride-free caustic is essential for rayon manufacture, and is therefore designated as "rayon-grade" quality. Furthermore, small quantities of impurities in the common salt starting material are of no great consequence. Each cell can take very high currents (over 200,000 amperes), which makes for high efficiency. Disadvantages are high cost, losses and risk of theft of mercury, additional hazard of dealing with sodium amalgam, and the health hazard.

5.6 Both types of cells generate hydrogen and chlorine, both of which are valuable raw materials. Indeed, for the past few years, in advanced countries chlorine was in greater demand than its equivalent in caustic soda,* while the demand for hydrogen is always insatiable, because it is so widely used for hydrogenating edible oils, for manufacturing ammonia, and for hydrogenation in petroleum refining and petrochemical processing. Indeed, quite often electrolytic cell installations come up for the sake of securing supplies of chlorine and hydrogen. In countries where industrialisation is just making a start, the demand for chlorine and hydrogen is

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* Just now, however, the production of chlorine is so much in excess of market demand that it is held to be a drag on electrolytic caustic production - Oil, Paint & Drug Reporter, 16 November 1964, p. 32.

generally far less than the corresponding amount of caustic soda. Efficiency and prudence dictate that when planning for the manufacture of caustic soda, adequate consideration should be given to the simultaneous installation of a complex which will use up at least the chlorine. Often there is a disastrous time lag between the production of caustic soda and the full utilization of chlorine. During this period there is no help for it but to send the chlorine to waste. Chlorine is a dangerous poison, as it is lethal in quite small doses, and can permanently damage the lungs in much smaller doses than the fatal minimum. The safe disposal of hydrogen is no problem at all, as it shoots upwards when released. The electrolytic process is costly if the co-products are not saleable at market prices, and any country which cannot arrange for profitable disposal of all the co-products of an electrolytic cell would do well to look to other processes for manufacturing soda. A graphic instance has recently been reported as follows -

> "...in Mexico there are now eleven plants manufacturing caustic soda, of which ten are electrolytic and the other, which is the largest, uses the causticizing method. ...In 1960, total capacity amounted to some 134,000 tons, but production in that year was only 65,900, less than half the installed capacity. Of that total, only 22,800 tons was produced by the electrolytic plants. ...the most important limiting factor is the fact that the use of chlorine and hydrochloric acid is still small." 1/

6.1 The caustic soda industry will be illustrated by the following examples.

(1) Soda sulphate of natural origin taken straight from solar evaporation factory into Leblanc soda factory, there mixed with quicklime and lignite char, roasted on simple reverberatory furnace and drawn. The black ash is lixiviated in a series of counter-current extraction tanks, the extract directly treated with quicklime, filtered and concentrated

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1/ United Nations, Possibilities of Integrated Industrial Development in Central America, (Sales No. 63:IIG.10) to 50% NaOH in open iron caustic pots over coal fire and siphoned into steel drums. (The tank waste is worked up for other products, but its costing will be self-contained).

(2) Solvay process of the conventional type attached to a solar salt factory, which produces a purified brine concentrate from seawater by solar evaporation. The concentrated brine is drawn into the Solvay plant by pipeline. In the Solvay plant limestone is burned to quicklime. The brine is ammoniated and carbonated as usual. The manufactured wet soda bicarbonate is directly causticised with lime slurry, without drying or calcining. Caustic liquor is concentrated and drummed as in (1). Ammonia is recovered and recirculayed, as well as carbon dioxide. Calcium chloride is returned to solar factory at low cost.

(3) Electrolytic process, using vertical diaphragm cells, and purified solar salt factory brine concentrate as in (2).

Chlorine liquified and stored under pressure. No recovery of hydrogen. Call liquor concentrated to 50% caustic and filled into drums. Recovered salt converted to table salt for sale.

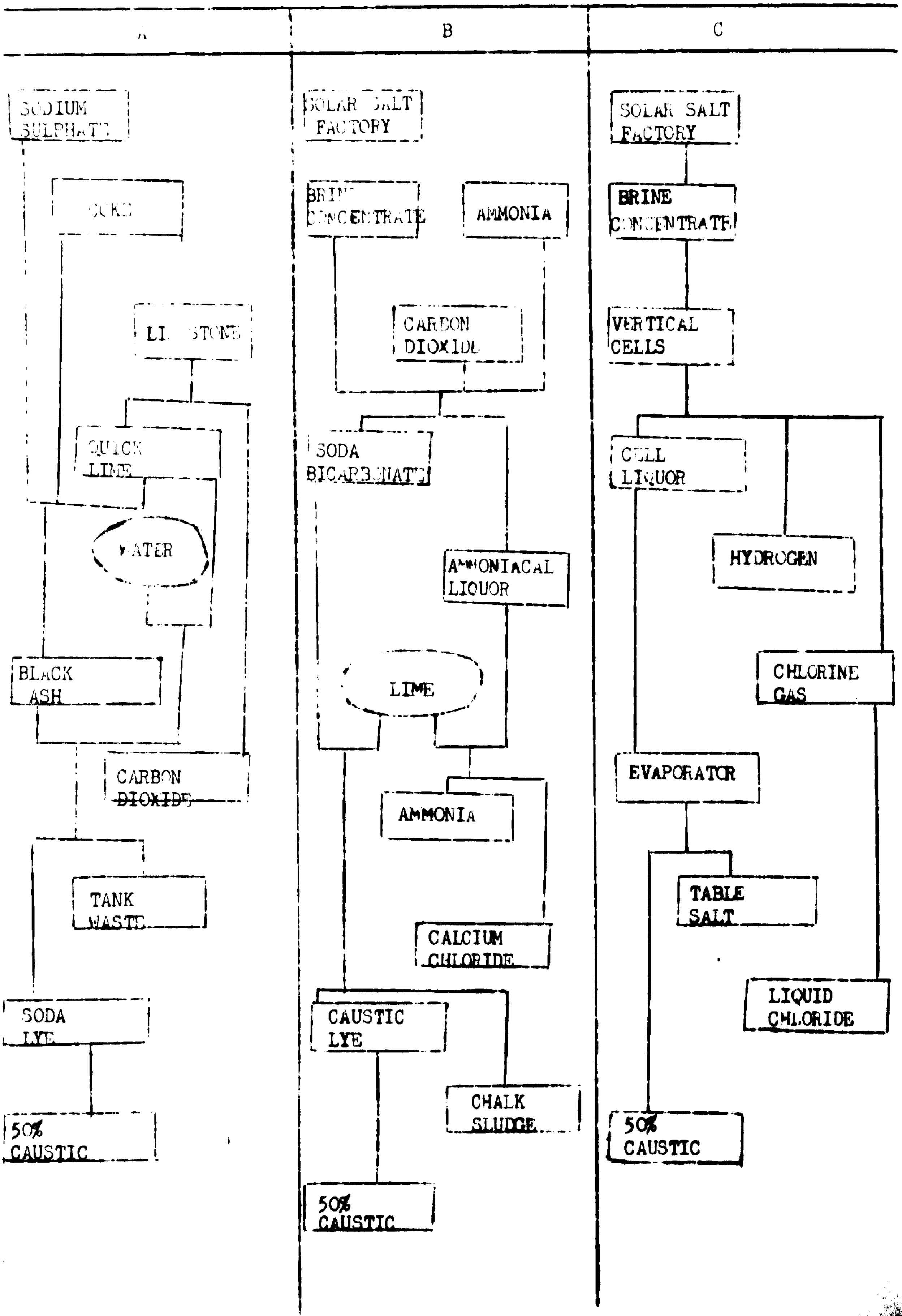
6.2 The processes will be examined on the following scales of operation -

Metric tons per day caustic soda

Small -3
Medium -30
Large -300

6.3 Flowsheets and tentative costing sheets are attached.

CAUSTIC SODA - FLOWSHEETS



Tentative Costing Statement

Caustic Soda

Item	Process	A			B			C		
	Scale	S	M	L	S	M	L	S	M	L
Capital ($ 1000)										
Fixed		200	1600	12000	360	3000	15000	150	1300	10000
Operating		20	180	1000	30	200	1200	12	110	1000
Sub-total		220	1780	13000	390	3200	16200	162	1410	11000
Manufacture ($/ton)										
Materials		30.2	27.2	23.9	20.5	18.3	16.1	11.3	10.1	9.7
Utilities		8.1	8.8	9.3	16.1	15.0	9.6	67.0	66.1	63.7
Wages		16.2	19.3	20.4	14.4	16.2	17.3	12.1	10.3	8.4
Supervision		2.1	2.5	3.3	2.0	2.2	2.4	1.8	2.2	2.6
Fixed charges		6.0	5.0	4.0	8	6	5	5.0	4.0	3.0
Plant overhead		14.0	13.0	12.0	12	11	10	13.0	11.0	9.0
Sub-total		76.6	75.8	72.9	73.0	68.7	60.4	110.2	103.7	96.4
General ($/ton)										
Administration		2.1	1.7	0.8	2.0	1.6	0.7	1.9	1.5	0.7
Packing		20.2	19.2	18.2	20.2	19.2	18.2	20.2	19.2	18.2
Sales		2.2	2.2	2.2	2.2	2.2	2.2	2.2	2.2	2.2
Other		3.0	3.0	3.0	3.0	2.9	2.8	2.8	2.8	2.8
Sub-total		27.5	27.1	27.2	27.4	25.9	23.9	27.1	25.7	23.9
Overall cost $/ton (100% basis)		104.1	103.9	100.1	100.4	94.6	84.3	137.3	129.4	119.3
Credits $/ton 100% basis		-	-	-	2.0	3.0	4.0	42.3	42.3	42.3
Final cost $/ton 100% basis		104	103	100	98	92	80	95	87	77

Soda Industry

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Nitrogenous Fertilizers

Case Study

1.1 It is now well known that there are three major ingredients which are essential for plant growth, namely, nitrogen, phosphorous and potash. Of the three, nitrogen is needed in largest quantity. It is a popular impression that tropical countries are lush, verdant and fertile, but this is far from being the case. Tropical soils are, in fact, generally much less fertile than temperate zone soils and need a great deal more nitrogen to give of their best.

1.2 Nitrogen occurs in inexhaustible supply in the atmosphere but this nitrogen is inert and of no use in nutrition, except to a limited (though important) extent for certain plants (Leguminosae) and animals (Ruminata). Another source of nitrogen is lightning, and this was, in fact, the major source in the nitrogen cycle of the earth before man took a hand. The annual quantities so brought down range from 1 to 10 lbs. per acre[1/] and over the whole world would amount to nearly 100 million tons per year. This is a large quantity, but the quantity now applied by man, which is over 20 million tons per year, is much more significant, since it is concentrated on only the producing land, and only a small part of it.

1.3 The spectacular results achieved by the informed and intelligent application of fertilizers to agriculture leaves no room for doubt that the world can easily feed double or treble its present population with no increase in acreage, but with the proper use of fertilizers, and with labour-saving techniques. In this connexion, it should be mentioned that recent work has disclosed that these inorganic nitrogenous fertilizers can be directly used by ruminant animals (chiefly cattle) to produce flesh. Young

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[1/] Clark - Data of Geochemistry, (US Superintendent of Documents, Washington, D. C.), p. 22. Another figure quoted is 17 lbs. per acre.

cattle fed with urea can put on nearly 2 pounds of flesh per day, and as the ruminant population of the world is comparable with the population of human beings, the importance of these nitrogenous substances can well be realised.

1.4 As already mentioned, elemental nitrogen by itself is an inert material, of little use to plant or animal. To make it useful, the nitrogen must be combined with something which will activate it. And, in the world of commerce, this something must be either as cheap as possible, or serve some functional need for which it can be valued in its own right. This consideration limits commercially practicable nitrogenous fertilizers to the following

Hydrogenated - Ammonia, hydrazine.
Oxygenated - Nitrogen oxides.
Nitrided - Cyanamides and nitrides.

1.5 From these three primary groups there are derived secondary products like -

Ammonium salts (sulphate, hydroxide, chloride)
Urea, urea salts, cyanates, amides, amines
Nitrates (calcium, magnesium)
Miscellaneous (e.g. ring compounds, cyanamides)
Double fertilizers (ammonium nitrate, urea nitrate)
Complex fertilizers (urea phosphate, potassium nitrate)

Ammonia is also secured from distillation of coal, while nitrates are obtainable from mineral deposits around the world (notably in Chile) or surface incrustations (e.g. India).

1.6 In the modern world, the most important nitrogenous fertilizers are -

Ammonium sulphate
Ammonium nitrate and other nitrates
Ammonium chloride
Urea
Ammonia itself
Ammonium phosphate
Calcium cyanamide
Potassium nitrate
Other products

1.7 At one time, hardly forty years ago, calcium cyanamide was the most popular fertilizer, and in 1923 over 2 million tons of it were used. A great deal of knowledge on the manufacture and use of this material exists, and Japan, in particular, still makes extensive use of it. Since the manufacture of calcium cyanamide is relatively simple, and as coal or coke can be directly used in the process, some countries might find it advantageous to start their nitrogenous fertilizer industry with the manufacture of calcium cyanamide. It is to be remembered that calcium cyanamide is a fertilizer in its own right, and is also a source of ammonia and through ammonia, of urea. It is also an important weedicide. Furthermore, it is the source of dicyandiamide, which is the basic raw material for the important melamine group of plastics, and many other useful organic nitrogen compounds. In the USA one company manufactures about 250,000 tons per annum.

2.1 Historically, the earliest methods of "fixing" nitrogen was to provide a kind of artificial lightning. An electric arc was struck between carbon rods, and the arc was drawn out into a large circular flame by electromagnets (an early application of plasma physics). Air was blown through the arc. The nitrogen and oxygen of the air combined to produce oxides of nitrogen, which were dissolved in water and neutralised by lime. A fairly large current was required and 1 H.P. yielded up to 1 ton calcium nitrate (14 to 16% nitrogen) per year, which works out to about 50,000 kwh per ton of nitrogen.

2.2 At one time this method was quite popular, but was quite rapidly displaced by the synthetic ammonia process. However, this arc process is a basically simple process. Modern advances in knowledge, especially in plasma physics, has enabled very high temperatures to be almost commercialised, and if a very high temperature can be imparted to the gaseous mixture even momentarily, it would result in a degree of reaction quite satisfactorily high for profitable operation. The possibility of adopting such a process for "fixing" of nitrogen should be borne in mind by all those interested in creating new nitrogenous fertilizer productive units.

3.1 Parallel with the development of the arc process the process of direct combination between nitrogen and hydrogen to yield ammonia was developed. Today synthetic ammonia has become a basic chemical of the highest importance in the world, exceeded in bulk only by sulphuric acid, salt and soda.

3.2 In principle, the manufacture of synthetic ammonia is very simple. The first stage is to prepare the right mixture of nitrogen and hydrogen, free of deleterious impurities. The second stage is to compress the gases, and the third stage is to pass the compressed mixture over or through a catalyst. The ammonia which is formed is drawn off or absorbed in water, and the unreacted gases are recirculated. In actual practice there are many variations in pressure, temperature, catalysts and storage, and therefore in equipment, power needs etc., but all these are matters of detail, while the essential processes are the same as those worked out by Haber and Bosch, Claude, Casale and others some fifty to sixty years ago.

3.3 One of the major differences in various processes is the source of the hydrogen. The following are the chief sources -

Petroleum fractions cracked or reformed with steam
Natural gas reformed with steam
Coke-oven gas with steam
Coke or charcoal or coal with air and steam

Underground gasification of coal
Electrolytic hydrogen from caustic soda or heavy water plants
Fermentation hydrogen, sewage gas, methane from deep lakes
Aluminium carbide to methane, and then as for natural gas
Iron scrap and steam
Miscellaneous, like lignite and steam, asphalt waste.

It is mainly a question of energy values. The competence of an ammonia factory designer is his ability to study the situation as it exists in a particular place and take maximum advantage of it. One place may have a petroleum refinery by-product available; another may have surplus coke, with too high an ash content to have value in metallurgy. A third place may have large blocks of electric power available outside the morning and evening peak-load hours. A fourth may have low-grade but cheap coal. Putting all this information and collected data together, and deciding how best to obtain the hydrogen and what alternatives to build into the design is a formidable but necessary task for scientific and economical results.

3.4 One basic question relates to the use of solid fuels, compared to petroleum and natural gas. The problem by no means admits of a ready answer. It is quite true that most of the world's ammonia is today produced from petroleum cuts or natural gas, but the solid fuel is also still a good source. As Strelsoff puts it-

> "Until World War II, the manufacture of ammonia in Europe was based on the use of solid fuels. The discovery of huge deposits of natural gas in France, Italy and the Netherlands has now induced the ammonia industry to switch over to natural gas. The same pattern takes place in Japan.
>
> However, it is to be noted that in the Federal Republic of Germany the ammonia industry is still tied very strongly to coal and lignite. In the Netherlands, up till the present time, the ammonia was largely produced from coke or coke-oven gas. This is also true of Belgium. In all of these countries, the arrival of natural gas has not necessarily been followed by the reduction of the consumption of solid fuelds..."[1]

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[1] "Economics of ammonia production in the developing countries" - Petrochemical Conference, Teheran, 1964, Paper 3, p. 30

According to Picciotto and Sweeney[1] plants are still being built using coal or lignite sources.

3.5 Ammonia by itself is rather inconvenient to apply in agriculture, and is therefore little used outside the USA. For most practical applications it must be converted into a relatively inactive solid. There are two methods of doing so.

1) To react the ammonia with an acidic component to produce the sulphate or nitrate or phosphate or chloride.
2) To change its constitution, like converting it to urea or nitric acid.

The first process is comparatively simple, and involves merely neutralisation with acids or soluble sulphates (e.g. the ferrous sulphate of steel pickling liquors) or insoluble sulphates like gypsum (Merseberg process) etc. Often this is a way of using up waste acids, which would otherwise present disposal problems. In the Solvay process for making soda, ammonia is used as a means of conveying the carbonate ion from limestone to salt. Ammonium chloride is formed in the process. Either the ammonium chloride can be reconverted into ammonia and re-circulated, or the ammonium chloride can be sold off as fertilizer. This latter is the basis of a Japanese process which has gained some popularity.

3.6 The manufactures of urea or nitric acid are complete chemical processes in themselves and are, naturally, costly to operate, as they are by no means simple. The advantages are that urea is a solid which has a high percentage of nitrogen, and is also in great demand for other purposes, chiefly for plastics and plastic intermediates, animal feed, etc. Nitric acid is made because it can be used to neutralise ammonia and convert it into a solid salt, which also finds much use as an explosive. The nitric acid has many other uses as well, and therefore has a special market.

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[1] "Ammonia manufacture from petroleum feedstocks" - Ibid, Paper 93, p.16

4.1 The third group of primary products of nitrogen fixation are the cyanamides and nitrides. There are only three important representatives in this group, viz.

Calcium cyanamide
Aluminium nitride
Silicon nitride

The last two are sources of ammonia and not generally used as direct fertilizers, but calcium cyanamide is a conventional direct fertilizer, and also a weedcide. Furthermore, it is a source of organic chemicals like guanidine.

4.2 In principle, the manufacture of calcium cyanamide is very simple. All that is needed is to make calcium carbide and then pass nitrogen over it. Calcium carbide, in turn, is made by heating limestone and coke. Very high temperatures are needed, and for many years the most convenient way of producing the high temperatures was by electricity, either in an arc furnace or resistance furnace. Quite recently, however, a process has been devised in Germany for passing heated oxygen through the mixture of limestone and coke in a vertical shaft kiln. The intense heat of reaction between coke and oxygen creates the temperature needed to enable limestone to react with coke and form carbide. The oxygen is channelled through only the central portion of the kiln, and the materials on the sides, which are not directly exposed to the oxygen, protect the kiln refractories from damage. Comparatively recent developments in the manufacture of tonnage oxygen, coupled with the fact that the nitrogen constituent of the air can also be put to profitable use, have made this route commercially feasible. Countries which have suitable coals and limestones, but insufficient electrical power, might well consider this rather simple process.

4.3 To this day calcium cyanamide is being produced in some quantities, principally in Japan, Germany and the USA. The USA, in fact, needs more than it produces, and has to import about 40,000 tons per annum.[1] Some developing countries could thus embark on the manufacture of calcium cyanamide and build a tidy and profitable complex of industrial chemical products around it.

4.4 When alumina (or bauxite) is substituted for limestone in the cyanamide process, what is formed is aluminium nitride. This process was commercialised by Serpek in England and France in 1910. The aluminium nitride was treated with caustic soda to yield ammonia, while the aluminium formed sodium aluminate, which was treated as in the convential Bayer process to yield pure alumina. The caustic soda was recovered and reused. If the aluminium nitride is treated with acids, it yields alumina and the corresponding ammonium salt, and this could be one way of using up waste acids.

4.5 One very notable advantage of this Serpek process is that, in addition to affording a comparatively simple means of fixing nitrogen, it provides a route for extracting alumina economically from impure bauxites, which contain too much silica to be worth considering for the convential Bayer process. In the Serpek process, the siliceous impurities were volatalised off, and the resultant alumina did command a wide sale. This process might therefore be of considerable interest under certain conditions. Thus, Malawi contains a hilltop of bauxite (the outcrop alone is estimated at 60 million tons) which is said to be too siliceous to be of much interest in the world market.[2] If this bauxite is treated by the Serpek process (there is plenty of cheap electric power in the area) it may be the means of marketing the bauxite profitably, as well as of generating nitrogenous fertilizers in a predominantly agricultural region.

1/ Minerals Yearbook, 1964 (USA Supt. of Doc., Washington, D.C.) Vol. I

2/ Atkins - The Mlanje Bauxites of Nyasaland - 1962

4.6 Silicon nitride can be manufactured simply by heating a mixture of powered sand and charcoal in a stream of nitrogen. A fairly high temperature is needed (about 1400° C) but such temperatures are quite common in the chemical process industries. When the silicon nitride is steamed, ammonia is generated. The silicon nitride contains a theoretical 33% nitrogen, and can be sold as direct fertilizer, or the ammonia can be steamed out and recovered, while the silicon hydroxide can be dried and sold as a fine powder or dried into silica gel globules or simply recirculated in the process. It is not widely known that sometimes the limiting factor in increasing agricultural production is shortage of silica in the soil. Of course, the earth contains large quantities of silica sand but surprisingly little of it is available to the plant to build up its tissues. Under these conditions, silicon nitride would supply two plant nutrients, and hence be doubly valuable.

4.7 The temperature used in the silicon nitride process are those which can be handled within the normal precautions observed in the chemical process industries, and the whole process is basically so simple that it could well be considered by countries which do not wish to start off with a huge synthetic ammonia factory.

5.1 To illustrate the effects of technology and scale in the nitrogenous fertiliser industry, the following processes will be considered for the manufacture of ammonia.

1) Synthesis gas obtained from water gas/producer gas, reacted by modified Haber process at 250 atmospheres pressure and 550° C, with doubly-promoted iron catalyst, to yield of 20% per pass, and recycle of unreacted gases.

2) Manufacture of nitrous gases by passing air through electric arc. Recovery through limestone and put into mixed fertiliser.

3) Bauxite reacted with charcoal and nitrogen in electric furnace, and the resultant aluminium nitride digested with caustic soda to yield ammonia and sodium aluminate. Latter to be treated to yield alumina and to recover and re-use the caustic soda.

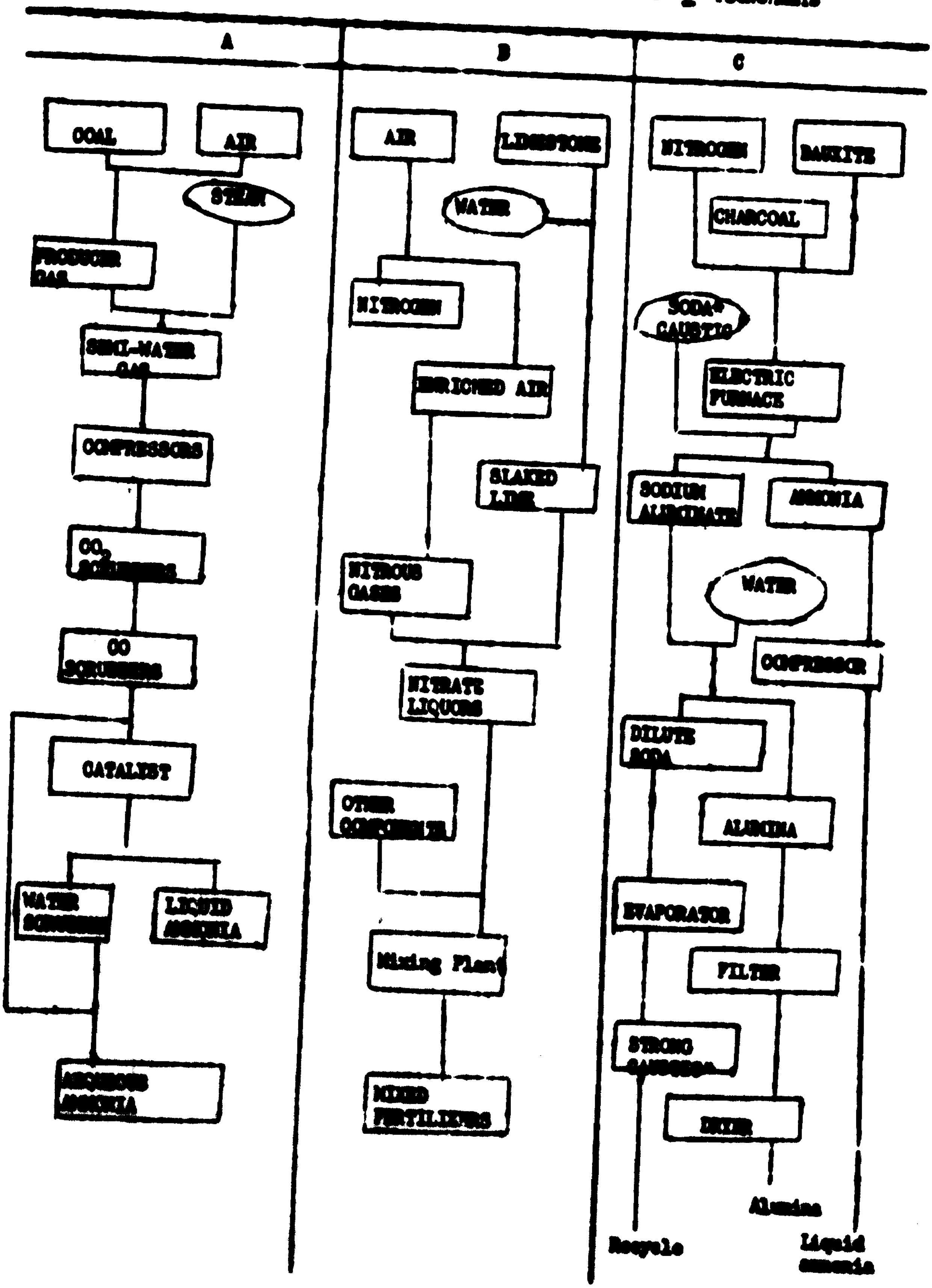
In all these cases, some allowance or credit will be given for useful or valuable co-products or by-products.

5.2 The following scales of operation will be considered -

Small	-	10 tons per day nitrogen
Medium	-	60 tons per day nitrogen
Large	-	300 tons per day nitrogen

5.3 Flowsheets and tentative cost estimates are attached. Costing is on fixed nitrogen basis.

NITROGENOUS FERTILIZERS _ FLOWSHEETS



Nitrogenous Fertilizers (Ammonia)

(per metric ton fixed nitrogen, bulk, f.o.b. factory)

Item	Process	A			B			C		
	Scale	S	M	L	S	M	L	S	M	L
Capital ($1000)										
Fixed		600	2400	8000	500	2200	7000	800	3600	9600
Operating		70	200	500	60	200	400	90	500	1100
Sub-total		670	2600	8500	560	2400	7400	890	4100	10700
Manufacturing cost ($/ton)										
Materials		19	17	15	24	22	21	46	52	52
Utilities		9	8	7	24	17	16	32	29	28
Wages		7	6	6	6	5	4	10	9	9
Supervision		1	1	1	1	1	1	3	2	2
Fixed charges		21	18	17	16	14	13	26	24	23
Plant overhead		14	12	11	11	10	9	17	20	24
Sub-total		71	62	57	82	69	64	134	136	138
General Costs ($/ton)										
Administration		7	5	4	4	3	3	8	6	5
Packing		-	-	-	-	-	-	-	-	-
Sales		1	1	1	1	1	1	3	2	2
Other		5	3	2	3	3	2	8	6	4
Sub-total		13	9	7	8	7	6	19	14	11
Overall cost		84	71	64	90	76	70	153	150	149
Credits		21	15	12	18	15	14	84	86	94
Cost of main product ($/ton)		63	56	52	72	61	56	69	64	55

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Sulphuric Acid

Case Study

1. This material is the most useful of all chemicals, and is needed for innumerable purposes.

2.1 The essential component of sulphuric acid is, of course, the sulphur. There are several main sources of sulphur in the world -

Elemental sulphur deposits in land and lakes
Sulphides of iron, copper, zinc, lead, etc.
Hydrogen sulphide in natural gas
Sulphides in crude petroleum and coal
Sulphate of seawater and fossil brines
Sulphates from inland lakes
Gypsum
Ferrous sulphate from steel pickling mills
Wastes from refineries, explosive factories, DDT factories, rayon factories
Sulphur from sewage, tankage, tanneries, etc.
Other miscellaneous sources

2.2 Sulphur manufacture is reported to be the cheapest from the sulphur mined in the Gulf of Mexico and in Canada by the Frasch process, or extracted from the sour natural gases of the Lacq deposits in the Rhone Valley of France or from the Polish gas wells in Galicia or from petroleum walls in the Middle East. If cost were the only consideration, in most cases, these will be the sources of sulphur. But when other considerations are taken into account, a wide choice becomes available. Almost every country in the whole world will have available to it some source or other of sulphur within its own national boundaries, even if the source is only seawater. It becomes a question of economics (which would embrace considerations of foreign trade, foreign exchange, employment, strategic value, etc.) whether to set up a sulphur industry or not.

3.1 There are several possible routes to the eventual production of sulphuric acid. Most depend upon the production of sulphur dioxide and its subsequent oxidation to sulphur trioxide, but there are several possible variations. Some may be listed as follows -

(1) Fermentation to hydrogen sulphide, which is oxidised by air to sulphur dioxide or direct to sulphur trioxide.

(2) Distillation of sulphates like ferrous sulphate to yield sulphur trioxide direct.

(3) Roasting of gypsum with coal and clay to yield cement clinkers and sulphur dioxide.

3.2 Having secured the sulphur dioxide, two methods are available for the conversion into sulphuric acid.

(1) The chamber process or its modern equivalent - the tower process.

(2) The contact process.

3.3 In the chamber process, the sulphur dioxide is oxidised by oxides of nitrogen in chambers of large volume in the presence of steam, so that the actual product is a dilute sulphuric acid, which is concentrated by evaporation. The oxides of nitrogen are recovered and re-circulated. The chamber process suffered a rapid eclipse when the contact process got into full stride, but recently there have been improvements in the chamber process and expertise is more readily available. The process is simple and easily controlled. Variations in working conditions do not have far-reaching effects, and are anyway capable of rectification. The chamber process affords very valuable training for technicians in many branches of chemical technology. Many of the objections to the old-fashioned lead chamber process no longer exist. Thus, in an effort to reduce the great weight and the high cost of chemical lead, extensive trials had been made with glass, but previously the results were not very good. Nowadays glasses can be tailored to suit almost every need, and the old lead chamber process could become a glass-house process. Similarly, in order to reduce the vast cavernous spaces of the lead chambers, attempts were made to use oxygen instead of air. This succeeded well, but in those days oxygen was costly. Today tonnage oxygen is quite commonplace and under certain circumstances, cheap. These and other improvements might lead to the revival of a chamber process at economic cost if the incentive were there.

3.4 The contact process is in essentials much simpler. It consists of mixing sulphur dioxide with the correct quantity of air and passing the mixture through a catalyst. Sulphur trioxide is formed as a result, and is absorbed in concentrated sulphuric acid to yield fuming sulphuric acid, which is diluted to whatever concentration is desired. This process is simple, neat, efficient, clean, economical, cheap and compact. It is the only commercial process for the manufacture of acid stronger than 93%. But the process is sensitive to many factors, and has, therefore, to be kept under careful control. Catalysts are easily spoiled. Sulphur of high purity is required. The process does not work easily with only a small proportion of sulphur dioxide.

3.5 In this paper three processes will be considered:

(1) Distillation of ferrous sulphate to sulphur trioxide, which will be absorbed in concentrated sulphur acid in a ceramic-packed tower and diluted down to 98% acid.

(2) A finely-ground mixture of gypsum (or anhydrite), clay and coal is shaped into bricks and fired in a continuous Hoffman tunnel kiln to yield cement clinker and sulphur dioxide. The sulphur dioxide is treated with air in a Kachkaroff tower system to yield dilute acid, which is concentrated in open pans fired with coal to 93% grade

BOV (brown oil of vitriol), and subsequently upgraded to 98% grade with fuming sulphuric acid.

(3) Elemental sulphur is burned to sulphur dioxide (with recovery of heat) and the sulphur dioxide converted into sulphur trioxide in a contact plant using vanadium pentoxide as catalyst. The sulphur trioxide is absorbed in concentrated sulphuric acid and reduced to 98% acid with water.

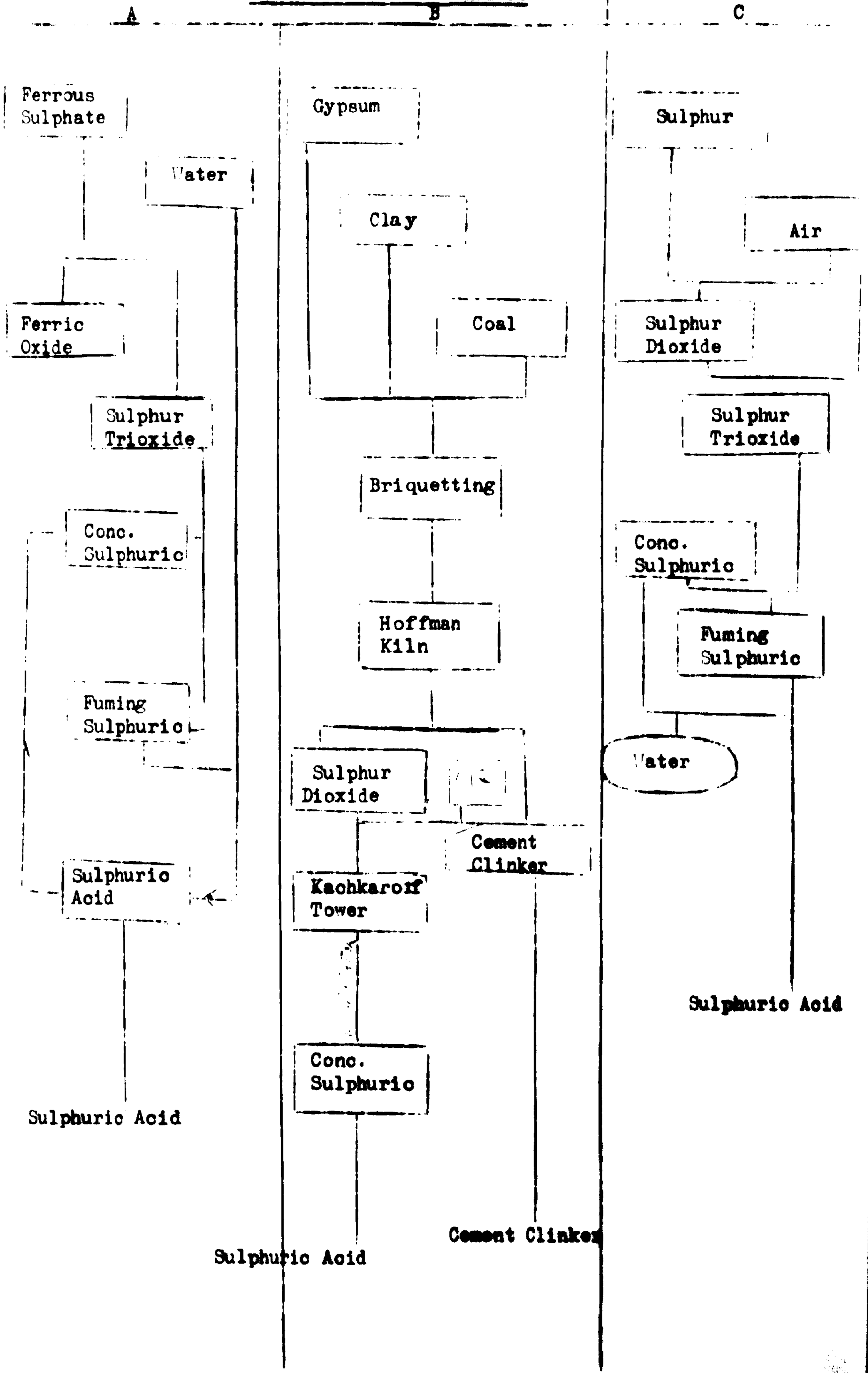
As before in this paper, credit is being given for value of co-products and by-products, leaving all residual costs applicable on the sulphuric acid.

3.6 The scales of operation considered are -

		Tons per day 98% sulphuric acid
Small	-	10
Medium	-	100
Large	-	500

3.7 Tentative flow sheets and approximate costing sheets are attached.

SULFURIC ACID FLOW SHEETS



Sulphuric Acid

(98% grade in drums f.o.b. factory)

Item	Process	A			B			C		
	Scale	S	M	L	S	M	L	S	M	L
Capital ($1000)										
Fixed		400	1800	4000	500	3000	6000	300	2000	4500
Operating		40	160	350	50	300	500	30	180	400
Sub-total		440	1960	4350	550	3300	6500	330	2180	4900
Manufacturing cost ($/ton)										
Materials		16	15	14	11	13	18	15	14	12
Utilities		3	6	3	3	4	3	2	2	1
Wages		2	3	2	3	4	3	3	3	2
Supervision		2	2	2	3	3	3	1	1	1
Fixed charges		5	5	4	6	6	5	4	4	3
Plant overhead		4	4	3	5	5	4	3	3	2
Sub-total		32	35	30	31	35	33	28	27	21
General Costs ($/ton)										
Administration		3	2	2	3	2	2	3	2	2
Packing		2	2	2	2	2	2	2	2	2
Sales		1	1	1	2	2	1	1	1	1
Other		8	5	4	8	5	4	6	4	3
Sub-total		14	10	9	15	11	9	12	9	8
Overall cost		46	45	39	46	46	42	40	36	29
Credits		10	12	12	10	12	12	6	4	3
Cost of main product ($/ton) (Net)		36	33	27	36	34	30	34	32	26

Sulphuric acid Industry

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PETROCHEMICALS

Case Study

1.1 What is commonly understood by this term nowadays is that group of separate chemicals which are made from petroleum or natural gas, excluding fuels and lubricants, but including derivatives of the chemicals, which are made by the petroleum processor.

1.2 A few examples will clarify the definition:

(a) Naphta is a petroleum-refinery fraction, used as fuel and as source of hydrogen for manufacturing fertilizers. It is not a definite chemical but a miscellaneous group of hydrocarbons and is therefore not classed as a petrochemical.

(b) Toluene is extracted by simple distillation processes from petroleum. It is a definite chemical compound, and therefore can be classified as a petrochemical.

(c) Toluene is nitrated to nitrobensene by the factory processing the petroleum fractions and is hence classed among the petrochemicals.

(d) Nitrotoluene is used by somebody else for manufacturing explosives. These explosives are not petrochemicals.

1.3 Nowadays there is an enormous range of products which, under this definition, could be classed as petrochemicals. It is estimated that petroleum is the source of 85% of all aliphatics and 75% of all aromatic organic chemicals in world production today. Even cellulose acetate, to be spun into acetate rayon yarn, has been claimed as a petrochemical industry product - a case of the tail wagging the dog.1/

1/ United Nations, Possibilities of Integrated Industrial Development in Central America - (Sales No. 63.II.G.10), p.53

1.4 The only petrochemical in large-scale production earlier than 1920 was carbon black. Today the petrochemicals include several thousand products The reasons are the abundance, free availability and low cost of petroleum feedstock, and the tremendous advances in technology in this field, especially in the use of catalysts.

1.5 Methane (from natural gas) is one very large source of hydrogen, ammonia, ammonium salts and urea. Natural gas also gives rise to carbon black, acetylene, methyl alcohol, and a long series of related products.

1.6 Ethylene (from natural gas or from cracking of ethane, propane and liquid fractions) is the largest source of aliphatic petrochemicals. Ethylene is the parent of alcohol, polythene, styrene, glycols, amines, detergents, plastics, elastomers, nylons, solvents, etc.

1.7 Thousands of benzene derivatives are manufactured from petroleum fractions, and the bulk of the production is in high polymers - plastics, synthetic resins, elastomers, fibres, etc.

1.8 Sulphur is today being made as a petrochemical to the tune of 4.4 million tons per year (out of a total of 23 million tons from all sources) and the output from this source is rapidly increasing.[1]

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[1] Oil & Gas Journal 18 January, 1965, p.51

1.9 The synthetic, neoprene (2 chloro 1:3 butadiene) is one of the most versatile and useful of the synthetic elastomers for synthetic rubber production.[1] It is manufactured by a three-stage process as follows.

(1) Dimerization of acetylene to vinyl acetylene (VA)
(2) Hydrohalogenation of VA to chlorobutadiene (CBD)
(3) Polymerization of CBD to neoprene

The material is produced as a latex, from which the solid can be recovered, if necessary.

This synthetic rubber sells at 33 to 40 cents per lb. (compared to about 22 cents per lb. for standard SBR). Neoprene contains about 35% of chlorine and the rest is hydrocarbon. Due to the difference in the unit costs of these two ingredients, their costs in the final neoprene are probably about 10% for chlorine and 90% for acetylene. With raw materials costing no more than about 10 or 12 cents per lb., and with only three stages of processing, it is not apparent why the final product has to be sold at 33 cents per lb.

> "Peculiarities of the chemical manufacture of neoprene require considerable knowledge and skill, which would have to be imported into a developing country. However, the simplicity of the basic raw material supply - acetylene and hydrogen chloride - is an attractive point for consideration. The general versality of the products is also an important advantage."[2]

2. Petrochemicals are the newest in chemistry, and developments are so rapid that processes frequently become obsolete before they are properly exploited comercially. The establishment of a really sound petrochemicals complex requires the support of a considerable

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[1] Othmer - Synthetic Rubber, paper No. 71 presented to the Petrochemicals Conference at Teheran in November 1964.

[2] Othmer, *loc. cit.*

mass of basic technology and many scientific disciplines of the latest types. This does not mean that this is an unsuitable field for a developing country to enter. On the contrary, when other processes are becoming obsolete, it provides a built-in advantage for new countries. However, since its products have so much applicability in the everyday life of the common man, most countries would like to secure domestic manufacture of these products. Further, with the establishment of petroleum refineries in developing countries to produce fuels (and, to a lesser extent, lubricants) it is comparatively a simple and certainly a profitable matter to increase the size of the plant to produce petrochemical feedstock. It is important to realise that, while the efficient manufacture of petrochemicals is very sensitive to the correct operating conditions and the right catalysts, basically the unit operations are simple. Once the best operating conditions have been determined, there is no great difficulty in establishing them and maintaining the conditions invariant (or variable to a previously set pattern.

3.1 The question of scale of operations is of importance. The total consumption of petroleum oils and natural gas in the world is approaching 1 1/2 billion tons per annum, or about 1/2 ton per head per annum. The average demand for a population of 10 million would be 5 million tons per year - a respectable amount by any standard. In actual practice, of course, averages do not apply. The advanced countries have an energy consumption far greater than the developing countries, first, because with their higher standards of living they consume much more themselves and secondly because they do most of the manufacturing processing for the developing countries. The developing countries all have programmes of rapid industrialisation and increase in productivity, with corresponding rise in their standards of living. Their consumption of energy is therefore likely to show a very steep rise when these processes get fully under way.

3.2 This industry nowadays produces both the bulk chemicals of low unit value, such as fertilizers, paint solvents, detergent stock, plastics, etc., and fine chemicals like pharmaceuticals, dyes, perfumes, essences, laboratory re-agents, test chemicals, etc. There is, therefore, room within the industry for any scale of operation, large or small.

4.1 The technology of petrochemicals is mainly a combination of the following basic chemical processes·

(a) Cracking or pyrolysis
(b) Polymerisation
(c) Alkylation
(d) Hydrogenation, oxidation and thiogenation
(e) Halogenation, nitration and amination
(f) Isomerisation and ring fission
(g) Aromatisation and cyclisation
(h) Esterification and hydrolysation

All these are effected by temperature, pressure, time and through various catalysts. So many products are being manufactured that there is no point in giving examples because almost the whole of chemistry can now furnish examples of petrochemicals.

4.2 One point which is of the utmost importance to developing countries is that, although the entire science is based upon the transformations of liquid and gaseous petroleum-derived feedstock, it is not necessarily limited to these sources. Ethylene, for instance, can produce quite a few hundred derivatives by petrochemical techniques. But ethylene is ethylene, from whatever source it may come. Petrochemists may find it convenient to derive ethylene from natural gas or petroleum cracking operations, but it is theoretically possible to derive ethylene from alcohol, which in turn can be produced by fermentation of molasses. This is, of course, unlikely to be seen in practice (save under unusual conditions) [*] but it illustrates the point that although the term "petrochemical" is a convenient historical term, it must be realised that the processes would be identical for similar feedstock from other sources.

> "All so-called petrochemicals have been or could be produced from agricultural products, coal, other minerals such as shale, or even animal matter. In the long run, economic factors determine which route is followed..." 1/

4.3 The point is of relevance to countries which have no petroleum refineries as yet, but wish to start their petrochemical complex immediately, and do not want to depend upon foreign feedstock for their essential raw materials. They may have coal or lignite or peat or firewood or agricultural wastes which can be carbonised. This carbonised product can be readily converted to carbon monoxide (producer gas) which can yield hydrogen. Agricultural residues can readily produce furfural, a reactive chemical with five carbon atoms in the chain. Molasses or starches give a plentiful supply of glucose, which has a chain of six carbon atoms. Neither molasses nor starch can be as cheap as petroleum oils, but if the former are available for national currencies and the latter only for foreign exchange, it might be preferable to go in for the national raw material despite higher cost.

> "...petroleum, coal and agricultural products are interchangeable for the production of organic chemicals... A vital factor in the trend away from agricultural products and towards petroleum as a raw material has been the desire...of becoming reasonably independent of foreign supplies of basic commodities..." 2/

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*/ See, however, the article on "Industrial Alcohol" (p. 152) for a practical instance.

1/ Kirk and Othmer - Encyclopoedia of Chemical Technology, (Inter-Science, New York) Vol. 10, p. 181.

2/ Kirk & Othmer, loc. cit.

The same motivation, in reverse, would impel developing countries to use their own national raw materials in preference to an imported product. The glucose, in turn, can give ethyl alcohol, which has two carbon atoms, or butyl alcohol, which has four carbon atoms, or lactic acid, which has three carbon atoms in a chain.

4.4 Even on the question of costs, the advantage is not always with petroleum. Thus -

> "...the initial United Kingdom acetylene cost from naphtha will be 7 - 7.5 c/lb. Acetylene from the old carbide route costs 8.5 - 10 c/lb. 1/

The difference can be wiped out in a developing country due to factors other than technology. Hence the "old carbide route" may not be so unattractive, after all.

5.1 To illustrate the choice of technology, the manufacture of polyvinyl chloride is taken up below. This substance can be produced by several different routes, of which the following will be chosen.

(1) Naphtha cracked to

	%
Ethylene	28
Other gases	42
C_3 and C_4	7
Motorcar fuel	20
Heavy oil	3

The ethylene is reacted with surplus chlorine from a nearby caustic soda plant to yield ethylene dichloride. This EDC is pyrolysed to give vinyl chloride monomer and hydrochloric acid. The monomer is polymerised to PVC.

(2) Heavy oil cracked to give ethylene, which is reacted with oxygen and hydrochloric acid to ethylene dichloride, followed by

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1/ "Chemical Week" 10 September 1966 p. 80

cracking to yield vinyl chloride monomer, which is polymerised.

(3) Calcium carbide is treated with water to yield acetylene, which is then reacted with hydrochloric acid to yield monovinylchloride (MVC) which is polymerised to PVC. (Neither calcium carbide nor hydrochloric acid is a petrochemical, but the process is included for comparison).

The costing does not include the cracking operations, but starts with ethylene or acetylene as the case may be.

5.2 All these processes are in commercial practice. The scales of operations chosen will be

	Metric tons per year of PVC
A	200
B	1000
C	10,000

5.3 The subject of petrochemicals is of such immense complexity that it is impossible to quote general figures of cost. There are so many determining factors, such as -

(1) Availability of raw materials and their cost. Thus, by-product chlorine or hydrochloric acid may be had for nothing under some conditions. Cheap naphtha may permit a lower conversion efficiency to be tolerated, and thus to economise on plant.

(2) Use of co-products. Sometimes these are saleable at attractive prices, and thereby enable the PVC plant to cost its own requirements at low rates. Thus, the C_3 and C_4 fractions of the naphtha cracker could be sold as bottled gas in towns at (comparatively) high rates.

(3) A sheltered market for the products would be invaluable - sometimes indispensable. PVC piping, for instance, may be used in domestic plumbing.

(4) If the PVC plant is just a part of a bigger chemicals complex it may be saved most, if not all, of its overhead costs.

5.4 These and other factors profoundly influence the size at which a plant can be operated profitably. Technologically there is no difficulty in constructing a plant which can function on a regular basis at the rate of 200 tons per year or 10,000 tons per year. At the lower reach, much skill is needed to assemble unit components of stock types to avoid the heavy costs of custom design and fabrication. Surplus pieces of equipment are often to be had at low prices. Thus, this costing, while not based upon the chance availability of suitable equipment at windfall prices, does not, on the other hand, provide for costs of special design and fabrication of custom-made and integrated equipment. Stock prices are assumed.

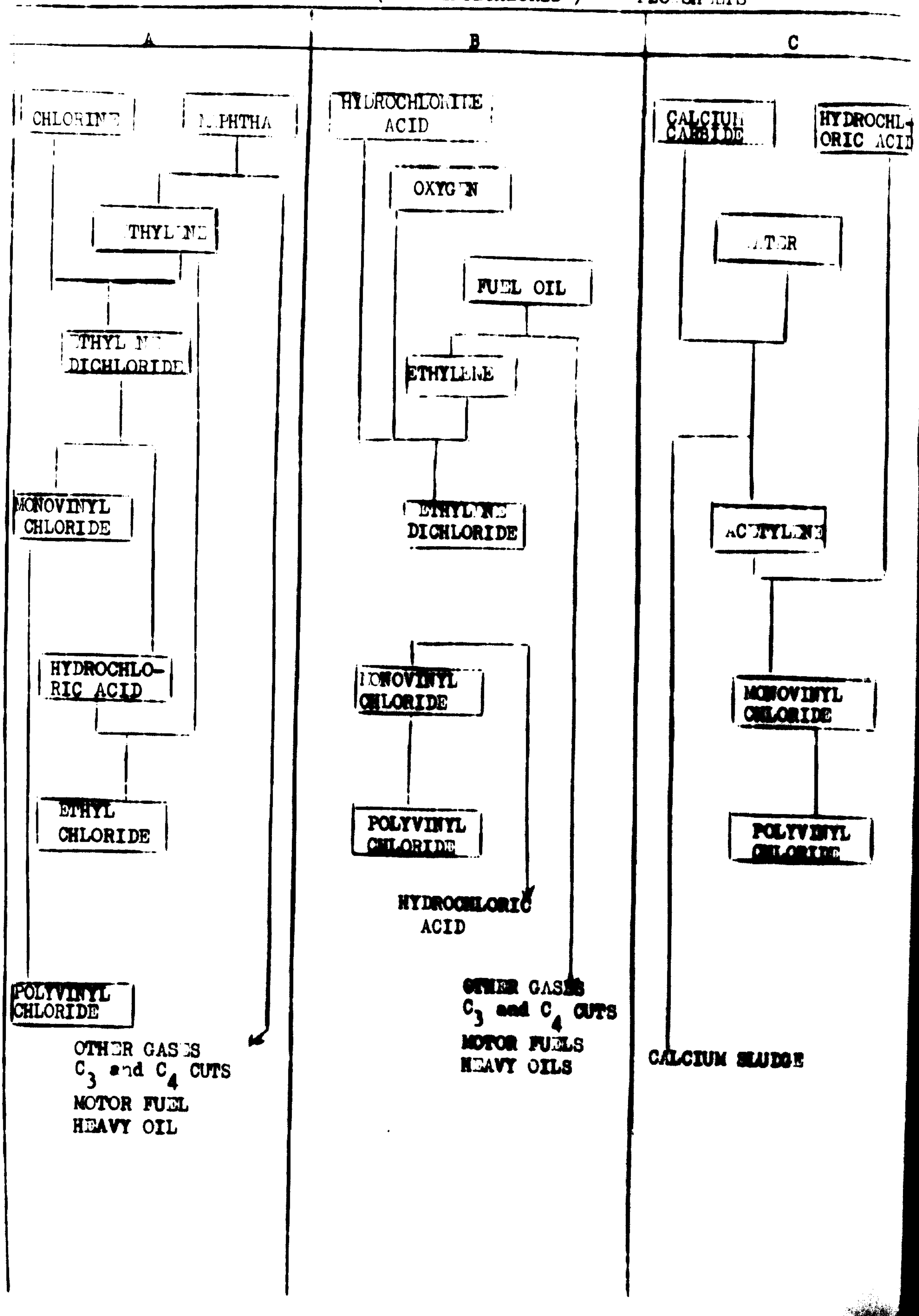
5.5 Likewise, while the costing does not assume fancy prices for co-products which are occasionally and by accident to be had in certain situations, it does not, on the other hand assume that co-products will have to be sold at giveaway prices as if they were waste products. Standard market prices are assumed, even though a particular developing country may not have an internal market able to absorb the whole of a particular co-product at that price. No other basis of costs can yield coherent or comparable results on this generalised pattern.

5.6 The following is a recent comment -

> "What size ethylene plants? .... At least four plants larger than 600 million pounds per year are in the works. And the Lummus Co. is putting together a 1 billion pounds per year plant for Imperial Chemist Industries....
>
> One engineering design firm, Chem Systems Inc. of New York...is offering a scheme...capacity is less than 35 million pounds of ethylene; required investment is only $ 1.5 million...total cost of producing...is less than 5 ¢ per pound..."1/

1/ "Think Small in Ethylene" - Chemical Week, 5 November 1966, p.41

PETROCHEMICALS (POLYVINYLCHLORIDE) - FLOWSHEETS



Tentative Costing Statement

Polyvinyl Chloride

(In paper bags f.o.b.factory)

ITEM — Process	A			B			C		
Scale									
Capital ($1000)									
Fixed	300	1000	3000	500	1500	4000	250	600	2700
Operating	50	100	350	60	140	400	30	60	270
Sub-total	350	1100	3350	560	1640	4400	280	660	2970
Manufacturing cost ($/ton)									
Materials	220	205	189	185	160	142	290	270	250
Utilities	35	30	26	65	48	39	30	26	21
Wages	20	22	24	29	31	34	9	9	8
Supervision	5	5	5	6	6	6	2	2	2
Fixed charges	86	74	68	98	85	79	61	57	52
Plant overhead	58	51	46	65	57	53	38	32	26
Sub-total	424	387	358	438	387	353	430	398	359
General costs ($/ton)									
Administration	3	3	4	4	4	5	4	4	5
Packing	8	10	12	8	10	12	8	10	12
Sales	2	2	3	2	2	3	2	2	3
Other	4	4	4	6	5	5	6	6	6
Sub-total	17	19	23	20	21	25	20	22	26
Overall cost	441	406	391	458	408	378	450	418	385
Credits	32	32	32	6	8	12	-	-	-
Cost of main product ($/ton)	409	374	359	452	400	366	450	418	385

Petrochemicals

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Industrial Alcohol

Case Study

1.1 The production of ethyl alcohol as a source of chemicals and energy and as solvent is comparatively recent. Today it has been outdone by petroleum oils, but that is because petroleum is extraordinarily cheap, relative to its usefulness, and because the petroleum industry has created an effective worldwide distribution system. Industrial alcohol, in addition to cost problems, is generally severely hampered by various excise laws and regulations. But it is easy to produce, and a valuable source of many consumer products essential to the functioning of a modern society. It should have strategic value to countries which do not have resources of fossil fuels like natural gas, petroleum, coal or peat. Even where these resources are available, it is often convenient to manufacture ethyl alcohol as an intermediate or final product. Thus, for instance, a large chemical firm, in embarking upon the manufacture of polyvinyl chloride plastic in Peru, set up a fermentation alcohol plant and dehydrated the alcohol to ethylene, instead of the more conventional process, viz, to crack some petroleum fraction to get ethylene direct.[1] This process has also been recommended for Turkey. [2]

1.2 In the chemical process industries involving the carbon

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[1] *Chemical Week* for 24 October 1964, p.103

[2] Ford, Bacon & Davis - Pre-investment survey of chemical industry of Turkey (USAID No. 2/14/00324, Washington, D.C.,1962) p.4

compounds (plastics, rubbers, paints, dyes, pharmaceuticals, insecticides, synthetic fibres, detergents, carbon black) and also some non-carbon products like fertilizers and sulphur, for nearly two centuries coal was dominant while the fermentation products were of second importance. Today, petroleum has taken over 70% of this area, and coal and fermentation industries are much less used. One of the least elements of importance in the petrochemicals industry is the availability of raw materials. They are so abundant and so cheap nowadays that the procurement of raw materials presents no problems, and the availability of raw materials at some specially advantageous price may not be so much of a benefit as in other industries. The petroleum industry is based upon a huge infrastructure of heavy engineering, instrumentation, research, and abstract knowledge, which is limited to a few advanced countries. Other countries aspiring to enter the petrochemical industry are required to pay a price for technology which sometimes makes local production uneconomic vis-a-vis imports.

> "...a nation's potential for petrochemical production is affected by its degree of industrial sophistication. Aside from their hydrocarbon feedstock, petrochemical plants draw on a vast array of other raw materials, process chemicals and operating supplies. They require ready access to replacement equipment and to the equipment manufacturer's technical advice. And, in large measure, the stimulus for petrochemical growth seems to be related to the availability of skilled technical personnel and to their ability to communicate readily with their colleagues in related industries.
>
> To a large extent, it is only in advanced industrial societies that we find the markets which alone can support a broad petrochemical industry..." 1/

1/ Korsmeyer - Natural gas as a raw material for petrochemicals - Petrochemical Conference, Teheran, 1964, Paper No.38,p.2

1.3 The profits on petrochemicals appear to be enormous. Thus, an international petrochemical company has sales in 1965 amounting to $112 millions, with net profit of $72 millions.1/ It seems clear that a developing country providing a home for such an industry would not get a large share of these profits, unless it is very sharp about it.

1.4 The route through industrial fermentation and the further chemical processing of the primary products are comparatively simpler operations than petrochemistry and can be managed on a smaller scale. They afford an excellent training ground for more sophisticated industries; require much less capital, and provide more employment, both primary as well as secondary. Other advantages are the considerable support of the agricultural industries, the introduction of the scientific attitude into agriculture, and the conservation of foreign exchange by the utilisation of indigenous raw materials.

2.1 There are many raw materials and processes for the manufacture of industrial alcohol. The oldest process and the best known is by the fermentation of sugars. These sugars may be derived from naturally-occurring syrups like the juices of sweet fruits or sugarcane or beet molasses. Or starches could be processed biologically or chemically to yield fermentable sugars. Or cellulosic wastes like sawdust or sugarcane bagasse or straw could be hydrolysed by physical or chemical means to fermentable sugars. Or celluloses could be hydrolysed, direct by the symbiotic microbial communities which live in the rumen of cattle and other ruminants. Paper pulp mill wastes are a valuable source - Sweden alone has about 30-35 plants using sulphite mill wastes. 2/

1/ "Chemical Week" 24 September, 1966, p.24

2/ United Nations - Pulp and Paper Prospects in Latin America- Sales No. 1955:II.G.4, page 385

2.2 In the manufacture of alcohol synthetically, the possibilities are indeed very many. Ethyl alcohol has two carbon atoms and one hydroxyl group in its molecule, and it can be formed from any two-carbon-chain hydrocarbon, like acetylene or ethylene or ethane. It can also be formed from the single-carbon methane by certain well-known transformations. Indeed, almost any carbon compound could be eventually converted into alcohol by a series of chemical transformations. In practice, however, the following would probably summarise the most economic synthetic processes.

(1) Cracking of petroleum or fractionation of coke-oven gases to ethylene and acetylene.

(2) Manufacture of calcium carbide and processing it to acetylene.

(3) Hydrogenation of coal to various hydrocarbons, gaseous and liquid, followed by cracking or catalytic decomposition in the same way as petroleum fractions.

(4) Burning fuels in a limited supply of air yields carbon monoxide, which on reacting with caustic soda or potash yields a two-carbon chain, the oxalate, which can be reduced to ethyl alcohol. Formates and oxalates were once made exclusively by this process, but it is now seldom used, because other processes are cheaper.

2.3 In the use of ethylene as starting materiel, the gas is passed into 98/99% concentrated sulphuric acid. When the product is boiled with water, it is hydrolysed into ethyl alcohol, with some formation of diethyl ether. The acid is again concentrated and re-used, or if there is a market for the diluted acid, sold as such. Overall output exceeds 92% conversion. Recently catalytic hydrolysis in the vapour phase has been introduced, and will, of course, greatly simplify the process. In this process, it does not matter what other gases are present, so long as they do not react with ethylene or alcohol. A gas with even 10% ethylene is usable.

2.4 With comparatively minor modifications, the methods of using acetylene are more or less the same as with ethylene. Normally, acetylene is such a valuable and powerful agent in the synthesis of various commercial organic products that it would not be used for manufacturing alcohol. However, if this is part of a complex, wherein, for instance, the manufacture includes calcium carbide, calcium cyanamide, ammonia, nitric acid and other related products, it might be feasible to produce some carbide for the manufacture of acetylene and then the acetylene could be used to make many products, including alcohol.*/

2.5 Most of the fermentation processes yielding alcohol result in a product ("beer") containing up to 95% water. As every "moonshiner" knows, dilute alcohol can be readily concentrated by straight evaporation in comparatively simple equipment up to about 94 or 95% alcohol. At this point, the alcohol and water mixture evaporates as a whole, and no further separation can be effected by straight distillation. To concentrate it further, two methods are used.

(1) A solid dehydrating agent like calcium chloride or sulphate.

(2) Aseotropic distillation i.e. by using a third volatile substance as carrier, like benzene.

In both cases the third agent is recovered and re-used. The use of solid dehydrating agents is simpler and cheaper in capital cost, but aseotropic methods are more effective and cheaper per unit of alcohol produced.

3.1 The following manufacturing technologies will be considered:

(1) Digestion of corn cobs with dilute hydrochloric acid to produce furfural, followed by treatment of solid residue with concentrated hydrochloric

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*/ A well-known complex in Japan does just this.

acid to yield glucose, which is fermented to alcohol, and the alcohol concentrated to industrial grade 95%, distilled azeotropically with benzene to 99% grade.

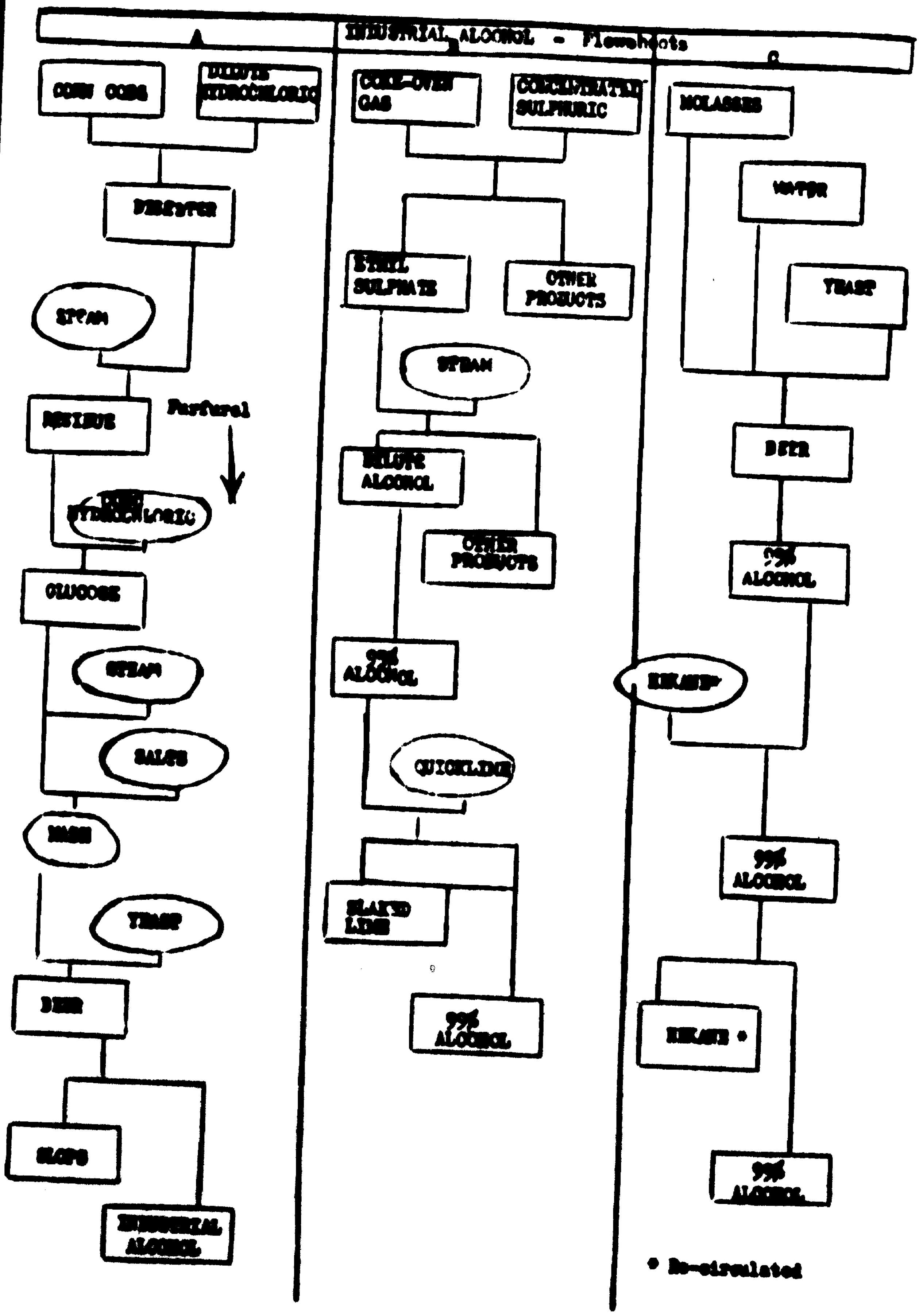
(2) Coke-oven gas is used as a source of ethylene. The ethylene is absorbed in concentrated sulphuric acid, and the product diluted and hydrolysed with steam to yield 95% alcohol, which is then dehydrated with calcium chloride in alcoholic solution to 99% grade. The calcium chloride and sulphuric acid are recovered and re-used.

(3) Sugar cane molasses are fermented, and the resultant alcohol is distilled to 95%, and thereafter subjected to azeotropic distillation with a hexane petroleum fraction to 99% grade.

3.2 In each case, three levels of production will be considered

Small	- 5 tons per day
Medium	- 30 " " "
Large	- 100 " " "

3.3 Flow sheets and tentative cost figures are quoted.



* Re-circulated

Tentative Costing Sheet

Industrial Alcohol

Item	Process	A			B			C		
	Scale	S	M	L	S	M	L	S	M	L
Capital ($1000)										
Fixed		300	800	2000	150*	600*	1400	350	1300	3000
Operating		20	100	200	15	40	100	50	120	250
Sub-total		320	900	2200	165	640	1500	400	1420	3250
Manufacturing cost ($/ton)										
Materials		8	9	10	30	28	26	14	14	14
Utilities		30	26	20	6	4	3	12	10	8
Wages		12	11	9	4	3	3	5	4	4
Supervision		4	3	2	1	1	1	2	2	2
Fixed charges		20	19	16	11	11	10	18	16	14
Plant overhead		11	14	11	7	10	10	11	9	9
Sub-total		85	82	68	59	57	53	62	55	51
General costs ($/ton)										
Administration		18	14	10	6	4	2	12	7	4
Packing		3	2	2	3	2	2	3	2	2
Sales		1	1	1	1	1	1	1	1	1
Other		7	5	4	2	2	1	4	3	3
Sub-total		29	22	17	12	9	6	14	12	10
Overall cost		114	104	85	71	66	59	76	67	61
Credits		25	30	35	2	4	8	2	3	4
Cost of main product ($/ton)		89	74	50	69	62	51	74	64 70	57 65

* Does not include cost of producing the ethylene.

Industrial Alcohol
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Paper

Case Study

1.1 Paper is the matted or felted sheets of fibre, generally of natural origin, formed from a water suspension. Thicker and stiffer papers are called paperboards, while hard wood-like sheets are called hardboards. The fibre goes through an intermediate stage, when it is called pulp.

1.2 The pulping and the actual paper-making are two quite distinct operations. Where both operations take place in one centre, the factory is called an integrated paper mill. A pulping mill would make only pulp, and sell it to paper-makers, sometimes in dilute water suspension (slush pulp) but more often in wet sheets or as air-dry boards. There are paper-making mills which buy either a part or the whole of their pulp requirements. Some paper mills use only waste paper, which are beaten up by the paper mill itself into a pulp. Some paper mills may use cotton or linen rags, which are simply beaten up without chemical processing. These last two types of mills (which do not involve pulping proper) are necessarily few, and have small outputs, but the rag papers may be important, at least by use, if not by volume or value.

2.1 In paper-making, the most important consideration is to locate a suitable source of the essential fibrous constituent. Natural vegetable materials always have fibres somewhere in their make-up, but not all fibres are suitable, nor are all fibres equal in strength. A fibre which is initially stronger than another may require more severe treatment, which may reduce its strength below the strength of the other. By and large, the coniferous woods of the temperate climates provide the longest and strongest fibres for paper-making. In the tropical countries, bamboo and other grasses (including sugarcane residues) are good sources of strong fibres. Another such source is Manila hemp, generally from old ropes or hempen fabrics. Cotton and linen provide excellent fibres, but are generally too costly. Seed-flax tow is used for cigarette paper. Several countries have established pulpwood plantation on a cutting cycle which will provide them with a certain quantity of wood every year. Nowadays sawdust has emerged as a major raw material. It is rarely necessary that all the materials of a particular paper be of the strongest fibres. For most papers there is a judicious blend of long and short fibres, strong and weak. It is not to be assumed that the short or weak fibres are purely adulterants or extenders, as they may have useful functions of their own to contribute.

2.2 The commonly used sources of paper-making fibres are -

Wood and wood wastes like sawdust
Cotton and flaxseed linters
Bamboo, bagasse, esparto, sabai, other grasses
Straws and cereal stalks
Reeds, like papyrus
Bast fibres (flax, hemp, jute, wattle, mulberry)
Palm leaves, stalks, stems
Coconut(and other palm-nut)husks
Plant stems like cotton, tobacco, soyabean, sunflower, etc.
Cotton and linen rags and cuttings, old ropes and nets
Waste papers
Artificial fibres (glass, nylon, rayon)
Mineral fibres (asbestos)

In developing countries, these materials are available at comparatively low cost. Thus, in one rubber-growing country, hundreds of thousands of tons of rubber trees were burned on the ground annually for want of any economic use for them. Now it is planned to convert these trees into charcoal, to support a local iron smelting factory, but it may be more beneficial and profitable to use the trees for making paper and hardboards. Similarly, several countries which produce cereals on a large scale often burn the straw on the ground or plough it back, for want of any useful outlet, and this straw could readily be converted into paper. Hundreds of thousands of tons of wattle trees are allowed to rot on the ground in African countries. Likewise tea plantations have to be pruned annually, and the prunings could be a valuable source of strong fibrous material.

3.1 There are hundreds of varieties of paper in the market.[1] The following is an abbreviated and broad classification.[2]

- Book paper
- Writing paper
- Newsprint
- Wallpaper
- Glassine and greaseproof
- Bag, wrapping and lining
- Twisting
- Towelling, toilet, cleansing, napkins
- Cigarette
- Blotting
- Roofing
- Paperboards, boxboard, corrugated, bristol
- Insulating board

3.2 The biggest demands are in the following order :

---

[1] See Dictionary of Paper - (American Pulp and Paper Association, New York 1951)

[2] Based on Witham and Calkin - Modern Pulp and Paper-making (New York, Reinhold 1957)

Paperboards (various types)
Bag and wrapping paper
Book and magazine
Newsprint and mechanical
Writing

Between them, these items would cover over 80% of the needs in most developing countries.

4.1 There are many processing methods to convert the fibrous raw materials into slush pulp (i.e. pulp suspension before it is sheeted). They may be divided into three broad groups.

(1) non-chemical
(2) semi-chemical
(3) full chemical processing

4.2 The non-chemical processes are dependent on simply grinding the fibrous material. When a log of wood is held hard against a grindstone, it rapidly disintegrates into small particles. Almost all the materials of the wood (95%) are found in the resultant pulp, including lignins. A great deal of energy is consumed - from 1,000 to 2,000 kwh per metric ton air-dry pulp. Large quantities of water are required - up to 40,000 US gallons per ton A-D pulp. Some amount of pre-treatment is sometimes done, e.g. steaming or caustic soda soaking, and after grinding some bleaching may be deemed necessary. Groundwood paper from non-coniferous woods alone will not be strong enough for modern newspaper printing speeds, and some addition of coniferous pulps would usually be required.

4.3 Other mechanical processes include stamping mills and two-tier grindstones, but are not important on a large scale. Disc grinders are however of some applicability.

4.4 The semi-chemical processes are those in which the necessary separation of the fibres is effected partly by mechanical means and partly by chemicals. Thus, for instance logs may be soaked in sulphite or sulphate liquor for several hours at high temperature before grinding. Or wood chips may be soaked in cold caustic soda prior to grinding in a disc mill. One simple process of special applicability to grasses, bamboos, reeds and cotton stalks is the cold lime process, in which the raw material is kept in wet quicklime for a week or so, and is then beaten. Another semi-chemical process of wide applicability to agricultural residues is the chlorine process, where chlorine is used, not as the bleaching agent alone, but to digest the raw material as well

4.5 The wholly chemical processes are mainly the following -

sulphate (soda sulphate or soda ash and sulphur)
soda (soda ash or caustic soda)
sulphite (bisulphite)

4.6 The sulphate process uses sodium sulphate as make-up chemical, but this chemical actually takes no part in the digestion of the raw material. The main active re-agents in this process are the caustic soda and soda sulphide which are formed when the residual black liquor is burned and dissolved in water, the water treated with lime, and the product re-introduced into circulation. This is the point (black liquor, pre-burn) at which fresh chemical is introduced. The paper is generally used in the unbleached form as strong, tough bag and wrapping paper (kraft). However, nowadays sulphate pulp can be bleached to high-grade dissolving pulp and a substitute for sulphite paper in high-grade papers as well.

4.7 The effective chemical in the soda process is caustic soda. Nowadays it is usual to add a little sulphur as well. It was the first commercially practical pulping process. The process is generally adopted with the broad-leaved species of trees, which do not have long or strong fibres, and the treatment itself is drastic. Hence the soda pulps are generally used as filler grade fibres in many magazine papers, printing papers and writing papers, where strength is not the prime consideration. The capacity of the soda digesters can vary from 2 tons to over 15 tons per digester per cook. Soda pulp is not popular nowadays.

4.8 In the sulphite process, the functional chemical is sulphur dioxide. It is held in solution by an alkali, such as calcium, magnesium, ammonium or sodium. The real chemical inside the digester is the bisulphite of one or more of these alkalis, with free sulphur dioxide in addition. Because the sulphite process uses very carefully selected and pre-treated wood, it produces pulp which is light in colour, easily bleached, and reasonably strong. Hence these pulps are used for all kinds of printing and writing papers, and as a source of dissolving pulp for rayon. A variant of this process is the neutral sulphite process, using the monosulphite, bufferred with an alkali. It is specially useful in pulping agricultural residues, but the chemicals might be rather costly in developing countries.

5.1 Pulp-making machinery involves -

Handling raw material
Cleaning and treating raw material
Cutting raw material to size
Cold digestion with chemicals
Hot digestion with chemicals
Separation of cooked fibres
Washing cooked fibres
Production of chemicals
Recovery of chemicals

5.2 In the pulping section of an integrated mill, the main specialised equipment are -

the digesters
the beaters
the chemicals recovery plant
the chemicals make-up plant

All the other equipment are more or less of general purpose types.

5.3 A certain amount of instrumentation and control equipment is called for but there is no automation to the extent that can be seen in, say, a petroleum refinery.

5.4 The critical factors in a pulp mill deciding the success or failure of an undertaking are the utilities and facilities - steam, electric power, water, transport, waste disposal, etc. Depending upon the circumstances, the pulping mill may be a net purchaser of these utilities, or a net vendor, or be self-contained.

5.5 Because of the large volumes of liquids to be handled, there are many pumps installed in a pulp mill, each pump powered by its own electric motor. Storage and processing tanks are also of large volume.

6.1 A simple pulp mill can dispose of its pulp in one of three forms -

1) Slush pulp, to be piped to some nearby paper-maker.
2) Wet felt i.e. pulp sheeted out into laps and pressed as free of water as possible, but not specially dried. Suitable for only short-distance transport.
3) Dried pulp sheets. These are made on standard paper-making machines, and are therefore costly.

6.2 An integrated mill passes the slush pulp direct into the paper-making section. There is not much storage capacity in the system.

7.1 Pulp direct from the pulp mill is the cellulose of the raw material, freed from most of the lignin, hemi-celluloses and other undesirable components, except in groundwood pulps which retain them. Mild chemicals or cooking conditions also tend to leave these non-cellulosics behind. If the pulp is dried as it is, there is a certain amount of inter-locking of the fibres, but insufficient to confer the strength demanded of modern papers.

In order to produce strong paper, pulp must be well beaten mechanically. This beating or grinding has three effects. In the first place, the fibres are cut to right size. Secondly, each fibre is made more "hairy", thus making for greater inter-locking strength. Finally, the cellulose is to some extent hydrated and gelatinised. This gelatinising promotes adhesion between the fibres so that on drying a strong mat results. Special adhesives are often added in the paper-making process, such as starch, glue, rosin, etc. and these contribute their share to the strength of the paper. The processes of mechanical treatment and addition of chemicals is called stock preparation.

7.2 The beating and pounding of paper pulp could be done by hand, as in Egypt, 5,000 years ago. A little over 200 years ago, a machine was invented in Holland to do the work, and was called the Hollander or beater. It is still in regular use. Its main function is to brush out the fibres into hairy fibrils. Later, another machine was devised to cut the fibres as well and this machine was called a jordan or jordan engine or refiner. The functions of both hollander and jordan overlap to some extent. Some cutting is required anyway, as very long fibres do not distribute themselves evenly, and may clot together, and of course the clots do not contribute any strength to the paper. Cutting permits the pieces to remain straighter, and thus retain at least some of their strength. The hollander is the more versatile machine, and can perform all the stock preparation, if so required. Generally, however, it is preferable to complete the stock preparation in the jordan. Part of the hollander's function can be taken up by a rod mill, while the jordan's duty could be shared with other types of refiners.

8.1 Several different pulps are often blended to give paper of exactly the desired characteristics.

8.2 Non-fibrous additives to the stock include -

size (glue, starch or rosin)
wax
alum
mineral fillers (clay, chalk, titanium dioxide, etc.)
soda silicate
pigments and dyes
other miscellaneous materials

8.3 When all these materials have been thoroughly blended, the pulp is ready for conversion into paper.

9.1 The first step in paper-making is to free the pulp of knots and other deleterious components. The pulp is then poured over a moving endless wire belt in a machine called a Fourdrinier. The wire may run at a speed of up to 3000 feet per minute or more. The pulp forms a mat on the wire, which is washed with showers of water, and dewatered by suction applied through vacuum boxes. The wet mat is then guided on to a woolen felt (nowadays often made of a synthetic plastic) and the composite is pressed on the run between moving rolls. The mat then passes over a series of steam-heated dryers, where the product becomes the paper of commerce, which is wound on to rolls. A certain amount of further processing may be done at this stage, such as glazing or colouring.

9.2 The rolls of paper can be sold in this form or cut up into sheets or processed still further before disposal.

10.1 This thesis will treat the following types of technology:

A - Digestion of lemongrass residues by cold-lime process, followed by hollander and jordan. Blended with 20% waste paper, some starch, resin and alum size, and sheeted into paper for making corrugated paper.

B - Rubber trees ground up into mechanical pulp, beaten in hollander and ground in disc refiner, mixed with 20% semi-bleached kraft pulp and usual ancilliaries, and sheeted into newsprint.

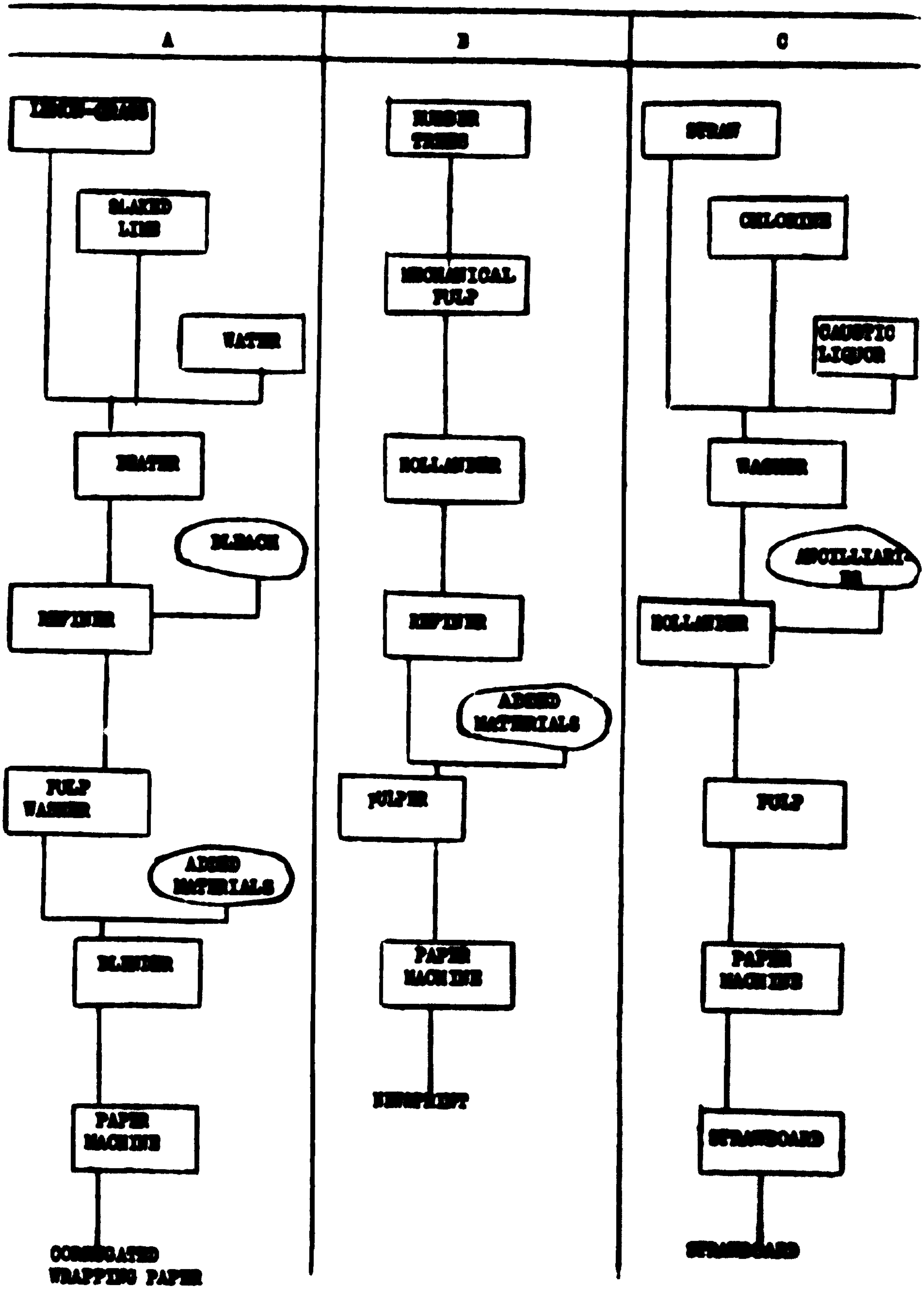
C - Straw treated by Pomilio chlorine-soda process and pulped with hollander only, with usual ancilliaries (no bleaching), to form unbleached strawboard.

10.2 The scale of operations will be fixed at

small - 2 tons per day
medium - 20 tons per day
large - 200 tons per day

10.3 Flow sheets and tentative costing statements are attached.

PAPER INDUSTRY - FLOWSHEETS



TENTATIVE COSTING SHEET

Paper Pulp

Item	Process	A			B			C		
		S	M	L	S	M	L	S	M	L
Capital ($1000)										
Fixed		100	600	5000	100	800	6000	60	500	4000
Operating		5	50	600	5	60	3000	8	100	500
Manufacturing cost ($/ton)										
Materials		20	23	26	18	16	14	23	25	26
Utilities		6	3	2	30	18	12	8	6	5
Wages		10	12	12	12	6	4	8	5	5
Supervision		2	2	1	2	1	1	2	2	1
Fixed charges		2	2	2	21	15	7	7	6	5
Plant overhead		2	2	2	8	6	5	3	4	5
Sub-total		42	44	45	91	62	43	51	48	47
General ($/ton)										
Administration		10	5	4	5	4	3	12	6	4
Packing		2	2	1	2	2	2	2	2	2
Sales		2	2	2	2	2	1	2	2	2
Other		7	3	2	6	4	2	8	3	3
Sub-total		21	12	9	15	12	8	24	13	11
Overall cost $ per ton		63	56	54	106	74	51	75	61	58

Paper Industry

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Man-made Fibres

Case Study

1. This is one of the most rapidly growing industries of the modern world. For some purposes, the natural fibres have largely been replaced by the artificial and synthetic fibres in the advanced countries. Even the developing countries have felt the impact of this advance of human science.

2. There is a bewildering variety of such fibres which science and technology have made available to the modern world, and it would be a formidable task to catalogue and codify the array of products which are available. Furthermore, both science and technology aremaking such great and rapid advances that obsolescence can occur within very short periods. To keep up with the research developments itself requires a specialised discipline. Hence no attempt is being made in this paper to cover any aspect of this field in detail

3. There are two broad groups of man-made fibres, namely :

   (1) Those regenerated from naturally-occuring products, (e.g. cellulosic fibres or long-chain proteins) without significant alteration of its basic chemical structure. These are the artificial fibres, i.e. those which are essentially fibrous to start with, and are either regenerated or modified in the processing.

   (2) The synthetic fibres are those which are just simple chemicals or non-fibrous complexes to start with, and have to be converted into fibres by chemical processing.

4. Nowadays, man-made fibres are in such demand that a raw material has to be really plentiful to warrant being used on a sufficient scale. Comparatively few materials occur in the world in sufficient

quantity. The major sources at present are

(1) Celluloses (including cellulosic wastes and seaweeds)
(2) Coal and coke, coaltar products, coal gas
(3) Natural gas
(4) Petroleum fractions
(5) Natural proteins, like casein or groundnut
(6) Fermentation products, like alcohol

5.1 In the early days of man-made fibres, just a generation ago, there were many technical problems. One of the important points was to produce a fibre thinner than a spider's thread at speeds and in quantities which would be commercially profitable. It was essential to prepare the liquid medium without the slightest trace of any solid particle, and to this day the filtration of the generating solution is one of the most important steps. Another equally important point was that the spinnerets had to be mass-produced to a precision utterly unknown until then, and done on a mass scale. These difficulties have now been overcome, and the technology is freely available to all countries of the world.

6.1 In order to limit the volume of this thesis, it is proposed to consider only the following :

(1) Viscose rayon staple
(2) Groundnut fibres (Ardil type) multifilament and staple
(3) Nylon, monofilament and staple

6.2 Viscose Rayon

This fibre is one of the earliest man-made fibres (patented in 1892), but took over 20 years to establish itself, and it was only in the 1930's that it became a world-wide force.

6.3 Viscose rayon is merely a regenerated cellulose. The cellulose can come from many sources, but the easiest and cheapest is wood. Other cellulosic raw materials in developing countries are bamboo, sugarcane bagasse, rice straw, etc. (more sources listed under "Paper"). The wood is converted into a pulp, and the pulp is purified and treated with caustic soda, when it yields alkali cellulose. When this is treated with carbon disulphide, it forms sodium cellulose xanthate, a substance which dissolves readily in dilute caustic soda, but in which the cellulose preserves its long-chain character, although somewhat degraded from its native condition. The xanthate solution is "ripened", pigmented, and just at the correct stage of "ripeness" is forced through minute holes (called "spinnerets") into an acid bath, where the thin streams of xanthate immediately coagulate into continuous cellulose filaments, and liberate the carbon disulphide. The filaments are bunched together and the yarn goes through further processes of stretching, purification and strengthening - also perhaps dyeing, twisting, crimping etc., and is then ready for the textile manufacturer. Staple is manufactured by cutting the bunched threads without putting twist into them.

6.4 Any wood could be used, but the strength of the fibre which comes out finally depends upon the strength of the fibrils of the wood. Hence the stronger the wood the better for rayon. Furthermore, in the process of pulping the wood, powerful chemicals have to be used to destroy the colouring matter inevitable in all wood, and this step weakens the fibres. Hence, the lighter the wood the better, because less chemical action is needed. Bamboo is an ideal material for rayon, and since only a few thousand tons would be needed, should generally be available in almost all developing countries. The caustic soda has to be specially free from sodium chloride, and this grade of caustic soda, usually designated as "rayon grade", commands higher prices than the ordinary grade. It is usually made in mercury amalgam electrolytic cells.

6.5 The cellulose and viscose solutions could be used for other purposes as well. Thus the same viscose could be used for making cellophane, another substance commanding a large market nowadays.

The purified cellulose would be very acceptable for making nitro-cellulose for explosives, lacquers, etc. Cellulose acetates are also in great demand for many purposes, and also hydro-cellulose, and the final degradation produce of cellulose, glucose. Hence, the plant which starts off to manufacture only rayon, could well be the nucleus for a large cellulose complex, as happened elsewhere - Germany, France, England, United States of America and Italy, for example.

6.6 Technological obsolescence in the rayon industry is so rapid that it should be quite easy to pick up almost complete plants in full working condition, for much less than the cost of new machinery. The value of secondhand plants for developing countries has been studied in some United Nations papers.1/

7.1 Artificial fibres can be readily manufactured from natural proteins like groundnuts, soya bean, milk casein, maize gluten, de-oiled coconut meat, blood fibrin, etc. Recent advances in the development of synthetic cattlefeed (incorporating urea) might be able to divert some vegetable protein from feeding cattle to the manufacture of artificial fibres, with no detriment to the production of meat or milk. Indeed, this is much the economic means of using the agricultural products, and would benefit both farmer and consumer.

7.2 In principle, the manufacture of protein fibres is exceedingly simple. Proteins are chains of amino-acids, and dissolve readily in alkalis. The resulting solution is squirted through spinnerets into an acid bath, which neutralises the alkali and thus regenerates the protein, in a filament form. The actual commercial practice requires purification of raw material and post-coagulation treatments. Urea can be used as the alkali, and possesses some advantage. During the spinning the fibres are stretched, to impart strength to the material. The filament has to be hardened while it is still wet, and

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1/ Report of Expert Group on Secondhand Equipment for Developing Countries — : United Nations, Sales No. 66:II.B.9 of 1966 and often this is achieved by the use of formaldehyde.

7.3 The resultant material is a substitute for naturally occurring protein fibres like wool, hair, fur, etc., and is generally much cheaper. The manufacture of artificial protein fibres could be used in developing countries where parts are cold enough to demand the use of warm fabrics.

7.4 A protein fibre factory would require a proteinaceous agricultural residue, generally an oil-cake. Hence it is best integrated with an oil mill. If urea is used as combining agent, and if the urea is readily recoverable, even in a crude form, it would be ideal material for combination with the oil cake residue to manufacture cattle food. Hence a complex of industries could grow in the area, and lead to considerable economies. The variables in this line of development are so great, however, that it is not possible to combine them with the economies of scale.

8.1 A typical plant would consist of :

(1) Intake of solvent-extracted groundnut cake.
(2) Purification of cake.
(3) Plant for manufacture of crimped, hardened, multi-filament staple of deniers suitable for various fabrics, from fine articles of clothing down to thick carpets and felt hats.

8.2 The fibre from groundnut is generally too weak for use by itself, but it can be easily blended with all the natural and artificial fibres, sometimes with unexpectedly better results than with the individual fibres separately.

Nylon

9.1 The origin of this material, which has today become a household word in every part of the globe, was an exercise in fundamental polymer chemistry by Wallace H. Carothers. Theoretical argument led to the conclusion that dicarboxylic acid diamides should polymerise, and this indeed turned out to be so. An early polymer of the species was nylon 66, i.e. the starting diamine and the dicarboxylic acid each contain 6 straight-chain carbon atoms in the chain. If the diamine contains 6 straight-chain carbon atoms and the dicarboxylic acid 10, the resultant polymer would be designated as nylon 610. This is actually being produced commercially, as also other nylons (3, 4, 5, 7, 8, 9, 10, 12 are ready for commercialization) but the nylon 66 which was the first to be synthesised, still remains the most popular in the USA. The reasons are because it is stronger, and because 6 carbon atoms in a chain occur very commonly in nature, and hence are cheaply available. Possibility of producing other long-chain dicarboxylic acids from agricultural products (e.g. the 10 carbon chain sebacic acid occurs in castor oil) suggests exploration of the other possibilities as well.

9.2 The 6 carbon chain with an amino group at each end is called hexamethylene diamine. The 6 carbon chain with a carboxylic group at each end is called adipic acid. The combination of the two results is hexamethylene diammonium adipate (nylon salt) which is polymerised to nylon itself. The degree of polymerisation is so adjusted that the material is as strong as possible, but melts at a low enough temperature (up to 265°C) without charring or decomposition. The nylon is melt-spun i.e. the melt is pumped through fine orifices at high speed and cooled by air to form hard monofilaments. The filaments are then cold-stretched to about four times their length, up to nearly breaking point, twist put into filaments, and the yarn taken up on bobbins.

9.3 A small modification of the raw material is to have a 6 carbon chain with an amine group at one end and a carboxylic group at the other end. The interaction between the end reactive groups of a single molecule produces a closed-chain compound called caprolactam. The polymer of caprolactam, although identical in ultimate chemical formula, is poly-caprolactam, nylon 6, not nylon 66, polyhexamethylene diammonium adipate. This material is more popular than nylon 66 outside the USA.

9.4 Nylon fibres are manufactured for many purposes, and the properties could be accurately tailored to meet customer specifications. Some require very strong fibres, but because these will have been stretched almost to the limit, they will have no further stretch. Some require good stretch properties, and naturally have to do with somewhat lesser strength, although the strength in absolute terms is still very high. Nylon is almost completely water-resistant and this valuable property is sometimes a disadvantage. Thus, fishing nets lost at sea never perish, and now present a serious hazard to shipping, because they can continue to foul propellors and propellor shafts for many years. Nylon also has inherently high elasticity, lightness, high melting point, high chemical stability, excellent electrical insulation, etc.

10. The principal raw materials for the manufacture of nylon 66 are hexamethylene diamine and adipic acid. There are several commercial routes to these materials.

(1) Distillation of coaltar or certain petroleum crude oils gives benzene, which can be sulphonated to phenol, which is hydrogenated to cyclohexanol, which is oxidised to adipic acid. These are defined stages, which are therefore controllable by the technician. Another popular method is to hydrogenate benzene direct to cyclohexane, which is oxidised to cyclohexanol. It is possible that some developing countries may find the first alternative better, especially if secondhand tried and tested plant is cheaply available. The adipic acid is reacted with ammonia to give the amide, which dehydrated to the nitrile which when reduced with hydrogen yields hexamethylene diamine. The hexa and the adipic acid are separately dissolved and mixed to give "nylon salt" - hexamethylene diammonium adipate.

(2) Butadiene is manufactured in enormous quantities for

manufacture of synthetic rubber, and a portion is used for manufacture of nylon. The butadiene itself comes from either petroleum or from industrial alcohol. Because the latter product is more conventional and more readily available, it is likely that it would be the better starting point for developing countries.

(3) The butadiene is chlorinated to dichlorobutene, which, when treated with hydrocyanic acid yields dicyanobutene which when reduced with hydrogen produces adiponitrile. Further reduction of the adiponitrile results in hexamethylene diamine, while hydrolysis of the adiponitrile results in adipic acid. The single butadiene, therefore, results in the production of both the components of nylon 66.

(4) A third commercial process is from agricultural wastes such as groundnut shells, rice husks, maize cobs, oat hulls, sugarcane bagasse, grape skins, coconut coir dust, sawdust, etc. These wastes when treated with dilute acids and steam yield furfural. In the USA,

> "The largest use for cobs, perhaps 150,000 tons per year, is for the manufacture of the important chemical, furfural. Two large plants, one at Cedar Rapids, Iowa, and the other at Memphis, Tennessee, which have a productive capacity of more than 20,000 tons per year, make furfural...It has been recently announced that about 12,000 tons per year of furfural will be used to produce a chemical required in the manufacture of nylon"1/

The manufacture of nylon from furfual has been functioning for some years. Furfural is converted to furane by alkali and the furane is hydrogenated to tetrahydrofurane. Hydrochloric acid converts the THF to dichlorobutane which, when treated with

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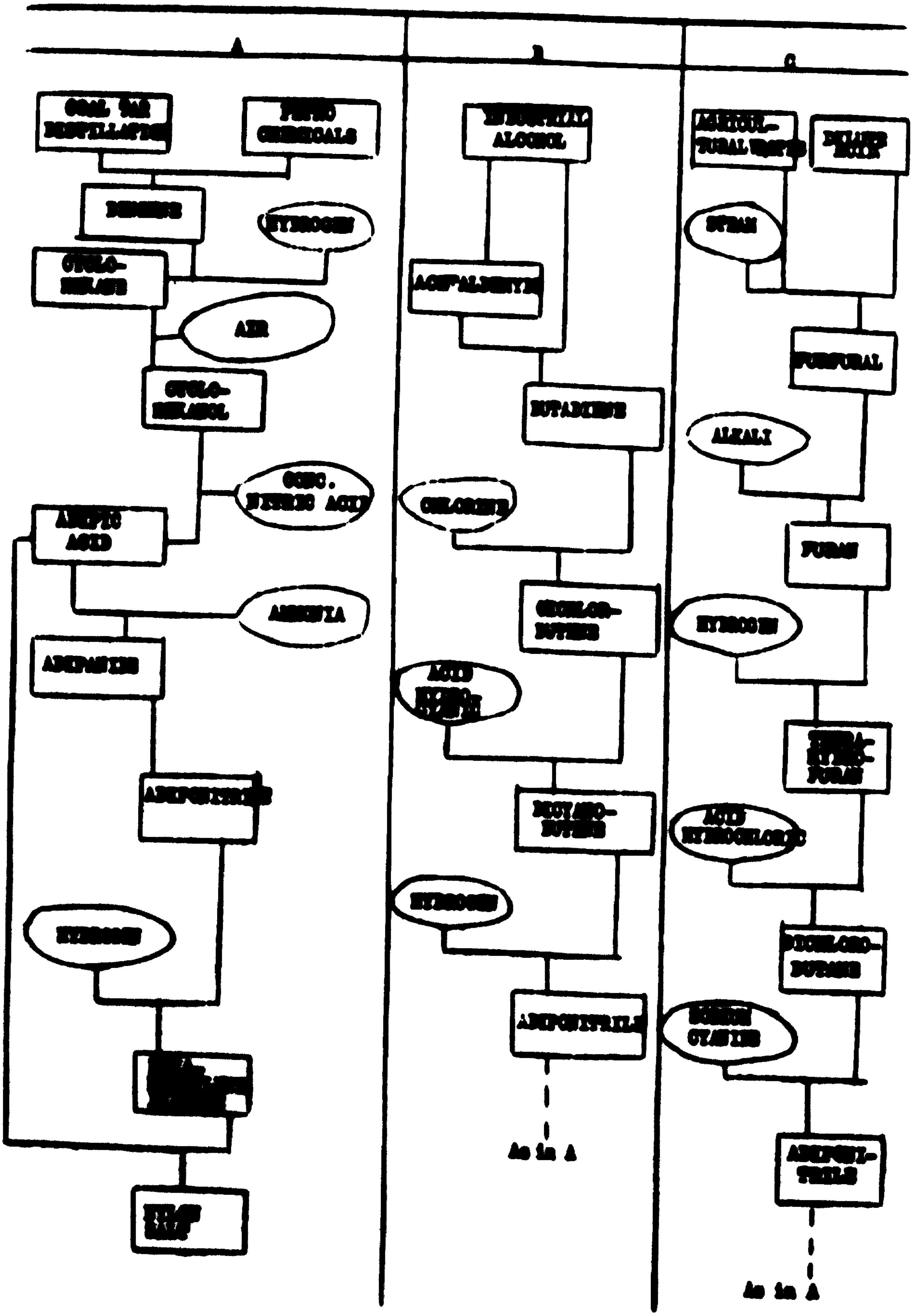
1/ Lathrop - Industrial Utilization of Corn Crop Residues - Northern Regional Research Laboratory, Peoria, Illinois, publication OP 5485 (n.d.)

MANUFACTURE OF NYLON - FLOWSHEETS



sodium cyanide yields adiponitrile. As in the case of butadiene, the adiponitrile can be treated to yield both the components of nylon 66, and furfural is, therefore a complete source of nylon.

(5) The merits and demerits of each process have to be exhaustively investigated separately in every individual case. There are many factors involved. Hence it is proposed to consider only the last route i.e. starting with the manufacture of furfural from groundnut shells.

11.1 In this paper the costing will be done on nylon, manufactured by the three routes described above. The three scales of production selected for this analysis would be

(1) 300 pounds per day
(2) 3,000 pounds per day
(3) 30,000 pounds per day

11.2 It is fully realised that the different strengths of the fibres meant for different purposes makes comparison by weight rather inappropriate, but there are so many non-textile uses for this fibre that the differences may even out.

12. Flow sheets and cost sheets are annexed, subject to the caution that the latter are only indicative of possible order of magnitude and are in no way to be taken as the costs in any actual installation.

Tentative Costing Sheet

(cents per pound of moulding resin chips)

ITEM — Process	A			B			C		
Scale	S	M	L	S	M	L	S	M	L
Capital ($1000)									
Fixed	400	600	4200	500	900	5800	750	1600	8600
Operating	30	50	420	40	100	600	50	120	500
Sub-total	430	650	4620	540	1000	6400	800	1720	9100
Manufacturing cost (cts/lb)									
Materials	33	30	28	33	32	30	12	23	29
Utilities	21	18	15	20	16	15	42	38	27
Wages	15	14	11	18	14	10	18	14	12
Supervision	4	4	3	4	3	3	5	4	4
Fixed charges	14	14	12	17	16	14	16	14	13
Plant overhead	9	11	8	12	13	10	12	12	10
Sub-total	96	91	77	104	94	82	105	105	95
General costs (cts/lb)									
Administration	6	5	4	10	8	6	12	9	7
Packing	1	1	1	1	1	1	1	1	1
Sales	1	1	1	1	1	1	1	1	1
Other	4	3	2	5	4	4	8	6	4
Sub-total	12	10	8	17	14	12	22	17	13
Overall cost	108	101	85	121	108	94	127	122	108
Credits	18	22	28	24	26	34	38	46	52
Cost of main product (cts/lb)	90	79	57	97	82	60	89	76	56

Man-made fibres

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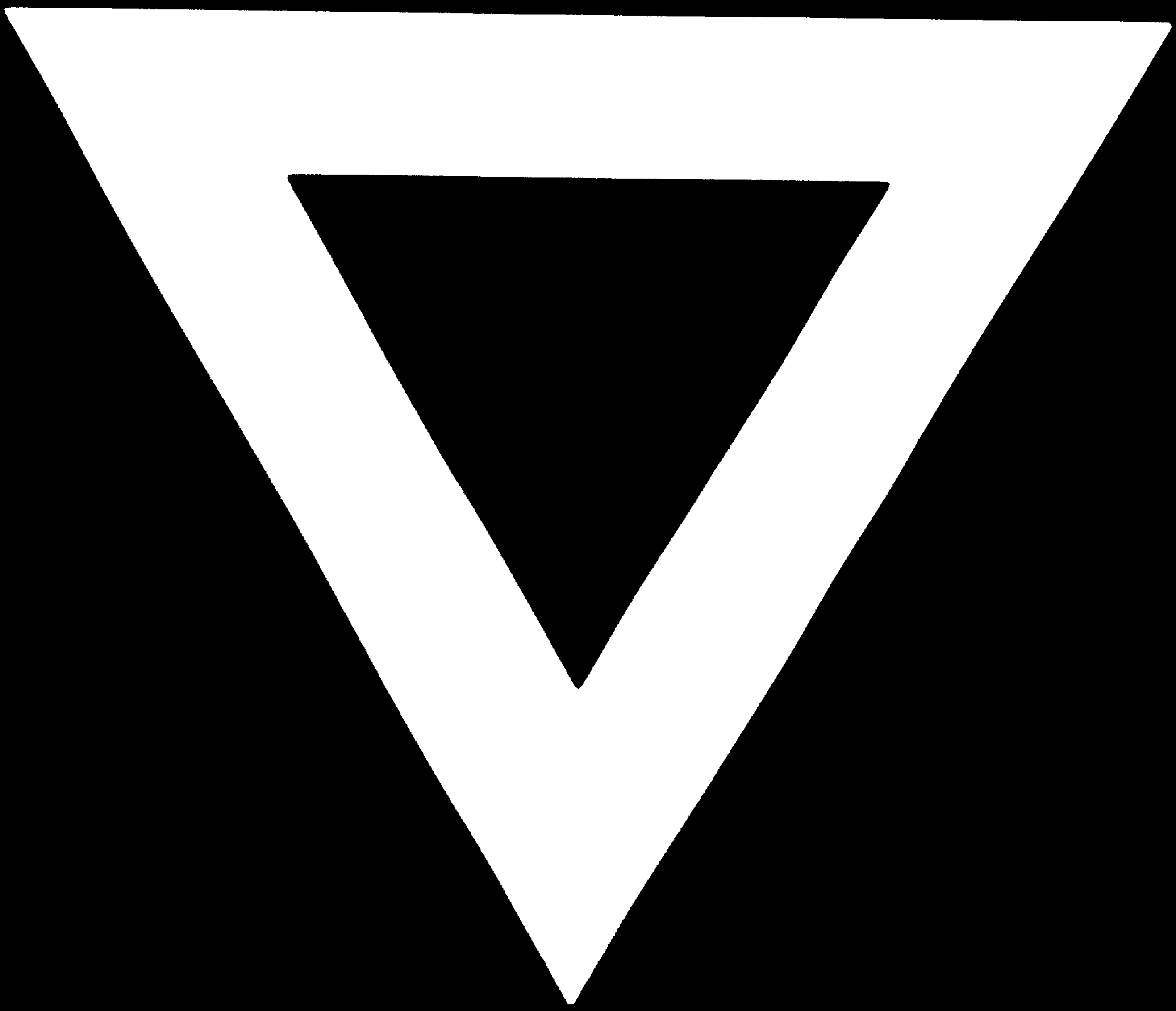

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