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The World Bank

OVERVIEW
OF
PORT RELATED INDUSTRIES

by
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Transportation Department

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Abstract

This paper is intended as a guide to port planners in the preliminary assessment of the requirements for port facilities, services, and layout to support the requirements of industries which benefit from colocation with a port. The basic characteristics and requirements of each type of industrial plant are discussed, and the demand for port resources is identified.

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PAPER

0. INTRODUCTION

0.1 Background

Waterborne transport is the cheapest and sometimes the only available alternative for moving materials in large amounts. In their effort to reduce transportation costs and to avoid multiple handling of materials, industries which depend on importing large volumes of raw materials and/or exporting significant quantities of end products often select shoreline sites to gain easy access to water.

In some cases, exporting needs are the most critical factor in siting an industry adjacent to a harbor. Typical example is the oil refinery industry. Since a refinery plant uses crude oil as feedstock while it has a spectrum of various products as output, domestic consumption of the refinery products creates the necessity of locating the plant close to the consumers. In this way, a number of pipelines or other land transport modes can be eliminated and a single pipeline is only needed for supplying the crude oil. However, if a great portion of the refinery production is going to be exported, port surroundings become the most favorable siting position.

Countries lacking adequate energy resources need to import large quantities of coal, oil or liquefied gases thus transforming many ports and harbors into energy sources. This fact, combined with the large cooling water needs of power plants, caused many such units to be located near ports, a fact which in turn attracted energy intensive industries to the adjacent waterfront. Large enough plants may have their own port terminals.

The role of ports is thus increased, as they combine their traditional function of link between land and sea transport with industrial activities.

The port's position as an operational link in the industrial production chain is emphasized by the fact that it is usually more economical for prime processing plants to be located close to sources of raw materials, or at least near the port of export since primary processing reduces the bulk of the materials to be handled and, thus, the transportation costs. In addition, this location enables the producers of raw materials to add value to their products through processing. However, finishing operations should be located close to the main markets, and it is the role of shipping to transport the intermediate products. This approach is very common today in industries with more than one processing stage, especially in cases where several kinds of raw materials from different origins are required for the manufacture of one end product. Shipping of intermediate products such as alumina and wood pulp are typical examples.

The creation of custom free areas ("free zones") within the port can further foster the development of industry in a port area by providing the opportunity for customs free processing of imported semi-finished and intermediate products, with shipping immediately adjacent. This is of considerable significance for labor intensive industries, which are able to operate plants in the free zones of countries with cheaper labor reserves. At the same time, valuable employment opportunities are provided in these countries.

Industrial ports and industrial free zones are credited with generating over 3.5 million new jobs in developing countries[1] as well as over $2 billion of new investment.

A significant number of industrial ports have been developed in recent years. Many of these have made or are expected to make contributions to the economic development of their hinterland and countries, in terms of:

1. Employment generation, direct and indirect. Total employment generated usually exceeds direct employment by a factor of 4;
2. Foreign exchange earnings, as exports, embodying domestic value added, are usually increased;
3. Increase in utilization of domestic services and capital for export generation;
4. Increase in potential for technology transfer;

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[1] AID Paper No. 18, 1983, "Free Zones in Developing Countries".

5. Increase in foreign capital investment;

6. Training of domestic labor in new skills;

7. Transfer of management know-how;

8. Development of marketing and sales opportunities for free zone and domestically manufactured products;

9. Increase in entrepot/transshipment trade.

Apart from industrial activities located at a port, ports have also benefited from the industry-port relationship, as they have been able to attract customers with large, and frequent transport needs. In addition, ports strongly related to heavy industries are relatively invulnerable to competition from other ports.

In their effort to cope with the needs of industry, ports are subject to technological changes of which the following are important:

- Increased vessel size. Increasing capital and operating costs, exploitation of natural resources in more distant locations, and high operating costs and great competition in the shipping industry, have all contributed to the production of larger vessels. While in 1965 no ship existed with a summer draught of more than 55 ft., in mid-1980 the draught of 31 petroleum tankers exceeded 75 ft. (0.9% of total), and 73 (1.6%) dry bulk carriers had a draught of 58 ft. and above2/. For the moment the trend

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2/ Figures according to Lloyd's Register of Shipping, Statistical Tables.

towards larger ships has been reversed, but many ports still need to deepen their berths and approach channels, as well as increase the length and capacity of the berths.

- Increased handling efficiency: The length of time spent by ships in port represents a loss of earning capacity which can be of critical importance in economic transportation, and thus there has been significant development in cargo handling efficiency, port layout and design. The introduction of special vessel types such as container ships, ro-ro vessels, and the various types of barge carriers, as well as the developments in modern methods of handling bulk commodities with greatly increased loading/discharging rates, have all resulted in the need to provide modern efficient port facilities.

Thus, the effective planning of a modern industrial port requires that port managers and engineers become familiar with the basic requirements of the industrial plants which may be interested or could be attracted to base their operations within or adjacent to the port.

0.2 Objective of the Report

This report has been produced with the primary objective of providing readily accessible information to appreciate the overall impact that the establishment or expansion of industry at or near a port will have. The report is aimed at use by the staff of the World Bank and its borrowers.

Bank's port and related industrial projects have in recent years often established the need for a simple information base on the main industrial characteristics, such as the demands for land, cooling water, energy, labor, etc. and the environmental impact of typical waterfront industries which would benefit from location near a port.

Although many different types of industry can be found on waterfronts or near ports throughout the world, not all of them really need to be located adjacent to navigable water. In this report only those industries which are best sited adjacent to navigable waterways or ports have been considered.

Thus, the following industries have been included:

1. Iron and steel industry.

2. Bauxite/aluminum industry.

3. Cement industry.

4. Fertilizers industry.

5. Petrochemicals industry.

6. Paper industry.

These industries either import major inputs or export their partial or end products using waterborne transportation. A great proportion of the world's fleet is engaged in such trades.

It should be noted that the report specifically excludes oil refineries. The reason for this is that this industry is extremely flexible in its plant size and although frequently sited adjacent to good, deep, navigable waterways, the inputs can be transported cheaply by pipelines while the products may be distributed through pipelines or land transport. Thus siting the refinery adjacent to the ultimate consumers has considerable advantages.

The report presents for each of the port related industries described the following basic criteria:

- Industrial processes: A short description of the major manufacturing processes used by each industry are presented, as the report is intended primarily to be used by port planners with no or little background in industrial operations.

- Raw materials requirements: Prediction of material handling requirements is one of the most important factors in effective port planning.

- Water requirements: For many industries, water is the most important commodity needed apart from the raw materials. It is so vital for both processing and cooling, that it frequently controls the choice of location.

- Energy requirements: Industries such as iron, aluminum, chemical, cement, etc. are intensive energy consumers. It is essential to investigate the type and extent of the energy needs for any new development. The cost of conservation and supply can have an important effect on industrial economics. Imports of energy may under certain conditions affect the transportation needs.
- Area requirements: Flat land is a prime requirement for port development and increases in importance where there is to be associated industry. Land availability may be a serious constraint for industries like petrochemical plants (a fully integrated ethylene plant may reqiure as much as 200 hectares).

- Labor requirements: The principle effect of labor is itsir influence on the operating costs of an industry. From the point of view of this report, however, labor requirements affect the infrastructure scope and the access to highly populated areas, as in the case of iron and steel industries.

- Environmental impacts: A major problem created by modern industry is that of pollution. Port-related industries have attracted a great deal of criticism because of water and atmospheric pollution, especially as industrial ports are usually adjacent to highly populated areas. In addition, bauxite and iron plants are major land pollutants. Environmental pollution may be a more severe problem in industrialized countries with high population densities but equal attention should be paid in developing countries if serious problems are to be avoided.

- Transport requirements: It is important to port planners to know the physical form of cargoes to be handled, the volumes of materials to be transported, and the usual practice for types of ships and handling equipment employed in the various trades.

- Other special issues of importance in each industry.

It should be noted, that capital and operating costs are not included in the analysis, as they are outside the scope of this study. Costs vary widely from country to country and from plant to plant, and the available figures are not always representative. In a few instances, costs are mentioned but only for the purpose of comparison between alternative methods.

For all industries included in this report, special attention has been given to developing countries, in terms of special problems or factors affecting the selection among alternative manufacturing processes.

It should be also noted, here that more detailed analysis of the environmental impacts of each industry branch can be found in the publication

"Environmental Guidelines", Office of Environmental Affairs, World Bank. In addition, valuable insights in bulk shipping and bulk terminals are offered by the World Bank Technical Paper No. 38, "Bulk Shipping and Terminal Logistics".

0.3 Presentation of the Industries

The report is presented in six chapters, one for each industry. Each chapter is divided into sections: Section A (data sheet) is a brief review of the industry, and serves as a quick ready reference to the industry requirements, in a way that the reader can have some idea of the critical issues involved, without having to read the entire chapter.

Section B provides a relatively detailed description of the industrial processes and the requirements in terms of energy, materials, transport, labor and other relative issues.

Section C is included in each chapter to give the user a better understanding of the industry. Brief descriptions of actual plants are presented. Figures and Tables are provided for each plant to offer some insights in plant layout and the way that certain problems have been tackled.

Section D includes a list of statistical tables where considered necessary.

Chapters IV and V are an exception to the above presentation as the multiplicity of the products of the fertilizer and petrochemical industries made it necessary to incorporate more sections with a different structure.

0.4 Further Development

It will be apparent that the six industries analyzed in this report do not cover the entire spectrum of port-related industries. Many more industrial plants are in many cases located on waterfronts for various reasons. Among them power plants, grain and other food processing industries and oil refineries are the most obvious to be found. In many cases the reason for their being sited adjacent to navigable water is not associated with transportation needs but, perhaps, the scarcity of flat land in the interior, adjacent communities and markets, or some other constraint provided the choice for the siting.

As the use of this report will later demonstrate, other industries considered suitable can be added in future editions. The present list is far from finite.

I.

IRON AND STEEL

I.A Data Sheet

I.A.1 General

Steel is produced via two routes from iron ore. The older established methods, using a blast furnace (BF) to extract the iron content of the ore which is then fed to a Basic Oxygen Process furnace (BOF) - also known as the Linz-Donawitz (LD) process - to produce steel, are still viable for large scale processing and where coke is available. Because of the economies of scale allied to such plant, raw material supply is also large and consequently so is any import requirement. Economies of scale here too apply, and bulk ore carriers of up to 350,000 dwt may be utilized.

However, modern technology has developed a more economical process route particularly adapted for small production units of about 500,000 - 600,000 t/a of steel but a number of such units may be installed at one site although, typically, beyond 3 to 4 the BF/BOF process is more economical. The modern process is by direct reduction (DR) of the iron ore in one of a number of different types of proprietary plant (HYL, Midrex, SL/RN etc) followed by steel making in an electric arc furnace (EAF). This route produces a low carbon steel and is generally more suitable for developing countries, particularly those which have an available supply of inexpensive natural gas. Economies of scale are not as apparent, and so the lower input requirements for shipments of raw materials, basically the iron ore, mean that smaller shipments are commonly used, and in consequence cheaper port facilities than for a BF/BOF process may be sufficient.

Numerous gaseous, liquid and solid wastes are produced in a steel making plant, and effective technologies should be applied to reduce emissions into acceptable limits, inactivate toxic and hazardous substances, and recycle by-products. Noise pollution is also a problem.

In world trade (1983) while over 90% of ore shipments was in bulk carriers of over 40,000 dwt, 37% was carried in ships of 100 - 150,000 dwt, 18% in ships of 150 - 200,000 dwt, and 11% in ships over 200,000 dwt. In the coal trade - raw material for coke production - while 73% was carried in ships of over 40,000 dwt, 35% was in bulk and combined carriers of over 100,000 dwt.

Iron ore has a bulk density of between 1.9 and 3.5 t/cu m but typically about 2.5 t/cu m, while coal's density is in the range of 0.75-0.85 t/cu m.

I.A.2 Direct Reduction/Electric Arc Furnace

Max unit size approx. 600,000 t/a steel (up to 3 to 4 units per complex before Blast Furnace/Basic Oxygen Process Furnace may be more economical.)

Requirements for 1 ton of steel produced by a plant of about 500,000 t/a, with scrap providing 30% of output:

Iron ore	1.5 t
Natural gas	13 million BTU
Fluxes (e.g. lime)	0.1 t
Scrap	0.3 t
Water	15 - 50 t
Elec. energy consumption	850 kWh - 1200 kWh
Installed energy capacity	220 W
Personnel	8000 t/man/a
Site area	0.6 - 1.5 sq m
Waste	0.15 t
Typical ship size	Panamax per unit, unless economies of scale with other units or plants permit.

I.A.3 Blast Furnace/Basic Oxygen Furnace

Economical for large production units and where coke/coal and/or low grade ore are supplied.

Requirements for 1 ton of steel produced,with scrap used to feed for 20% of steel output:

Iron ore	1.43 t
Coke	0.50 t
Limestone	0.21 t
Scrap	0.20 t
Water	150 t (but may be reduced with recycling)
Elec. energy consumption	400 kWh
Installed capacity avail.	80 W
Personnel	500 - 1,000 t/man/a
Site space	0.6 - 3.2 sq m
Waste	0.6 t
Typical ship size	As economies scale can be achieved so carriers of circa 200,000 - 350,000 dwt should be allowed for.

I.B Iron and Steel Industry Description

The following sections will briefly review the basic processes and technology utilized by modern steel plants. The material flows and the area, labor, and shipping requirements will be presented. The environmental impact of iron and steel manufacture will be shortly discussed; and available typical figures of capital and operating costs will be also presented.

I.B.1 Iron and Steel Manufacturing Processes

The basic steps in iron and steel manufacture are:

(i) extraction of iron metal (in the form of "pig iron" or "sponge iron") from iron ores;

(ii) raw steel production from pig iron, sponge iron or iron/steel scrap; and

(iii) fabrication of steel mill products by various rolling and finishing operations.

Figure I.B-1 provides a schematic overview of iron and steel making operations.

I.B.1.1 Ironmaking

Iron ores contain iron in mineral form, chemically combined with oxygen. The following are the principal ores with their iron content:

magnetite	$Fe_3 O_4$	72% Iron
haemetite	$Fe_2 O_3$	70% Iron
limonite	$2 Fe_2 O_3 3H_2O$	60% Iron
geothite	$H Fe_3 CO_2$	63% Iron
siderite	$Fe CO_3$	48% Iron

Almost all iron ores are treated to increase the iron content or to prepare them, as feedstock of appropriate size. This process, often referred to as "beneficiation", may include crushing, grinding, screening, washing, separation and drying.

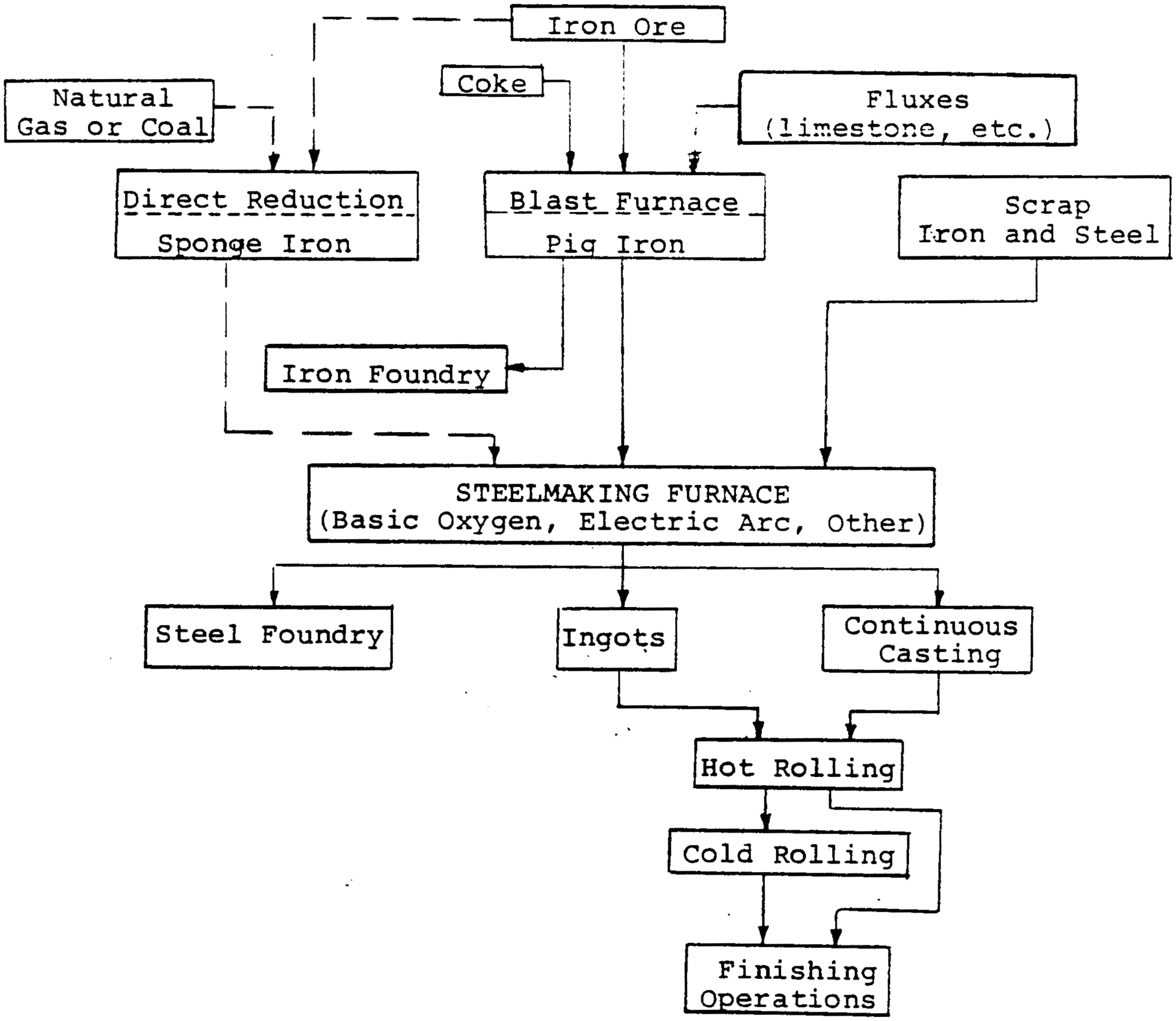


FIGURE I.B-1

SCHEMATIC SUMMARY OF IRON AND STEELMAKING

Source: Staff.

"Sintering" or "pelletization" processes may also be used with low grade or fine ores. The sintering process, in which the fine ore is mixed with coke breeze and fluxes, is normally carried out at a blast furnace site. Pelletization is a process whereby fine grained ore is concentrated, by magnetic separation, gravity or flotation, and compacted with moisture and a binder to form small 10 - 20 mm diameter balls. These are then hardened by heating, cooled and screened, and are then ready for shipment.

Iron metal can be extracted by heating (smelting) the ore to high temperatures in the presence of reagents that combine with the unwanted ore constituents, leaving behind molten iron, which is readily separated from the other reaction products. The main reagents are a carbonaceous material (coal, coke, natural gas) and a fluxing material (limestone or dolomite); the former combines with mineral oxygen in the ore to form carbon monoxide and carbon dioxide, while the latter serves to remove silicon, aluminum, and other impurities as a slag.

As shown in Figure I.B-1, two iron extraction technologies are in widespread use, the blast furnace and the direct reduction processes, which produce pig iron and sponge iron respectively.

I.B.1.1.a Blast Furnace

Most of the world's primary iron is produced in blast furnaces, which consist of a refractory-lined steel shaft continuously fed with iron ore, coke, and limestone charge at the top and with preheated air (1090°C) at the bottom. The hot air rises countercurrent to the descending solids, provides for partial combustion of the coke, and is emitted, along with combustible coke gases, as "top gas". The latter is thoroughly scrubbed and filtered and then fed to refractory-lined stoves where it is burned, to preheat the blast furnace air supply, and then released into the atmosphere via smoke stacks. (See Figure I.B-2.)

Molten pig iron containing some dissolved carbon and silicon collects at the bottom of the blast furnace, along with a slag layer containing the remaining mineral constituents of the iron ore. Molten iron and slag are intermittently tapped from the hearth. The pig iron is either transferred directly to an integrated steelmaking furnace or cast into "pigs" for subsequent sale or in-plant use. The slag is disposed of as waste or used for concrete aggregate, railroad ballast, soil conditioner, or landfill.

I.B.1.1.b Direct Reduction Furnace

Blast furnace pig iron contains relatively high dissolved carbon percentages, which must be lowered when the iron is refined into steel. Alternative iron extraction methods are available that yield low-carbon iron directly from the ore and are referred to as "direct reduction" processes.

Direct-reduced iron is produced in vertical shaft furnaces and rotary kilns from a charge of pelletized ore and dolomite or limestone. The carbonaceous reducing agent may be coal, fuel oil, or natural gas depending on the particular process technology in use.

The fundamental difference between direct reduction and blast furnace processes is that the former requires temperatures below the melting point of iron, while the latter produces molten metal. Direct-reduced iron

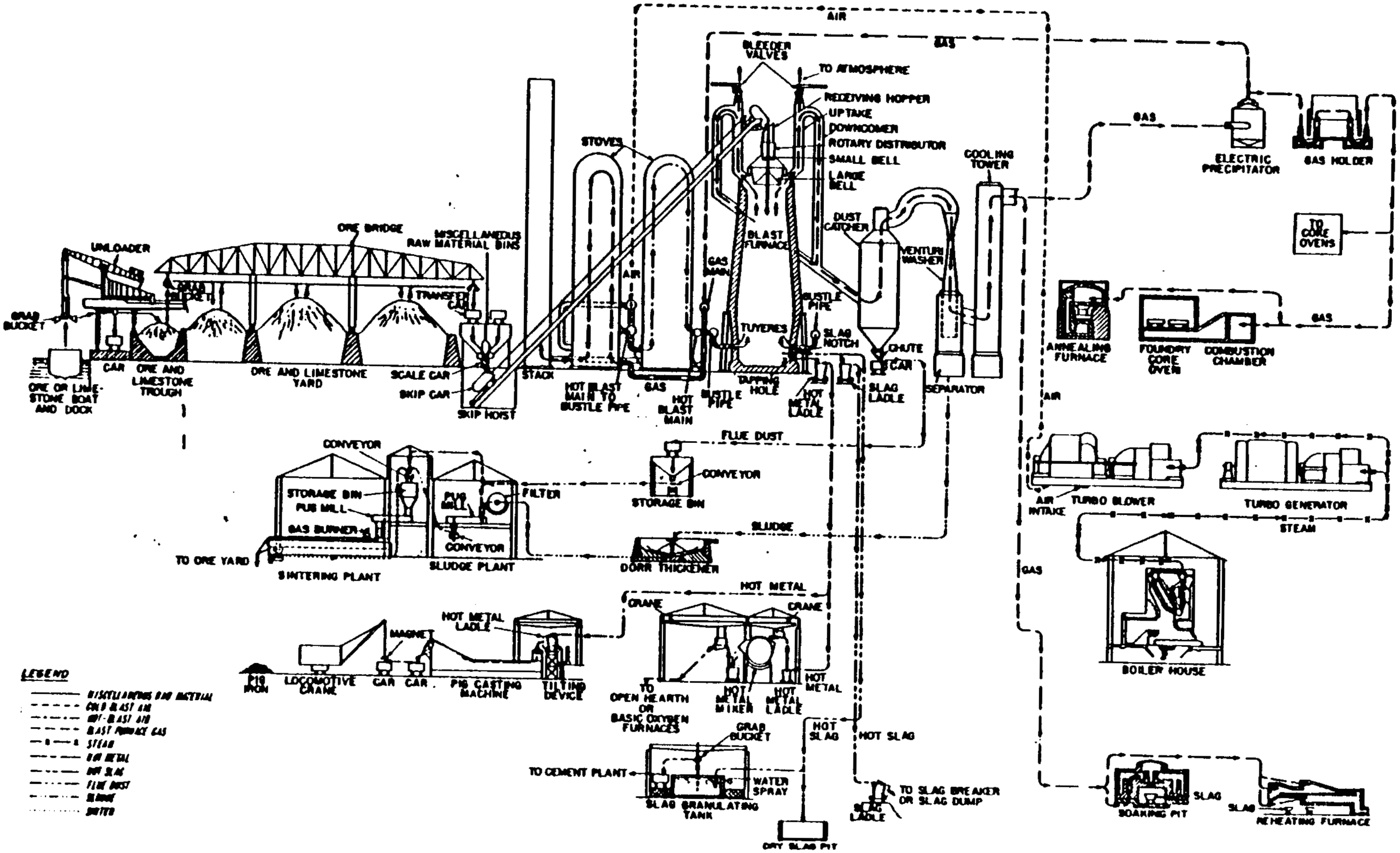


FIGURE I.B-2

SCHEMATIC OF A TYPICAL BLAST FURNACE OPERATION

Source: U.S. Steel Corp., Making, Shaping, and Treating of Steel, 9th Ed., 1971.

therefore maintains the pellet shape of the ore charge, with a sponge-like surface texture from which the name "sponge iron" has originated. Sponge iron is a primary metal that, unlike pig iron, has a low carbon content and is generally suitable for electric furnace steelmaking, either as a substitute for scrap metal or as the main feed source.

I.B.1.2 Steelmaking

In the steelmaking process, pig iron, scrap, or direct-reduced iron are melted (or remelted) and refined to reduce the carbon content and/or to remove impurities such as phosphorous and sulfur. All processes must provide some means of supplying controlled amounts of oxygen to the molten iron, the oxygen combining with unwanted elements to form oxides, which escape as gases or are removed as slag. Several deoxidizing elements, such as manganese, silicon, or aluminum are then added to remove excess oxygen remaining in the molten steel and to otherwise improve the metal's properties.

As shown in Figure I.B-1, modern steelmaking is basically dominated by two technologies. One centers on the electric arc furnace, which is fed a charge of close to 100 percent scrap or direct-reduced iron. The other technology, which accounts for about 65 percent of world steel capacity outside Comecon, utilizes the so-called Linz-Donawitz (LD) or basic oxygen process (BOP) to melt and refine a charge of about 72 percent pig iron and 28 percent scrap.

I.B.1.2.a LD Steelmaking

The LD process was developed in Austria during the early 1950s and rapidly replaced the open hearth process during the 1960s in the U.S., Western

Europe, and the Far East. LD utilizes a refractory-lined concrete converter in which heats of up to 350 tons of steel can be produced in about 45 minutes from a combination charge of molten pig iron and scrap.

In the top blowing LD process, oxygen is introduced as a high speed jet from a water-cooled lance positioned above the bath. The jet must penetrate an upper slag layer and then enter the metal bath, where oxidation reactions take place. The bottom-blown LD process (also known as OBM or Q-BOP) employs a sheath of propane or natural gas around the oxygen stream and injects this combination into the bottom of the bath from a set of concentric tuyeres. More recently, hybrid systems have been developed to exploit the advantages of each blowing method.

I.B.1.2.b Electric Furnace Steelmaking ("Minimills")

The electric arc furnace, originally used only for production of specialty stainless and alloy steels, has been increasingly used for the tonnage production of plain carbon steels. In most cases, the electric arc furnaces operate with a cold charge in which the ferrous content is close to 100% scrap. Direct-reduced iron, however, is a potential substitute for scrap, and is used as the major iron input in some electric arc furnace plants, such as Venezuela's SIDOR complex, which produces 3.6 million tons of steel annually.

A major advantage of electric furnace processes is the relatively low capital cost per ton of steel produced. Plants can be located to take advantage of local supplies of industrial steel scrap and of local markets for steel. Small electric arc furnace plants, known as "minimills", are located where large integrated steel mills would be uneconomical in parts of the U.S., in Europe (especially Italy and Spain), in Japan, and in the developing countries. Some large integrated plants in the U.S. are also being converted to "minimills" by closing their blast furnace/BOF facilities and installing modern arc furnace technology.

In the U.S., there are 60 minimills operated by 47 companies, the largest of which are the following:

Company	No. of Plants	Annual Capacity (Tonnage)
Nucor Corp.	4	1,750,000
Florida Steel Corp.	5	1,493,000
Georgetown Steel Corp.	2	1,220,000
Connors Steel Co.	2	1,150,000
North Star Steel Co.	3	1,050,000
Chaparral Steel Co.	1	900,000
Atlantic Steel Co.	2	700,000
Raritan River Steel Co.	1	600,000

Source: Industry Week, July 13, 1981.

A primary consideration in siting an electric furnace steel plant is the cost and availability of electric power. Energy consumption is determined by many variables, but modern units require on the order of 450-500 kilowatt hours for melting and refining one ton of crude steel. Electric furnace plant operations create highly variable loads for their power sources, because peak power consumption during the melting period is about three times the consumption during refining.

I.B.2 Steel Plant Size and Raw Material Requirements

Integrated steel plants using the BF/LD (Blast Furnace/Linz-Donawitz) process may have a capacity in the range of 1 to 12 mt/a. A very large integrated steel plant in Japan has five blast furnaces and a total production of 12 million tons of crude (ingot) steel per year, with over 24 million tons of solid raw material inputs. Small integrated plants produce on the order of 1 to 1.5 million tons of raw steel with two or three blast furnaces.

"Minimills", which are small electric furnace plants located near heavy steel-consuming and scrap-producing areas, may produce from 250 thousand up to one million tons of steel annually. While the DR/EAF (Direct Reduction/Electric Arc Furnace) process is particularly viable at low production volumes of about 500,000 t/a especially if cheap natural gas is available, it is not generally competitive for high volume production with the BF/LD process (a 1.0 Mt/a ore plant came on stream in 1980 in Venezuela using high grade ores and cheap, locally available natural gas). Higher annual production may be achieved by the installation of more than one DR/EAF units at one site although, typically, beyond 3 to 4 the BF/LD process is more economical.

The following may be taken as typical raw material supplies for the BF/LD process, per ton of iron produced.

Ore	1.7 t
Coke	0.5 - 0.6 t
Limestone/Dolomite	0.25 t
Energy	15 - 21 million BTU's

Since this process is allied to an integrated plant it is more useful to consider the plant requirements overall.

Assuming scrap is used as a feed to yield 20% of output, then requirements for one ton of steel produced are:

Iron ore	1.43 t
Coke	1.50 t
Limestone	0.21 t
Scrap	0.20 t
Water	150 t (of which recycling may typically be in the range 50-90%)
Elec. energy consumption	400 kWh
Installed capacity available	80 W
Personnel	0.002 - 0.001 (for 2 M t/a to 8 M t/a plants equiv. to 500 - 1000 t/man/a)
Site space	0.6 - 3.2 sq m
Waste	0.6 t

The following may be taken as typical raw material supplies per ton of steel produced by a DR/EAF plant of about 500,000 t/a with scrap providing 30% of output:

Iron ore	1.5 t
Natural gas	13 million BTU
Fluxes e.g. lime	0.1 t
Scrap	0.3 t
Water	15 - 50 t
Elec. energy consumption	850 kWh - 1200 kWh
Installed capacity	220 W
Personnel	.00012 (equivalent to 8000 t/man/a)
Site space	0.6 - 1.5 sq m
Waste	0.1 - 0.15 t

I.B.3 Steel Plant Site Requirements

Location on a coastal site would normally mean that all or most of the necessary raw materials, as presented in the previous section, are vessel imported, requiring extensive berthing, unloading, and transfer facilities, in addition to the spacious storage areas found at all steel plants. Characteristic basic data pertaining to the equipment and facilities at various major iron ore discharging terminals is presented in Table I.B-1.

TABLE I.B-1

SELECTED IRON ORE DISCHARGE FACILITIES FOR LARGE CARRIERS

Country Port	Terminal	Max. Draft (Meters)	Max. LOA (Meters)	Max. Beam (Meters)	Max. Ship DWT	Discharge
Brazil						
Aratu	USIBA Ore Pier	12.2	-	-	55,000	1 600 tph unloader serves adjacent steel plant
Italy						
Taranto	Italsidor Pier 4	24.4	350	53	300,000	2 x 60 t bridge unloaders with total capacity of 3000 tph. Stockpile of 1.7 million tons. Over 10 million tons annual throughput.
Japan						
Chiba	Kawasaki Steel	16.0	310	-	120,000	2000 tph
Netherlands						
Igmuiden	Hoogovens Outer Harbor	13.7	400	50	80,000	3 bridge cranes, two berths, 1875 tph. Throughput 7 million tons.
Taiwan						
Kaohsiung	CS Terminal	13.1	-	-	70,000	1500 tph. Throughput 3.5 million ton/yr.
South Korea						
Pohang	POSCO Pier 3	15.5	-	-	110,000	2 bridge unloaders, 1100 tph. 3.9 million tons annual throughput.

Source: Cargo Systems Research Consultants, Ltd., Large Bulk Carrier Ports and Terminals, 1981.

Comparison of maximum DWT and throughput for some of the terminals shown indicates only a weak correlation between the two, but the significant economies of scale encountered in oceanborne iron ore transportation make draft availability an important factor in selecting sites for modern steel plants. The vessel discharge rates also show only a rough correlation with maximum deadweight and annual throughput. Total storage capacity, as a percentage of annual throughput, is variable, but roughly on the order of 15 percent.

EAF steel plants are located in relation to feedstock supply (iron, steel and fuel) and to demand centers. Plant solely using scrap as steel feedstock, and with piped natural gas for fuel may not require port facilities. When ore has to be imported port facilities at the plant are of less importance than for BF/BOF because of the smaller tonnages involved and because coal is not required for fuel. Ores may be transported by rail from the import port to the plant.

Table I.B-2 shows the site area occupied by several different Japanese steel plants along with the ratios of area to annual output. The figures show the effects of economies of scale, but also reflect technological improvements which have helped to reduce unit area requirements from 2-3 square meters per ton to the current figure of 0.8 per ton. Unit area also depends on product-mix factors such as the percentage of flat-rolled products, which require less space.

TABLE I.B-2

SITE SPACE OF JAPANESE STEEL PLANTS

Site	Crude Steel Output (1000 t/yr)	Total Area		Area:Production (m^2/ton)
		Hectares	Acres	
A	3653	846	2089	2.32
B	1084	351	867	3.24
C	4236	501	1237	1.16
D	7489	714	1763	0.95
E	4517	255	630	0.57
F	11120	814	2010	0.73
G	5716	415	1025	0.73
H	7629	809	1998	1.06
I	5895	490	1210	0.82

Source: Sato, M., "Plant Location and Cost Aspects of Integrated Steel Plants in Developing Countries", UNIDO, ID/WG.146/22, 1973.

Land for waste disposal, as well as additional land for new communities and satellite industries when the plant is to be located in undeveloped and isolated areas should also be taken into account. Waste disposal is a particular problem because of the considerable amounts of slag generated from the blast and steelmaking furnaces, on the order of 0.6 tons of solid waste per ton of product. Environmental considerations limit the possibilities for using slag materials to reclaim and expand coastal sites.

Shape and load-bearing characteristics of the potential site are also important factors. Circular or long and narrow perimeters are generally not suitable for proper equipment layout. Load-bearing forces are typically 15 to 20 tons per square meter in the raw materials and products yards, 20 to 60 for the steelmaking and rolling facilities, and 100 to 120 for the blast furnace, which requires safety allowances for heavy winds and, in some areas, earthquakes.

I.B.4 Steel Plant Water and Power Consumption

An integrated plant circulates on the order of 150 tons of water per ton of crude steel, with varying ratios of fresh, salt, and recycle water. Coastal plants may draw 50 to 60 percent of their total intake from the sea, whereas inland plants necessarily use river water only. Japanese plants have attained recycling levels of over 95% of the total, in which case the make-up water amounts are about 4 cubic meters per ton. Table I.B-3 shows the water consumption by processing area for a moderately-sized Japanese steel plant. Even a small plant, however, requires the availability of an ample and nearby water supply, which in some locations may be possible only through construction of a dam and reservoir system.

TABLE I.B-3

WATER CONSUMPTION IN A JAPANESE STEEL PLANT PRODUCING 2.5 MILLION TONS OF STEEL PER YEAR

Equipments	Sea Water (M^3/D)	River Water (M^3/D)	Recycling Rate (%)	Net Input of River Water (M^3/D)
Blast Furnace	235,000	19,500	80	3,900
Coke	26,000	2,500	-	2,500
Sintering	-	5,800	-	5,800
Converter	-	23,500	75	5,900
Blooming	-	62,500	80	12,500
Hot Rolling	62,500	155,000	80	31,000
Cold Rolling	-	69,000	60	27,500
Others	-	5,300	-	5,300
Loss	26,500	5,600	-	5,600
Total	350,000	348,700	71	100,000

Source: Sato, M. UNIDO, ID/WG, 146/22, 1973 "Plant Location and Cost Aspects of Integrated Steel Plants in Developing Countries".

Electricity consumption per ton of crude steel is on the order of 400 KWH for an integrated plant, of which about 50% can be generated on-site with a power station which utilizes by-product gases. To allow for load fluctuations, a plant producing 2.5 million tons of crude steel per year requires a supply of 200 MW, 100 of which comes from a power grid. If the plant site is distant from a large distribution center, significant investment for transmission line construction must be taken into account. Conversely, if the site is in an industrial complex, where a large power plant is in operation, large economies in power transmission costs can be obtained.

I.B.5 Steelmaking Personnel Requirements

Operation of a steel plant involves many kinds of jobs, most of which are carried out in three shifts, 365 days a year. The number of employees is consequently in the thousands, even without taking into account the workers required for various satellite industries which are normally required to support the plant. Figure I.B-3 shows the plant labor force size as determined by the output level, indicating that for a plant with a capacity of 2 million tons per year, roughly 4 thousand workers are needed. If employees in satellite industries are taken into account, the labor force is almost twice again as large. Even a plant established in a heavily populated area would have a measurable impact on the labor supply in the area, and would create new demands on the community infrastructure. A plant constructed in an undeveloped, sparsely populated region could require a new community capable of supporting 30 to 40 thousand people.

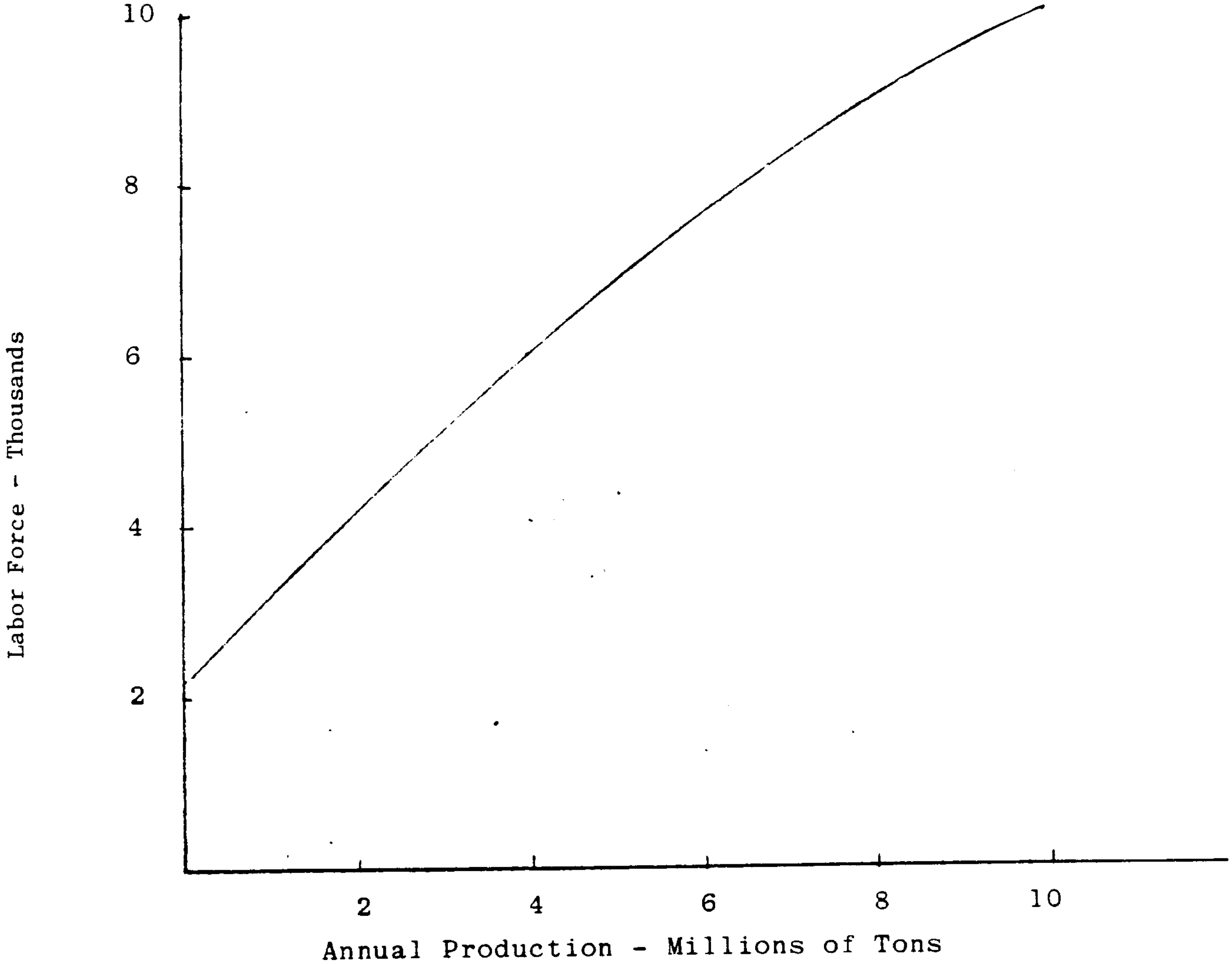


FIGURE I.B-3

STEEL PLANT LABOR FORCE AND ANNUAL OUTPUT

Source: Sato, M. UNIDO, ID/WG, 146/22, 1973.

I.B.6 Iron and Steelmaking Technology Alternatives

Selection of the appropriate iron and steelmaking technology is a primary task of plant planners and requires that several complexly interrelated factors be taken into account, including:

- site location and other characteristics
- raw material type and sources
- energy sources
- plant size
- product mix
- investment constraints
- transportation costs

The selection process obviously requires in-depth studies based on a range of specialized knowledge and expertise found only in steel plant design groups. Nonetheless some general observations can be made regarding the suitability of the following combinations, which cover currently viable alternatives for new plant furnace technology:

(1) BF + LD (blast furnace ironmaking and Linz-Donawitz steelmaking)

(2) DR + EF (direct reduction ironmaking and electric furnace steelmaking)

(3) S + EF (scrap iron and electric furnace steelmaking)

Large-scale plants (over 3 million tons annual output) have tended to be BF + LD types due to scale economies associated with blast furnace ironmaking. Blast furnaces have significantly lower unit energy consumption than the DR + EF plants, but high investment costs associated with these facilities, along with a long-term surplus of worldwide steel production capacity make it unlikely that any large BF + LD plants will be built in the foreseeable future.

Direct reduction furnaces have a worldwide capacity of roughly 25 million tons per year, less than 5 percent of the world's annual pig iron production in blast furnaces. However, the DR + EF industry has seen rapid growth during the past decade; and this combination was selected for several integrated plants of intermediate capacity (1 to 3 million tons per year) installed in developing countries since 1980 (refer to Table I.D-8). In the developing world direct reduction plant accounts for about 15% of production. Conditions favorable to DR + EF include small to intermediate capacity, low energy costs, natural gas as a reductant and a sufficiently large market to act as a base-load outlet for the product.

As a guide, capital and operating costs are reproduced here, based on 1980 figures. Table I.B-4 shows the capital costs of a DR + EF plant which produces 500,000 tons of steel per year. Table I.B-5 shows estimated operating costs for a 400,000 ton capacity sponge iron plant, while the effect of natural gas and electricity prices on costs is indicated in Table I.B-6. Costs for production of steel in a 500,000 ton per year electric arc facility, in this case using scrap as approximately 30% of feedstock, are shown in Table I.B-7.

It can thus be seen that the energy costs of producing steel are of vital importance and that the higher the scrap content, the lower the energy costs. This fact makes S + EF process favorable, especially for small plants located close to scrap-producing industrial centers. Proximity

TABLE I.B-4

CAPITAL COSTS OF A DR+EF PLANT PRODUCING 500,000 TONS OF STEEL PER YEAR

	Millions of US dollars
Site development	48
Storage buildings	4
Direct reduction plant	75
Steelmaking plant (electric furnace)	53
Continuous casting plant	50
Miscellaneous	10
	$240

Source: Mineral Processing in Developing Countries - A U.N. Study.

TABLE I. B-5

OPERATING COSTS (EXCLUDING ENERGY) FOR A 400,000 TON/YEAR CAPACITY SPONGE IRON PLANT

	Millions of US dollars
Iron ore: 1.5 tons per ton product, at $35/ton	21.0
Labour and supervision: 60 man-years at $10,000	0.6
Maintenance supplies $4 per ton product	1.6
Miscellaneous	0.7
Total	23.9

Source: Mineral Processing in Developing Countries - A U.N. Study.

TABLE I.B-6

EFFECT OF GAS AND ELECTRICITY PRICES ON OPERATING COSTS FOR A 400,000 TONS/YEAR CAPACITY SPONGE IRON PLANT

	Natural gas prices (US $/million BTU)		
	4	8	12
Basic operating charges (Table I.B-5)	23,900,000	23,900,000	23,900,000
Natural gas (12,500,000 BTU per ton product)	20,000,000	40,000,000	60,000,000
Electricity (150 kWh per ton):			
2.4¢/kWh	1,440,000		
5.2¢/kWh		3,120,000	
8.0¢/kWh			4,800,000
Total	45,340,000	67,020,000	88,700,000
Cost per ton	$113	$167	$222

Source: Mineral Processing in Developing Countries - A U.N. Study.

TABLE I.B-7

ELECTRIC ARC STEEL OPERATING COSTS (MELTING AND CASTING) AT AN ANNUAL CAPACITY OF 500,000 TONS STEEL

Operation	Annual charge $
Smelting and casting	
Scrap iron 150,000 tons at $80 p.t.	12,000,000
Labour and supervision: 300 at $10,000 p.a.	3,000,000
Fluxes: 50,000 tons at $35 p.t.	1,750,000
Ferroalloys: 10,000 at $600 p.t.	6,000,000
Refractories: 20,000 tons at $400 p.t.	8,000,000
Electrodes: 3000 tons at $2000 p.t.	6,000,000
Maintenance and supplies	2,400,000
Miscellaneous	1,050,000
Total	40,200,000

	Natural gas prices ($/million BTU)		
	4	8	12
Smelting and casting	40,200,000	40,200,000	40,200,000
Natural gas at 400,000 BTU p.a.	1,600,000	3,200,000	4,800,000
	41,800,000	43,400,000	45,000,000
Electricity 700 kWh p.t.			
at 2.4¢ per kWh	8,400,000		
at 5.2¢ per kWh		18,200,000	
at 8.0¢ per kWh			28,000,000
Totals	50,200,000	61,600,000	73,000,000
per ton	100	123	146
Combined sponge iron and slab production			
Annual sponge iron costs Range: ($ million)	45.34 -	67.02 -	88.70
Annual melting and casting costs Range: ($ million)	50.20 -	61.60 -	73.00
Total	95.54	-128.62	-161.70
Final operating cost per ton slab	$191	$257	$323

Source: Mineral Processing in Developing Countries - A U.N. Study.

to iron ore reserves, while obviously advantageous, is apparently not a prerequisite for DR + EF facilities. Two of the newest ones, the ISCOTT plant in Trinidad and Tobago, and the HADEED plant in Saudi Arabia, have built port facilities to handle iron ore imports.

In most developing countries it is likely that the best route to new or increased installed capacity is by the DR + EF process. The reasons for this include lower capital costs and the possibility of using natural gas, which is perhaps the principal feature enabling domestic steel production. Where there are deposits of both iron and coal, coupled with high demand, which is the case of developed countries relying mainly on importing large quantities of foreign ores, the BF + LD route retains advantages.

I.B.7 Environmental Impact

The conversion of iron ore into steel produces a number of gaseous, liquid and solid wastes, which require proper treatment before releasing into the environment. A brief description of the waste sources, waste character and volumes, effluent limitations based on best practicable treatment technology currently available, and applicable waste treatment methods can be found in "Environmental Guidelines", World Bank, Office of Environmental Affairs (1984). In this paper, the iron and steel manufacture is broken down into five segments: (a) ore preparation, sintering and pelletizing; (b) by-product coke production; (c) blast furnace and direct reduction process; (d) steel production; and (e) rolling and finishing operations. For each individual segment, a document has been prepared which presents information as needed for assessing the environmental effects of the waste produced by the operation.

In general, the production of waste gases is of major significance in a steel plant. A large number of organic and inorganic air pollutants are generated, some of which are toxic substances. The list of gaseous waste includes among others sulfur dioxide, carbon monoxide and dioxide, nitrogen oxides, oxides of iron and zinc, alkaline oxides, sulfides, cyanides, fluorine compounds, gaseous ammonia, fumes, dusts and a large amount of particulate matter.

A number of different techniques are employed sequentially in order to limit or eliminate the air pollutants from the produced gases, depending on the waste character and its source. Wet scrubbing which results in waste water production, and dry filtration which results in solid waste generation are two common stages in the cleaning processes of the gaseous emissions.

Wastewaters are also generated from the cooling, crushing, and screening of the products of the different manufacturing stages. Large volumes of wastewaters are produced during the rolling and finishing operations, since water is used in cleaning, surface preparation, and plating. Due mainly to the use of watel-oil solutions for cooling materials and rolls in the rolling stage, high concentrations of solids, oils and greases are discharged. Heavy metals and toxic organic pollutants are also present and must be removed before discharge of the effluent.

In addition, large volumes of water are used for indirect (non-contact) cooling operations of different parts of the plant. However, these waters are normally not contaminated, except from leaks in coils, tubes, or other equipment, and are of little or no significance from the pollution standpoint.

Combinations of physical, chemical and biological methods are widely used to reduce the concentrations of contaminants and to bring the pH into acceptable levels.

Solid waste originate either from the treatment of the gaseous and liquid emissions or directly from the manufacturing processes. Blast furnace slag, refractory materials, ladle skull (the metal shell which solidifies on the sides and bottoms of the ladle), slag fines, fumes, slurries, steel scrap, millscale, scarfing residues, used oils and greases, and sludges are the main solid waste. Most of these are separated and recovered or recycled back into the iron or steelmaking process.

The slags are processed and used as a building material (reinforcement of river and canal banks, road building, railway track ballast), raw material for blast furnace cement, and other similar purposes. Slags containing high levels of P_2O_5 can be ground and used as fertilizer. Steel scrap resulting from steel pouring can be readily recycled. Millscale, dusts and slurries can be fed back into the sinter plant. The residue which cannot be recycled or used for other purposes is dumped to landfill sites.

Noise pollution is a major concern in a typical integrated iron and steel works. Noise results from: (a) production and processing operations; (b) handling and transport of raw materials and semi-finished products; and (c) aerodynamic and hydrodynamic sources.

Efforts should be aimed at lowering noise level in the working environment and removing noise problems in nearby residential areas. The employment of isolated and acoustically sealed machines, careful design and isolation of pipes, use of low noise valves and ventilators, replacement of road or railway haulings by conveyor belts and systems, and the acoustically treatment of entire buildings if necessary are some of the measures which may be taken in order to reduce noise levels.

I.B.8 Seaborne Iron Ore and Coal Transport

Iron ore and coal, the main raw materials in steel industry, have always been big ship trades. The reason is that these commodities are easy to handle and store, are required regularly at the point of consumption in large tonnages and are of low value.

Iron ore is the most important dry commodity in world seaborne trade with 14% of the volume of dry cargo trade in 1983. In the same year, coal accounted for about 11% of the total seaborne dry cargo trade. However, only about 58% of the total volume of transproted coal was metallurgical coal mainly consumed by the steel industry.

The iron ore volume, distance, and average loaded haul for the ten year period 1973-83 are shown in Table I.B-8. The volume of shipped iron ore in 1983 was 13.76% less than ten years ago, and the ton-miles were 5.58% less. The average trading distance, however, increased from 4690 miles in 1973 to 5140 miles in 1983, which represents a 9.49% increase. The volume of metallurgical coal annually transported in ships during the last decade is shown in Table I.B-9.

TABLE I.B-8

WORLD SEABORNE TRADE OF IRON ORE 1973-1983

Year	Volume in million metric tons	Ton-miles in billion	Average distance of loaded voyage in miles
1973	298	1398	4691
1974	329	1578	4796
1975	292	1471	5038
1976	294	1469	4997
1977	276	1386	5022
1978	278	1384	4978
1979	327	1599	4890
1980	314	1613	5137
1981	303	1508	4977
1982	273	1443	5286
1983	257	1320	5136

Source of data: Fearnleys, "World Bulk Trades", 1983.

TABLE I.B-9

COMPOSITION OF WORLD SEABORNE HARD COAL TRADE: 1973-82
(Million Tons)

YEAR:	1973	1974	1975	1976	1977	1978	1979	1980	1981	1982
Metallurgical	87	96	94	94	95	85	104	114	124	120
Thermal*	19	28	32	33	37	40	53	74	87	85
% Thermal	18	23	25	26	28	32	34	39	41	42

*** Steam coal + anthracite**

Source: Drewry Shipping Consultants Ltd., "Coal Trade and Shipping in the 1980s", 1983.

Any bulk vessel may find employment in the iron ore trade. It is, in fact, the physical constraints at ports, together with traditional practices which determine the preference for particular sizes or types of ship. The types of ships employed in the iron ore trade are: (a) "pure" ore carriers; (b) bulk carriers suitably strengthened for the carriage of ore; (c) combined ore-oil or ore-bulk-oil vessels; and (d) other specialized types including self-unloaders and "slurry carriers".

Ore carriers are ships designed specifically for the carriage of ore, and they used to be more prominent in the iron ore trade. However, their share of trade is steadily declining due to their lack of flexibility. Now, only very large ore carriers are used on the routes to Japan. At present, self-unloaders are confined to the short-haul Great Lakes ore traffic, while the slurry concept has drawbacks which preclude it from having a wider application (it has been applied only by producers in Peru and New Zealand supplying Japan). Thus, the main volume of the iron ore trade is carried in bulk carriers and combined ships. Combined vessels conveyed about 32% of the iron ore shipped volume in 1983. Bulk carriers' share was about 60%.

The size distribution of ships used for iron ore shipments in the decade 1968-78 is shown in Table I.B-10, while Table I.B-11 presents more recent figures. As these tables reveal, the smaller ships of less than 40,000 DWT have steadily lost ground, their share of shipping being reduced from 46% in 1968 to 9% in 1983. This trend towards large vessels can be explained by: (a) the economies of scale; (b) the upgrading of port facilities; and (c) the dramatic change in the utilization of the combined carrier fleet following the collapse of the tanker market in late 1973.

TABLE I.B-10

SIZES OF SHIP TRANSPORTING IRON ORE 1968-78
(% Share of Total Seaborne Trade)

SIZE GROUP: YEAR	UNDER 25,000	25,000-40,000	40,000-60,000	60,000-80,000	80,000-100,000	OVER 100,000
1968	27	19	34	17	2	1
1969	23	18	35	18	4	2
1970	21	19	32	17	5	6
1971	20	16	29	20	4	11
1972	15	15	25	21	5	19
1973	14	13	23	20	5	25
1974	12	10	19	20	7	32
1975	11	9	17	18	8	37
1976	9	8	14	18	9	42
1977	10	5	12	17	8	48
1978*	8	5	11	16	6	54

* Estimated

Source: H.P. Drewry Ltd., "The Prospects for Seaborne Iron Ore Trade and Transportation", 1979.

TABLE I.B-11

IRON ORE SHIPMENTS. SIZE DISTRIBUTION OF VESSELS 1983
Figures in % of total seaborne trade of each area.

	Size groups of vessels in '000 dwt					Total
	-40	40-60	60-80	80-100	100+	
Exporting areas						
Scandinavia	11	2	19	13	55	100
West Africa	10	7	19	32	32	100
Other Africa	33	6	5	2	54	100
North America	3	3	21	5	68	100
S. America Atl.	4	7	16	3	70	100
S. America Pac	20	-	-	2	78	100
Asia	21	12	12	5	50	100
Australia	4	2	8	5	81	100
Importing areas						
UK/Continent	6	1	17	10	66	100
Mediterranean	12	8	14	14	52	100
Other Europe	22	28	30	9	11	100
USA	21	10	53	11	5	100
Japan	6	2	4	1	87	100
Others	14	11	13	16	46	100
Total 1983	9	5	13	7	66	100
Total 1982	10	6	10	9	65	100
Total 1981	7	7	12	9	65	100

Note: Percentages for vessels below 40 000 dwt are residuals, calculated as the difference between total quantity of iron ore movements and shipments by vessels over 40 000 dwt.

Source: Fearnleys, "World Bulk Trades", 1983.

A more detailed analysis of shipments by vessels over 100,000 DWT in 1983 shows that the percentage shipped by 100-150,000 DWT was 37%, by 150-200,000 DWT 18%, and by vessels over 200,000 DWT 11%. The largest vessels were employed in the long hauls from Australia, South America and South Africa to Japan and UK/Continent, were large-scale BF + LD steel plants are installed.

For a DR plant of 500,000 t/a output, iron ore requirements would be, say, 750,000 t/a. The economics of shipment would have to be considered in relation to other discharge requirements of the trade route, but use of fully loaded large vessels of say 100,000-200,000 DWT for full parcel deliveries may not be practical in view of inventory and stock pile costs, as well as due to draft restrictions. In such circumstances "panamax" size ships (although, in fact, little ore passes through the Panama Canal) may be more appropriate and port facilities scaled accordingly.

The same trend towards larger vessels appears in the coal seaborne trade. Table I.B-12 shows the size distribution of ships (mainly bulk carriers and combined vessels) used for transporting coal. The size and distance of the shipment, draft restrictions of exporting and importing ports, and other route considerations (such as passing through the Panama Canal) are again the main factors for selecting the proper type and size of ship.

TABLE I.B-12

SIZE OF SHIPS TRANSPORTING COAL
(% of trade)

SIZE (DWT)	YEAR: 1973	1975	1978	1979	1980	1981	1982	1983
Under 40,000	47	41	29	35	30	32	30	27
40 - 60,000	29	25	19	15	14	10	10	8
60 - 80,000	13	21	27	20	23	23	24	23
80 - 100,000	2	3	4	4	5	5	5	7
Over 100,000	9	10	21	26	28	30	31	35

Data derived from Fearnleys, "World Bulk Trades", 1983; and H.P. Drewry Ltd., "Coal Trade and Shipping in the 1980s", 1983.

I.C Steel Plant Descriptions

I.C.1 ISCOTT Steel Plant

Plant location: Point Lisas, Trinidad and Tobago.

Owner: ISCOTT (Iron and Steel Company of Trinidad and Tobago).

Ironmaking process: two direct reduction modules based on Midrex design, each rated for 420,000 tonnes/year of direct reduced iron.

Steelmaking process: two electric arc furnaces; two 4-strand casting machines producing 600,000 tonnes/year; one rolling mill, capacity of 485,000 tonnes/year wire rod products.

Dock: permanent finger dock 378 meters long, 16 meters wide, berths one general cargo vessel and one bulk carrier.

Draft: dredged to 13.5 meters to handle vessels up to 60,000 DWT fully laden.

Unloading: two 25-tonne level luffing cranes rated at 600 tonne/hour, with bucket capacity of 15 tonnes, bucket speed of 90-108 meters/min, and a lift of 37 meters.

Raw material conveyors (dock to storage): rated at 1200 tonnes/hr, with a speed of 2.54 meters/sec. They can move 529 cubic meters of pellets/hr or 680 cubic meters of ore and limestone/hr.

Raw materials storage: 200,000 tonnes of ore/limestone. DRI pellets are stored in six 5000-tonne silos and a 30,000-tonne warehouse.

DRI conveyors: from shaft furnace to silo and from silo to meltshop via 500 ton/hr conveyor system.

Electrical service: supplied from nearby generating station via two 132-KV overhead circuits. Two 132/33 KV stepdown transformers rated at 70/93 Mva provide power to furnaces. Two 132/13.8 KV stepdown transformers rated at 37.5/50 Mva provide power to the plant motive load, but one can support total consumption.

Construction figures: piled foundation, over 7100 piles driven. Heavy loads (160 kips in compression, 120 kips in uplift, and 11 kips laterally) are supported by H-section steel piles driven to an average depth of 100 ft. 70,000 cubic meters of concrete and 19,500 tonnes of steel were used to build the plant. Work force numbered 2500 at peak activity and a total of 750 person-years was spent in construction.

I.C.2 HADEED Steel Plant

Plant location: Al-Jubail, Saudi Arabia.

Owner: HADEED (Saudi Iron and Steel Company).

Startup: 1982.

Plant investment: construction of integrated plant cost 2.4 billion Saudi Riyals, and start-up costs (training, initial raw materials, spare parts) were 600 million Saudi Riyals.

Annual production: 800,000 tonnes of sponge iron, 850,000 tonnes of steel billets (100-150 mm square x 5 to 14 m long) that are converted to 800,000 tonnes of rod products.

Site: 440 hectares, with sea, road, and rail access.

Ironmaking: two 400,000 tonnes per year Midrex DR modules.

Steelmaking: three 120-ton nominal capacity electric arc furnaces with 160 minutes tap-to-tap time.

Raw materials storage: 400,000 tons iron ore storage yard.

Scrap storage: local scrap storage, and a 10,000 ton upgraded scrap storage yard.

Annual raw materials and energy consumption:

(1) 1,200,000 tons of iron ore imported from Brazil and Sweden in pellets to lumps ratio 60:40.

(2) 175,000 tons of scrap, of which 85,000 is in-house generated and 90,000 from local industries.

(3) 20,000 tons of metallurgical additives.

(4) 50,000 tons of burnt lime for fluxing.

(5) 200 million cubic meters of natural gas.

(6) 1 billion KWH electric power.

Energy costs assumed: natural gas @ .05 DM/m^3 (1983)

electrical @ .03 DM/KWH (1983)

Steel plant details: five main bays, a 7 x 150 m DRI additives bay, a 24 x 165 m furnace bay housing 3 electric arc furnaces and three service cranes, a 30 x 150 m casting bay with three casters and three service cranes, a 27 x 150 m cooling bed bay with 25t handling crane, and a 32 x 210 m billet storage and shipping bay with 25t crane.

Sea water cooling: DR plant, rolling mills, and steel plant utilize 24,000 m^3/h sea water for cooling. Sea water conveyed from a sea water canal through 2m diameter concrete pipes via seven centrifugal pumps of 3800 m^3/h capacity at 35.5 m head.

Manpower: technical manpower is over 1600 men (on 4 shifts), of which 179 work in the DR plant, 363 in the steel plant, 330 in the rolling mill, and 786 in auxiliary services such as the oxygen plant, natural gas desulfurization, water treatment, maintenance, etc.

I.C.3 Fukuyama Iron Works

Location: Fukuyama, Japan.

Owner: Nippon Kokan.

Output: 12 million tons crude steel/year.

Site area: about 900 hectares.

Layout: see Figure I.C-1.

Material flows: see Figure I.C-2.

Maximum vessel size: up to 250,000 DWT.

Raw material discharge: each berth is equipped for unloading iron ore and coal via two 1,500 ton per hour dischargers.

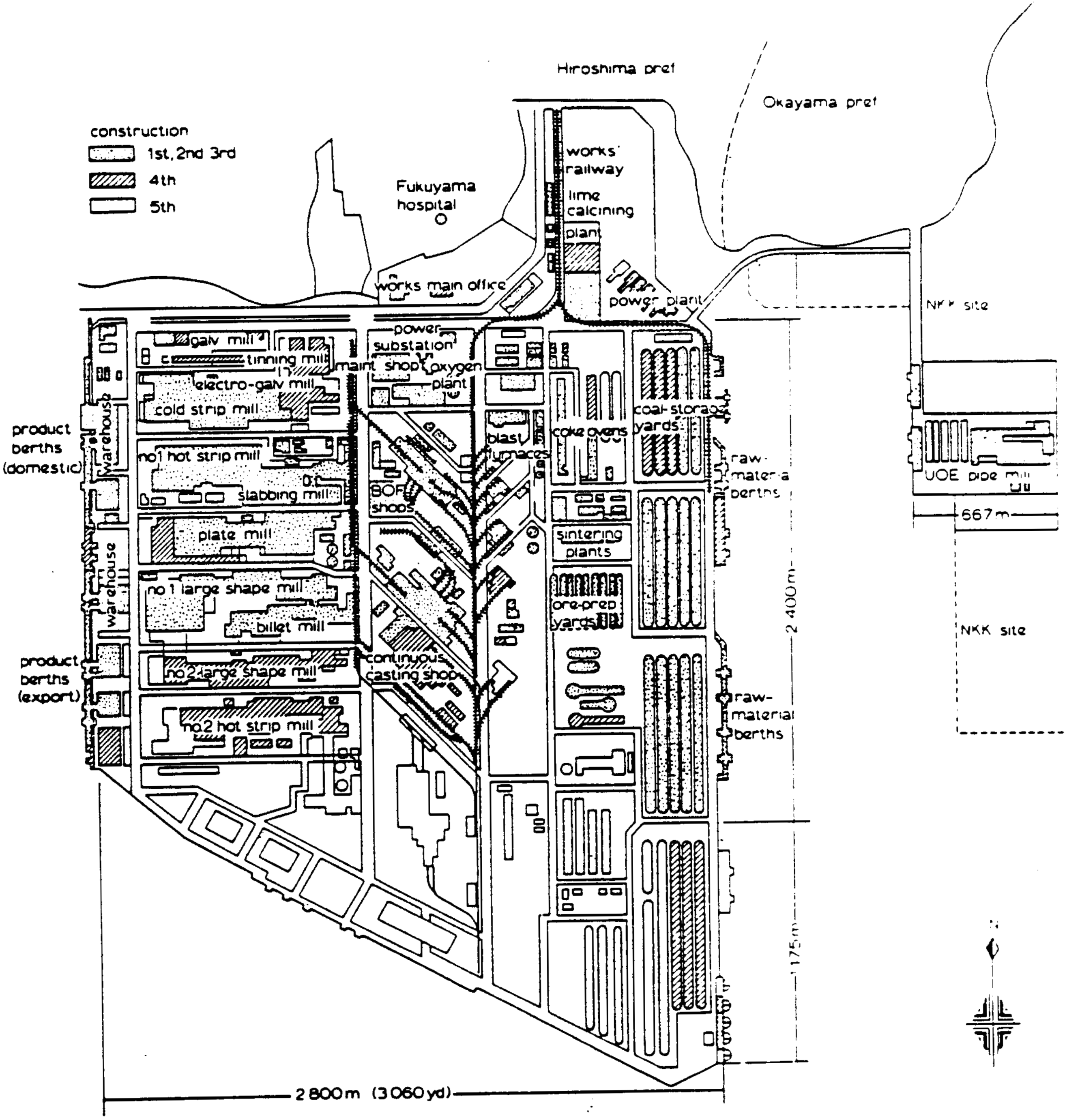
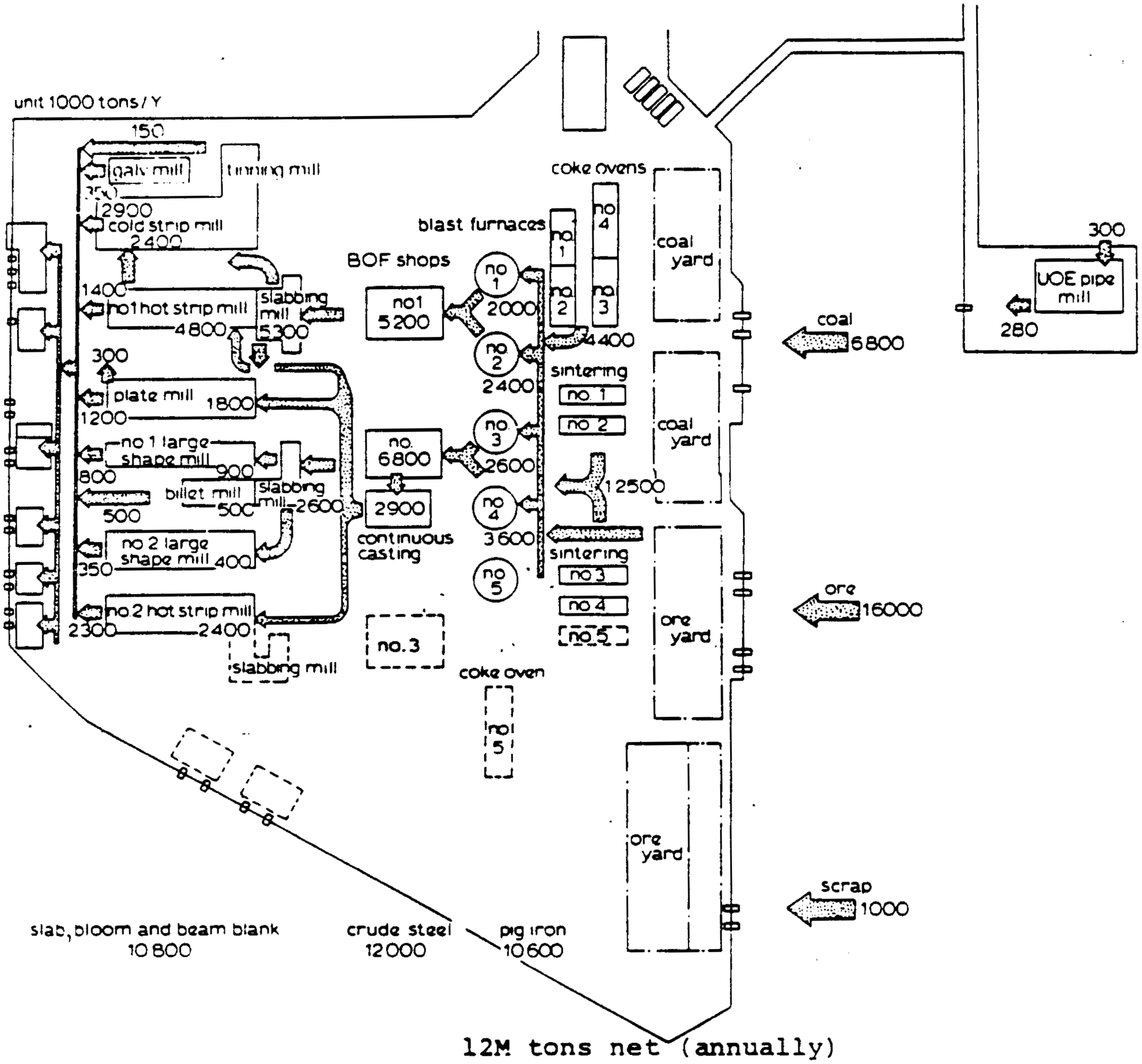


FIGURE I.C-1

LAYOUT OF FUKUYAMA IRON WORKS

Source: Suzuki, G., and Saito, M. UNIDO, ID/WG, 146/23, 1973. "Factors Affecting Iron and Steel Works at Coastal Sites"



12M tons net (annually)

FIGURE I.C-2

MATERIAL AND PRODUCTS FLOW AT THE FUKUYAMA IRON WORKS

Source: Suzuki, G., and Saito, M. UNIDO, ID/WG, 146/23,1973. "Factors Affecting Iron and Steel Works at Coastal Sites".

I.C.4 SIDOR Steel Plant Expansion Complex

Plant location: Matanzas, Venezuela, on the south bank of the Orinoco River, about 250 km from the sea and 500 km from Caracas.

Plant owner: SIDOR-CVG (Siderurgica del Orinoco, C.A.).

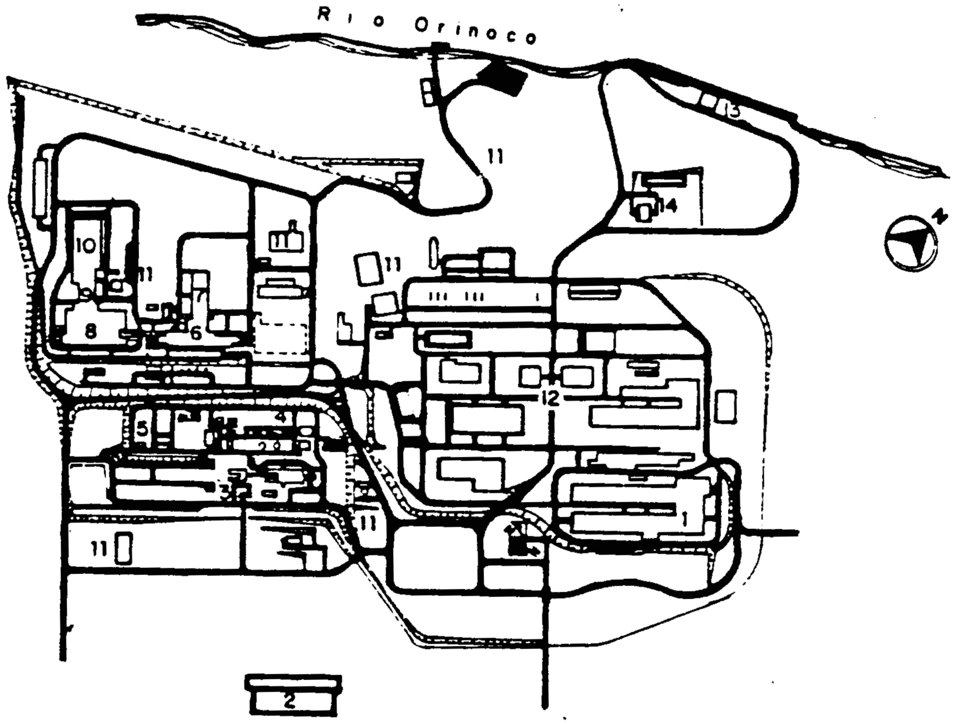
Startup: 1977-1980.

Annual output: The expansion complex produces 2.56 million tons/year of HYL direct-reduced iron; 1.67 million tons/year of MIDREX direct reduced iron, and 3.8 million tons/year of electric arc crude steel. Original open hearth plant has a capacity of 1.2 million tons/year.

Iron ore source: Ore from the Cerro Bolivar ore mining complex is processed in the Ferrominera ore yards to separate a 0-10 mm fraction for shipment by rail to SIDOR, where it is reclaimed by a bucket reclaimer and stored in four 800-ton silos.

Plant layout: see Figure I.C-3.

Materials flow: see Figure I.C-4.



1–expansion of plate mill; 2–Guayana substation; 3–pellet plant; 4–HYL III direct reduction; 5–MIDREX II direct reduction; 6–slab electric furnace shop; 7–slab continuous caster; 8–Billet electric furnace shop; 9–billet continuous casters; 10–rod and bar mills; 11–warehouses; 12–original plant area; 13–dock; 14–lime plant.

FIGURE I.C-3

SIDOR PLANT LAYOUT

Source: Miller, K.J., Iron and Steel Engineer, Sept. 1982.

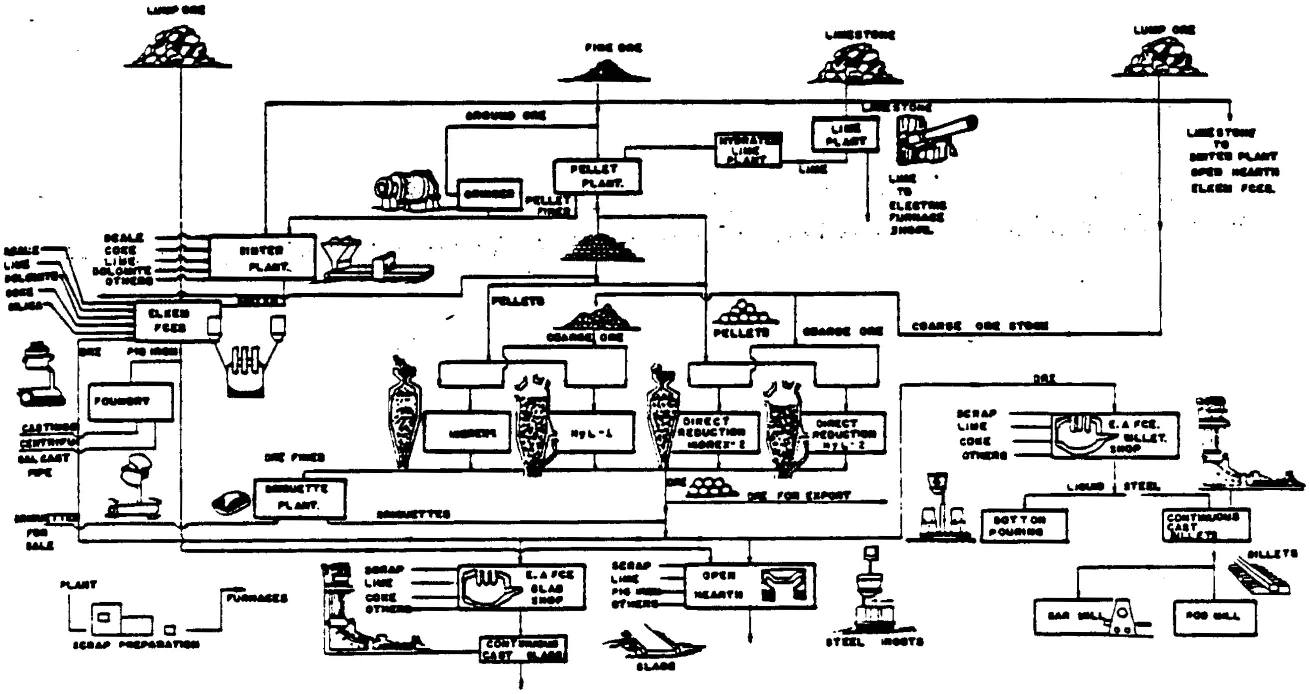


FIGURE I.C-4

MATERIALS FLOW AT THE SIDOR DRI STEEL PLANT

Source: Miller, K.J., Iron and Steel Engineer, Sept. 1982.

I.C.5 Hunterston Coal/Ore Import Terminal

Terminal location: Hunterston, Scotland, on a natural deepwater channel (Firth of Cylde - see Figure I.C-5).

Terminal owner: British Steel Corporation (BSC).

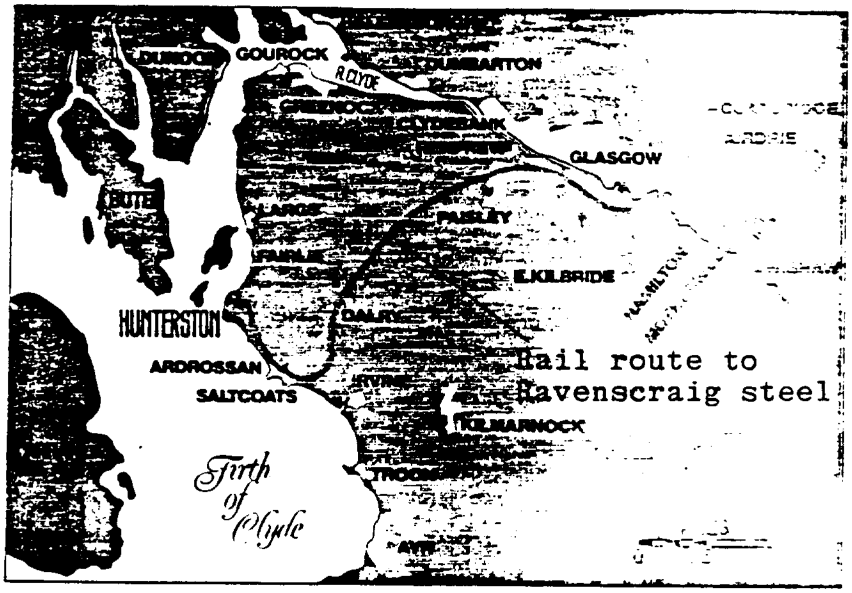
Steel plants supplied: The Ravenscraig Works, a 2 million ton-per-year integrated plant located at Motherwell, 40 miles away from the terminal, is supplied by a rail link. A large Midrex direct reduction plant was built at Hunterston and, although completed, was not put into operation due to economic conditions.

Throughput: With Ravenscraig producing 2 million tons of liquid steel per year, the terminal would supply 2.9 million tons of ore. Ultimately, as much as 4.1 million tons of ore could be required if the steel plant is expanded to its planned maximum capacity (3.2 million tons per year).

Unloading pier: The jetty head stands in 36 meters of water at low tide, is 443 meters long, and is connected to the shore by a mile-long causeway. Total length of piling used amounted to 29 km for 410 marine piles (longest pile was 92 meters).

Vessel accommodation: The outer berth can accommodate ships up to 350,000 DWT, and the inner berth (25.5 meters at low tide) can take a 70,000 DWT vessel.

Unloading equipment: Two unloaders 72 meters high and weighing 2,500 tons each, have a capacity of 3,000 tons per hour each. These are grab cranes of 63 ton gross capacity. Jetty is also equipped with a 4,000 tph ship loader for export of cargoes in smaller vessels.



Rail route to Ravenscraig steel works

FIGURE I.C-5

LOCATION OF THE HUNTERSTON ORE AND COAL TERMINAL

Source: Metals and Materials, Sept. 1979.

Ore conveyors: Ore moves to shore by an enclosed system of conveyor belts designed to suppress dust and noise pollution. Total length of raw materials conveyor is 5 miles. Handling rates are 6000 tons per hour.

Stockyard: The stockyard occupies about 150 acres and can hold 1,175,000 tons of ore and 250,000 tons of coal. The annual throughput capability of 8 million tons could be doubled by expansion allowance. Ore is laid out in 15-meter high piles along three parallel beds, each bed served by a stacker/bucket reclaimer machine. Stacking can match the ship unloading rate (6,000 tons per hour) and reclaiming can be performed at 4,000 tons per hour. A 32-meter high control tower monitors and controls storage operatings and dust/noise levels in the yard.

Rail car loading/unloading: Ore or coal for dispatch to Ravenscraig can be conveyed from the stockyard or directly from a ship. Feed from the conveyor discharges into storage bunkers holding 2,500t of coal and 3,500t of ore. Materials are next fed into weigh hoppers for gravity loading of 100 ton rotary-wagons. Simultaneous loading allows a 21-wagon train to be completed in less than 30 minutes. At Ravenscraig, the train can be rotated without uncoupling, with an unloading time of 45 minutes. Only 3 hours are required from start of rail loading at Hunterston to completion of unloading at Ravenscraig.

I.C.6 Tubarao Iron Ore Loading Facility

Terminal location: Tubarao, Brazil

Terminal owner: Cia Vale de Rio Doce

Yard layout: See Figure I.C-6

Yard facilities:

(1) First-stage construction (1965-1969)

6000 tph stacker	1 unit
6000 tph shiploader	1 unit
8000 tph shiploader	1 unit

(2) Second-stage construction (1970)

16000 tph shiploader	2 units
16000 tph stacker	1 unit
8000 tph reclaimer	3 units

(3) Third-stage construction (1980-1982)

16000 tph stacker	1 unit
16000 tph slave-stacker	2 units
8000 tph stacker-reclaimer	1 unit

Equipment dimensions: See Figure I.C-7.

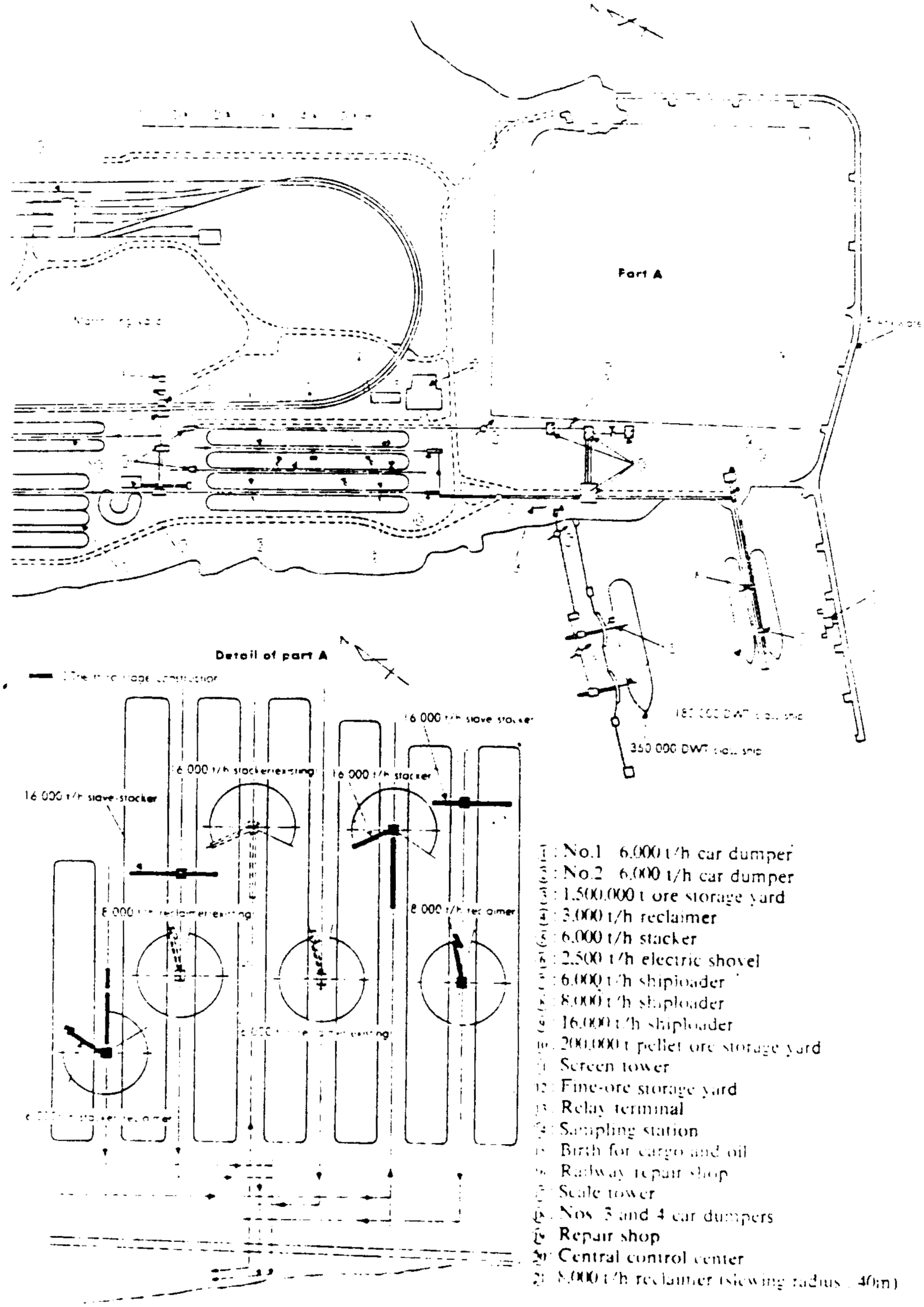
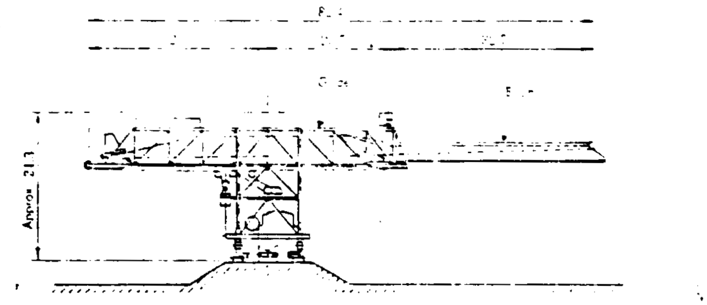


FIGURE I.C-6

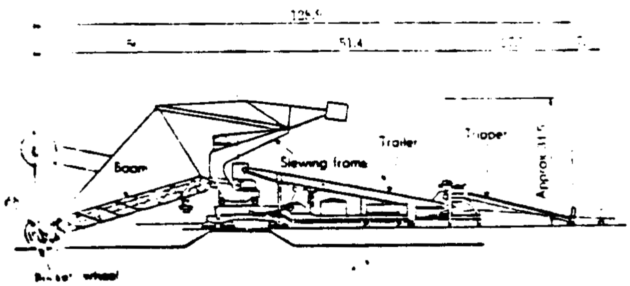
LAYOUT OF TUBARAO IRON ORE LOADING TERMINAL

Source: IHI Engineering Review, April 1983.

16000 tph Slave Stacker



8000 tph Stacker-Reclaimer



Dual Unit Operation

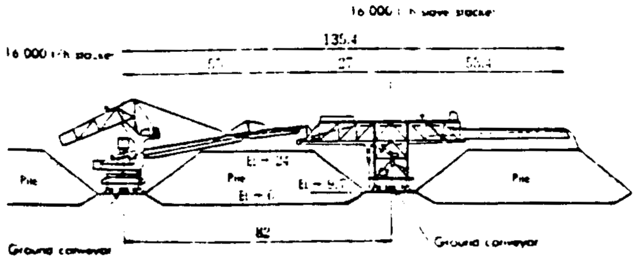


FIGURE I.C-7

EQUIPMENT ARRANGEMENTS AT THE TUBARAO IRON ORE TERMINAL (Dimensions in meters)

Source: IHI Engineering Review, April 1983.

I.D Steel Industry Statistics

List of Tables

TABLE I.D-1

IRON ORE MINING STATISTICS, 1981

RANK	COMPANY	COUNTRY	CONCENTRATE	PELLETS	HIGH-GRADE ORE	PRODUCTION (1000 GROSS TONS)
1	Cia. Vale do Rio Doce					
	Export	Brazil	C	P	R	4[illegible]
	Domestic	Brazil	C	P	R	14,3[illegible]
	Nibrasco	Brazil		P		4,26[illegible]
	Barrasco	Brazil		P		2,0[illegible]
	Hispanobras	Brazil		P		1,6[illegible]
	Total					67,5[illegible]
2	US Steel Corp.					
	La Cie. Miniere Quebec Cartier	Canada/Quebec	C	P		18,06[illegible]
	Minnesota Ore Operations	USA/Minnesota	C	P		13,46[illegible]
	Western Ore Operations	USA/Wyoming, Utah		P	R	2,119
	Total					3[illegible]
3	The Cleveland-Cliffs Iron Co.					
	Marquette Range	USA/Michigan		P		14,19[illegible]
	Cliffs Western Australian Mining Co.	Australia/(West)		P	R	12,42[illegible]
	Adams Mine	Canada/Ontario		P		1,2[illegible]
	Sherman Mine	Canada/Ontario		P		1,00[illegible]
	Mesabi Range	USA/Minnesota	C			95[illegible]
	Total					29,85[illegible]
4	Hamersley Iron Pty. Ltd.	Australia/(West)	C	P	R	28,518
5	Mt. Newman Mining Co. Pty. Ltd.	Australia/(West)	C		R	27,19[illegible]
6	The Hanna Mining Co.					
	Iron Ore Co. of Canada	Canada/Quebec (Labrador)	C	P	R	20,99[illegible]
	Mesabi Range	USA/Minnesota		P		5,17[illegible]
	Pilot Knot Pellet Co.	USA/Missouri		P		22[illegible]
	Menominee Range	USA/Michigan		P		16[illegible]
	Total					26,5[illegible]
7	Pickands Mather & Co.					
	Erie Mining Co.	USA/Minnesota		P		7,643
	Hibbing Taconite Co.	USA/Minnesota		P		6,605
	Wabush Mines	Canada/Quebec (Labrador)		P		5,209
	Savage River Mines	Australia/Tasmania		P		2,215
	The Griffith Mine	Canada/Ontario		P		1,513
	Total					23,385
8	Iscor Ltd.					
	Sishen Mine	South Africa	C			19,937
	Thabazimbi Mine	South Africa	C			2,147
	Total					22,085
9	Luossavaara-Kiirunavaara AB					
	Kiruna u. Svappavaara	Sweden	C	P	R	11,325
	Malmberget	Sweden	C	P	R	6,475
	Total					17,801
10	Exploration & Bergbau GmbH					
	Ferteco Mineracao S.A.	Brazil	C	P	R	8,7[illegible]
	Bong Mining Co.	Liberia	C		R	7,6[illegible]
	Total					16,5[illegible]
11	C.V.G. Ferrominera Orinoco S.A.					
	Piar Division	Venezuela	C		R	1[illegible]
	Pao Division	Venezuela	C			[illegible]
	Total					1[illegible]
12	Mineracoes Brasileiras Reunidas S.A.	Brazil	C		R	12,[illegible]
13	Granges AB Lamco Joint Venture	Liberia	C	P		11,[illegible]
14	Societe Nationale Industr. and Miniere	Mauritania			R	8,7[illegible]
15	Cia de Acero Del Pacifico S.A.					
	Romeral Mine	Chile	C			3,4[illegible]
	El Algarrobo	Chile		P		3,0[illegible]
	Santa Fe Mines	Chile	C			99[illegible]
	Total					7,5[illegible]
16	National Mineral Develop. Corp. Ltd.					
	Bailadila 14 u. 15	India	C			5,9[illegible]
	Donimalai	India	C			1,2[illegible]
	Total					7,2[illegible]
17	S.A. Mineracao de Trindade	Brazil			R, M	6,4[illegible]
18	Reserve Mining Co.	USA/Minnesota		P		6,25[illegible]

TABLE I.D-1 (Cont'd)

RANK	COMPANY	COUNTRY	CONCENTRATE	PELLETS	HIGH-GRADE OR	PRODUCTION ('000 GROSS TONS)
19	The Broken Hill Pty. Co. Ltd.					
	Yampi Sound	Australia/(West)			R	2,734
	Groote Eylandt Mining Co. Pty. Ltd.	Australia/North)			M	1,402
	Whyalla	Australia/(South)	C	P	R	1,051
	Koolyanobbing	Australia/(West)			R	813
	Total					6,000
20	Oglebay Norton Co.					
	Eveleth Mines	USA/Minnesota		P		5,8[illegible]
21	Minero Peru Comercial	Peru	C	P	Si	5,642
22	Mt. Goldsworthy Mining Assoc.	Australia/(West)			R	5,435
23	Arbed S.A.					
	Arbed Mines Francaises	France			R	4,769
	Arbed Mines Luxembourgeoises	Luxemburg			R	42[illegible]
	Total					5,187
24	Samarco Mineracao S.A.	Brazil	C	P		4,015
25	Inland Steel Co.					
	Minorca Mine	USA/Minnesota		P		2,444
	Jackson Country Iron Co.	USA/Wisconsin		P		853
	Caland Ore Co. Ltd.	Canada/Ontario			R	149
	Total					3,447
26	Cia. Andaluza de Minas S.A.	Spain	C			3,25[illegible]
27	Voest Alpine AG	Austria	C		R	2,9[illegible]
28	V.M. Salgaocar & Bro. Pvt. Ltd.	India/Goa	C		R	2,4[illegible]
29	Kaiser Steel Corp.	USA/California	C	P		2,34[illegible]
30	Quit-Fer & Titane Inc.	Canada/Quebec			[illegible]	2,0[illegible]
31	SSAB Gruvor					
	Grangesberg	Sweden	C			1,36[illegible]
	Dannemora	Sweden	C			34[illegible]
	Strassa	Sweden	C	P		27[illegible]
	Total					1,978
32	New Zealand Steel Ltd.	New Zealand	C			1,917
33	V.S. Dempo & Co. Pvt. Ltd.	India/Goa				1,57[illegible]
34	Cie. Miniere de L'Ogooue	Gabon			M	1,519
35	The Algoma Steel Corp. Ltd. Algoma Ore Division	Canada/Ontario			Si	1,46[illegible]
36	Chowgule & Co. Pvt. Ltd.	India/Goa	C	P		1,39[illegible]
37	Sesa Goa Pvt. Ltd.	India/Goa			R	1,377
38	Waipipi Iron Sands Ltd.	New Zealand	C		Si	1,254
39	National Iron Ore Co. Mine Management Assoc. Ltd.	Liberia	C			1,146
40	Pea Ridge Iron Ore Co.	USA/Missouri		P		1,0[illegible]
41	Societe Metallurgique de Normandie	France			R, Si	94[illegible]
42	Sociedade de Fomento Industrial	India/Goa	C			9[illegible]
43	Cia. Minera de Sierra Meneva S.A.	Spain	C			90[illegible]
44	Rautaruukki Oy	Finland	C			85[illegible]
45	Industria & Commercio de Minerios	Brazil		P		822
46	Jones & Laughlin Steel Corp. Northwest Ore Division	USA/Minnesota	C			624
47	A. V. Sarmalkar	India/Goa	C			550
48	Timblo Pvt. Ltd.	India/Goa	C			478
49	Orient Goa Pvt.	India/Goa			R	47[illegible]
50	Barbara Rohstoffbetriebe GmbH	W. Germany	C			44[illegible]
51	B.N.S. Bandebar	India/Goa			R	38[illegible]
52	Pittsburgh Pacific Co.	USA/Minnesota	C			372

TABLE I.D-1 (Cont'd)

RANK	COMPANY	COUNTRY	CONCENTRATE	PELLETS	HIGH-GRADE OF	PRODUCTION ('000 GROSS TONS)
53	Minerals & Metals Trading Corp.	India	C			330
54	Pandurong Timblo	India/Goa	C			307
55	Mandovi Pellets Ltd.	India/Goa		P		287
56	Damodar Mangalji	India/Goa	C			257
57	Fior de Venezuela	Venezuela				240
58	Ghana National Manganese Corp.	Ghana			M	194
59	Kudremukh Iron Ore Co. Ltd.	India	C			192
60	Rhude & Fryberger Inc.	USA/Minnesota	C			155
61	Emco Goa Pvt. Ltd.	India/Goa	C			135
62	Vassantram Metha	India/Goa			R	127
63	Empresa de Mineracao Esperanca S.A.	Brazil			R	96
64	G.N. Agrawal	India/Goa			R	65
65	C.F. & I. Steel Corp.	USA/Utah			R	63
66	Agencia C. Maritima	India/Goa			R	19
67	Lima Leitao	India/Goa			R	10

M = MANGANESE ORE, Sl = SLURRY, Si = Sinter, I = Ilmenite

Source: Stahl und Eisen 102 (1982) No. 24

TABLE I.D-2

IRON ORE: PRODUCTION, TRADE AND APPARENT CONSUMPTION, 1981

Million metric tons actual weight.

	Fe Content (1)	Production	- Exports	+ Imports	= Apparent Consumption
Belgium/Luxemburg	(27)	0.4	-	21.1	21.5
France	(33)	21.6	6.4	16.5	31.7
FR Germany	(28)	1.6	-	44.3	45.9
Italy	(50)	0.1	-	15.2	15.3
United Kingdom	(27)	0.7	-	14.5	15.2
Other EEC		1.3	-	7.3	8.6
EEC Total		25.7	6.4	118.9	138.2
Austria	(32)	3.1	-	3.4	6.5
Norway	(65)	4.1	3.7	-	0.4
Spain	(48)	8.4	2.1	4.7	11.0
Sweden	(63)	23.4	17.7	-	5.7
Other Western Europe		7.9	-	4.0	11.9
Total Western Europe		72.6	29.9	131.0	173.7
Canada	(55)	49.7	41.5	5.8	14.0
United States	(60)	75.5	5.6	29.0	98.9
Brazil	(66)	101.5	81.0	-	20.5
Venezuela	(64)	14.9	12.4	-	2.5
Chile	(61)	7.7	6.7	-	1.0
Peru	(60)	6.1	5.2	-	0.9
Mexico	(65)	5.6	-	-	5.6
Other Latin America		1.2	-	2.4	3.6
Total Latin America		137.0	105.3	2.4	34.1
Liberia*	(68)	19.5	20.7	-	-1.2
Mauretania	(65)	8.3	8.9	-	-0.6
South Africa	(65)	25.3	14.0	-	11.3
Other Africa		6.8	1.7	-	5.1
Total Africa		59.9	45.3	-	14.6
Middle East		-	-	0.6	0.6
India	(61)	41.1	24.2	-	16.9
Japan	(57)	0.4	-	123.3	123.7
Other Asia		1.2	-	17.4	18.6
Total Asia		42.7	24.2	140.7	159.2
Australia	(65)	84.7	71.7	-	13.0
New Zealand		3.5	2.9	-	0.6
Western World Total		525.6	326.4	309.5	508.7
USSR and other Eastern Europe	(60)	248.7	34.2	49.0	263.5
China & DPR Korea		78.0E		2.1	80.1
WORLD		852.3	360.6	360.6	852.3

(1) of domestic production: percentage Fe of total weight.

* No domestic consumption of iron ore: negative figure indicates that reduction of inventories occurred.

Source: Iron and Steel Engineer, Aug. 1983.

TABLE I.D-3

THE MAJOR STEEL-PRODUCING COUNTRIES

1981 and 1982

Million metric tons crude steel production.

	1982		1981	
	Rank	Tonnage	Rank	Tonnage
USSR	1	147.0	1	148.5
Japan	2	99.5	3	101.7
United States	3	67.6	2	109.6
China	4	37.0	5	35.6
FR Germany	5	35.9	4	41.6
Italy	6	24.0	6	24.8
France	7	18.4	7	21.3
Czechoslovakia	8	15.0	10	15.3
Poland	9	14.5	8	15.7
United Kingdom	10	13.7	9	15.6
Spain	11	13.1	14	12.9
Romania	12	13.0	13	13.0
Brazil	13	13.0	12	13.2
Canada	14	11.9	11	14.8
Rep. of Korea	15	11.8	17	10.8
India	16	11.0	16	10.8
Belgium	17	9.9	15	12.3
South Africa	18	8.2	18	9.0
German DR	19	7.1	21	7.5
Mexico	20	7.1	20	7.6
Australia	21	6.4	19	7.6
DPR Korea	22	5.8	22	5.5
Netherlands	23	4.4	23	5.5
Australia	24	4.3	24	4.7
Taiwan (ROC)	25	4.2	29	3.2
Sweden	26	3.9	27	3.8
Yugoslavia	27	3.9	25	4.0
Hungary	28	3.8	28	3.8
Luxemburg	29	3.5	26	3.8
Argentina	30	2.9	30	2.5
Turkey	31	2.8	33	2.4
Bulgaria	32	2.6	31	2.5
Finland	33	2.4	32	2.4
Venezuela	34	2.3	34	2.0
Others		12.5		12.4
WORLD TOTAL		644.4		707.5

This table lists all countries producing more than two million metric tons of crude steel in 1982.

Source: Iron and Steel Engineer, Aug. 1983

TABLE I.D-4 CRUDE STEEL PRODUCTION BY PROCESS, 1982

	Production Million Metric Tons	Oxygen %	Electric %	Open Hearth %	& Other %	Total %
Belgium	9.9	92.6	7.4	-	-	100.0
Denmark	0.6	-	100.0	-	-	100.0
FR Germany	35.9	80.9	17.6	1.5	-	100.0
France	18.4	80.9	18.9	0.2	-	100.0
Italy	24.0	47.4	52.6	-	-	100.0
Luxemburg	3.5	100.0	-	-	-	100.0
Netherlands	4.4	94.7	5.3	-	-	100.0
United Kingdom	13.7	65.9	34.1	-	-	100.0
EEC	110.3	73.5	25.9	0.6	-	100.0
Austria	4.3	86.8	10.9	2.3	-	100.0
Finland	2.4	90.7	9.3	-	-	100.0
Norway	0.8	49.7	50.3	-	-	100.0
Portugal	0.5	42.2	53.4	-	4.4	100.0
Spain	13.1	45.2	51.5	4.4	-	100.0
Sweden	3.9	45.9	54.1	-	-	100.0
Turkey	2.8	55.3	25.7	19.0	-	100.0
Yugoslavia E	3.9	35.8	26.4	37.8	-	100.0
Other W. Europe	31.7	54.2	37.8	8.0	0.1	100.0
Total W. Europe	142.0	69.2	28.6	2.2	-	100.0
Canada	11.9	61.1	25.1	13.9	-	100.0
United States	67.6	60.8	31.1	8.2	-	100.0
North America	79.5	60.8	30.2	9.0	-	100.0
Argentina	2.9	22.9	53.3	21.8	1.9	100.0
Brazil	13.0	66.4	26.3	7.4	-	100.0
Chile	0.5	98.3	1.7	-	-	100.0
Mexico	7.1	41.2	43.5	15.4	-	100.0
Venezuela E	2.3	-	83.4	16.6	-	100.0
Latin America	25.7	49.3	38.6	11.9	0.2	100.0
India E	11.0	23.5	21.6	53.5	1.5	100.0
Rep. of Korea	11.8	74.8	25.2	-	-	100.0
Japan	99.5	73.4	26.6	-	-	100.0
Taiwan (ROC)	4.2	63.7	36.3	-	-	100.0
Australia	6.4	85.6	1.7	12.7	-	100.0
South Africa E	8.2	73.2	26.8	-	-	100.0
Total Others	141.0	69.6	25.3	4.7	0.1	100.0
All Above	388.3	66.4	28.4	5.2	0.1	100.0
Bulgaria*	2.6	57.9	25.0	17.1	-	100.0
German DR*	7.1	9.0	28.7	60.8	1.5	100.0
Hungary*	3.8	14.0	8.8	77.2	-	100.0
Poland*	14.5	38.2	14.0	47.8	-	100.0
Romania*	13.0	44.5	19.7	35.9	-	100.0
USSR*	147.0	29.5	10.9	59.1	0.5	100.0
Eastern Europe	188.0	30.5	12.5	56.4	0.5	100.0
TOTAL ALL COUNTRIES	576.3	54.7	23.2	21.9	0.2	100.0

* 1981 percentage breakdown.

Source: Iron and Steel Engineer, Aug. 1983.

TABLE I.D-5 APPARENT STEEL CONSUMPTION, 1976 to 1982

Million metric tons crude steel equivalent.

	1976	1977	1978	1979	1980	1981	1982
Japan	65.2	65.1	67.9	78.5	78.8	72.3	69.9
EEC	114.7	107.2	105.1	114.4	108.1	98.7	91.6
Other Western Europe	33.3	33.7	31.5	31.2	32.3	31.8	32.4
United States	127.1	137.4	145.2	142.6	118.4	128.2	91.3
Canada	12.6	12.8	13.6	14.9	13.8	14.4	10.5
South Africa	5.4	4.5	5.1	6.0	6.9	6.6	5.9
Oceania	6.4	5.8	5.7	7.2	7.1	7.4	6.8
Total Industrialized Countries	367.4	366.5	374.1	394.8	365.4	359.4	308.4
Latin America	25.0	28.0	30.2	32.4	36.7	34.3	30.2
Africa except South Africa	7.2	8.5	8.1	7.3	8.6	8.6	8.6
Middle East	15.1	14.3	16.0	16.3	15.8	15.8	15.9
Asia except Japan, China, N. Korea	24.0	29.8	33.7	36.5	36.4	38.9	39.6
Total Developing Countries	71.3	80.6	88.0	92.5	97.5	97.6	94.3
Total Western World	436.0	447.1	462.1	487.3	462.9	457.0	402.7
USSR and Eastern Europe	200.9	203.4	212.4	210.8	207.5	203.3	204.5
China and North Korea	29.5	35.7	47.7	50.4	48.9	45.1	47.0
Total Centrally Planned Economies	230.4	239.1	260.1	261.2	256.4	248.4	251.5
Total World	666.4	686.2	722.2	748.5	719.3	705.4	654.2
Unallocated	+9.0	-10.7	-5.2	-1.8	-3.3	+2.1	-9.8
World Crude Steel Production	675.4	675.5	717.0	746.7	716.0	707.5	644.4

Source: Iron and Steel Engineer, Aug. 1983.

TABLE I.D-6 WORLD CRUDE STEEL PRODUCTION, 1973-1982

(Thousand Metric Tons)

	1973	1974	1975	1976	1977	1978	1979	1980	1981	1982*
Belgium	15522	16227	11582	12145	11256	12601	13442	12322	12283	9894
Denmark	453	536	557	722	686	863	804	734	612	560
France	25270	27021	21531	23227	22094	22841	23360	23176	21258	18402
FR of Germany	49521	53232	40412	42413	38984	41253	46040	43838	41610	35878
Greece	1087	926	666	715	759	936	1000	935	909	910
Ireland	116	110	81	58	47	69	72	2	32	61
Italy	20995	23804	21865	23455	23335	24283	24250	26501	24777	24010
Luxembourg	5924	6447	4624	4565	4329	4790	4949	4618	3790	3510
Netherlands	5623	5837	4817	5178	4923	5590	5805	5272	5472	3510
United Kingdom*	26594	22323	20098	22274	20411	20311	21464	11277	15573	13705
EEC	151105	156463	126233	134752	126824	133537	141186	128675	126316	111264
Austria	4238	4699	4069	4476	4093	4335	4917	4623	4656	4258
Finland	1615	1656	1616	1649	2169	2333	2454	2508	2428	2434
Norway	963	913	891	866	704	797	891	862	848	753
Portugal	459	387	419	461	531	608	650	659	554	504
Spain	10800	11502	11102	10982	11169	11339	12248	12643	12896	13146
Sweden	5663	5988	5611	5139	3968	4325	4733	4237	3770	3900
Switzerland	584	592	420	545	656	784	856	929	966	1000E
Turkey	1354	1590	1703	1972	1902	2172	2396	2536	2425	2843
Yugoslavia	2676	2836	2916	2751	3182	3456	3535	3634	3977	3851
WESTERN EUROPE	179457	166626	154980	163613	155225	163686	173906	161306	158836	143953
Bulgaria	2246	2188	2265	2460	2589	2470	2482	2567	2483	2600E
Czechoslovakia	13158	13640	14324	14693	15054	15294	14817	14925	15270	15000E
DR Germany	5855	6165	6480	6740	6850	6976	7024	7308	7467	7100E
Hungary	3332	3468	3673	3652	3723	3877	3907	3767	3645	3800E
Poland	14057	14556	15007	15640	17841	19250	19218	19485	15719	15000E
Romania	8161	8840	9549	10970	11457	11779	12909	13175	13025	13000E
USSR	131481	136200	141325	144805	146655	151436	149087	147931	148517	147500E
EASTERN EUROPE	178290	185057	192623	198960	204169	211082	209444	209158	206126	204000
Canada	13388	13623	13025	13290	13631	14899	16054	15901	14811	11871
United States	136802	132195	105816	116120	113700	124313	123688	101455	109614	67656
NORTH AMERICA	150190	145818	118841	129410	127331	139212	139742	117356	124425	79527
Argentina	2205	2353	2208	2410	2684	2782	3199	2687	2556	2913
Brazil	7150	7515	8387	9253	11253	12205	13893	15309	13175	12997
Central America	10	10	10	13	62	64	98	100	105	43
Chile	549	634	508	503	559	616	643	746	657	483
Colombia	362	311	390	370	330	390	361	402	396	425
Cuba	220E	240E	300E	296	302	300E	300E	330E	330E	330E
Ecuador	0	0	0	0	0	0	0	16	26	27
Mexico	4760	5138	5272	5298	5601	6711	7005	7099	7605	7068
Panama	0	0	0	0	0	0	0	6	50	50
Peru	356	481	431	349	379	377	436	470	360	272
Trinidad & Tobago	0	0	0	0	0	0	0	0	15	200E
Uruguay	12	14	16	16	19	9	14	16	14	19
Venezuela	1063	1041	1063	936	803	860	1506	1820	2029	2278
LATIN AMERICA	16687	17737	18585	19444	21992	24314	27454	29001	27318	27105

TABLE I.D-6 (Cont'd)

	1973	1974	1975	1976	1977	1978	1979	1980	1981	1982*
Algeria	195	173	221	356	410	580	417	534	700E	700E
Nigeria	12	15	14	15	15	15	15	20	22	100E
Tunisia	140	132	130	102	157	150	150	178	180	180
South Africa	5722E	5839E	6831	7106	7295	7902	8876	9067	9005	8200
Zimbabwe	485	491	524	733	734	778	740	805	691	550
Other	55E	60E	60E	60E	60E	60E	65E	70E	70E	70E
AFRICA	6609	6710	7780	8372	8671	9485	10263	10674	10668	9800
Egypt	525	500	500	500	600	600	800	800	900	950
Iran	240E	567E	551	549	1825	1300	1430	1200	1200	1200
Israel	65	75	60	70	72	94	107	115	114	87
Qatar	0	0	0	0	0	127	396	396	469	495
Other	80E	85E	70E	65E	51E	55E	170E	170E	180E	200E
MIDDLE EAST	910	1227	1181	1184	2548	2176	2903	2681	2863	2932
Bangladesh	68	74	76	90	108	120	125	131	131	78
China	25219	21119	23903	20459	23740	31780	34484	37121	35600	37000
Hong Kong	115E	120E	120E	120E	120E	120E	120E	120E	120E	120E
India	6889	7068	7991	9364	10009	10099	10126	9514	10765	10997
Indonesia	50	80	100	139	250	225	305	360	500E	500E
Japan	119322	117131	102313	107399	102405	102105	111748	111395	101676	99548
Malaysia	180	182	183	190	194	203	207	210E	210E	210E
DR of Korea	2900E	3200E	2900E	3000E	4000E	5080E	5400E	5800E	5500E	5800E
Philippines	216	237	316	357	364	276	397	330E	350E	350E
Singapore	211	194	188	194	206	280	297	340	263	359
Rep. of Korea	1157	1947	1994	3515	4347	4969	7610	8558	10753	11758
Taiwan (ROC)	535	597	680	1098	1710	3426	3186	3417	3157	4152
Thailand	324	326	251	281	309	346	440	450E	300E	350E
Other	200E	200E	200E	200E	250E	230E	225E	225E	220E	250E
ASIA	157386	152475	141215	146406	148012	159259	174670	177971	169548	171472
Australia	7699	7813	7869	7794	7338	7596	8119	7589	7635	6371
New Zealand	190	194	185	222	218	225	229	230	221	252
OCEANIA	7899	8007	8054	8016	7556	7821	8348	7819	7856	6623
TOTAL	697418	703657	643259	675405	675504	717035	746730	715966	707640	645412
OF WHICH:										
29 IISI Reporting Cts.	484911	487892	417770	446381	435098	460380	487600	453997	450337	388274
IISI Member Countries	488832	492005	421505	450580	441001	466239	494124	460643	457249	395518
Developing Countries	28399	30814	32699	37368	43699	48292	54711	56844	58507	60683
Industrial Countries	462390	463227	390834	415322	399594	420501	442391	406713	401577	337599
Western World	490789	494041	423533	452690	443293	468793	497102	463557	460084	398282
Comecon, China, N. Korea	206639	209616	219726	222715	232211	248242	249628	252490	247556	247130

Source: Iron and Steelmaking, (July 1983). International Iron and Steel Institute.

TABLE I.D-7

1983 L-D STEELMAKING CAPACITY

Company	L-D Basic Oxygen Steel Plant Location	No. of Furnaces & Output per Heat Short Tons Raw Steel	Start Up Date	Annual Capacity Short Tons Raw Steel Existing	To Be Added
UNITED STATES					
Allegheny Ludlum Steel Corp.	Brackenridge, PA	2 x 80	1966	600,000	
Armco Inc.	Ashland, KY	2 x 180	1963	2,000,000	
	Middletown, OH	2 x 200	1969	2,000,000	
Bethlehem Steel Corp.	Lackawanna, NY	3 x 310	1964/68	3,000,000	
	Sparrows Point, MD	2 x 220	1966	3,200,000	
	Bethlehem, PA	2 x 270	1968	3,000,000	
	Burns Harbor, IN	3 x 300	1969/78	5,300,000	
CF&I Steel Corp.	Pueblo, CO	2 x 120	1961	1,300,000	
Inland Steel Co.	East Chicago, IN	2 x 255 LBE	1966	3,800,000	
		2 x 210	1974	2,200,000	
Interlake Inc.	Chicago, IL	2 x 87	1959	1,000,000	
Jones & Laughlin Steel Corp.	Aliquippa, PA	3 x 207	1968	3,500,000	
	Cleveland, OH	2 x 210	1961	2,850,000	
	East Chicago, IN	2 x 285 CB	1970	3,500,000	
Kaiser Steel Corp.	Fontana, CA	2 x 220	1978	2,800,000	
McLouth Steel Products Corp.	Trenton, MI	5 x 110	1958/69	2,800,000	
National Steel Corp.					
Great Lakes Steel Division	Ecorse, MI	2 x 300	1962		shut down 1981
		2 x 230 LBE	1970	2,700,000	
Granite City Steel Co.	Granite City, IL	2 x 235	1967	2,350,000	
Weirton Steel Division*	Weirton WV	2 x 360	1967	3.850,000	
Republic Steel Corp.	Warren, OH	2 x 150	1965	2,500,000	
	Gadsen, AL	2 x 150	1965	1,500,000	
	Cleveland, OH	2 x 220	1966	2,800,000	
	Buffalo, NY	2 x 130	1970	1,000,000	
	South Chicago, IL	2 x 225 Q-BOP	1977	1,200,000	
Rouge Steel Co.	Dearborn, MI	2 x 240	1964	2,900,000	
Sharon Steel Corp.	Farrell, PA	2 x 150	1974/82	1,500,000	
United States Steel Corp.	Duquesne, PA	2 x 220	1963	2,600,000	
	Fairfield, AL	3 x 200 Q-BOP	1976	3,000,000	shut down 1982
	Gary, IN	3 x 215	1965	4,000,000	
		3 x 200 Q-BOP	1973	3,000,000	
	South Chicago, IL	3 x 200	1969	3,900,000	
	Lorain, OH	2 x 225	1971	2,800,000	
	Braddock, PA	2 x 220	1972	2,800,000	
Wheeling-Pittsburgh Steel Corp.	Monessen, PA	2 x 200	1964	1,800,000	
	Steubenville, OH	2 x 275	1965	2,700,000	
			SHORT TON TOTAL	**91,750,000**	
			EQUIVALENT METRIC TON TOTAL	**83,260,000**	
ALGERIA					
Societe National de Siderurgie	El-Hadjar (Annaba)	3 x 85	1980	1,200,000	
		3 x 60	1981	700,000	
			TOTAL	**1,900,000**	
ARGENTINA					
Altos Hornos Zapala	Palpala	2 x 25 OBM	1984		300,000
SIDINSA—Siderurgica Integrada Saic	Bahia Blanca	2 x 350	1983/84		3,800,000
SOMISA—Sociedad Mixta Siderurgia Argentina	San Nicholas	3 x 200	1973/78	3,000,000	KMS
			TOTAL	**3,000,000**	**4,100,000**
AUSTRALIA					
The Broken Hill Proprietary Co. Ltd.	Newcastle	2 x 200 LBE	1962	2,040,000	
	Port Kembla	2 x 270 LBE	1973)	5,900,000	
		1 x 270	1983)		
	Whyalla	2 x 120 LBE	1965	1,300,000	
			TOTAL	**9,240,000**	
AUSTRIA					
VOEST-ALPINE AG	Linz	3 x 50	1959/68	1,400,000	
		2 x 130	1973/76	1,650,000	
	Donawitz	3 x 60	1953/74	1,100,000	
			TOTAL	**4,150,000**	
BELGIUM					
Forges de Clabecq S.A.	Ittre	2 x 75	1964/69	1,300,000	
N.V. SIDMAR	Gent	2 x 285	1967	3,200,000	
S.A. Cockerill-Sambre	Chertal	3 x 165	1963/68	3,000,000	
	Montignies-sur-Sambre	3 x 175	1969/72	3,500,000	
	Seraing	2 x 233	1965	2,215,000	
S.A. Usines Gustave Boel	La Louviere	3 x 85	1967/71	2,000,000	
Thy Marcinelle	Marcinelle	3 x 150 OBM	1976	2,300,000	
			TOTAL	**17,515,000**	

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*Weirton Division is being sold to employees

TABLE I.D-7 (Cont'd)

Company	L-D Basic Oxygen Steel Plant Location		No. of Furnaces & Output per Heat Metric Tons Raw Steel	Start Up Date	Annual Capacity Metric Tons Raw Steel	
					Existing	To Be Added
BRAZIL						
Aco Minas Gerais S.A.	Ouro Branco MG		2 x 200	1984		2,000,000
Cimetal Siderurgia S.A.	Barao de Cocais		1 x 25	1979	200,000	
Companhia Acos Especiais Itabira	Acesita		1 x 35	1972	245,000	
			1 x 80	1979	520,000	
Companhia Siderurgica Belgo-Mineira	Joao Monlevade		2 x 40	1957	620,000	
			2 x 100**	1985		380,000
Companhia Siderurgica Nacional	Volta Redonda		3 x 220	1977/81	4,600,000	
Companhia Siderurgica Paulista (COSIPA)	Piacaguera		2 x 85	1965)	3,000,000	
			2 x 100	1977/78)		
			2 x 130	1985		1,200,000
Companhia Siderurgica Tubarao	Carapina/Serra ES		2 x 280	1983		3,000,000
Mannesmann S.A.	Belo Horizonte		2 x 70	1978	750,000	
Siderurgica Barra Mansa S.A.	Barra Mansa		2 x 15	1971	120,000	
Usinas Siderurgicas de Minas Gerais S.A. (USIMINAS)	Ipatinga		3 x 80	1963/73	1,600,000	
			2 x 160	1975	1,800,000	
				TOTAL	**13,455,000**	**6,580,000**
BULGARIA						
Kremikovtsi Iron & Steel Works	Kremikovtsi (nr. Sofia)		3 x 100	1966	1,265,000	
				TOTAL	**1,265,000**	
CANADA						
The Algoma Steel Corp., Ltd.	Sault Ste. Marie, Ont.		3 x 95	1958/64	1,313,000	
			2 x 236	1973	2,767,000	
DOFASCO Inc.	Hamilton, Ont.		3 x 150 LBE-1 fce	1954/66	2,800,000	
			1 x 250	1978	1,000,000	
STELCO Inc.	Hamilton, Ont.		3 x 127 LBE-1 fce	1971	2,540,000	LBE-1 fce
	Nanticoke, Ont.		2 x 227	1980	1,440,000	
				TOTAL	**11,860,000**	
CHILE						
Cia. de Acero del Pacifico S.A. (CAP)	Talcahuano		2 x 110	1976	1,100,000	
				TOTAL	**1,100,000**	
CHINA	**City**	**Province**				
Maanshan Steel	Maanshan	Anhwei	3 x 50	1981	1,500,000	
San-Ming Iron & Steel	San Ming	Fukien	2 x 15	1978	***	
Anyang Steel	Anyang	Honan	3 x 15	1970	***	
Chidong (near Tiensin)	Chidong	Hopeh	large	after 1985		3,000,000
Lienyuan Steel	Lienyuan	Hunan	2 x 15	1976	***	
Wu-Han Iron & Steel	Wu Han	Hupeh	3 x 50	1979	1,500,000	
Paotou Steel	Paotou	Inner Mongolia	3 x 50	1970/85	500,000	500,000
Jiayuguan Complex	Jiayuguan	Kansu	large			
Nanking Steel	Nanking	Kiangsu	2 x 15	1971	***	
Liu-Chow Municipal Foundry	Liu Chow	Kwangsi	3 x 15	1977	***	
Canton Steel	Canton	Kwangtung	3 x 6	1970	***	
Anshan Steel	Anshan	Liaoning	2 x 150	1970's	1,500,000	
Penchi	Penchi	Liaoning	2 x 120	1977	800,000	
Capital Iron & Steel (Shoudu)	Shih-Chingshan	Peking	3 x 30	1964/70	1,400,000	
Shanghai Steel Works	Shanghai	Shanghai	3 x 30	1966	800,000	
Baoshan Steel	near Shanghai	Shanghai	2 x 300	1985		3,000,000
Changchih	Changchih	Shansi	3 x 6	1979	***	
Tai-Yuan Steel Works	Tai Yuan	Shansi	2 x 50	1968/70	500,000	
Yen-T'ai Iron & Steel	Yen-T'ai	Shantung	1 x 1.5	1968	***	
Hangzhou Steel	Hangzhou	Sinkiang	1 x 5	1978	***	
Panchihhua	Panchihhua	Szechwan	3 x 120	1977	1,250,000	
Kunming Iron & Steel	Anning	Yunnan	3 x 15	1970	***	
China Steel Corporation	Kaohsiung	Taiwan	3 x 150/160	1977/81	3,250,000	
				TOTAL	**13,000,000**	**6,500,000**
COLUMBIA						
Paz del Rio	Belincinto		2 x 30 LWS	1980	380,000	
				TOTAL	**380,000**	

**To replace existing vessels

***May be side blown. 2.5 MT of side blown production reported in 1981

TABLE I.D-7 (Cont'd)

Company	L-D Basic Oxygen Steel Plant Location	No. of Furnaces & Output per Heat Metric Tons Raw Steel	Start Up Date	Annual Capacity Metric Tons Raw Steel	
				Existing	To Be Added
CZECHOSLOVAKIA					
East Slovakian Iron & Steel Works	Kosice	3 x 150	1966/80	3,000,000	
		2 x 160	1974/80	1,800,000	
Trinec Iron Works	Trinec	2 x 180	1983		2,500,000
			TOTAL	**4,800,000**	**2,500,000**
EGYPT					
Egyptian Iron & Steel Co.	Helwan/Cairo	3 x 70	1974/79	1,200,000	
			TOTAL	**1,200,000**	
FINLAND					
Ovako Oy Ab, Koverhar	Lappohja	2 x 50	1971	550,000	
Rautaruukki Oy	Raahe	3 x 80	1967/76	1,700,000	
			TOTAL	**2,250,000**	
FRANCE					
Acieries et Usines Metallurgiques de Decazeville	Decazeville	2 x 15	1969	130,000	
SACILOR — Acieries et Laminoirs de Lorraine	Gandrange	2 x 250 OLP/LBE	1971/82	3,400,000	
Societe Metallurgique de Normandie	Mondeville	1 x 65 +	1967	400,000	
		2 x 100 LBE	1977	1,200,000	
SOLLAC — Ste. Lorraine de Laminage Continu	Seremange	2 x 250 LWS	1978	3,000,000	
Societe Nouvelle des Acieries de Pompey	Pompey	2 x 80	1964	600,000	
SOLMER — Societe Lorraine et Meridionale de Laminage Continu	Fos-sur-Mer	2 x 310 LBE	1974	3,800,000	
USINOR — Union Siderurgique du Nord et de l'Est de la France	Dunkerque	3 x 160 LBE	1962	3,500,000	
		3 x 220 LBE	1972	4,500,000	
	Longwy Rehon	3 x 80 OBM	1979	1,500,000	
	Neuves Maison	2 x 125 OBM	1979	1,250,000	
Cie. Francaise des Aciers Speciaux/Usine des Dunes	Dunkerque	1 x 65	1971	400,000	
			TOTAL	**23,680,000**	
GERMANY (EAST)					
VEB Eisenhuttenkombinat Ost	Eisenhuttenstadt	2 x 225	1984		2,200,000
VEB Maxhutte	Unterwellenborn	4 x 20 OEK	1974	500,000	
			TOTAL	**500,000**	**2,200,000**
GERMANY (WEST)					
AG der Dillinger Huettenwerke	Dilligen (Saar)	2 x 200 LBE	1968	2,900,000	
ARBED Saarstahl GmbH	Volklingen (Saar)	3 x 150 LBE	1980/82	3,240,000	
Hoesch Huettenwerke AG	Dortmund-Hoerde	3 x 180	1963/66	4,200,000	
Kloeckner Werke AG	Bremen	2 x 280	1968	4,000,000	
Georgsmarienhuette	Osnabrueck	1 x 125 + + KS	1981	1,000,000	
Maximillianshuette	Sulzbach-Rosenberg	3 x 60 KMS	1977	1,200,000	
Krupp Stahl AG	Rheinhausen	2 x 300 CB	1975	3,600,000	
		2 x 115	1967	1,800,000	
Mannesmannroehren-Werke AG	Duisburg-Huckingen	2 x 220 + +	1966	3,600,000	
Stahlwerke Peine-Salzgitter AG	Peine	3 x 90	1964	1,940,000	
	Salzgitter	3 x 210	1968/77	5,160,000	
Thyssen AG	Beeckerwerth	3 x 260	1962/70	7,200,000	
	Bruckhausen	2 x 380	1969	6,000,000	
	Ruhrort	4 x 140	1966/75	4,320,000	
	Hattingen	1 x 150 + +	1970	1,680,000	
			TOTAL	**51,840,000**	
GREECE					
Halyvourgiki Inc.	Elefsis	4 x 50	1963/70	1,000,000	
			TOTAL	**1,000,000**	

\+ Vessel out of service

\+ + Vessel exchange system

TABLE I.D-7 (Cont'd)

Company	L-D Basic Oxygen Steel Plant Location	No. Furnaces & Output per Heat Metric Tons Raw Steel	Start Up Date	Annual Capacity Metric Tons Raw Steel Existing	To Be Added
HUNGARY					
Danube Works/Dunai Vasmu	Dunaujvaros	2 x 130	1981	1,200,000	
Lenin Metallurgical Works	Miskolc	1 x 80 + +	1980	700,000	
			TOTAL	**1,900,000**	
INDIA					
Steel Authority of India Ltd.					
Bokaro Steel Plant	Bokaro Steel City, Bihar	5 x 100	1973/78	2,500,000	
		2 x 300			1,500,000
Bhilai Steel Plant	Bhilai, Madhya Pradesh	3 x 100/130	1981	1,500,000	
Rourkela Steel Plant	Rourkela, Orissa	5 x 50/60	1959/67	1,600,000	
Daitari	Orissa	2 x 150	1985		1,500,000
USSR Sponsored	Vishakhapatnam, Orissa	2 x 150	1985		1,500,000
Maharashtra Elektrosmelt Ltd.	Chandrapur, Maharashtra	2 x 15	1979	150,000	
Tata Iron & Steel Co. Ltd.	Jamshedpur	2 x 130	1983	1,200,000	OBM
Visvesvaraya Iron & Steel Ltd.	Bhadravati, Karnataka	2 x 15 OBM	1965/·	82,000	62,000
			TOTAL	**7,032,000**	**4,562,000**
IRAN					
National Iranian Steel Co.	Esfahan	2 x 80/130	1972	550,000	
			TOTAL	**550,000**	
ITALY					
Acciaierie de Piombino S.p.A.	Piombino	3 x 100	1970/81	2,000,000	
Italsider S.p.A.	Bagnoli	3 x 150	1964	2,700,000	
	Taranto	3 x 330	1964	5,400,000	
		3 x 350	1973	6,300,000	
	Cornigliano	2 x 250 OBM	1980	2,400,000	
			TOTAL	**18,800,000**	
JAPAN					
Godo Steel Ltd.	Osaka	2 x 41	1964	528,000	
Kawasaki Steel Corporation	Chiba	2 x 85 K-BOP	1970	1,160,000	
		3 x 150 LD-KG	1962/65	4,020,000	
		2 x 230 Q-BOP	1977	3,600,000	
	Mizushima	3 x 180 LD-KG	1967/69	4,630,000	
		3 x 250	1970/73	7,070,000	K-BOP
Kobe Steel Ltd.	Kobe	3 x 80	1961/66	2,300,000	
	Kakogawa	3 x 235 LD-OTB	1970/73	6,000,000	
Nakayama Steel Works Ltd.	Funamachi	2 x 75	1975	1,300,000	
Nippon Kokan K.K.	Fukuyama No. 1	3 x 180	1966/68	4,800,000	
	Fukuyama No. 2	3 x 250	1969/71	7,200,000	
	Fukuyama No. 3	2 x 300	1970	4,000,000	
	Keihin	3 x 250	1976/79	6,000,000	
Nippon Steel Corporation	Yawata No. 1	1 x 150	1974	1,500,000	
	Yawata No. 2	3 x 150	1962/70	4,300,000	
	Yawata No. 3	2 x 320 LD-OB	1979	4,100,000	
	Muroran No. 1	2 x 270	1977	2,600,000	
	Muroran No. 2	2 x 110	1961/67	1,500,000	
	Kamaishi	2 x 90	1965	1,400,000	
	Hirohata No. 1	2 x 100	1960/65	1,500,000	
	Hirohata No. 2	3 x 100	1968/73	2,700,000	
	Nagoya No. 1	3 x 160	1964/67	3,800,000	
	Nagoya No. 2	2 x 250	1969	3,200,000	
	Sakai	3 x 170	1965/67	4,500,000	
	Kimitsu No. 1	3 x 220	1968/69	5,900,000	
	Kimitsu No. 2	2 x 300	1971	3,600,000	
	Oita	3 x 340	1972/76	8,200,000	
Tokai Special Steel Co., Ltd.	Nagoya	2 x 75	1968	800,000	
Nisshin Steel Co., Ltd.	Shunan	2 x 40	1970	360,000	
	Kure	3 x 90	1965	2,400,000	
		1 x 150 + +	1980	2,600,000	
Sumitomo Metal Industries Ltd.	Kokura No. 1	2 x 70	1961		Shut down 1982
	Kokura No. 2	3 x 70	1970/76	1,945,000	
	Wakayama No. 1	1 x 70	1968	810,000	
	Wakayama No. 2	3 x 160	1963	3,642,000	
	Wakayama No. 3	3 x 160	1967	4,600,000	
	Kashima No. 1	3 x 250	1971	6,400,000	
	Kashima No. 2	2 x 250	1974	3,750,000	
			TOTAL	**128,715,000**	

+ + Vessel exchange system

TABLE I.D-7 (Cont'd)

Company	L-D Basic Oxygen Steel Plant Location	No. Furnaces & Output per Heat Metric Tons Raw Steel	Start Up Date	Annual Capacity Metric Tons Raw Steel Existing	Annual Capacity Metric Tons Raw Steel To Be Added
KOREA					
Pohang Iron & Steel Company Ltd.	Pohang	3 x 100	1973/76	2,300,000	KG-1 fce.
		3 x 300	1978/81	6,800,000	
			TOTAL	**9,100,000**	
LUXEMBOURG					
ARBED S.A.	Dudelange	1 x 77 + + LBE	1962	1,050,000	
(All plants use LD-AC)	Esch-Schifflange	1 x 80 + + LBE	1976	960,000	
		1 x 80 + + LBE	1978	590,000	
	Esch-Belval	2 x 150 LBE	1976	2,450,000	
	Differdange	1 x 160 + + LBE	1973	2,450,000	
			TOTAL	**7,500,000**	
MALAYSIA					
Malayawata Steel Berhad	Prai/Penang	2 x 15	1967	180,000	
			TOTAL	**180,000**	
MEXICO					
Altos Hornos de Mexico S.A. (AHMSA)	Monclova, Coah.	3 x 80	1971/74	1,400,000	
		1 x 125	1976	800,000	
		1 x 125	1984		800,000
Fundidora Monterrey S.A.	Monterrey, N.L.	2 x 150	1977	1,500,000	
Siderurgica Lazaro Cardenas Las Truchas, S.A. (SICARTSA)	Lazaro Cardenas, Mich.	2 x 125	1976	1,035,000	
			TOTAL	**4,735,000**	**800,000**
MOROCCO					
Societe National de Siderurgie (SONASID)	Nador	2 x 105	1985	-	1,000,000
			TOTAL		**1,000,000**
NETHERLANDS					
Hoogovens Groep BV	IJmuiden	3 x 100	1958/61	2,500,000	
		3 x 300	1968/76	5,700,000	
			TOTAL	**8,200,000**	
NEW ZEALAND					
New Zealand Steel Development Ltd.	Glenbrook, S.Auckland	1 x 65 + + OBM	1984		630,000
			TOTAL		**630,000**
NIGERIA					
Abaokuta Steel	Abaokuta, Kwara	2 x 130	1984/85		1,300,000
			TOTAL		**1,300,000**
NORWAY					
A/S Norsk Jernverk	Mo i Rana	2 x 72	1976	700,000	CB
			TOTAL	**700,000**	
PAKISTAN					
Pakistan Steel Mills Corp. Ltd.	Bin Qasim, Karachi	2 x 130	1982	1,100,000	
			TOTAL	**1,100,000**	
PARAGUAY					
Acepar-Acero del Paraguay SA	Villa Hayes	2 x 15	1984		180,000
			TOTAL		**180,000**
PERU					
Empresa Siderurgica del Peru (SIDERPERU)	Chimbote	2 x 30	1967	310,000	LBE
			TOTAL	**310,000**	
POLAND					
Kombinat Huta Im. Lenina	Krakow	3 x 130	1966/70	3,000,000	
Kombinat Metalurgiczny Huta Katowice	Dabrowa Gornicza	3 x 350	1976/-	4,500,000	4,000,000
			TOTAL	**7,500,000**	**4,000,000**
PORTUGAL					
Siderurgia Nacional, E.P	Seixal	2 x 45 LBE	1961	400,000	
		2 x 120 LBE	1986		1,100,000
			TOTAL	**400,000**	**1,100,000**
ROMANIA					
Combinatul Siderurgic Galati	Galati	3 x 150	1968/69	3,500,000	
		3 x 150	1975	3,500,000	
		3 x 150	1980/81	3,000,000	
Combinatul Siderurgic Calarasi	Calarasi	3 x 150	1984/85		3,600,000
		3 x 250	after 1985		6,000,000
			TOTAL	**10,000,000**	**9,600,000**

+ + Vessel exchange system

TABLE I.D-7 (Cont'd)

Company	L-D Basic Oxygen Steel Plant Location	No. Furnaces & Output per Heat Metric Tons Raw Steel	Start Up Date	Annual Capacity Metric Tons Raw Steel Existing	Annual Capacity Metric Tons Raw Steel To Be Added
SOUTH AFRICA					
Highveld Steel & Vanadium Corp. Ltd.	Witbank	3 x 60	1968/78	900,000	
ISCOR Limited	Newcastle	3 x 150	1974/75	2,800,000	
	Vanderbijlpark	3 x 150	1974/75	3,300,000	
			TOTAL	7,000,000	
SPAIN					
Altos Hornos de Vizcaya, S.A.	Sestao	3 x 70	1967/69	1,400,000	
Altos Hornos del Mediterraneo, S.A.	Sagunto	3 x 45	1969/76	1,000,000	
Empresa Nacional Siderurgica, S.A. (ENSIDESA)	Aviles	3 x 70	1966	1,500,000	
		2 x 100	1969	1,200,000	
		2 x 250	1986/87		2,500,000
	Verina	3 x 115	1971	2,500,000	
			TOTAL	7,600,000	2,500,000
SWEDEN					
Svenskt Stal AB	Oxelosund	1 x 160/180 + + LBE	1977	1,000,000	
	Lulea	2 x 105	1972/75	1,600,000	LBE
			TOTAL	2,600,000	
TUNISIA					
Societe Tunisienne de Siderurgie (ELFOULADH)	Menzel Bourguiba	2 x 22	1965	200,000	
			TOTAL	200,000	
TURKEY					
Eregli Demir ve Celik Fabrikalari T.A.S. (Erdemir)	Eregli	3 x 90	1965/76	1,800,000	
Iskenderun Demir ve Celik Isletmeleri (Isdemir)	Iskenderun	2 x 130	1977/80	1,000,000	
		1 x 130	1984/85		1,200,000
			TOTAL	2,800,000	1,200,000
UNITED KINGDOM					
British Steel Corporation	Appleby Frodingham	3 x 300	1973	3,800,000	BAP
	Lackenby (S. Teesside)	3 x 261	1971/78	3,500,000	
	Llanwern	3 x 175	1962/74	2,800,000	
	Port Talbot	2 x 330	1969	2,900,000	
	Ravenscraig, Motherwell	3 x 130	1964/78	2,800,000	
			TOTAL	15,800,000	
USSR					
Met. Zavod Imeni Petrovskogo	Dnepropetrovsk (Ukraine)	3 x 50	1956	1,500,000	
Met. Zavod Krivorizhstal	Krivoy Rog (Ukraine)	4 x 50	1957/58	2,000,000	
		6 x 150	1965/71	6,500,000	
			planning		8,000,000
Yenakiyevskiy Met. Zavod	Yenakiyevo (Ukraine)	3 x 135	1968/69	3,500,000	
Zhdanovskiy Met. Zavod Ilyich	Zhdanov (Ukraine)	3 x 150	1964/65	3,000,000	
Dneprodzerzhinskiy	Dzerzhinsk (Ukraine)	large OBM	planning		
Azovstal Zavod	Zhdanov (Ukraine)	2 x 400	1977	5,000,000	
Cherepovetskiy Met. Zavod	Chereoovets (Cen. Russia)	2 x 400	1979	5,000,000	
Novolipetskiy Met. Zavod	Lipetsk (Cen. Russia)	3 x 160	1963/67	4,200,000	
		3 x 300	1974/80	6,000,000	
Magnitogorskiy Met. Kombinat	Magnitogorsk (Urals)	3 x 350	planning		10,000,000
Novo-Tagilskiy Met. Zavod	Nizhniy-Tagil (Urals)	3 x 160	1963/67	3,500,000	
Chelyabinskiy Met. Zavod	Chelyabinsk (Urals)	3 x 130	1969	3,000,000	
West Siberian Steel Works (Zapsib)	Novokuznetsk (W. Siberia)	3 x 130/250	1969/77	4,000,000	
		3 x 350	1973/77	4,000,000	
			planning		8,000,000
Eastern Siberian Works	Svobodniy (E. Siberia)	2 x 300	long term plan		
Karagandinskiy Met. Zavod	Temir-Tau (Kazakh) (nr. Karaganda)	3 x 310	1970/72	5,000,000	
			TOTAL	56,200,000	26,000,000

+ + Vessel exchange system

TABLE I.D-7 (Cont'd)

Company	L-D Basic Oxygen Steel Plant Location	No. Furnaces & Output per Heat Metric Tons Raw Steel	Start Up Date	Annual Capacity Metric Tons Raw Steel	
				Existing	To Be Added
VENEZUELA					
Siderurgica del Zulia	Maracaibo, Zulia	2 x 150	after 1990		1,375,000
			TOTAL		**1,375,000**
YUGOSLAVIA					
Metalurski Kombinat Smederevo	Smederevo	3 x 100	1975/80	1,650,000	
Rudarsko Metalurski Kombinat RMK	Zenica	2 x 110	1975/-	1,100,000	1,100,000
Rudnici i Zelezarnica Skopje RZS	Skopje	2 x 110 LDAC	1967	700,000	
Zeljezara Sisak	Sisak	2 x 100	after 1985		1,100,000
			TOTAL	**3,450,000**	**2,200,000**
ZIMBABWE					
Zimbabwe Iron & Steel Co. Ltd.	Redcliff	2 x 55	1969/74	1,000,000	
			TOTAL	**1,000,000**	
			WORLD TOTAL	**548,767,000**	**78,327,000**

Source: Iron and Steel Engineer, Aug. 1983.

TABLE I.D-8

DIRECT-REDUCED IRON OPERATIONS

(as of March 1983)

Start-up	Company	Location	Process - No. of Units	Major Fuel	Capacity (000's tpy)
1957	Hylsa	Monterrey, Mexico	HyL	Gas	95
1960	Hylsa	Monterrey, Mexico	HyL-III	Gas	275
1967	Tamsa	Vera Cruz, Mexico	HyL	Gas	250
1969	OSM	Portland, Oregon, USA	Midrex-2 units	Gas	300*
	Hylsa	Puebla, Mexico	HyL	Gas	315
1970	Thyssen	Obernausen, W. Germany	SL/RN	Coal	150*
	NZS	Glenbrook, New Zealand	SL/RN	Coal	165
1971	GSC	Georgetown, S. Carolina, USA	Midrex	Gas	400
	HSW	Hamburg, W. Germany	Midrex	Gas	400
1972	Armco	Houston, Texas, USA	Armco	Gas	330*
1973	NML	Niagara Falls, Canada	Accar	Gas/Coal	30*
	Sidbec	Contrecoeur, Canada	Midrex	Gas	400
	Dunswart	Benoni, South Africa	Codir	Coal	150
	Piratini	Charquedas, Brazil	SL/RN	Coal	65
	K-M	Buttrio, Italy	Kinglor Metor	Coal	10*
1974	Usiba	Bahia, Brazil	HyL	Gas	250
	Hylsa	Monterrey, Mexico	HyL-III	Gas	500
1975	Stelco	Red Lake, Canada	SL/RN	Coal	350*
1976	SMC	Falconbridge, Canada	Accar	Gas/Oil	240*
	Arvedi	Cremona, Italy	Kinglor Metor	Coal	40*
	Fior de Venezuela	Matanzas, Venezuela	FIOR	Gas	350
	Dalmine	Campana, Argentina	Midrex	Gas	330
	Sidor	Matanzas, Venezuela	HyL	Gas	360
1977	Sidor	Matanzas, Venezuela	Midrex	Gas	355
	Cosigua	Santa Cruz, Brazil	Purofer	Oil	350*
	NSC	Hirobata, Japan	NSC	Kerosene	150*
	Hylsa	Puebla, Mexico	HyL	Gas	625
	Sidbec	Contrecoeur, Canada	Midrex	Gas	600
	NISCO	Ahwaz, Iran	Purofer	Gas	330*
1978	DRC	Rockwood, Tennessee, USA	DRC	Coal	60*
	QASCO	Umm Said, Qatar	Midrex	Gas	400
	ACINDAR	Villa Constitucion, Argentina	Midrex	Gas	420
	Krakatau	Kota Baja, Indonesia	HyL	Gas	575
1979	Sidor	Matanzas, Venezuela	Midrex-3 units	Gas	1275
	Government	Khor Al-Zubair, Iraw	HyL-2 units	Gas	485*
	British Steel Corp.	Hunterston, UK	Midrex-2 units	Gas	800*
1980	Krakatau	Kota Baja, Indonesia	HyL	Gas	575
	Sidor	Matanzas, Venezuela	HyL-3 units	Gas	2112
	ISCOTT	Point Lisas, Trinidad	Midrex	Gas	420
	Siderperu	Chimbote, Peru	SL/RN-3 units	Coal	100
	SIIL	Paloncha, India	SL/RN	Coal	30
1981	SKF	Hofors, Sweden	Plasmared	Gas/Oil/Coal	70
	Nordferro	Emden, W. Germany	Midrex-2 units	Gas	880*
	Government	Mandalay, Burma	Kinglor Metor	Coal	20
1982	ISCOTT	Point Lisas, Trinidad	Midrex	Gas	420
	Delta Steel	Warri, Nigeria	Midrex-2 units	Gas	1100
	NADEED	Al Jubail, Saudi Arabia	Midrex-2 units	Gas	800
	OSIL	Keonjhar, India	Accar	Coal/Oil	150
	Krakatau	Kota Baja, Indonesia	HyL-2 units	Gas	1150
1983	Scaw Metals	Germiston, South Africa	DRC	Coal	75
	SIIL	Paloncha, India	SL/RN	Coal	30
1984	Sicartsa	Las Truchas, Mexico	HyL III-4 units	Gas	2000
	OEMK	Kursk, USSR	Midrex-4 units	Gas	1667
	I&S Project	Misurata, Libya	Midrex-2 units	Gas	1100
	Government	Khor Al-Zubair, Iraq	HyL-2 units	Gas	1000
	Sabah Gas Industries	Labuan Island, Malaysia	Midrex	Gas	650
	NISCO	Ahwaz, Iran	Midrex-3 units	Gas	1200
	NISCO	Ahwaz, Iran	HyL-3 units	Gas	1000
	ISCOR	Vanderbijlpark, South Africa	SL/RN-4 units	Coal	400
1985	Government	Trengganu, Malaysia	NSC	Gas	600
	Union Steel	Vereeniging, South Africa	Plasma	Coal	250
1986	Ipitata Sponge Iron Ltd.	Joda, India	Tisco	Coal	90

* Shut down.

Source: Iron and Steelmaking, July 1983

TABLE I.D-9

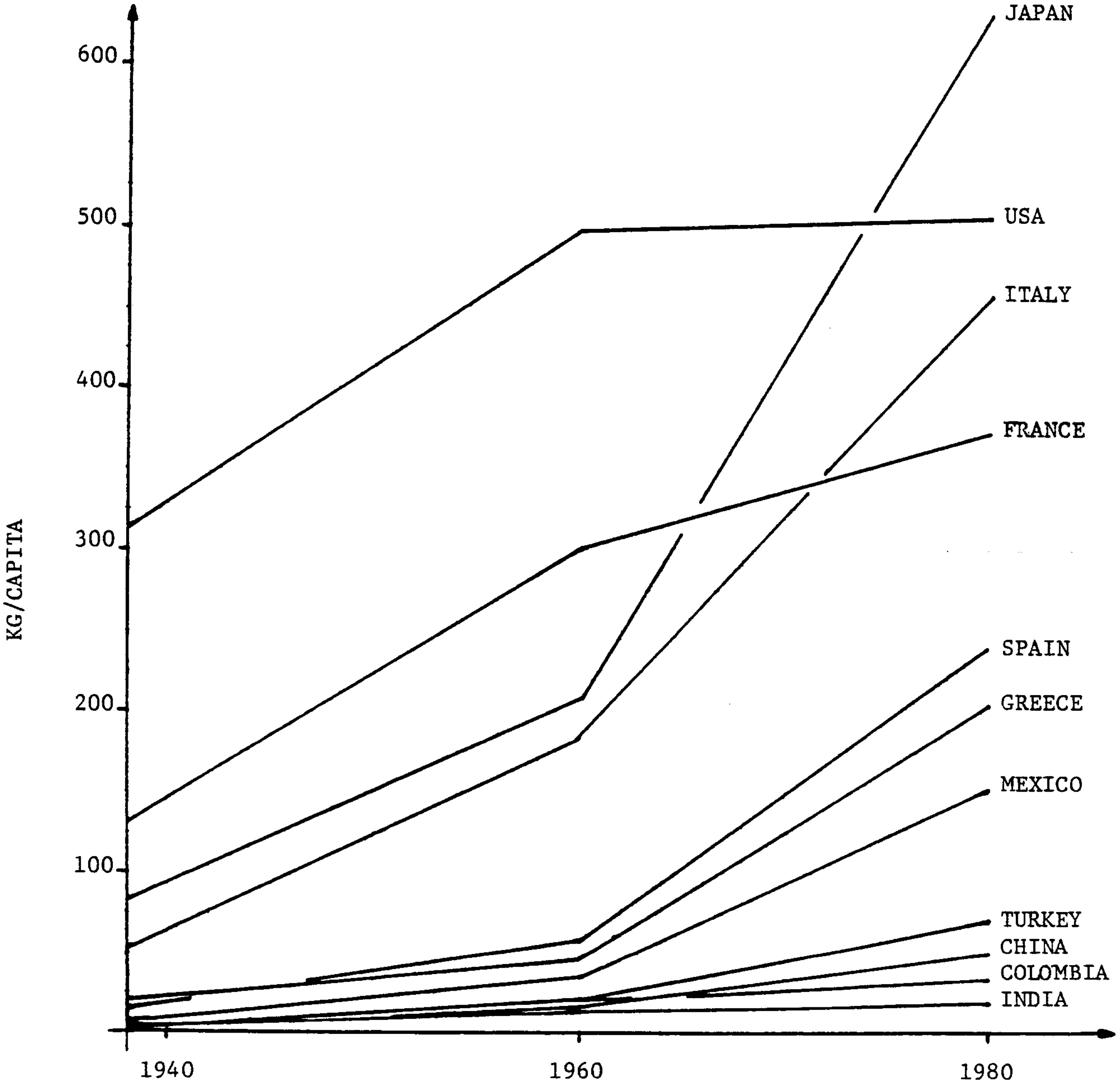
CRUDE STEEL OUTPUT OF THE WORLD's 50 LARGEST PRODUCERS IN 1983

RANK	COMPANY/COUNTRY	OUTPUT, MT*	MAXIMUM CAPACITY, MT*	EXPORTS AS % OF SHIPMENTS	NUMBER OF EMPLOYEES (STEELMAKING)	TONS PER EMPLOYEE
1	Nippon Steel/Japan	26.85	54.51	36.0	64,100	418.9
2	U.S. Steel/USA	13.44	28.41	1.0	49,095	273.7
3	British Steel/UK	12.70	21.00	26.8	81,100	156.6
4	Finsider/Italy	12.16	21.40	33.0	94,100	129.3
5	Nippon Kokan KK/Japan	11.11	21.03	33.0	25,337	450.4
6	Kawasaki Steel/Japan	10.36	20.78	37.3	28,524	363.1
7	Sumitomo Metal Industries/Japan	10.34	21.68	38.1	28,784	359.2
8	Bethlehem Steel/USA	9.70	19.64	2.0	35,052	276.7
9	Siderbras/Brazil	9.10				
10	Thyssen Stahl (F2)/ West Germany	8.81	20.83		49,638	177.5
11	USINOR/France	8.50	11.40	N/A	39,963	212.7
12	Pohang Iron & Steel/ South Korea	8.44	9.10	30.0	12,241	689.3
13	Jones & Laughlin/LTV/ USA	6.99	11.80		29,000	240.9
14	Sacilor/France	6.98		48.7	67,500	103.3
15	SAIL/India	6.10				
16	Kobe Steel/Japan	6.02	8.66	23.7	13,069	463.6
17	Inland Steel/USA	5.72	9.30		20,500	279.1
18	Republic Steel/USA	5.70				
19	Broken Hill Pty./ Australia	5.60	7.62	28.2	30,836	181.6
20	Armco, USA	5.43	7.90	1.3	21,596	251.5
21	Iscor/South Africa	5.41	5.80	35.0	43,615	124.0
22	National Steel/USA	4.81				
23	Cockerill Sambre/ Belgium	4.72		62.0	19,899	237.4
24	Klockner-Werke/ W. Germany	4.40				
25	Stelco/Canada	4.33	7.25	23.0	19,519	222.0
26	Hoogovens Grocp./ Netherlands	4.28	7.20	67.4	17,850	
27	Hoesch Werke/W. Germany	3.93		34.0	35,300	111.3
28	Krupp Stahl/W. Germany	3.90		27.0	29,075	134.3
29	Voest-Alpine/Austria	3.80		61.0	18,500	205.4
30	ENSIDESA/Spain	3.80	6.00	38.0	22,356	170.0
31	Sidermex/Mexico	3.77	5.70	22.0	39,098	96.6
32	China Steel/Taiwan	3.41	3.25	33.0	7,554	451.6
33	Dofasco/Canada	3.36	4.20		12,600	266.7
34	Arbed/Luxembourg	3.20	4.60	96.0	13,500	237.0
35	Salzgitter/ W. Germany	3.12	7.10	39.1	14,132	220.9
36	Mannesmann/W. Germany	3.10				
37	COSIPA/Brazil	3.02	3.16	45.0	14,096	214.1
38	CSN/Brazil	2.86	N/A	49.0	21,863	131.0
39	N.V. Sidmar/Belgium	2.81	3.50	92.0	6,306	446.1
40	USIMINAS/Brazil	2.69	3.50	22.0	12,994	207.0
41	Svenskt Stal/Sweden	2.60	3.10	38.0	9,900	262.6
42	Nisshin Steel/Japan	2.59	5.48	25.3	8,965	288.3
43	Arbed Saarstahl/W. Germany	2.40	3.70	41.0	16,236	147.6
44	SIDOR/Venezuela	2.16	4.80	42.0	15,446	139.8
45	Algoma/Canada	2.09				
46	Wheeling-Pittsburgh Steel/USA	2.02	4.00	0.0	7,512	268.9
47	Tata Iron & Steel/ India	1.93	2.12		64,757	29.9
48	Rautaruukki Oy/Finland	1.63		46.0	5,560	293.5
49	Altos Hornos de Vizcaya/Spain	1.38	1.35	30.0	9,880	139.4
50	Nucor/USA	1.16	1.70			

Source: Iron Age, April 16, 1984

TABLE I.D-10

APPARENT PER CAPITA CRUDE STEEL CONSUMPTION IN SELECTED COUNTRIES, 1938, 1960, AND 1980



Source of data: Economic Commission for Europe, "The Steel Market in 1982".

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II.

ALUMINUM

II.A Data Sheet

II.A.1 General

Aluminum is produced from bauxite, the natural ore, in two distinct stages. The first stage from bauxite yields alumina (aluminum hydrated oxide), in the so-called alumina plants using the Bayer process. Alumina is the raw material which is smelted(Hall-Heroult process)in the second stage to produce aluminum ingots, in the aluminum plants. The ingots are then transformed into mill and finished products by rolling, extrusion, and casting.

Bauxite may be shipped after limited benefication processing to remove unwanted clays, silicas and other loose wastes, or as alumina. The Bayer process yields large volumes of waste - red muds - which are unusable for agricultural purposes and have to be disposed of. Variations on the basic Bayer process are virtually universal although the Pederson process, which was developed to process high iron content ores and is energy intensive in operation, has been used in Norway, Sweden and the USSR.

The Hall-Heroult electrolytic smelting process is energy-intensive (13-17,000 kwh per tonne of aluminum produced are required), and this is the reason for the recent trend of building aluminum smelters in developing countries with abundant energy resources, away from the major markets of North America, Europe and Japan. Alumina plants tend to be located in the vicinity of bauxite mines to reduce transportation costs which may be up to 50% of in-plant bauxite cost.

The production of secondary aluminum from scrap needs only 5-6% of the energy required for the production of primary aluminum, and the location of such plants is determined by the availability of scrap and proximity to markets.

The principal environmental concerns include the disposal of red muds, dust, and the fluorides contained in the gaseous and liquid emissions of alumina plants and smelters. Modern environmental protection methods can be up to 99% effective.

Bauxite and alumina are shipped in bulk carriers, typically of up to 40,000 dwt but also up to panamax, particularly for bauxite and for alumina derived from high output sources such as those in Australia. The shipment characteristics of aluminum raw materials are:

Bauxite

bulk density	1.03 to 1.38 t/cu. m.
ship size	typically to 40,000 - 80,000 dwt
loading rate	up to 4,000 t/h
disch. rate	up to 1,500 t/h

Alumina

bulk density	0.88 t/cu.m.
ship size	typically up to 40,000 dwt but also panamax
loading rate	500 - 1,000 t/h
disch. rate	400 - 1,000 t/h

II.A.2 Plant Requirements

To produce 1 ton of aluminum from 1.95 t of alumina between 3.6 and 5.9 t of bauxite are required. The following are typically required for such production depending on source rock.

Alumina Production (1.95 t)

Bauxite	3.6 - 5.9 t
Lime (CaO)	0.06 - 0.08 t
Caustic (NaOH)	0.18 - 0.27 t
Steam	6.6 - 7.8 t
Starch	0.004 - 0.019 t
Fuel Oil (for calcination)	0.25 - 0.31 t
Energy	32 - 50 M BTU's
Labour	0.005 - 0.002 (200-650 t/man/yr)
Plant size	0.75 - 1.20 sq m
of which bauxite storage	18 - 30%
of which red mud disposal	8 - 13%

Aluminum Production (including casting)

Alumina from above	1.95 t
Cryolite	10 - 70 lbs
Aluminum Fluoride	25 - 60 lbs
Calcium Fluorite	4 - 8 lbs
Energy	
Alumina reduction	45 - 60 M BTU
Petroleum coke (700-950 lbs)	9 - 12 M BTU
Pitch (280-300 lbs)	3 - 4 M BTU
Anthracite coal (40-80 lbs)	0.5 - 1 M BTU
Anode and cathode baking	0.1 - 5.5 M BTU
Holding Furnace, melting and casting	5.2 - 7.8 M BTU
Labour	0.013 - 0.004 men (80-250 t/man/yr)
Area required	6 sq m

Minimum economical size for an aluminum smelter is about 150,000 tpy, while for alumina plants is in the range of 2-3 million tpy.

II. B Aluminum Industry Description

The following sections will briefly review the basic processes and technology utilized by modern aluminum plants. The material flows and the power, area, labor, and shipping requirements will be presented. The environmental impact of aluminum manufacture will be also shortly discussed.

II.B.1 Aluminum Manufacturing Processes

Aluminum metal is not extracted directly from its ore (bauxite). Instead, a separate manufacturing step is required in which the bauxite's aluminum compounds are separated from other mineral constituents and converted into aluminum oxide (alumina). The metal is subsequently extracted (smelted) from alumina by electrochemical processing (electrolysis), cast into ingots, and finally fabricated into mill products. A schematic outline of the entire process is given in Figure II.B-1.

II. B.1.1 Bauxite

The term "bauxite", named after Lex Baux a medieval town in Southern France where it was first found, refers to ores containing significant quantities of aluminum hydrate or hydroxide minerals. Bauxite is formed by tropical weathering (leaching) of various parent minerals, and is the most plentiful ore on this planet, with reserves far in excess of demand. Known bauxite reserves cover present annual requirements over 250 times, and today, no major aluminum company is carrying out large programs to find new deposits. Before the recent recession, affecting both production (88 million short tons in 1982) and prices, over twenty countries produced 100 million short tons per year of which over half was produced by Australia, Guinea,

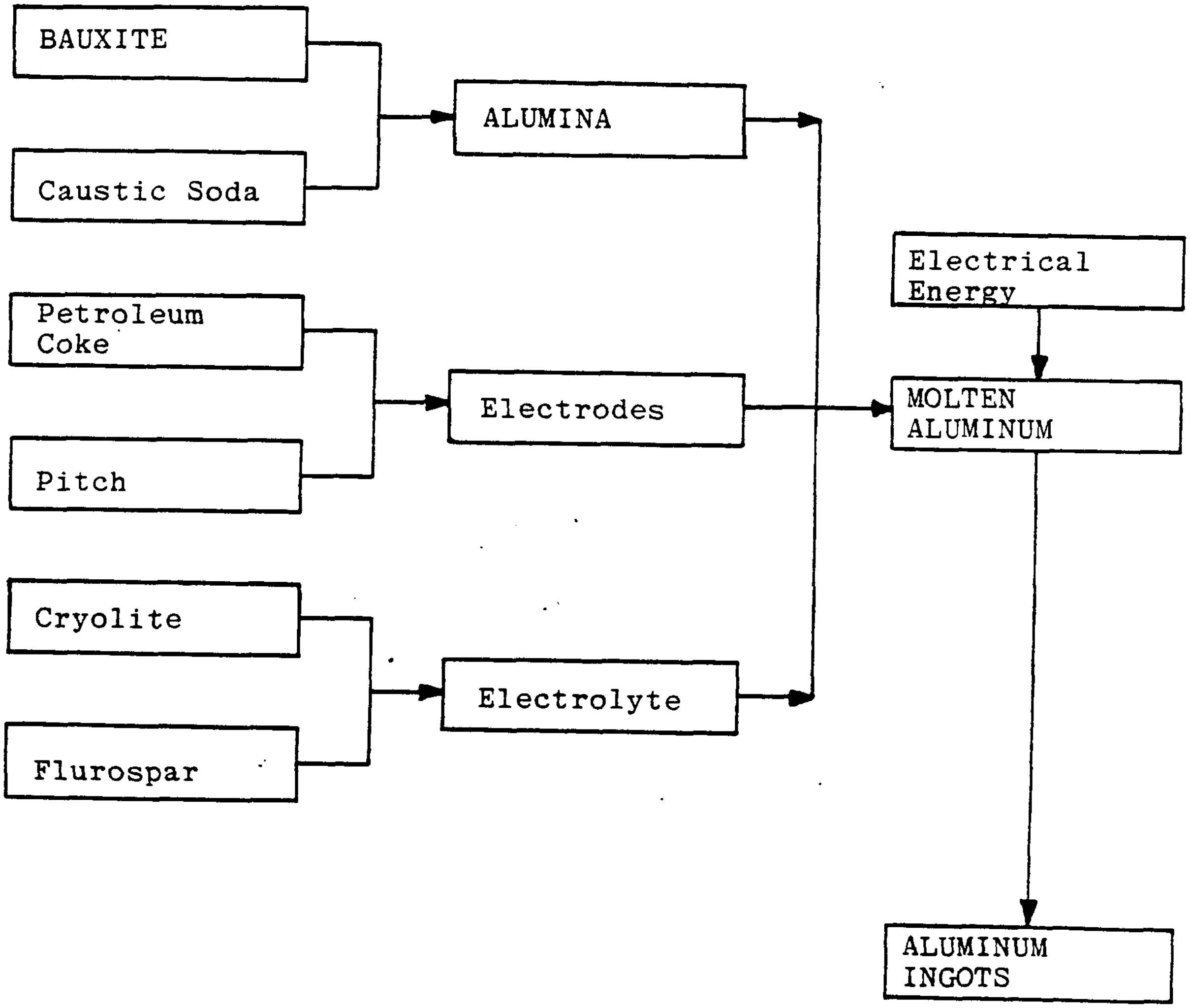


FIGURE II.B-1

SCHEMATIC OVERVIEW OF ALUMINUM MANUFACTURING PROCESS

Source: Staff.

Jamaica and Brazil (refer to Table II.D-1).

Bauxites are characterized by the types of impurities present and by the predominant form of aluminum hydrate mineral. The types of bauxite used for alumina are: (a) trihydrate, consisting chiefly of gibbsite, $Al_2O_3 \cdot 3H_2O$; (b) monohydrate, consisting chiefly of boehmite, $Al_2O_3 \cdot H_2O$; and (c) mixed bauxite, consisting of both gibbsite and boehmite. These bauxite types require critically different digestion conditions during alumina production. Therefore, most of alumina plants have been designed to consume a specific type of bauxite and costly adjustments are required when the type of bauxite is changed.

Wide variations occur in the location, size, shape and depth of the deposits. Most of them allow open-pit mining, while others required underground mining. Most of the bauxites do not require costly beneficiation techniques to improve ore qualities. Many bauxites, however, are upgraded by crushing, screening and washing to remove clay, silica and other loose waste material. After these beneficiation steps, the bauxite is dried in kilns and transferred to a nearby alumina plant or loaded in trucks, covered hopper cars, barges, or bulk cargo carriers for shipment to more distant refining plants. Most commercial alumina refineries use bauxite with an alumina content of 40% minimum.

The level of silica impurity will determine the quantity of bauxite to produce a ton of alumina. This can range between 2:1 to 3:1 and typically would be 2.37:1.

Currently, there are no substitutes for bauxite in alumina refining on a commercial base, except for the Kola Nepheline used in the USSR, which accounts for less than 2% of world alumina output. Aluminum companies, however, have been engaged heavily in developments of substitutes for bauxite such as laterites, clays, anorthosites, nepheline, syenite, dawsonite, and alunite. Actual substitution depends not only on purely technological developments but also on international economic conditions.

The principal commercial deposits of bauxite are located at considerable distance from the main industrial centers of North America, Europe and Japan. As long as processing of non-bauxite raw materials remains economically infeasible, dependence of industrialized countries on imported bauxite and/or alumina will continue to be high.

About 85% of bauxite mined is used for the production of aluminum and 15% for other purposes. Sixty percent of the bauxite used in other than aluminum industries is consumed in various chemical applications and 40% in cement, refractories and abrasives production.

II. B.1.2 Alumina Refining

Practically all the world's alumina production is still made by the Bayer process and its variations. The only other process used on a commercial scale is the Pedersen process, used in Norway, Sweden and the USSR. This latter process, which was developed for use with bauxites containing a high proportion of iron, smelts the ore with limestone and coke in an electric furnace and the iron compounds are drawn off as pig iron. The slag is pulverized and treated with soda solution to produce sodium aluminate. It is a versatile process but uses energy intensively. This is economical in Norway where there is ample hydro-power available. Because of the iron output, the process may have application elsewhere. Other methods have been applied only in pilot-scale plants. The Bayer process involves the following sequence of primary operations:

(1) dissolution (digestion) of the ground bauxite aluminum hydroxides in a high-temperature caustic soda solution, under high pressure, to form sodium aluminate.

(2) separation of the soluble aluminum hydroxide and caustic soda from the insoluble bauxite impurities (red muds).

(3) precipitation of aluminum trihydroxide at lower temperatures.

(4) evaporative regeneration of the caustic solution for recycle to step (1).

(5) conversion of the filtered hydroxide to anhydrous alumina (aluminum oxide) by fluidized bed calcination at 1100-1200^{o}C.

Figure II.B-2 presents the idealized flow sheet for alumina production with the Bayer process, while Figure II.B-3 shows the material balance for producing one tonne of alumina. Figure II.B-4 illustrates the main equipment items and the facilities required for alumina manufacture.

All modern alumina plants are capital and energy intensive and rely on sophisticated automatic process control systems to maximize their productivity and to decrease energy usage. Conservation efforts have resulted in a drop of unit energy consumption by more than 30% over the past decade. (The current range is 750 KWh per metric ton of alumina.) A major reduction was achieved by introduction of stationary fluidized bed calciners in place of the traditional rotary kiln.

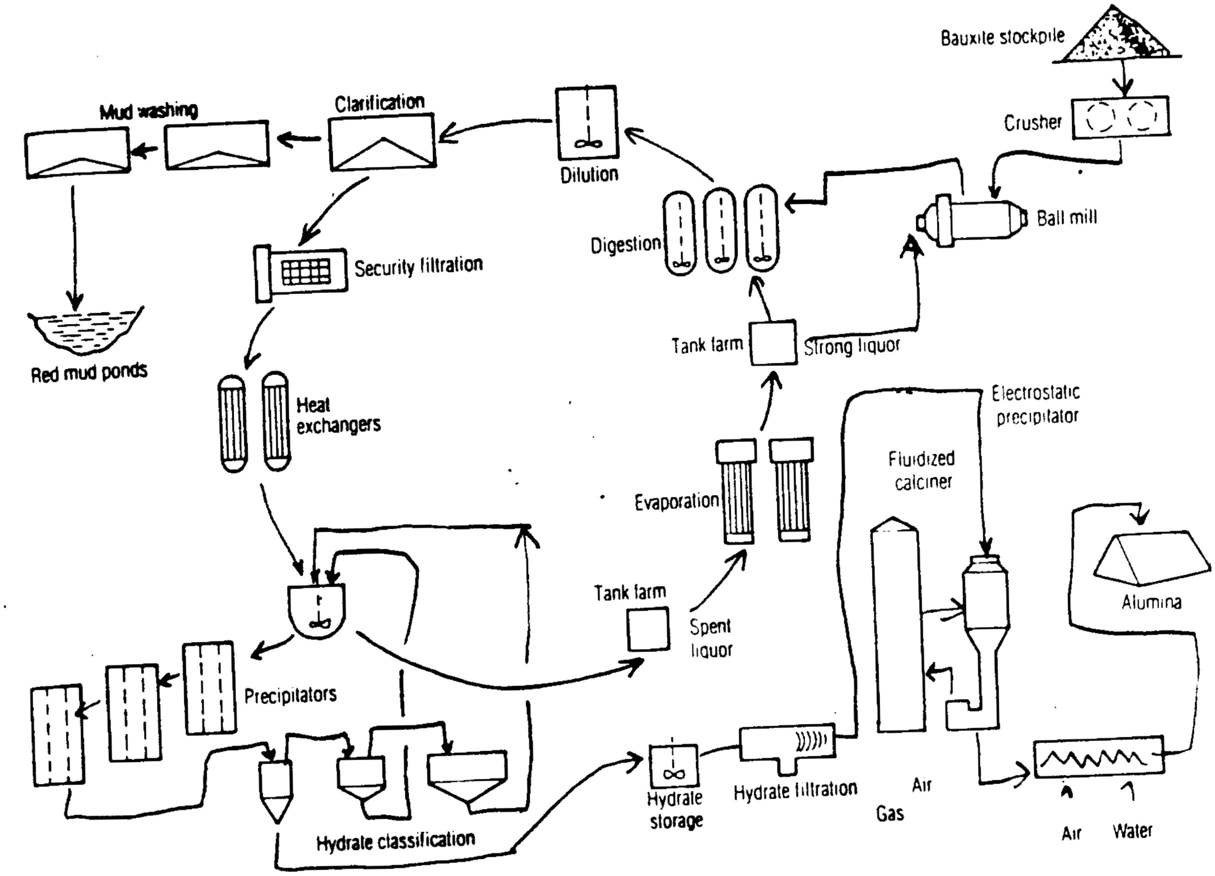


FIGURE II.B-2

IDEALIZED BAYER PROCESS FLOW SHEET

Source: Engineering and Mining Journal, May 1983.

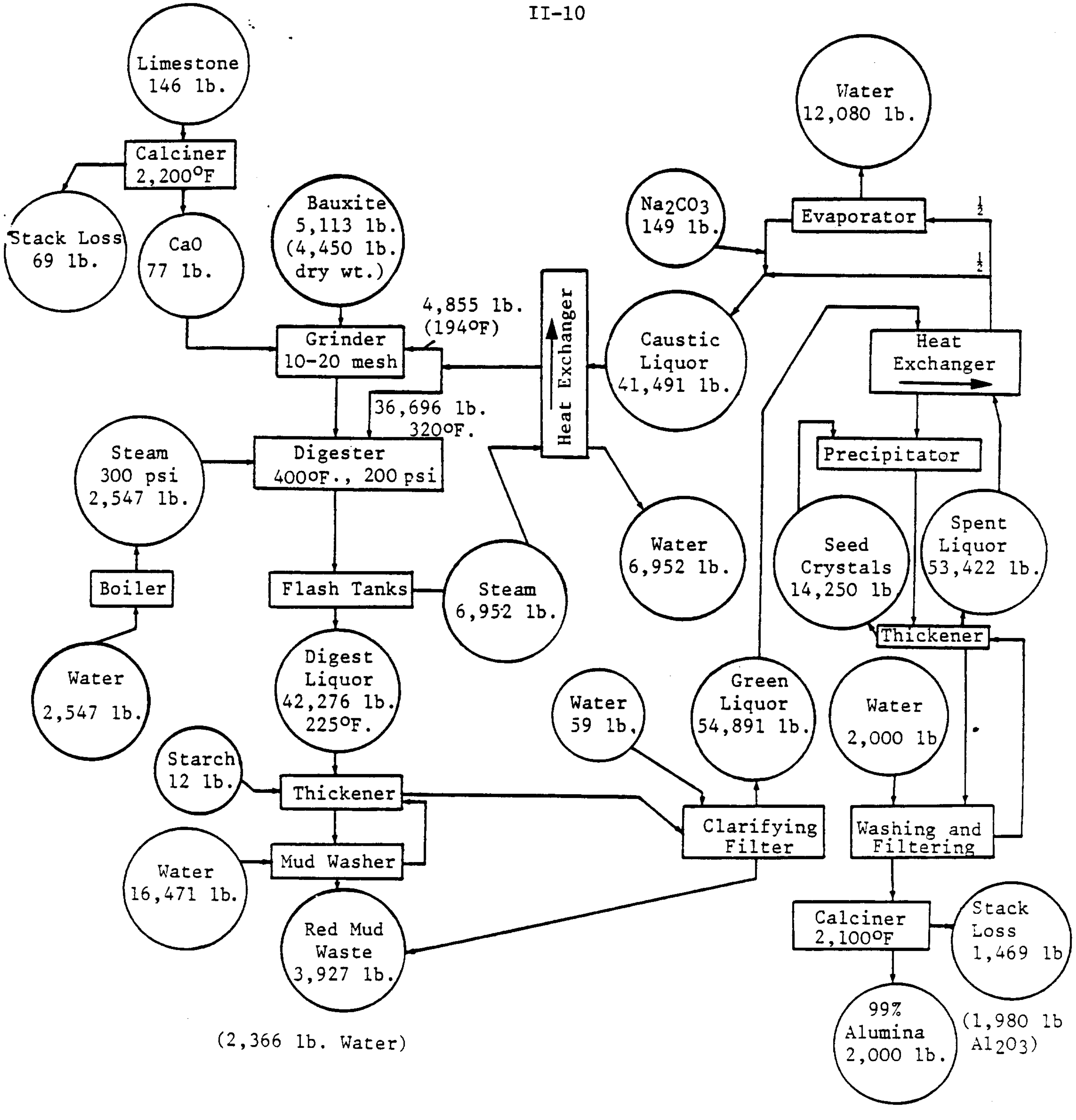


FIGURE II.B-3

BAYER PROCESS FOR PRODUCING ONE TONNE OF ALUMINA

Source: Battelle Columbus Laboratories, Evaluation of Theoretical Potential for Energy Conservation in Seven Basic Industries (Columbus, Ohio: July 1975; PB 244 772), p. 150.

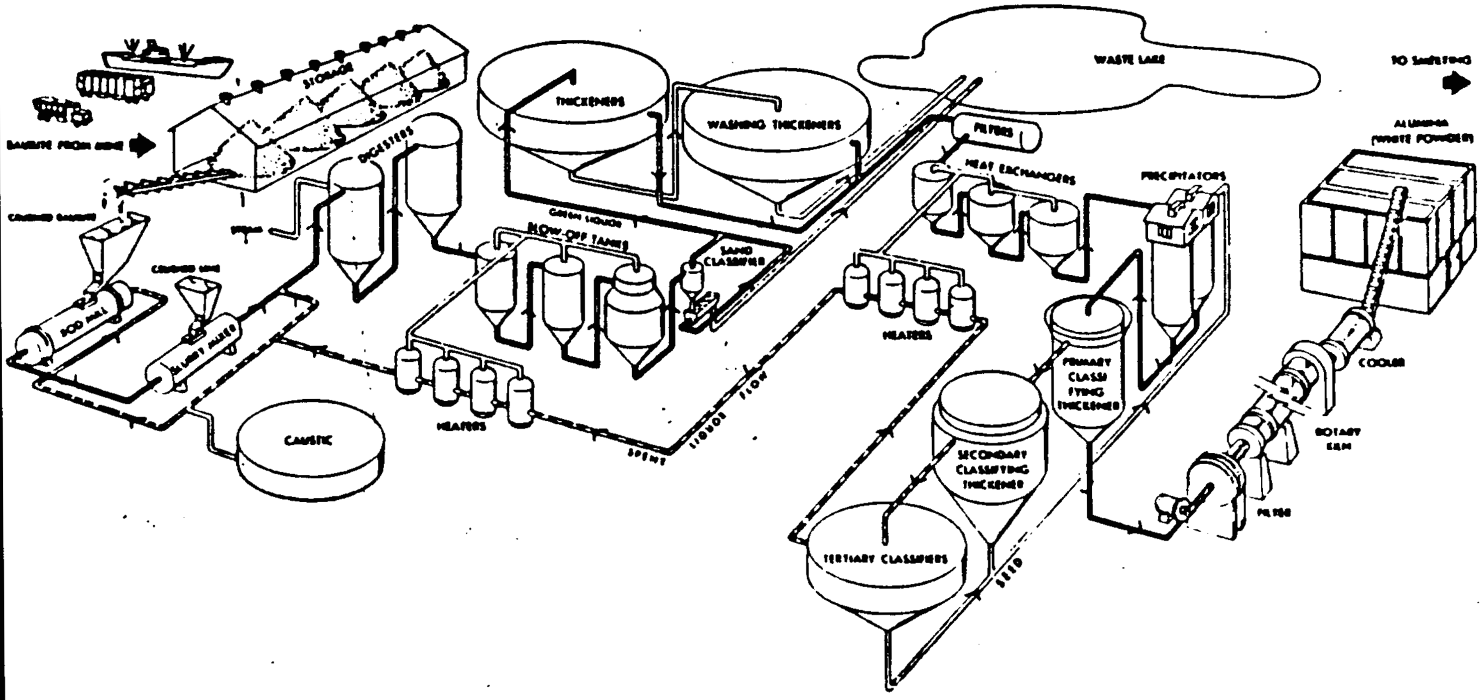


FIGURE II.B-4

ALUMINA REFINING

Source: U.S. Bureau of Mines, Mineral Facts and Problems, 1975.

Alumina plants generate large quantities of a slurry waste that is referred to as "red mud" and contains all impurities separated from the bauxite as well as by-products formed during the refining process. The slurry is deposited in ponds which are eventually filled, dried out, and covered with top soil for revegetation. Up to one square kilometer of lagoon area is required for a plant processing 3.3 million tons of bauxite per year, but the same lagoon can be used for many years. A plant in Lousiana developed a method of filtering the red mud over sand and storing the solids for use as landfill. (Residual alkalies make it unsuitable for agricultural purposes.)

Table II.B-1 indicates unit raw material, labor, and energy requirements for alumina manufacture.

II.B.1.3 Aluminum Production

Aluminum winning involves the extraction (smelting) of metal from alumina, which is a chemical compound (oxide) formed by aluminum and oxygen. Considerable energy is needed to separate the two elements from each other. The only known technically feasible method is based on electrolysis, the Hall-Heroult process developed in 1886. In this method, an electric current supplies separation energy to molten alumina dissolved in a high-temperature bath of molten cryolite. The latter is a fluoride salt of sodium and aluminum - Na_3AlF_6 - that lowers the temperature needed to melt alumina. Figure II.B-5 presents the material balance for producing one tonne of aluminum from alumina with the Hall-Heroult process, while the whole process of producing one tonne of primary aluminum from bauxite is summarized in Figure II.B-6.

TABLE II.B-1

RANGES OF BAUXITE, ENERGY, LABOR, AND RAW MATERIALS TO MAKE ALUMINA REQUIRED* TO PRODUCE 1 SHORT TON OF PRIMARY ALUMINUM METAL

	Type of Bauxite	
	Caribbean	South American
Bauxite, short dry tons	4.7-5.0	4.0-4.5
Energy, million BTU		
Mining and Drying (oil, gas, electricity)	1-2	2-3
Shipping to alumina refinery (oil)	2-3	4-5
Total labor and supervision, manhours	4-9	3-9
Alumina Production		
Caustic or equivalent soda ash and lime, lbs NaOH	200-700	220-280
Lime	60-200	100-200
Starch	30-40	4-6
Energy, million BTU		
Steam (coal, oil, gas)	25-30	20-25
Calcining alumina (oil, gas, electricity)	7-10	7-10
Miscellaneous (coal, gas, electricity)	2.4	2.5
Total labor and supervision, manhours	3-5	3-5

* 1.9-1.95 tons Alumina per ton of aluminum.

Source: "Aluminum", Bureau of Mines, U.S. Department of Interior, 1978.

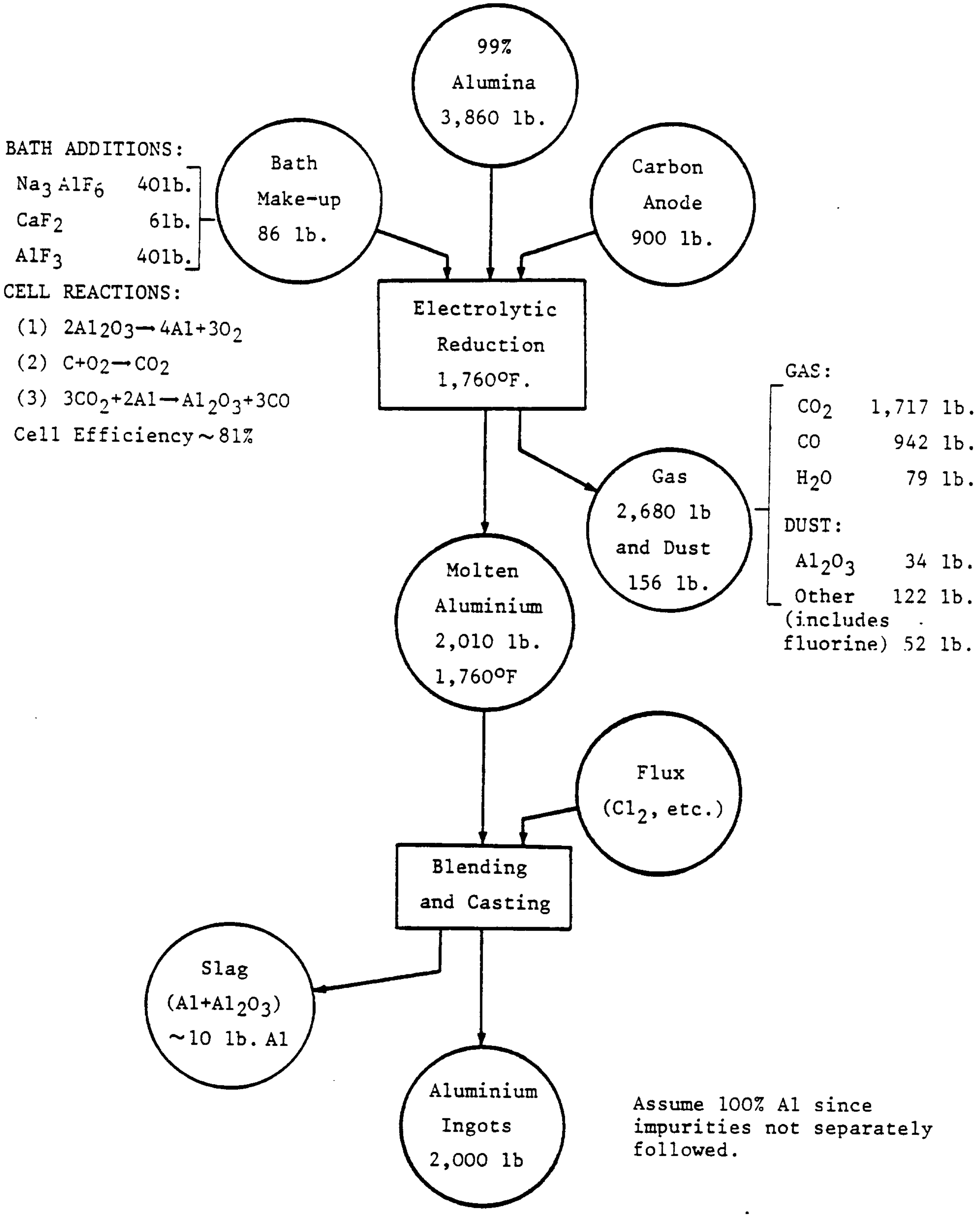


FIGURE II.B-5

HALL-HEROULT PROCESS FOR PRODUCING ONE TONNE OF ALUMINUM FROM ALUMINA

Source: Battelle Columbus Laboratories, Evaluation of the Theoretical Potential for Energy Conservation in Seven Basic Industries (Columbus, Ohio: July 1975; PB 244 772), p. 154.

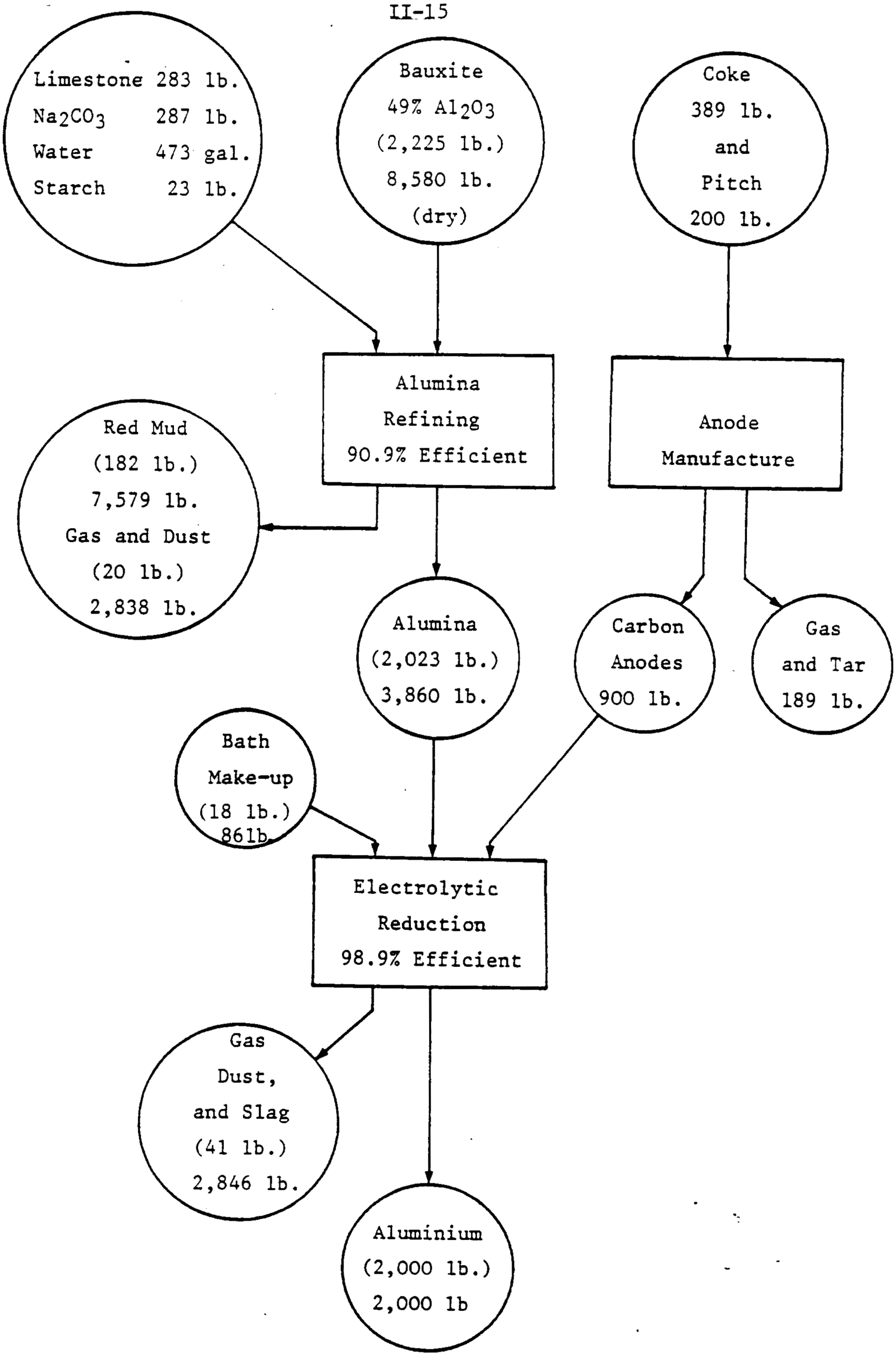


FIGURE II.B-6

MATERIAL BALANCE FOR PRODUCTION OF ONE TONNE OF PRIMARY ALUMINUM (Aluminum content in brackets)

Source: Battelle Columbus Laboratories.

An alumina smelting cell is typically a refractory-lined rectangular steel shell, 9-12 meters long, 3-4 meters wide, and 1-1.2 meters high. It has an inner lining of baked carbon, which serves as a cathode and contains the molten aluminum as it is produced by the electrolysis reaction. Current enters the cell through specially prepared carbon anodes, which are consumed in carbon dioxide production as the carbon combines with oxygen from the alumina. The consumed anodes are replaced by the Soderberg continuous method or the prebaked method. By the Soderberg method, the carbon is fed in a continuous column, and therefore the method obviates the necessity of halting production to replace the anodes. However, the prebaked anodes have returned to favor since the 1960's because they give better power performance (refer to Table II.B-2), and they can be hooded more easily to offer improved fume protection, an important factor as environmental considerations assumed wider proportions in the last decade. Molten metal is tapped from the cell and cast in primary ingots.

The industry average for electrical energy consumption is 15 KWH per kilogram of metal, but intensive efforts to improve cell efficiency have reduced consumption of 13.5 KWH per kilogram in new smelters. Each cell operates at 4.5-5 volts (dc), and, to reduce capital costs for rectifying equipment, up to 240 cells are connected in series to form a "potline" operating at 175 KVA and 1000 V DC. Potlines are housed in the long (up to 800 meters), narrow buildings that are characteristic of aluminum smelters. An aluminum potline must be protected against sudden extended power outages because in such cases the cell contents will quickly solidify and then several months may be required to restore full production.

TABLE II.B-2

ESTIMATED RANGES OF ALUMINA, ENERGY*, LABOR, AND RAW MATERIALS TO MAKE ONE SHORT TON OF PRIMARY ALUMINUM METAL

	TYPE OF ANODE	
	Pre-baked	Soderberg
Alumina - short tons	1.9-1.95	1.9-1.95
Makeup cryolite (Na_3AlF_6) - pounds	10-70	10-70
Makeup aluminum fluoride (AlF_3) - pounds	25-60	25-60
Calcium fluoride (CaF_2) - pounds	4-8	4-8
Energy, million BTU		
Alumina reduction (electricity)	45-56	55-60
Electrode Carbon		
Petroleum coke, calcined (700 to 950 pounds)	9-12	9-10
Pitch (280 to 300 pounds)	3-4	3-4
Anthracite coal (40 to 80 pounds)	0.5-0.7	0.7-1
Anode and cathode baking (oil, gas, electricity)	2.3-5.5	0.1-0.2
Holding furnace, ingot casting, and melting operations (gas, oil, electricity)	5.2-7.8	5.2-7.8
Total labor and supervision - manhours	8-15	10-20

* Assumed energy equivalents: oil, 150,000 BTU/gal; natural gas, 1000 BTU/cubic ft.; coal and pitch, 24 million BTU/short ton; petroleum coke, 26 million BTU/short ton; electricity, 3,413 BTU/kwh.

Source: "Aluminum", Bureau of Mines, U.S. Dept. of the Interior.

About 80% of total aluminum consumption is filled with primary aluminum which is made with the above-mentioned process. The balance is produced by recycling material coming mainly from new scrap, aluminum cans, discarded automobile bodies, and other residues containing economically recoverable quantities of aluminum.

The smelting process for secondary aluminum generally consists of six steps: charging scrap into the furnace, addition of fluxing agents, addition of alloying agents, mixing, demagging (magnesium removal) or degassing, and skimming. Some plants also process residues to recover a high aluminum fraction for smelting and a low aluminum fraction for use by steel manufacturers as ingot topping. High-iron scrap undergoes presmelting treatment for iron removal. Prospective increases in aluminum prices are likely to prompt more scrap uses.

II.B.1.4 Mill and Finished Aluminum Products

Primary and secondary ingots and some molten aluminum are transformed into so-called mill products by independent or smelters' affiliated fabricators through processes such as hot and cold rolling, extrusion, and casting. Mill products are largely classified into three categories: (a) sheets, plates and foil; (b) extruded shapes and tubes; and (c) other products such as rods, bars, wires, forgings, and fabricator castings.

Mill products are either transformed into finished products such as residential siding, aluminum cans, cooking utensils, fasteners and closures, or they are consumed as parts of other goods in various industries. For the major OECD consuming countries the share of each main end-use sector in total domestic use of aluminum in 1980 was within the following range:

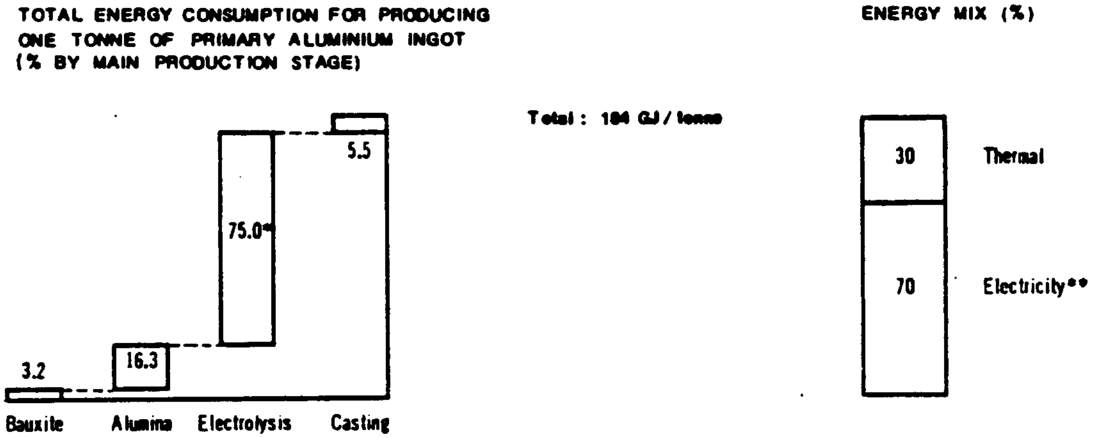
Transport	19-31%
Packaging	6-28%
Construction	12-33%
Mechanical and Electrical Engineering	13-31%

II.B.2 Power Requirements

Primary aluminum is the second most energy-intensive major metal after magnesium in terms of unit energy values (energy required to produce a tonne of metal). It has been estimated that in total 184 GJ are required to produce one tonne of primary aluminum. In contrast, secondary smelting requires only 5 to 6% of the energy needed for the production of primary aluminum, while downstream activities, such as rolling and extrusion, add very little to the energy requirement of the sector (refer to Table II.B-4).

Electricity accounts for 70% of total energy requirements, while process steam and process heat account respectively for 10.5% and 19.5% of this requirement. As illustrated by Figure II.B-7, 3.2% of total energy requirements is consumed at the bauxite stage, 16.3% at the alumina refining stage, 75% for the electrolysis, and 5.5% for casting. The major energy flows in the production of primary aluminum ingots from bauxite are shown in Figure II.B-8.

Over 95% of the electricity consumed is used for the electrolysis of alumina. The current operating range is 13,000 kWh/tonne for the most efficient new smelters to 17,000 kWh/tonne for older plants. Table II.B-3 shows the power requirements for a number of new and planned smelters. The major factors which affect the energy efficiency of a plant are the following:



* Including the manufacture and consumption of electrodes.
** For hydropower : 1 kWh = 3.6×10^{-3} GJ.
For thermal power, conversion efficiency : 33 %.

FIGURE II.B-7

ENERGY CONSUMPTION IF THE PRIMARY ALUMINUM INDUSTRY (Western World - 1981)

Source: OECD Secretariat, "Aluminum Industry. Energy Aspects of Structural Change", 1983.

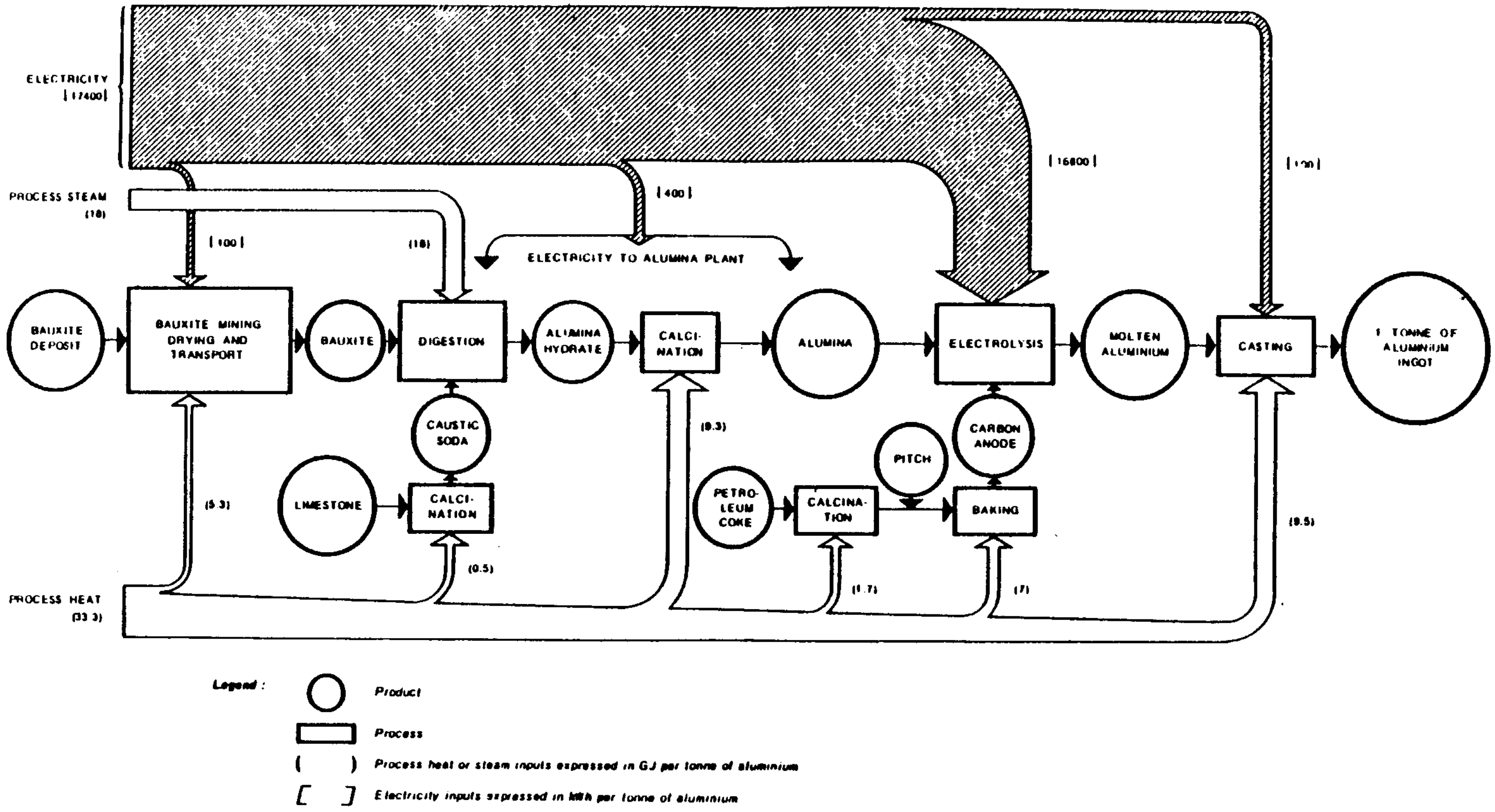


FIGURE II.B-8

MAIN ENERGY FLOWS WITHIN THE ALUMINUM INDUSTRY
(Western World - 1981)

Source: OECD Secretariat, "Aluminum Industry. Energy Aspects of Structural Change", 1983.

TABLE II.B-3

POWER REQUIREMENTS FOR RECENTLY CONSTRUCTED AND PLANNED NEW SMELTERS

Country and location	Planned capacity,(1) primary aluminium (000 tonnes/year)	Power Requirements (MW)
Australia:		
Gladstone, Qld. (2 potlines)	206	320
Tomago, NSW (2 potlines	220	380
Lochinvar, NSW (2 potlines)	236	380
Portland, Vic. (1 potline)	132	227
Kurri Kurri, NSW (2 potlines)	90	190
Point Henry, Vic.	165	285
Bunbury area, W.A. (1 potline)	132	200
Worsley, W.A. (2 potlines)	220-250	400
New Zealand (South Island)		
2 potlines	200	300
Dubai (2)	180	515
Egypt	100	240
Bahrain	170	300
Mt.Clarendon, North Carolina	181	350
India:		
Hirakud, Orissa	54	120
Talcher, Orissa	218	720
Indonesia (Asahan, 3 potlines)	225	550
Malaysia	90	200-300

(1) Eventual capacity may be larger; data are for 1982-1985 and planned capacity after 1985.

(2) Power plant designed as multi-purpose.

Source: Australian Mineral Economics Pty Ltd.

TABLE II.B-4

PRIMARY ENERGY CONSUMPTION FOR SOME MILL PROCESSES AND FOR SECONDARY SMELTING IN EUROPE, 1980

	Hot rolling	Cold rolling & finishing	Extrusion	Secondary smelting
Electricity	52%	61%	63%	12%
Fuels	48%	39%	37%	88%
%	100%	100%	100%	100%
Total GJ per tonne	4.4	4.9	13.4	12.1
GJ per tonne as % of energy requirement for 1 tonne of primary ingot	2.2%	2.4%	6.7%	6.0%

Source: OECD Secretariat, "Aluminum Industry. Energy Aspects of Structural Change", 1983

- Age of the plant: modernization of existing pot lines is costly, and therefore the possibilities of improving the energy efficiency of a plant are small. Actual power savings of the order of 1 to 2% per year have been achieved over the last decade, despite the fact that recent environmental considerations have led to increased power requirements.
- Availability of energy resources at the plant site: to a certain extent, less efficient smelters are built in energy rich countries, while in areas with less abundant energy resources, the energy performance of the smelters tends to be better.

About 4% of total electricity consumption in OECD countries is used for aluminum production, while there are countries, where this percentage is much higher. In Iceland, the share of aluminum in total electricity consumption is 44%. However, aluminum smelting is an easy way to take advantage of remote energy resources, especially renewable hydro resources*, without necessarily restricting energy available to other consumers.

II.B.3 Plant Site and Size Requirements

The essential elements for the integrated aluminum industry are: capital, raw materials, energy, and markets. Seldom does a single country possess all four of these elements. Therefore, the world's aluminum industry is international by necessity, and is an industry where resources are

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* A study done by the OECD Secretariat estimated that in 1981 the breakdown of power sources for the aluminum industry in the Western World was as follows: hydro, 52.6%; coal, 27.5%; oil, 6.8%; natural gas, 7.2%; and nuclear, 5.9%.

allocated in response to international market forces rather than national political policies.

Aluminum smelters used to be located in developed countries close to the major consumers of North America, Europe, and Japan. However, the high energy consumption in the electrolysis process combined with the disappearance of low cost energy in developed countries tend to favor smelter sites in developing countries close to a hydroelectric supply (a new smelter built in Indonesia), coal deposits (India's Angul plant, scheduled to open in 1986), or domestic natural gas (a plant recently started up in Jeba-Ali, Dubai). Increases in energy prices have forced smelters to close in Japan and Taiwan.

Alumina plants, on the other hand, are sited based on numerous economic considerations and may be located in the vicinity of a bauxite mine, or adjacent to a smelter, or at an intermediate site. The location of alumina plants is mainly the result of a compromise between the incentive to reduce transportation costs by locating close to bauxite mines and the attempt to reduce investment costs and risks by locating in developed countries.

In the case of secondary aluminum, availability of scrap and proximity to markets are the main factors determining location. The geographical breakdown of bauxite, alumina and aluminum in 1981 is illustrated by Figure II.B-9.

The cost components of the aluminum industry vary so widely that no generalizations are possible. However, the following factors should be borne in mind:

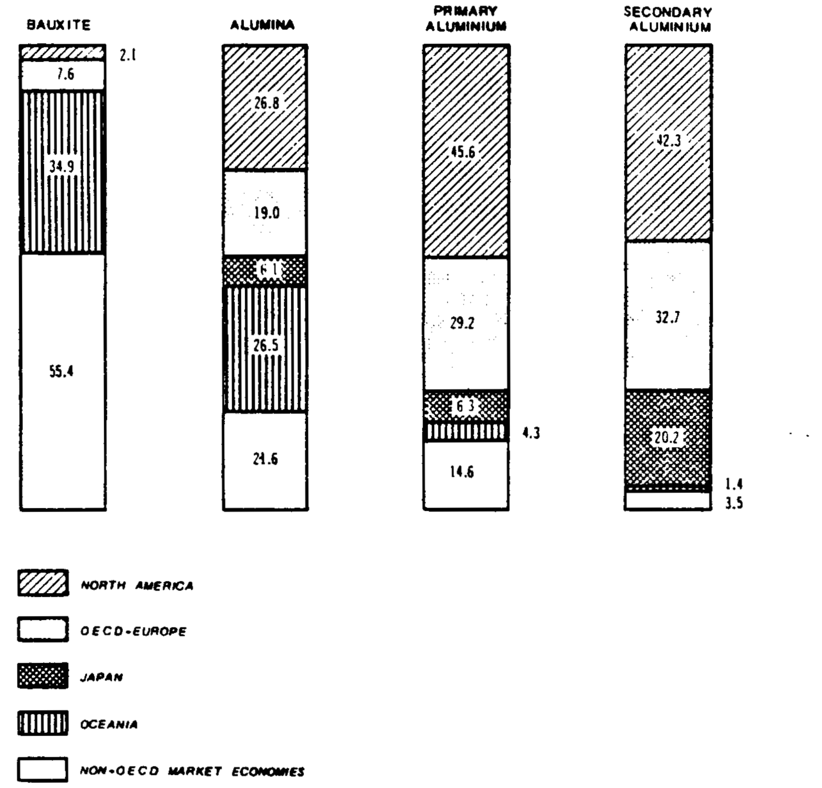


FIGURE II.B-9

GEOGRAPHICAL BREAKDOWN OF BAUXITE, ALUMINA AND ALUMINUM 1981
(% of western world production)

Source: OECD Secretariat, "Aluminium Industry. Energy Aspects of Structural Change", 1983.

- Capital cost: new alumina plants tend to cost more than $1,000 per installed ton of annual capacity, while this figure for a large new smelter varies between $3,000 and $4,000 a ton (1981 prices). The capital-intensity of the industry raises difficulties to entry, and makes it mandatory to keep older, partly or completely amortized plants in a good state of repair.
- Delivery costs: transportation and handling charges of raw materials are a large component of the delivered cost, sometimes accounting for as much as 50%.
- Government involvement: arrangements with governments are usually made in terms of pricing of energy, transport and other utilities. A large percentage of primary aluminum capacity in the world is under direct government influence.
- Foreign exchange: the high added value to alumina in smelting makes aluminum production a potentially large earner of foreign exchange.
- Pollution: might impose cost on the economy of a developing country.

The minimum economic size for a new bauxite deposit where large investments in transport systems and infrastructure are required, is estimated as high as 5 to 8 million tons per year. The minimum economical size for alumina plants today is somewhere in the 2 to 3 million tpy range, while a greenfield smelter of 150,000 tons is large enough to be profitable and only few are built larger than that at the initial stage. This mismatch in minimum economical units has strengthened the trend in the industry towards forming consortia for mining bauxite and building new alumina plants.

An area of 0.75 - 1.20 sq m per ton of installed capacity is usually required for alumina plants, of which bauxite storage accounts for 18-30%, and red mud disposal for 8-13%. Aluminum smelters usually require an area of about 6 sq m per ton of installed capacity.

II.B.4 Water and Labor Requirements

Water requirement is not considered as a problem in aluminum plants. In the alumina plants, the specific consumption of water is in the range of 3-4 cu m per metric ton of alumina produced.

Labor requirements vary widely depending on plant location and technology used. Typical productivities are 200-650 tons per man per year for alumina plants and 80-250 t/man/y for aluminum smelters. Table II.B-5 is a staffing summary for a proposed alumina plant in Jamaica.

II.B.5 Environmental Impact

The wastes resulting from the aluminum industry's operations are significant, and hence their effects must be considered in environmental impact assessments. This section is a summary of the information presented in the "Environmental Guidelines", The World Bank, Office of Environmental Affairs (1984).

Major environmental concerns in bauxite mining are land reclamation, runoff water control, dust control and infrastructure impact. It is generally accepted that in mining operations land should be restored to an equal or more useful state than existed before the start of such operations. Runoff waters should be carefully considered in terms of suspended solids, pH,

TABLE II.B-5

LABOR REQUIREMENTS FOR A PROPOSED ALUMINA PLANT IN JAMAICA

	600,000 shtpy capacity			900,000 shtpy capacity		
	Sub-total	Salaried	Hourly	Sub-total	Salaried	Hourly
Works Manager's Staff	8	8	-	8	8	-
Operations	210	58	152	231	59	172
Technical	48	20	28	54	22	32
Production Services	317	46	271	421	48	373
Industrial Relations	62	16	46	63	17	46
Port Forces	51	5	46	61	5	56
Administration	38	38	-	43	43	-
Engineering Department	17	17	-	22	22	-
Management	6	6	-	6	6	-
Total	757	214	543	909	230	679

Source: ALUTERV-FKI, "A feasibility study report for the JAVEMEX Alumina Plants of 600,000 and 900,000 shtpy capacities", 1976.

dissolved solids, and metals. Noise can also be generated from blasting and the use of heavy excavation and transportation equipment.

In the processing of bauxite to produce aluminum the principal environmental concerns include: (a) disposal of bauxite residue (red mud); (b) dirt losses; (c) emissions from fuel burning; and (d) waste liquid and slurry streams.

Gaseous emissions originate from the potlines, potroom, paste plant, anode bake plant, and the degassing operation. The emissions contain dusts, sulfur compounds, fuel combustion products, phenols, cyanides, certain organic pollutants, and fluorides which are released from the electrolysis cells and used to be the most serious air pollution problem. Stringent standards have led to extensive use of both wet and dry methods for control of particulates and gases. Dry systems are preferable to wet systems, since liquid waste flows are reduced. Today most plants effectively collect and remove the various emissions and therefore very little escapes to the atmosphere.

Process wastewater originates from the wet scrubbers used for air pollution control, the cryolite recovery, ingot cooling,and cathode making. For secondary aluminum operations, the wastewater results from demagging, wet milling of residues, and contact cooling. Significant parameters in wastewaters are the total fluorides, total suspended solids, and pH. For secondary production, ammonia nitrogen, aluminum, and copper must be added to them. Recycling is used to control the volume of wastewater discharged. Other applicable technology includes treatment of wet scrubber water and other effluents to precipitate the fluorides.

Solid wastes include bauxide residues (red mud), spent cathodes, and residues from air pollution control devices and from the waters used to cool the ingots and castings. Some form of dumping is currently considered to be the best disposal method for red muds, including (a) land impoundment; (b) ocean dumping by ships, barges, or pipelines; and (c) seashore reclamation. Land impoundment in a diked impervious area is most frequently used, and is the method to be generally employed for Bank-supported projects. Care must be taken to avoid contamination of ground waters. Drying beds, lagoons, landfills, or incineration are used to treat solid wastes other than red muds. Metal recovering and other conditioning may be applied ahead of ultimate disposal.

II.B.6 Seaborne Bauxite and Alumina Transport

Both bauxite and alumina can be handled as bulk cargoes and have similar shipping costs on a tonnage basis. On an aluminum-content basis, however, the cost of transporting alumina is about one-half that of bauxite, which has influenced the production of alumina near the mine in recent years. Nevertheless, even with falling exports, the ratio of alumina exports to total aluminum bearing bulk exports (alumina plus bauxite) has remained fairly constant at between 25 - 30%. However, where shallow draft problems pertain at either loading or discharge point, shipment of alumina has obvious advantages because of its higher elemental content.

Transport is an important factor in raw material costs representing, in some instances, half of in-plant costs. As a result, the industry is generally highly integrated and supply contracts are often long term.

Consequently, ships are usually in industry ownership or on long term charter, and they operate on specific routes.

The volume, ton-miles, and average loaded haul of seaborne bauxite and alumina trade over the ten-year period 1973-83 are shown in Table II.B-6. The volume of shipped bauxite/alumina in 1973 has been increased three-fold ten years later, while the total ton-miles have shown a two-fold increase over the same period.

Any bulk vessel - with, or without cargo handling gear - is suitable for the transport of aluminum raw materials, provided it can be accommodated by the available facilities for loading and unloading bauxite or alumina. However, specialized "bauxite carriers" have been built, which are equipped with sophisticated conveyor-fed, self-unloading devices to avoid investments in the shore-based facilities. These ships operate usually between fixed points of origin and destination, and are mainly employed in the cross-Caribbean trade.

Shiploads above 20,000 tons are almost always transported by vessels of the bulk carrier type. For smaller shipments mainly on short-haul routes, "break-bulk" tweendeck dry cargo ships are usually employed, partly because of the shallow drafts available at some ports, but also because their use enables the backhaul of other general cargoes, eliminating long ballast runs. The participation of bulk vessels in bauxite/alumina trading rose from 40% in 1981 to 50% in 1983, indicating the growth of large shipments on the long-haul routes from Australia and West Africa.

TABLE II.B-6

WORLD SEABORNE TRADE OF BAUXITE/ALUMINA 1973-83

Year	Volume in million metric tons	Ton-miles in billion	Average distance of loaded voyage in miles
1973	6	40	6670
1974	8	57	7130
1975	10	75	7500
1976	13	80	6150
1977	16	78	4880
1978	15	72	4800
1979	17	82	4820
1980	19	88	4630
1981	18	80	4440
1982	16	71	4440
1983	18	80	4440

Source of data: Fearnleys, "World Bulk Trades", 1983.

TABLE II.B-7

SIZE OF SHIPS TRANSPORTING BAUXITE/ALUMINA

SIZE GROUP (DWT)	1970	1971	1972	1973	1974	1975	1976	1977	1978	1982	1983
Under 40,000	92	90	87	83	80	76	70	66	65	58	50
40-60,000	7	8	9	12	13	13	16	17	18	20	19
Over 60,000	1	2	4	5	7	11	14	17	17	22	31

Source of data: H.P. Drewry Ltd, "Structure of Bauxite/Alumina Trade and Trends in Ocean Transportation", 1980; and Fearnleys, "World Bulk Trades", 1983.

The size distribution of ships transporting aluminum raw materials is shown in Table II.B-7. The participation of smaller ships (under 40,000 dwt) is constantly decreasing, as they are used only on the short-haul routes. On the longer hauls, however, despite the fact that there are cost incentives for shippers to employ ships of large capacity, vessels of "Panamax" size (50–70,000 dwt) are almost exclusively used, because of the low material throughputs of individual plants, the high cost of providing modern handling equipment, the need for covered storage, and the existing port depths. Today the employment of bulk or OBO carriers of up to 80,000 dwt is feasible on some routes.

Most port facilities for handling and storing incoming raw materials are owned by consuming plants at coastal locations. Only a relatively small part of the trade is directed to large, multi-purpose port complexes linked to inland transportation systems. Port loading facilities for bauxite are generally limited to handling ships of up to 50–70,000 dwt, but many facilities are available only up to the 25–30,000 dwt range. Table II.B-8 shows the principal loading ports for aluminum raw materials.

Bauxite, after drying, is generally loaded by gantry via conveyors and rates of up to 4,000 t/h may be achieved. Discharge is generally at a lower rate using grabs or clamshells and can achieve up to about 1,500 t/h. Stockpiling requires extensive storage, which is an additional factor limiting shipment sizes.

TABLE II.B-8

PRINCIPAL PORTS LOADING BAUXITE/ALUMINA

EXPORTER	TERMINAL (OPERATOR)	CONTROLLING DEPTH (FT)	MAX. DRAFT (FT)	MAX. SHIP SIZE (DWT)	APPROXIMATE LOADING RATE (TONS/HR)	REMARKS
			1. BAUXITE PORTS			
Jamaica	Ocho Rios (Reynolds)	40'	42'	60,000	3,500	Max. freeboard 53'
	Port Rhoades (Kaiser)	39'	37'	40,000	4,000	Max. length 660'
Haiti	Miragoane (Reynolds)	-	38'	45,000	2,000	One fixed shiploader
Dominican Republic	Cabo Rojo (Alcoa)	-	40'	50,000	800	Max. length 600'
Trinidad	Chaguaramas (Alcan)	34'	32'	25,000	1,400 load 900 discharge	Transhipment terminal
	Tembladora (Alcoa)	36'	35'	35,000+	1,200 load 800 discharge	Transhipment terminal
Surinam (1)	Moengo (Alcoa)	24'	24'	20,000	800/1,000	Max. length 525'
	Paramaribo (Panama)(Alcoa)	30'	25'	20,000	1,500	
	Smalkalden (Billiton)	30'	25'	20,000+	800	
Guyana (1)	Everton (Guybau)	19'	20'	15,000	500	
	Mackenize (Guybau)	18-22'	21' 6"	15,000	800	Max. length 570'
Brazil	Porto Trombetas (MRN)	-	+37'	50,000	4,000	
Australia	Gove (Nabalco)	46'	45'	80,000	3,000	
	Weipa (Comalco)	37'/39'	39'	60,000	3,000 & 6,000	
Indonesia	Bintan (PN Aneka Tambang)	28'	30'	30,000	1,000	Terminal is at Kijang
Malaysia	Telok Ramunia (Seaba)	-	+30'	25,000	About 5,000 tons /day by lighters	Vessels must be grab-fitted
Ghana	Takoradi (Baco)	32'	32'	25,000	350	Max. length 505
Sierra Leone	Sherbro (Alusuisse)	40' at buoy	+35'	35,000	About 9,000 day from lighters	Vessels must be grab-fitted
Guinea	Conakry (Kindia)	36'	31'/32'	25,000	1,000	
	Port Kamsar (Halco)	42'	42' 6"	70,000	4,000	Max. length 740'
Greece	Itea	26' & 32'	27'	15,000	300	
			2. ALUMINA PORTS			
Canada	Port Alfred (Alcan)	39'	39'	60,000	1,000	
US	Corpus Christi (Reynolds)	40'	38'	45,000	600	Max. length 750'
	Point Comfort (Alcoa)	38'	38'	45,000	750	
	Baton Rouge (Kaiser)	40'	35'/37'	40,000	-	
	Gramercy (Kaiser)	40'	37'	40,000	-	
Jamaica	Port Kaiser (Alpart)	43'	36'	30,000	1,000	
	Port Esquivel (Alcan)	36'	35'	30,000	1,000	
Trinidad	Tembladora (Alcoa)	36'	35'	35,000	800/1,200	Transhipment terminal
Surinam	Panama (Alcoa)	30'	25'	20,000	850	
Guyana	Mackenzie (Guybau)	18-22'	21' 6"	15,000	400	Max. size controlled by bar draft
Australia	Gladstone (QAL)	42'	38'/42'	60,000	1,200	
	Kwinana (Alcoa)	38'	41' 6"	45,000	2,000	
	Banbury (Alcoa)	40'	38'	40,000	2,000	
	Gove (Alusuisse)	46'	45'	80,000	2,000	
Guinea	Conakry (Frialco)	36'	31'/32'	25,000	1,000	
Virgin Islands	St. Croix (Martin Marietta)	35'	33'	30,000	750/1,000	One fixed shiploader
Italy	Porto Vesme (Eurallumina)	39'	38'/39'	60,000	1,000	
W. Germany	Stade (AOS)	46'	45'	80.000	500	

(1) Max. size governed by bar draft; vessels of 25/30,000 DWT may part load and top-up at the Trinidad transfer stations.

Source: H.P. Drewry Ltd., "Structure of Bauxite/Alumina Trade and Trends in Ocean Transportation", 1980.

While dusting is a problem with bauxite, it is particularly so with alumina which should be loaded in enclosed conveyor systems. Typically, loading rates are in the 500 to 1,000 t/h range but for the bigger shipments from Australia, 1,500 to 2,000 t/h capable loaders have been installed. Discharge is usually with suction unloaders of 400 - 600 t/h capacity but facilities with 1,000 t/h unloaders have been installed.

II.C Plant Descriptions

II.C.1 Alumina Plant

Plant location: Matanzas industrial zone in Ciudad Guayana, Venezuela on the Orinoco River, 180 nautical miles from the Atlantic Ocean.

Owners: Fondo de Inversiones de Venezuela, Corporacion Venezolana de Guayana, Alusuisse.

Start-up: September 1982 - March 1983.

Annual production: 1 million metric tons/year alumina (20% exported).

Annual raw materials consumption:

2,000,000 tons trihydrate bauxite.
200,000 tons caustic soda solution (50% NaOH).
35,000 tons burnt line (CaO).
2,400 tons starch (floculant).
125 tons synthetic floculants.
1600 tons carbon filter aid.
1000 tons sulfuric/hydrochloric acid.
3,000,000 tons water.

Annual energy inputs:

240,000 tons fuel oil.
250 Gwh electricity.

Plant layout: See Figure II.C-1.

Total area: 80 hectares (excluding waste disposal sites).

Bauxite sources: Brazil, Surinam, Jamaica (domestic sources will be utilized after development of mining production.

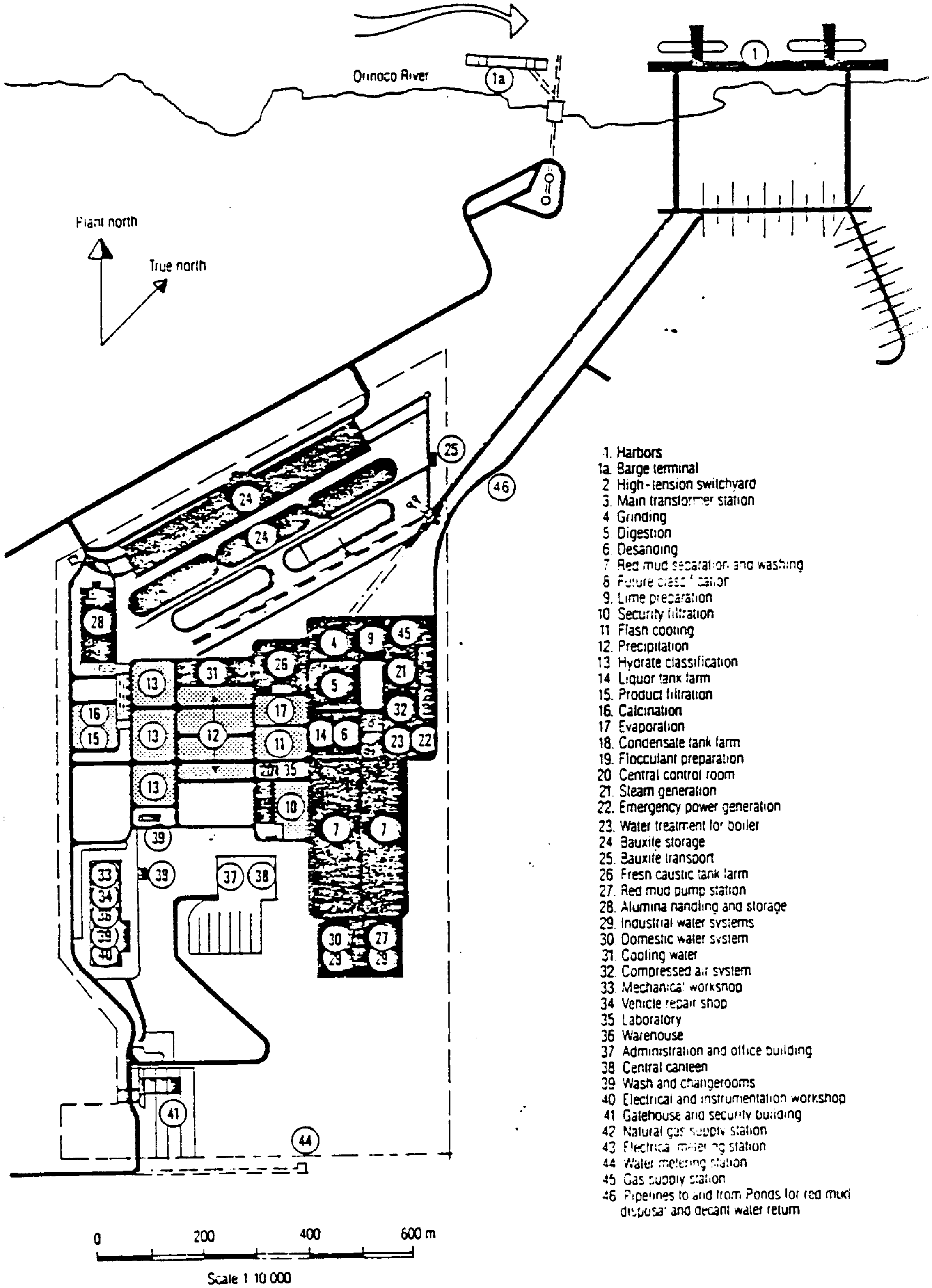


FIGURE II.C-1

GENERAL LAYOUT OF INTERALUMINA PLANT SITE

Source: Engineering and Mining Journal, May 1983.

Terminal draft: Maximum vessel draft varies from 8.2 to 12 m depending on the season. Ships up to 50,000 DWT can be handled at the dock.

Bauxite unloading: Two clam shell unloading cranes rated at 1200 mt/hr each unload bauxite from ship into hoppers. Entire operation is computer-controlled.

Bauxite conveyors: 2,400 mt/hr. Plant can be fed from either of 2 stockpiles or directly from the ship.

Bauxite storage: Bauxite is conveyed to two stockpiles - one covered measuring 570 x 49 m and providing 220,000 mt of "dry" storage, and the other measuring 570 x 47 m for 270,000 mt of uncovered storage.

Bauxite handling: Discharge belt to the covered stockpile is fitted with a tripper car capable of discharging the bauxite along the length of the building in either a "cone shell" or a "chevron" pattern. Each stockpile has an 800 mt/hr portal scraper for reclaiming bauxite.

Alumina storage/transport: Shed-type structure with 150,000 mt storage capacity. Alumina is received from the plants calciners on two conveyors, each rated at 200 mt/hr. It is then fluidized and moves via an air-slide to a series of distribution stations located at the apex of the shed. Discharge of alumina from the sheds proceeds by gravity flow over open air-slide pads that feed reclaim belt conveyors located in a concrete tunnel running along the center of the shed.

Caustic handling/storage: A 50% caustic solution is unloaded from ships by a marine arm and two shore-side centrifugal pumps rated at 520 m^3/hr each. It is transferred through a 300 mm diameter, 1.5 km pipeline to 2 storage tanks 59 m above dock level. Each tank holds up to 10,000 m^3 or about 30,000 mt of solution. Storage capacity is roughly enough to permit two months operation at full production rate.

Plant utilities: Three 200 mt/hr steam boilers designed to fire either No. 6 fuel oil or natural gas. A 70-Mv power supply/distribution system for purchased power from a nearby hydroelectric station. Main power transformers reduce 115 Kv supply to 13.8 Kv for in-plant distribution. No power is generated in the boiler house, but two gas-turbine alternator sets are provided for essential services in case of main supply shut-off.

Waste water lagoons: Three ponds receive about 4 million m^3 of slurry annually, of which about 70% is recovered as pond water. The remaining red mud amounts to 740,000 m^3 at about 70% solids by weight.

Miscellaneous construction facts:

plant area	800,000 m^2
excavated volume	3,000,000 m^3
concrete poured	93,000 m^3
structural steel	25,000 mt
tankage steel	24,000 mt
length of conveyors	6,000 m
piping	205,000 m
electrical cables	325,000 m
instrument cables	485,000 m
number of equipment items	1,000
number of motors	1,480

II.C.2 Aluminum Smelter

Plant location: Boyne Island, Australia

Plant owners: Comalco Ltd. (consortium)

Start-up: February 1982

Output: 206,000 mt/yr aluminum

Furnaces: Two potlines, with 240 cells each

Technology: Sumitomo low-density furnace (LDF)

Alumina source: Obtained from a refinery at Gladstone via an 8-Km-long overland conveyor system.

Raw materials:

412,000 mt/yr alumina.
80,000 mt/yr petroleum coke (imported from US)
12,000 mt/yr fuel oil
20,000 mt/yr pitch
12,000 mt/yr fuel oil

Electricity supply: coal-fired power station at Gladstone

Work force: Almost 1000 permanent operating and shipment employees.

Product shipment: Ingots are trucked 9 km to a wharf where a specially built bulk vessel with full open hatches, squared holds, and two deck-mounted gantry cranes load them for shipment to Japan. Metal destined for the US is shipped in banded pallets rolled onto vessels equipped with side-loading ramps.

II.C.3 Aluminum Smelter

Plant location: Jebel Ali, Dubai

Plant owners: Dubai Aluminum Company (80% owned by the government of Dubai)

Start-up: 1980

Output: 135,000 mt/yr

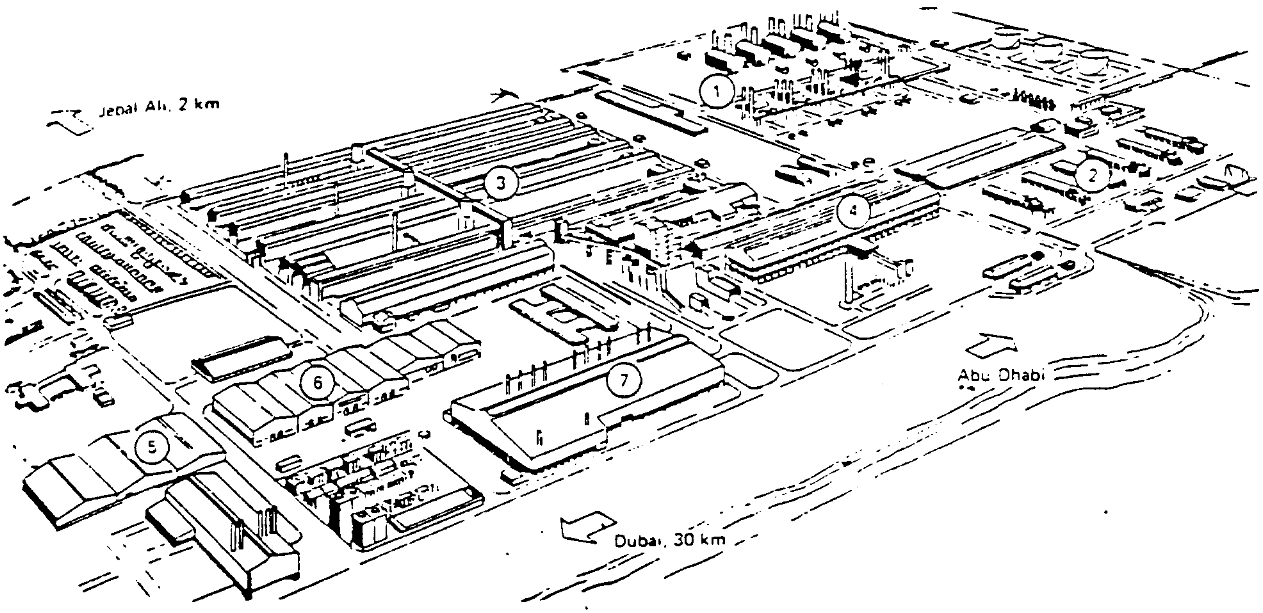
Layout: See Figure II.C-2

Alumina: Imported from Australia

Power station: 515 Mw gas-fired station to be fueled by 3,150,000 cu.m. per day dry gas or by 2,888 mtpd of distillate as back-up fuel. Waste heat from the power plant is to be used for a desalination plant producing 25 million imperial gallons of fresh water daily from the Persian Gulf.

Smelting cells: Six potlines, each of which will measure 380 meters x 20 meters

Work force: 1750 workers



Legend: 1) power station; 2) desalination plant; 3) potrooms; 4) anode plant; 5) warehouse; 6) workshops; 7) cast house.

FIGURE II.C-2

LAYOUT OF DUBAI ALUMINUM SMELTER

Source: Engineering and Mining Journal, November 1983.

II.C.4 Aluminum Smelter

Plant location: Mount Holly, South Carolina, USA

Owners: Alumax Inc., (50% Amax, 45% Mitsui, 5% Nippon Steel)

Start-up: 1980

Furnaces: Alcoa technology. Two potlines of 180 cells each, housed in two 800-meter long buildings

Output: 197,000 short tons/yr.

Alumina source: Australia

Alumina receipt: One 35,000-short ton shipload per month is received at the Alumax terminal in North Charleston, unloaded from the holds of the ships by pneumatic vacuum at a rate of 400 tph, and stored in twin silos, each with a capacity of 35,000 mt.

Site area: Plant is located on a 300-acre site within a 6000 acre tract

Construction time: 21 months from ground-break

Electrical energy costs: $62.4 million/yr reported.

Environmental controls: Total expenditures reported as $40 million. More than 3 billion cubic feet of air per day are cleaned at efficiencies of over 99%.

Product: Five basic ingot shapes - T-shapes, rolling ingot, extrusion, billet, 50-lb. pure aluminum ingot, and 30-lb. foundry ingot.

Work force: 700 employees.

II.C.5 Bauxite/Alumina/Aluminum Complex

Location: State of Orissa, India (see Figure II.C-3)

Startup: Scheduled for 1986

Bauxite: 2,400,000 tons per year of low alumina bauxite mined at Panchpatmali, where large reserves (400 million tons) were discovered in 1975)

Ore transport: Bauxite will be moved to an alumina plant via conveyor belt. The belt will be 14.5 kilometers long and provide a 140 meter drop in elevation. Capacity will be 900 tons per hour with a speed of 2.25 m/sec. Belt width will be 950 mm.

Alumina plant: Located near the town of Koraput, the plant will have a capacity of 800,000 tons per year. About half will be moved by rail to the port of Vishakhapatnam for foreign export. The rest will be transported to a new smelter located in Angul, 500 Km to the north.

Aluminum smelter: The Angul site was chosen because of its proximity to large coal reserves, which will supply a 600 Mw power plant, whose output will be used for smeltering 218,000 tons of primary metal annually. The smelter will contain 480 pots and will be fitted with an advanced fume treatment system for treating 4 million cubic meters per hour of exhaust fumes.

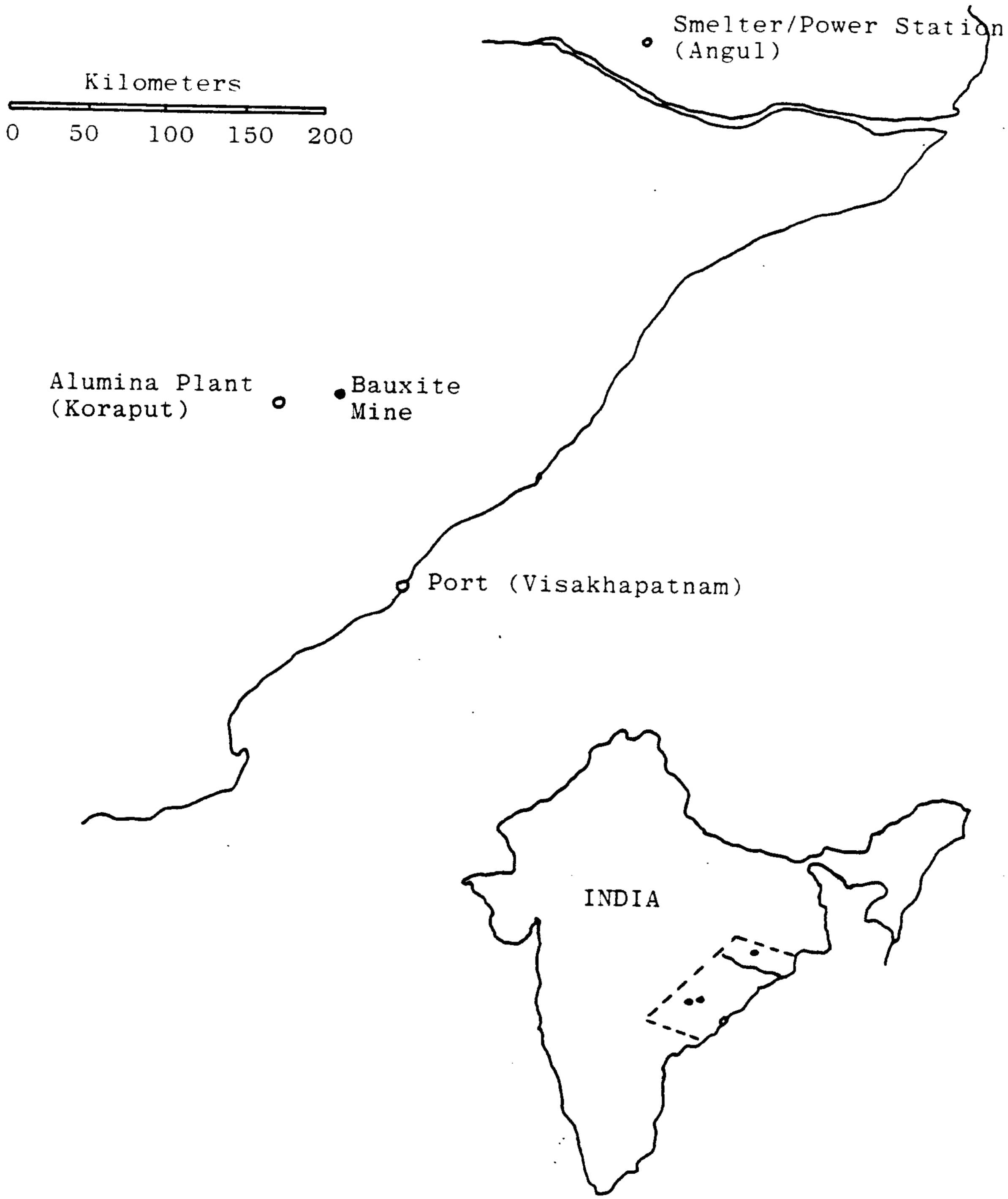


FIGURE II.C-3

LOCATION OF PROPOSED INDIAN ALUMINA PLANT AND SMELTER

Source: Staff

II.C.6 Self-discharging Alumina Carrier

Owner: TNT Bulkships

Builder: Hitachi

Year of build: 1983

Discharge rate: 1000 tons/hour

Vessel characteristics:

Length, oa	189.0 m
Length, bp	180.0 m
Beam (mld)	29.4 m
Depth	16.3 m
Draft - design	10.0 m
- scantling	10.15 m
Displacement	44,150 t
Deadweight	34,000 t

Cargo holds: Four holds providing a total capacity of 41,100 cubic meters with a non-aerated bulk stowage of 0.993 t/m^3.

Dust control: Special attention was paid in the ship's design to limiting the health hazards and environmental nuisances associated with alumina. The self-unloading system is fully enclosed to contain the large amount of alumina dust generated during handling. All mechanically ventilated spaces aboard the vessel are provided with filters, and all air for the main engine room is drawn through an air washer. Air washers are also installed on the air-conditioning intakes. These washes have watersprays ("curtains") followed by inertial vanes that effectively wash alumina dust particles out of the entering air.

Cargo loading: Alumina is loaded by a travelling gantry loader rated at 1500 tph. The gantry has a boom from which a telescopic chute hangs down into the hold.

Cargo discharge: Cargo hold bottoms are sloped at 8 degrees towards a centerline tunnel which extends the full length of the cargo space.

The bottoms are covered with aeration panels to reduce the required slope angle. (Aerated alumina was found to readily flow down a slope of 8 degrees, while its normal angle of repose is 29 degrees.) Bottoms are also sloped in the fore and aft direction to provide a low point at the mid length of each hold. At the outlet from each hold, port and starboard, there is an electrically operated rotary flow control gate, which controls flow and serves as a shut-off device. (Manually operated sluice valves upstream of each rotary valve allow flow shut-off if maintenance is required on the rotary valves.) The rotary valve opening is regulated by a signal from a belt weighter, which provides a monitoring system.

Alumina from the holds is carried along the centerline tunnel by two conveyor belts to a main collection point amidships. To raise the alumina from the central collection point to a position high enough to allow discharge ashore, vertical bucket belts were adopted.

The two horizontal conveyors, running from the two aft and two forward holds respectively, are rated at 500 tph each. The 33 meter high vertical belt conveyor (146 KW) operates at 2.5 m/s and has a discharge capacity of 1000 tph.

An aeroslide with a swivel boom supported on wires from the vertical belt structure is used to transfer the alumina shoreside.

II.D Aluminum Industry Statistics

List of Tables

TABLE II.D-1

WORLD PRODUCTION OF BAUXITE
(Thousands of Short Tons)

	1978	1979	1980	1981	1982
United States*	1,839.8	2,007.3	1,718.5	1,664.5	759.5
Haiti	704.4	617.3	508.2	594.1	622.4
Jamaica**	12,936.5	12,682.1	13,298.3	12,793.4	9,000.0
Dominican Republic	637.1	577.7	562.7	446.9	175.0
Brazil	1,246.3	1,810.2	4,577.2	5,139.1	4,960.4
Guyana	3,834.9	3,697.1	3,364.3	2,102.1	2,102.2
Surinam	5,636.1	5,226.1	5,404.7	4,415.9	3,374.2
TOTAL AMERICA	26,835.1	26,617.8	29,433.9	27,156.0	20,993.7
France	2,180.1	2,171.0	2,085.0	2,014.5	1,914.7
Greece	2,936.3	3,181.7	3,320.2	3,545.4	3,301.0
Italy	26.9	28.8	25.7	20.9	33.0
Spain	11.0	9.0	11.0	11.0	11.0
Yugoslavia	2,828.5	3,320.2	3,459.0	3,581.4	4,043.3
TOTAL EUROPE	7,982.8	8,710.7	8,900.9	9,173.2	9,303.0
India	1,833.1	2,150.8	1,967.3	2,119.3	2,043.4
Indonesia	1,110.8	1,159.6	1,376.8	1,326.3	809.3
Malaysia	678.0	426.0	1,014.6	772.6	649.3
Pakistan	-	1.1	-	2.4	4.1
Turkey	494.9	173.5	576.5	557.1	533.0
TOTAL ASIA	4,116.8	3,911.0	4,935.0	4,777.7	4,039.1
Guinea	12,839.7	16,151.8	14,800.8	14,145.6	14,145.0
Ghana	363.7	235.6	217.0	276.7	350.0
Sierra Leone	789.3	749.6	844.4	674.1	674.0
Zimbabwe	5.5	5.5	4.4	5.5	5.6
TOTAL AFRICA	13,998.2	17,142.5	15,866.6	15,101.9	15,174.6
Australia	26,777.9	30,405.0	29,959.7	28,044.3	26,037.7
SUBTOTAL	79,710.8	86,787.0	89,096.3	84,253.1	75,548.1
U.S.S.R.	7,385.5	7,165.0	7,065.8	7,065.8	7,054.8
Hungary	3,196.7	3,280.5	3,251.8	3,212.1	2,895.8
Rumania	780.4	782.6	782.6	749.6	749.6
China	1,543.2	1,653.5	1,873.9	1,929.0	1,929.0
SUBTOTAL	12,905.8	12,881.6	12,963.1	12,945.5	12,629.2
TOTAL	92,616.6	99,668.6	102,059.4	97,198.6	88,177.3

* Dried equivalent of crude ore. ** Dry tons.

Source: American Bureau of Metal Statistics, Inc., U.S. Bureau of Mines, Metallgesellschaft AG, World Bureau of Metal Statistics, and various other sources.

TABLE II.D-2

WORLD PRODUCTION OF ALUMINA*
(Thousands of Short Tons)

	1978	1979	1980	1981	1982
United States**	6,757.2	7,330.4	7,749.2	6,823.2	5,929.3
Canada	1,161.4	908.4	1,325.0	1,331.4	1,330.0
Jamaica	2,360.0	2,286.0	2,640.1	2,762.4	1,900.0
Brazil	478.4	495.0	543.4	572.0	570.0
Guyana	275.6	308.3	326.6	220.7	220.0
Surinam	1,388.9	1,445.1	1,587.0	1,376.7	1,375.0
TOTAL AMERICA	12,421.5	12,773.2	14,171.6	13,086.5	11,324.3
France	1,345.8	1,365.2	1,476.4	1,362.3	1,200.0
Germany, F.R.	1,714.1	1,696.3	1,772.5	1,819.9	1,819.0
Greece	526.5	546.4	556.3	552.9	552.0
Italy	902.2	941.5	992.5	866.9	886.0
Spain	-	-	68.5	766.3	766.0
United Kingdom	103.6	97.1	112.4	99.6	98.0
Yugoslavia	547.3	922.0	1,166.7	1,143.3	1,213.0
TOTAL EUROPE	5,139.5	5,568.5	6,145.3	6,611.2	6,534.0
India	538.0	551.3	544.5	538.6	539.0
Japan	1,947.8	2,008.4	2,444.9	1,785.1	1,700.0
Taiwan	56.5	65.0	88.0	21.1	21.0
Turkey	81.7	82.7	151.6	144.8	144.0
TOTAL ASIA	2,624.0	2,707.4	3,229.0	2,489.6	2,404.0
Australia	7,468.9	8,173.2	7,987.9	7,803.3	7,306.8
Papua New Guinea	685.2	729.7	780.8	748.4	610.0
TOTAL OCEANIA	8,154.1	8,902.9	8,768.7	8,551.7	7,916.8
SUBTOTAL	28,339.1	29,952.0	32,314.6	30,739.0	28,179.1
U.S.S.R	3,637.6	3,527.4	3,582.5	4,188.8	4,188.8
Czechoslovakia	99.2	99.2	99.2	99.2	99.2
Germany, D.R.	41.9	45.2	47.4	44.1	44.1
Hungary	865.3	901.7	918.2	880.7	821.2
Rumania	494.9	553.4	588.6	573.2	573.2
China	771.6	771.6	771.6	771.6	771.6
SUBTOTAL	5,910.5	5,898.5	6,007.5	6,557.6	6,498.1
TOTAL	34,249.6	35,850.5	38,322.1	37,296.6	34,677.2

* Alumina hydrate. ** Calcined alumina.

Source: American Bureau of Metal Statistics, Inc., U.S. Bureau of Mines, Metallgesellschaft AG, World Bureau of Metal Statistics, International Primary Aluminum Institute, International Bauxite Association, and other sources.

TABLE II.D-3

WORLD PRODUCTION OF PRIMARY ALUMINUM
(Thousands of Short Tons)

	1978	1979	1980	1981	1982
United States	4,804.0	5,023.0	5,130.0	4,948.0	3,609.0
Canada	1,155.8	952.0	1,184.4	1,229.8	1,173.7
Mexico	47.5	47.6	47.0	47.6	45.3
Argentina	54.5	130.5	146.7	147.6	151.5
Brazil	205.5	262.8	287.3	282.6	300.0
Surinam*	62.7	69.0	60.5	45.5	66.4
Venezuela	92.3	225.6	349.5	344.1	200.0
TOTAL AMERICA	6,422.3	6,710.5	7,205.4	7,045.2	5,545.9
Austria	100.6	102.2	104.1	103.8	103.9
France	431.4	435.5	476.1	480.2	430.3
Germany, F.R.	815.3	817.8	805.5	803.5	800.0
Greece	158.6	155.2	160.5	161.0	148.7
Iceland	81.4	79.5	82.5	82.2	82.9
Italy	298.5	296.8	298.9	297.1	255.5
Netherlands	285.7	281.8	284.6	288.7	276.6
Norway	724.1	742.4	729.4	701.2	702.1
Spain	233.9	286.0	426.0	437.2	402.6
Sweden**	90.4	90.4	89.9	91.2	86.0
Switzerland	87.6	91.5	95.1	90.6	83.0
United Kingdom	381.6	396.3	412.7	373.9	265.4
Yugoslavia	194.0	184.9	177.9	190.4	200.0
TOTAL EUROPE	3,863.1	3,960.1	4,143.2	4,101.0	3,837.0
Bahrain	135.4	139.0	139.3	155.8	188.5
Dubai	-	-	38.6	117.6	118.1
India	222.0	233.0	203.6	234.6	238.8
Iran	28.1	12.1	17.5	17.6	25.0
Japan	1,165.9	1,113.8	1,203.2	849.4	386.6
South Korea	19.5	19.3	19.4	19.0	16.2
Taiwan	55.6	61.8	68.9	33.1	11.1
Turkey	35.6	35.1	37.0	44.5	35.7
TOTAL ASIA	1,662.1	1,614.1	1,727.5	1,471.6	1,020.0
Cameroon	45.5	49.1	47.5	72.1	87.0
Egypt	110.7	111.6	132.3	156.5	157.2
Ghana	125.1	186.0	206.9	210.0	191.8
South Africa	89.4	95.1	95.5	94.0	110.0
TOTAL AFRICA	370.7	441.8	482.2	532.6	546.0
Australia	290.3	297.2	334.6	418.2	399.3
New Zealand	166.6	169.9	172.2	171.3	181.2
TOTAL AUSTRALASIA	456.9	467.1	506.8	589.5	580.5
SUBTOTAL	12,795.1	13,193.6	14,065.1	13,739.9	11,529.4
U.S.S.R.	2,535.3	2,590.4	2,667.6	2,645.4	2,645.5
Czechoslovakia	40.6	40.7	42.2	41.3	41.3
Germany, D.R.	71.7	66.1	66.1	66.1	66.1
Hungary	78.7	79.3	81.0	81.9	81.8
Poland	110.5	106.5	104.8	72.8	72.8
Rumania	234.8	239.2	265.7	253.5	253.5
China	396.8	396.8	385.8	385.8	385.8
North Korea	11.0	11.0	8.8	11.0	11.0
SUBTOTAL	3,479.4	3,530.0	3,622.0	3,557.9	3,557.8
TOTAL	16,274.5	16,723.6	17,687.1	17,297.8	15,087.2

* Exports. ** Includes alloys.

Source: American Bureau of Metal Statistics, Inc., U.S. Bureau of Mines, Metallgesellschaft AG, World Bureau of Metal Statistics, and various other sources.

TABLE II.D-4

WORLD CONSUMPTION OF PRIMARY ALUMINUM
(Thousands of Short Tons)

	1978	1979	1980	1981	1982
United States	5,487.4	5,531.1	4,909.5	4,563.7	3,880.0
Canada	373.5	374.8	343.4	311.5	216.7
Mexico	91.8	109.8	116.5	109.8	110.0
Argentina	66.7	89.4	65.6	57.7	72.0
Columbia	19.2	18.1	14.9	15.7	15.0
Brazil	260.7	283.4	314.0	265.5	240.0
Peru	5.5	7.7	8.8	11.0	11.0
Venezuela	76.1	81.6	89.3	81.1	70.0
Other America	18.1	19.8	27.6	28.7	25.0
TOTAL AMERICA	6,399.0	6,515.7	5,889.6	5,444.7	4,639.7
Austria	118.9	123.2	112.9	116.2	125.4
Belgium	282.9	266.8	256.7	237.3	266.1
Denmark	8.0	12.2	16.4	12.0	14.4
Finland	23.9	29.8	27.8	33.0	24.0
France	587.2	656.9	682.4	593.8	637.9
Germany, F.R.	1,049.7	1,177.0	1,148.9	1,128.3	1,103.2
Greece	75.0	84.3	94.2	72.8	60.0
Iceland	0.1	0.2	0.1	0.1	0.1
Ireland	4.4	6.0	3.8	3.3	3.0
Italy	445.3	493.8	504.9	455.3	434.0
Netherlands	104.4	110.3	117.2	87.7	100.4
Norway	92.6	107.5	130.5	122.6	117.0
Portugal	21.7	23.0	30.2	46.2	46.0
Spain	259.7	258.8	290.3	222.3	245.6
Sweden	108.0	113.9	115.6	93.0	97.1
Switzerland	115.7	122.7	130.3	117.9	122.4
United Kingdom	443.5	460.3	451.2	364.5	358.6
Yugoslavia	175.0	180.8	185.4	183.0	196.0
TOTAL EUROPE	3,916.0	4,227.5	4,278.6	3,887.3	3,951.2
Bahrain	11.0	13.0	20.0	19.1	15.4
Hong Kong	25.2	27.0	33.2	23.8	24.0
India	228.4	233.6	257.7	275.0	280.0
Indonesia	13.6	16.8	15.5	15.4	15.0
Iran	58.9	25.5	25.0	29.1	30.0
Iraq	8.8	3.1	16.4	29.1	30.0
Israel	26.7	22.0	21.3	10.5	11.0
Japan	1,825.5	1,987.9	1,806.7	1,726.9	1,814.4
South Korea	116.6	103.9	84.9	112.0	120.0
Lebanon	14.8	17.0	17.4	12.9	12.0
Malaysia	16.0	26.6	27.6	27.6	28.0
Philippines	18.5	31.3	18.8	18.7	19.0
Taiwan	99.1	120.2	101.3	85.8	80.0
Thailand	37.1	47.3	49.4	49.6	50.0
Turkey	49.6	49.4	49.6	82.2	82.1
Other Asia	21.4	27.1	39.1	30.1	30.0
TOTAL ASIA	2,569.2	2,751.7	2,583.9	2,547.8	2,640.9
Cameroon	26.2	29.7	32.5	30.5	30.6
Egypt	35.3	38.6	44.1	49.6	50.0
Ghana	6.6	6.6	6.6	6.6	7.0
South Africa	56.1	60.6	85.6	84.7	76.2
Other Africa	22.0	14.6	33.0	22.4	23.0
TOTAL AFRICA	146.2	150.1	201.8	193.8	186.8
Australia	202.6	237.2	243.8	258.6	233.6
New Zealand	25.5	27.7	25.1	28.8	21.5
Other Australasia	-	-	1.0	-	-
TOTAL AUSTRALASIA	228.1	264.9	269.9	287.4	255.1
SUBTOTAL	13,258.5	13,909.9	13,223.8	12,361.0	11,673.7

TABLE II.D-4 (Cont'd)

	1978	1979	1980	1981	1982
SUBTOTAL	13,258.5	13,909.9	13,223.8	12,361.0	11,673.7
U.S.S.R.	2,017.2	2,055.8	2,039.3	2,050.3	2,050.3
Albania	1.7	1.8	2.2	2.2	2.2
Bulgaria	51.8	52.9	55.1	55.1	55.1
Cuba	1.1	1.3	1.3	1.7	1.7
Czechoslovakia	145.3	137.8	144.7	137.8	137.8
Germany, D.R.	246.0	253.5	253.5	264.6	264.6
Hungary	187.2	183.4	182.8	157.6	157.6
Poland	178.4	187.4	176.4	156.5	156.5
Rumania	161.5	167.6	162.0	154.3	154.3
China	617.3	639.3	606.3	617.3	617.3
Other Countries	33.1	38.6	38.6	38.6	38.6
SUBTOTAL	3,640.6	3,719.4	3,662.2	3,636.0	3,636.0
TOTAL	16,899.1	17,629.3	16,886.0	15,997.0	15,309.7

Source: American Bureau of Metal Statistics, Inc., U.S. Bureau of Mines, Metallgesellschaft AG, World Bureau of Metal Statistics, and various other sources.

TABLE II.D-5

ALUMINUM INGOT PRODUCTION CAPACITY
End of 1982 - Short Tons

Company	Location of Plant	Annual Capacity
	UNITED STATES	
Aluminum Company of America	Evansville, IN	292,000
	Badin, NC	126,800
	Massena, NY	226,000
	Alcoa, TN	220,500
	Anderson County, TX	16,500
	Point Comfort, TX	159,800
	Rockdale, TX	341,700
	Vancouver, WA	121,200
	Wenatchee, WA	220,500
	Subtotal	1,725,000
Alumax		
Eastalco (50% interest)	Fredrick, MD	88,200
Intalco (50% interest)	Bellingham, WA	140,000
South Carolina	Mt. Holly, SC	197,000
	Subtotal	425,200
ARCO Aluminum, Division of ARCO Metals	Columbia Falls, MT	180,000
	Sebree, KY	180,000
	Subtotal	360,000
Consolidated Aluminum Corp.	New Johnsonville, TN	146,000
	Lake Charles, LA	36,000
	Subtotal	182,000
Howmet Corp.		
Eastalco (50% interest)	Frederick, MD	88,200
Intalco (50% interest)	Bellingham, WA	130,500
	Subtotal	218,700
Kaiser Aluminum & Chemical Corp.	Chalmette, LA	260,000
	Mead, WA	220,000
	Tacoma, WA	81,000
	Ravenswood, WV	163,000
	Subtotal	724,000
Martin Marietta Aluminum Inc.	The Dalles, OR	90,000
	Goldendale, WA	185,000
	Subtotal	275,000
National-Southwire Aluminum Co.	Hawesville, KY	180,000
Noranda Aluminum Inc.	New Madrid, MO	225,000
Ormet Corp.	Hannibal, OH	250,000
Revere Copper & Brass Inc.	Scottsboro, AL	120,000**
Reynolds Metal Co.	Listerhill, AL	202,000
	Arkadelphia, AK	68,000
	Jones Mills, AK	125,000
	Massena, NY	126,000
	Troutdale, OR	130,000
	San Patricio, TX	114,000
	Longview, WA	210,000
	Subtotal	975,000
TOTAL		5,659,900
	CANADA	
Alcan Smelters and Chemicals Ltd.	Kitimat, British Columbia	295,000
	Arvida, Quebec	476,000
	Beauharnois, Quebec	52,000
	Grande Baie, Quebec	188,000
	Isle Maligne, Quebec	80,000
	Shawinigan, Quebec	93,000
	Subtotal	1,184,000
Canadian Reynolds Metal Company, Limited	Baie Comeau, Quebec	175,000
TOTAL		1,359,000
	MEXICO	
Aluminio, S.A. De C.V.	Veracruz	45,000
	SOUTH AMERICA	
Argentina		
Aluminio Argentino (Aluar)	Puerto Madryn	140,000
Brazil		
Aluminio Do Brasil Nordeste, S.A.	Aratu	28,000
Aluminio Do Brasil, S.A.	Saramenha, Minas Gerais	60,000
Cia. Brasileira De Aluminio	Sorocaba, Sao Paulo	83,000
Companhia Mineira De Aluminio-Alcominas	Pocos de Caldas	90,000
Surinam		
Suriname Aluminum Company (Suralco)	Paranam	66,000
Venezuela		
Aluminio Del Caroni, S.A. (Alcasa)	Matanzas, Ciudad Guayana, Estado Bolivar	76,800
Industria Venezolala de Aluminio C.A. (Venalum)	Matanzas, Ciudad Guayana, Estado Bolivar	280,000

TABLE II.D-5 (Cont'd)

Company	Location of Plant	Annual Capacity
	EUROPE	
Austria		
Salzburger Aluminum-Gesellschaft m.b.H.	Lend, Salzburg	12,000
Vereinigte Metallwerke Ranshofen-Berndorf Aktiengesellschaft	Braunau-Ranshofen	82,500
Czechoslovakia		
Ziar Aluminum Plant	Ziar on River Hron	60,000
France		
Aluminium Pechiney (P.U.K. Group)	L'argentiere, Hautes-Alpes	40,500
	Auzat, Ariege	44,500
	Sabart, Ariege	24,300
	Riouperoux, Isere	24,700
	Nogueres (Basses Pyrenees)	113,500
	Lannemezan, Hautes-Pyrenees	43,500
	La Saussaz, Savoie	9,200
	La Praz, Savoie	4,100
	Saint-Jean-De Maurienne, Savoie	47,800
	Venthon, Savoie	31,000
Germany		
Alcan Aluminiumwerke G.m.b.H.	Ludwigshafen/Rh.	44,000
Aluminium-Hutte Rheinfelden G.m.b.H.	Rheinfelden, Baden	64,000
HAW Hamburger Aluminium-Werk	Hamburg	100,000
Kaiser Aluminium Europe Inc.	Schleusenstrasse 4223 Voerde/ Niederrhein	72,000
Leichtmetall-Gesellschaft m.b.H.	Essen-Borbeck	133,000
Vereinigte Aluminium-Werke A.G.	Toeging, Bavaria	80,000
	Stade/Hamburg	65,000
	Stuettgen/Neuss, Rhineland	165,000
	Luenen, Westphalia	35,000
Germany, D.R.		
Lautawerk	Lauta	30,000
V.E.B. Elektrochemisches Kombinat	Bitterfeld	55,000
Greece		
Aluminium De Grece	Distomon, Boeotia	150,000
Hungary		
State Owned Plants	Ajka	17,250
	Inota	35,000
	Felsogalla-Totis	15,000
Iceland		
Icelandic Aluminium Company Ltd.	Straumsvik Hafnarfjordur	88,000
Italy		
Soc. Alluminio Veneto Per Azioni (S.A.V.A.)	Fusina, Venezia	30,000
	Porto Marghera, Venezia	30,000
Alluminio Italia	Bolzano	36,000
	Porto Vesme (Cagliari)	125,000
	Moro (Trento)	21,000
	Fusina (Venezia)	35,000
Netherlands		
Aluminium Delfzijl B.V.	Delfzijl	93,750
Pechiney Nederland B.V.	Vlissingen	170,000
Norway		
A/S Ardal Og Sunndal Verk	Ardal	185,000
	Hoyanger	25,000
	Sunndalsora	122,000
Den Aluminium A/S	Eydehavn	17,600
	Tyssedal	30,100
Elkem Aluminium A/S & Co.	Mosjoen	95,000
Lista Og Mosjoen Aluminiumverk	Lista	55,000
Norsk Hydro a.s. Karmoy Fabrikker	Karmoy, Haugesund	160,000
Sor-Norge Aluminum A/S	Husnes	70,000
Poland		
Centrozap	Konin	49,000
Skawina Aluminium Works	Skawina	49,000
Rumania		
State Owned Plants	Slatina (On Olt River)	108,000
	Tarnavena (North of Sibiu)	30,000
Spain		
Aluminio de Galicia	Sabinanigo, Huesco	14,000
	La Coruna (La Grela)	76,000
Empresa Nacional Del Aluminio S.A.	Aviles (Oviedo)	100,000
	San Ciprian	180,000
	Valladolid	26,000

TABLE II.D-5 (Cont'd)

Company	Location	Annual Capacity
Sweden		
Granges Aluminium AB	Sundsvall	83,000
Switzerland		
Swiss Aluminium Ltd.	Chippis, Valais	28,000
	Steg, Valais	48,000
Usine d'Aluminium Martigny S.A.	Martigny, Valais	10,000
Union of Soviet Socialist Republics (European and Asiatic)		
State Owned Works	Bratsk	800,000
	Kamensk (Urals)	140,000
	Kanaker (Near Erivan, Armenia)	75,000
	Kandalaksha (Kola Peninsula)	30,000
	Krasno-Turinsk, Bogoslavsk	140,000
	Krasnoyarsk (W. Siberia)	300,000
	Nadvoitsy (Karelia)	35,000
	Novokusnetzk (W. Siberia)	125,000
	Pavlodar (W. Siberia)	200,000
	Regar	40,000
	Shelikhovo (Near Irkutsk, E. Siberia)	275,000
	Sumgait (Near Baku)	75,000
	Volgograd	150,000
	Volkhov (Near Leningrad)	18,000
	Zaporozhye (On River Dnieper)	
United Kingdom		
Anglesey Aluminium Metal Ltd.	Holyhead	113,000
British Alcan Aluminium Ltd.	Kinlochleven	10,000
	Lochaber	38,000
	Lynemouth	125,000
Yugoslavia		
Alumina and Aluminium Works, 'Boris Kidric'	Kidricevo (SR Slovenia)	49,000
Kombinat Aluminijuma	Titograd	100,000
T.L.M. 'Boris Kidric' Light Metal Factory	Sibenik/Lozovac	10,000
	Sibenik/Razine	75,000
	AUSTRALIA	
Alcan Australia Limited	Kurri Kurri, NSW	90,000
Alcoa of Australia Limited	Point Henry, Victoria	169,000
Comalco Aluminium (Bell Bay) Ltd.	Bell Bay	112,000
	NEW ZEALAND	
New Zealand Aluminium Smelters Lts.	Tiwai Point	150,000
	ASIA	
Taiwan (Republic of China)		
Taiwan Aluminium Corp.	Kaohsiung, Taiwan	50,000
India		
Aluminium Corporation of India, Ltd.	Jaykaynagar, West Bengal	10,000
Bharat Aluminium	Korba, Madhya Pradesh	100,000
Hindustan Aluminium Corp. Ltd.	Renukoot, Mirzapur, Uttar Pradesh	120,000
Indian Aluminium Company Ltd.	Alupuram, Kerala	20,000
	Belgaum, Mysore	73,000
	Hirakud, Orissa	25,000
The Madras Aluminium Company, Ltd.	Mettur Dam-R.S., Tamil Nadu	25,000
Japan		
Mitsubishi Light Metal Industries Limited	Naoetsu	160,200
	Sakaide	147,200
Mitsui Aluminium Co. Ltd.	Miike	163,800
Nippon Light Metals Co. Ltd.	Kambara	64,000
	Tomakomai	72,000
Showa Denko K.K.	Chiba	127,500
	Kitakata	28,700
	Oomachi	23,800
Sumikei Aluminium Industries, Ltd.	Sakata	98,700
Sumitomo Aluminium Smelting Co., Ltd.	Isoura	79,000
	Kikumoto	n.a.
	Nagoya	n.a.
	Toyama	177,700
	Tooyo	98,700
South Korea		
Aluminium of Korea Ltd.	Ulsan	18,000

TABLE II.D-5 (Cont'd)

Company	Location	Annual Capacity
China		
State Owned Works	Fushun (Liaoning)	100,000
	*	100,000
	AFRICA	
Cameroon		
Cie. Camerounaise de L' Aluminium Pechiney-Ugine (Alucam)	Edea	84,000
Ghana		
Volta Aluminium Company Limited	Tema, Ghana	200,000
South Africa		
Alusaf (Pty.) Ltd.	Richards Bay	132,000

* Covers plant locations at Hofei (Anhwei), Sanmen Gorge (Kansu), Changling (Kirin), Wuhan (Hupeh), Nanning (Kwangsi) and Yangchuan (Shansi). There are plans for plants at Sian (Shensi) and Kweiyang (Kweichow).

**Has 33% interest in Ormet, Hannibal, Ohio plant.

Source: Non-ferrous Metal Data, 1982, American Bureau of Metal Statistics

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III

CEMENT

III.A Data Sheet

III.A.1 General

Cement is manufactured by mixing calcium carbonate with aluminum silicates in a 4:1 ratio, and roasting the mixture at high temperatures in a kiln to produce clinker. The clinker is then cooled and ground along with about 5% gypsum to a fine gray powder. Cement is an intermediate building material product, and is mainly used (together with other raw materials) in forming concrete, the most widely used construction material in the world. Other uses of cement include mortar manufacture and soil stabilization.

There are many types of cement, each one having different properties, the most important being the setting time and the strength of the produced concrete. The most widely used cement type is "portland" cement, which hardens in the presence of water (hydraulic cement). To produce 1 ton of portland cement from an 1,000,000 t/a plant, the following are required:

Limestone/chalk*	1.1-1.25 t/1.5 - 1.6 t
Clays	0.3-0.4 t
Gypsum	0.05 t
Energy (on average)	
fuel	1.07 million kcals
electricity	120 kWh
Average installed power	19 W
Area	0.25 sq m
Personnel	0.0007 (1,500 t/man/yr)

* mix proportions depend on relative contents of raw materials.

Cement is a highly energy intensive product, generally requiring between 1,000 and 2,000 megacalories of energy (both fuel and electrical) per metric ton, depending upon the specific manufacturing process. On average, 82% of the total energy requirement, is consumed in the kiln operation.

There are two types of kilns: vertical or shaft kilns which are efficient only at capacities of up to 100,000 t/a (account for about 5% of world production), and modern rotary kilns with capacities exceeding 1.25 million tons per year. Vertical kilns may be economical either for small plants mostly in developing countries, or to be added in parallel with older equipment to increase total plant capacity. Two processes are mainly used with rotary kilns: the wet and dry processes. In the wet process, the crushed and proportioned raw materials are ground with water and fed to the kiln as a slurry, while in the dry process, the raw materials are fed to the kiln as a powder. Significant savings in fuel consumption make the dry process favorable (especially if combined with modern preheater/precalciner systems), unless if the physical and chemical characteristics of the raw materials inhibit its application.

III.A.2 Cement Shipment

Cement plants are always located close to limestone resources, and therefore the transportation requirements of raw materials necessary in cement manufacture are insignificant. Fuel materials (oil or coal) when imported, usually have their own port facilities. However, there is a substantial seaborne trade of cement products, which can be shipped in the form of bulk clinker, bulk finished cement, or bagged cement.

Bagged cement has traditionally been shipped in general cargo or multi-purpose ships of up to 15,000 DWT or when unitized, in small bulk carriers of up to 30,000 DWT.

Clinker is fairly readily shipped as a normal bulk cargo in small or handy-sized bulk carriers of up to 35,000 DWT, as the only cargo-imposed constraint is that it should be kept reasonably dry.

Bulk cement, however, is shipped in dedicated "cement carriers", because of: (a) its fine powdered form which requires protection from the wind during loading/unloading, (b) its highly hygroscopic character, (c) its 45° angle of repose which means steeply raked cargo holds, and (d) its stowage factor of 1.5 t/cu m which means that holds have limited capacity for less dense cargoes.

Bulk cement is a traditional short-haul trade due to its low unit value, and 50% of the cement carrier fleet are ships of less than 10,000 DWT, usually self-unloaders, which are employed in domestic or short-haul shipments. On longer routes, such as Japan-Middle East, larger vessels are used, the largest being about 45,000 DWT.

III.B Cement Industry Description

III.B.1 Cement and Its Uses

Cement is manufactured by mixing mainly calcium carbonate with aluminum silicates in a 4:1 ratio, and roasting the mixture at 1500°C in a rotary kiln to make "clinker". The latter, in the form of small round lumps up to 40 mm in diameter, is cooled and ground along with about 5% gypsum to a fine gray powder.

The calcium carbonate is normally derived from limestone or chalk, and the aluminum silicates from clay or shale. Additional raw materials such as silica sand, iron oxide (iron ore), and bauxite or alumina may be added in small quantities. The gypsum added in the grinding stage controls the cement's setting time. All the main raw materials, except the large amounts of energy required for cement manufacture, are abundant in most countries. The proporitons of the basic raw materials and additives, as well as the way of processing, are varied according to the type of cement to be produced, as each cement type has different physical and chemical properties.

Table III.D-3 indicates the various types of cement and their uses. Cement that hardens in the presence of water is termed "hydraulic". "Portland" cement is the most widely used hydraulic cement (about 95% of the hydraulic cement output in the United States is of this type), and has the following composition:

Lime	60-67%
Silica	19-25%

alumina	3-8%
sulphur trioxide	1-3% (mainly from gypsum)
iron oxide	0.3-6%
magnesia	0.5-5%
other alkalies	0.3-1.3%

Cement is an intermediate building material product, and is mainly used (together with other raw materials) in forming concrete, the most widely used construction material in the world. Approximately 1 ton of portland cement is used to make 4 cubic yards of concrete. Other uses of cement include mortar manufacture (a mixture of cement, water, and fine aggregate), and soil stabilization.

III.B.2 Cement Manufacturing Process*

Cement-making, as shown in Figure III.B-1, involves a small number of apparently simple physical processing steps and a single chemical step: calcining. The flow sheet is deceptively simple, however, because exacting product quality standards and the energy/capital intensiveness of cement manufacture have led to use of highly sophisticated technology for accomplishing each operation. Another important feature of modern cement making is the enormous quantities of raw and finished materials to be handled, which have resulted in some of the largest moving machinery and storage structures of any processing industry.

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*Source: U.S. Bureau of Mines, "Mineral Facts and Problems", Ed. 1980; Fog, M.H., and Nadkarni, K.L., "Energy Efficiency and Fuel Substitution in the Cement Industry with Emphasis on Developing Countries", World Bank Technical Paper, 1983; and various other sources.

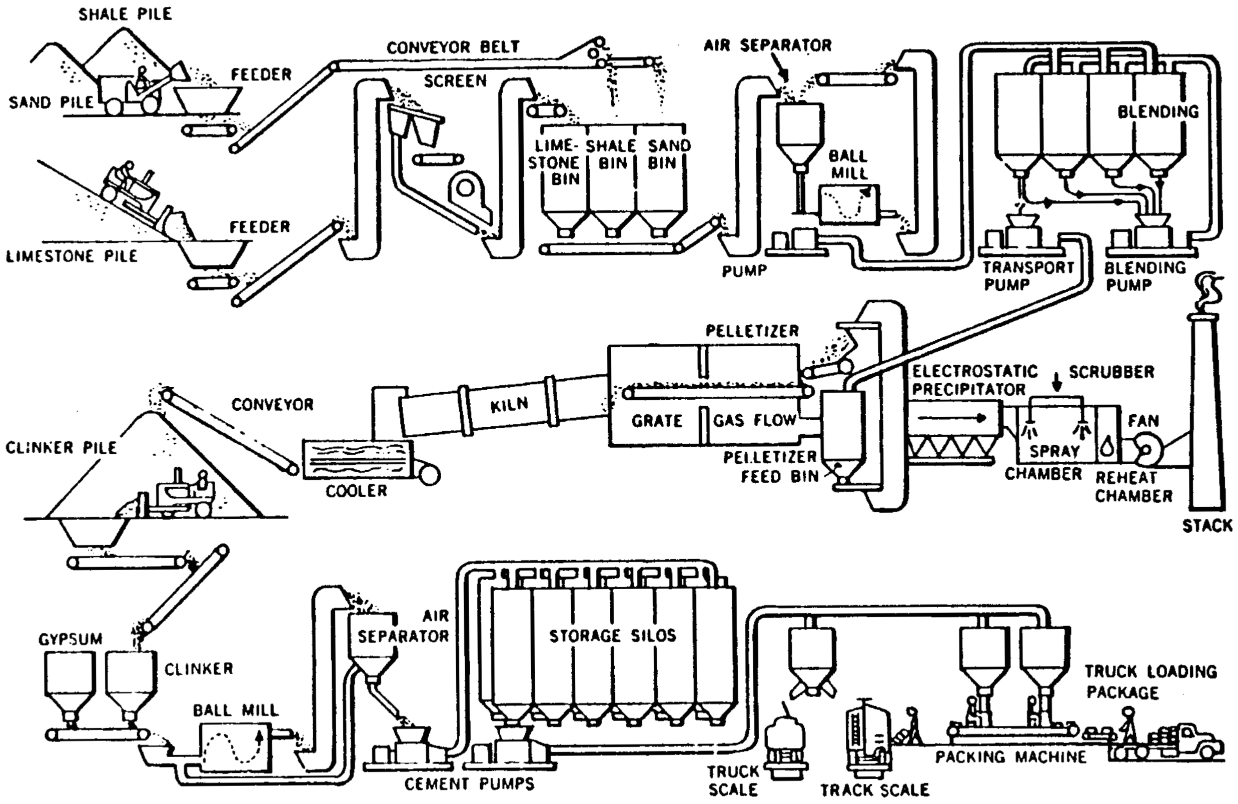

FIGURE III.B-1

LINE DIAGRAM OF CEMENT MANUFACTURING PROCESS

Source: UNIDO, "The Manufacture of Cement and Sulphuric Acid from Calcium Sulphate", ID/63, New York, 1971.

III.B.2.1 Raw Material Preparation

The requirements of a 1,000,000 t/a cement plant per ton of product are:

Limestone/chalk*	1.1-1.25 t/1.5-1.6 t
Clays	0.3-0.4 t
Gypsum	0.05 t
Energy (on average)	
fuel	1.07 million Kcals
electricity	120 kWh
Average installed power	19 W
Area	0.25 sq m
Personnel	0.0007 (1,500 t/man/yr)

*mix proportions depend on relative contents of raw materials.

About 1.5 tons of crushed dry rock are required to produce one ton of cement. The difference in weight primarily represents the loss of carbon dioxide driven off during the calcination process. Because of these large losses, cement plants tend to locate close to their limestone source in order to reduce transportation requirements.

Preparation of raw materials for the kiln involves crushing, grinding, mixing and storage of kiln feed.

Following excavation the rock is loaded on transport vehicles (usually trucks) and hauled to the crushing plant, where it must be reduced by gyratory or jaw crushers to a size suitable for grinding. In a typical limestone crushing plant, the rock is reduced from a size of up to 1.4 meters across to as small as 3 centimeters. Crushing power consumption ranges from 1.5 to 3.5 kWh/ton rock. Crushed rock is transported to the grinding mills by rail, barges, or conveyor belts, depending on the distance and the topographical features of the area.

In general, limestone and shale, clay, etc. are proportioned prior to grinding, although some plants grind the principal raw materials separately and blend them after grinding. The object of grinding is to attain the optimum fineness required for the raw materials to combine during the calcination stage, since the particle size and mixture of raw material fed to the kiln affect the properties of the final product.

Two processes are mainly used in grinding raw materials: the wet and dry processes. In the wet process, the crushed and proportioned raw materials are ground with water, and fed to the kiln as a slurry having typically about 35% moisture. In the dry process, the raw materials are ground, mixed and fed into the kiln in powdered form. In this process, the moisture content of the kiln feed (raw meal) must be reduced to about 0.5% prior to or during grinding. Simultaneous drying/grinding is accomplished by adding a drying compartment to the mill and using the kiln waste gases to remove moisture. In other respects, the wet and dry processes are essentially the same.

Two other, less common raw material preparation processes are also in use: the semi-wet and semi-dry processes. In the semi-wet process the raw meal enters the kiln in the form of plastic cylindrical slugs, having typically a 17-22% moisture content. In the semi-dry process the kiln feed is in the form of small pellets, produced by mixing the dry powdered raw materials with typically 11-14% water.

The choice between the different processes is dictated by various economical and physical factors, such as:

- the specific energy consumption of each process. The dry process has lower energy requirements.
- the physical and chemical characteristics of the raw materials, and mainly the moisture content. The dry processing of raw materials with moisture content over 20% requires large amounts of auxiliary heat. In addition, the wet process may be more economical if wet limestone benefication processing is required.
- the raw material transport alternatives. For example, remote quarries and existing pipelines favor the wet processing.

The raw meal grinding mill is a key equipment item in terms of cost, size, energy consumption, and function. A typical mill can handle 250-300 tons of materials per hour. The basic types of modern grinding mills include ball mills, rod mills, compound mills, air-swept mills, and closed-circuit mills operating with bucket elevators and centrifugal separators.

Both ball and rod mills are horizontal rotating drums with alloy steel liners ranging from 8 to 18 feet in diameter, 10 to 73 feet in length, with 300 - to 8,700-horsepower motors. Ball mills, appropriate for coarse grinding, have a large diameter to length ratio and are charged to about 45% of the volume with steel balls of up to 5 inches in diameter.

Rod mills, best suited for fine grinding, have a small diameter to length ratio, and are charged with steel rods 2 to 5 inches in diameter and nearly equal to the inside length of the mill. In both mills, raw materials are reduced in size by impact and attrition by the grinding media in cascading and cataracting motions while the mill is rotating 15 to 18 revolutions per minute.

Compound mills have a ball compartment and a rod compartment in a single shell and operate by the continuous method, in which finished material is used without any further separation or screening. In the closed-circuit process, a bucket-fed centrifugal separator system follows the mill and returns oversized particles to the mill for regrinding. Closed-circuit systems are more adjustable to specific requirements regarding particle size distribution of the raw meal, a matter of considerable importance in cement manufacture. In air-swept mills, the pulverized material is swept out by a current of air and fed to an air separator for recycling of oversized particles.

After the grinding process, the raw meal is transferred to homogenizing silos and then to storage silos prior to being fed to the calcining system. Figure III.B-2 shows a schematic of the basic operations and equipment of a dry process raw grinding department, while the cement manufacture as a whole is illustrated by Figure III.B-3.

III.B.2.2 Calcination

The kiln system represents the largest capital expenditure of any equipment item in a cement plant, and calcination is the most important operation in manufacturing cement because (a) fuel consumption is the major

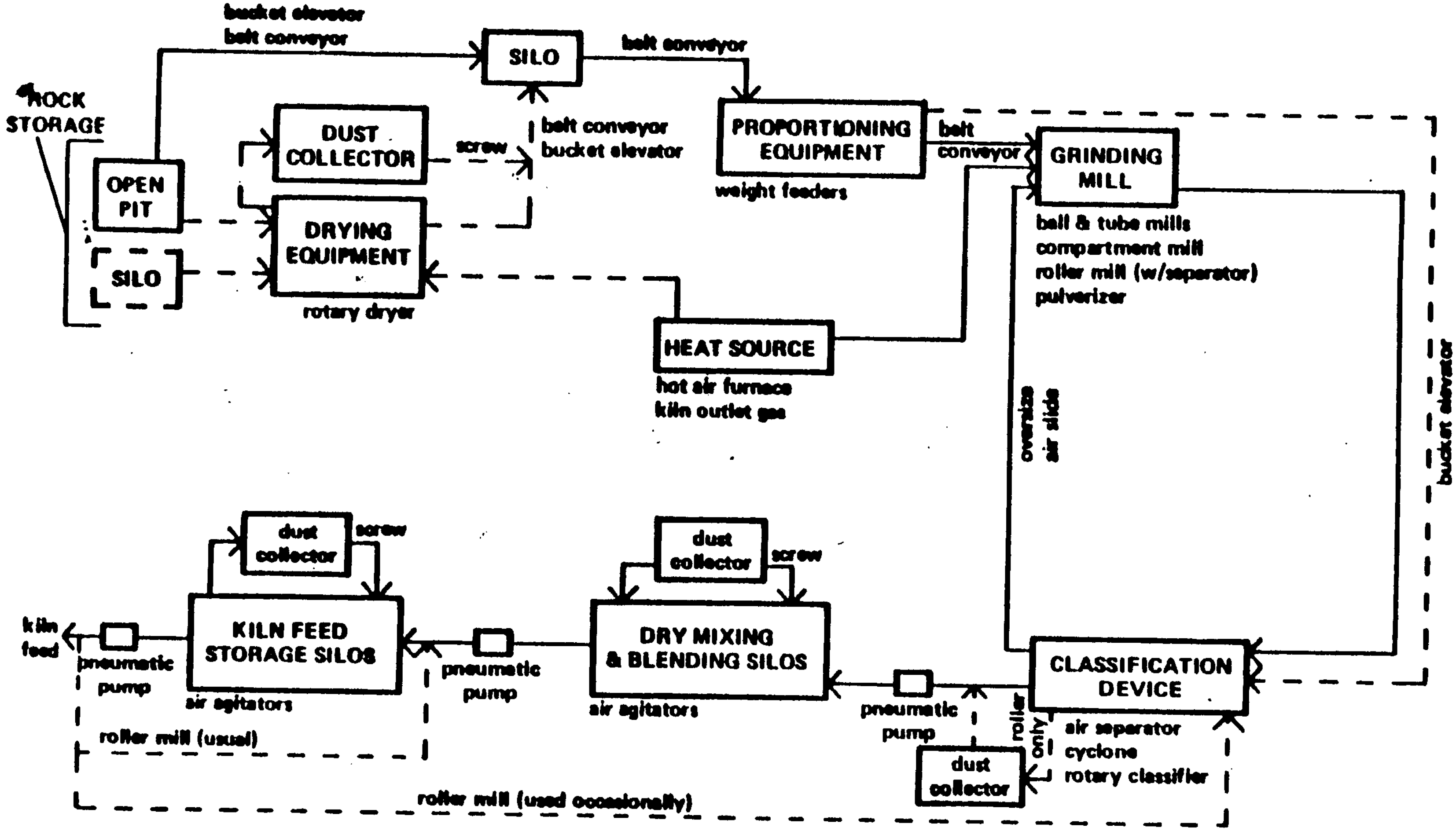

FIGURE III.B-2

RAW GRINDING DEPARTMENT (DRY PROCESS) SCHEMATIC

Source: I.E.E.E. Cement Industry Technical Conference, 1976.

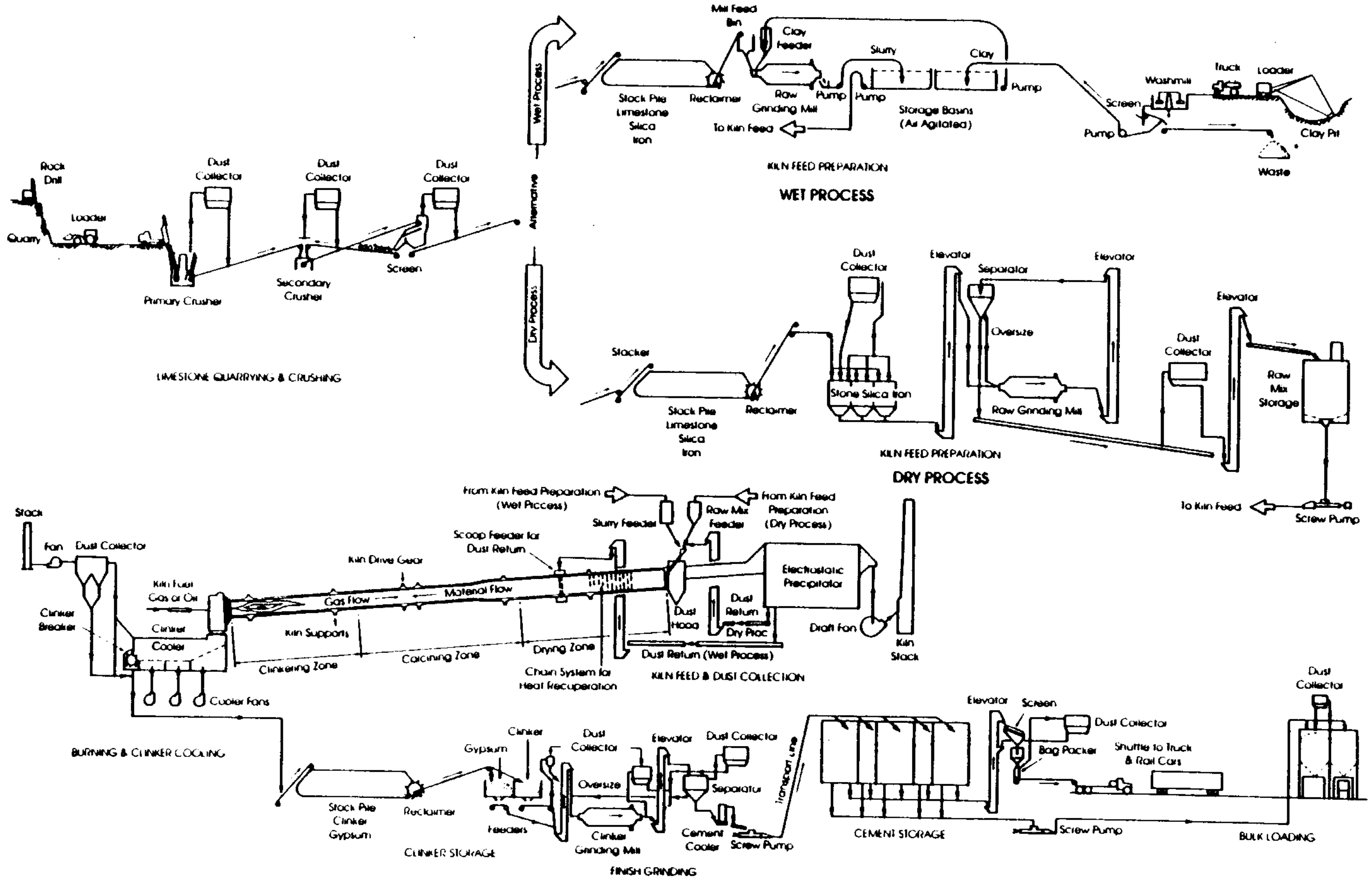

FIGURE III.B-3

MATERIAL FLOWS IN CEMENT MANUFACTURING

Source: Fog, M.H., and Nadkarni, K.L., "Energy Efficiency and Fuel Substitution in the Cement Industry with Emphasis on Developing Countries", World Bank Technical Paper, 1983.

expense in the process, (b) capacity of a plant is measured by kiln output, and (c) strength and other properties of cement depend on the quality of clinker produced.

Two types of kilns are in use: vertical or shaft kilns and rotary kilns. Vertical kilns, common in Europe and some developing countries, are generally only efficient at capacities of up to 100,000 tons per year, and account for only about 5% of world production. The steady trend to economies of scale has led to the development of large rotary kilns with capacities exceeding 1.25 million tons. A rotary kiln is a refractory-lined steel cylindrical shell that rotates around an axis inclined at 3/8 to 1/2 inch per foot. Kilns in the United States range in size from 6 feet in diameter and 120 feet long to 25 feet in diameter and 760 feet long, and rotate at 50 to 90 revolutions per hour. While most large plants use rotary kilns, recent developments of vertical kiln technology have proved commercially attractive for small units and consequently may be of particular application in some developing countries. Small vertical kilns may also be added in parallel with older equipment to increase total plant capacity.

Rotary kilns are amenable to both wet and dry processes, whereas vertical kilns are limited to dry process only. The ground, proportioned and homogenized dry mix or slurry enters the upper or feed end of the rotary kiln and is conveyed by the slope and rotation to the firing or discharge end of the kiln, in counterflow to the hot combustion gases. During passage through the kiln (1 to 4 hours) the feed is exposed to increasingly higher temperatures and is heated, dried, calcined (removal of carbon dioxide from the limestone), and finally heated to about 1500°C, a temperature at which a substance called "clinker" is produced. The quality of the finished cement depends primarily on burning conditions in the kiln.

Modern rotary kilns are fitted with an elaborate system of up to six inter-connected cyclones (usually four or five - see Figure III.B-4) called a <u>suspension preheater</u>, which serves to improve heat transfer between kiln exit gases and incoming raw meal. The preheater is a tall structure, often reaching 85 meters in height. The feed enters the top stage and gradually moves through the cyclones until it enters the rotary kiln. The hot kiln exit gases are simultaneously moving in the opposite direction and the highly turbulent mixing action between the feed and gases promotes efficient heat exchange sufficient to induce 40-50% calcination of the raw feed by the time it enters the rotary kiln.

Introduction of suspension preheater systems resulted in drastically reduced heat consumption and increased productivity in the rotary kiln. For example, a kiln producing 3300 tons per day without suspension preheating would require a diameter of 8 meters and a length of 220 meters, while the same production could be obtained from a 5.5-meter (diameter) x 75-meter (length) kiln equipped with a preheater.

Although preheater systems improve fuel economy, they can have the disadvantage that certain impurities like alkali metal compounds, which are vaporized in the kiln and would usually be removed from the process in the hot kiln exit gases, can be introduced into the raw mix as it is preheated with the recycled kiln gases. To avoid the problem of alkali build-up, the

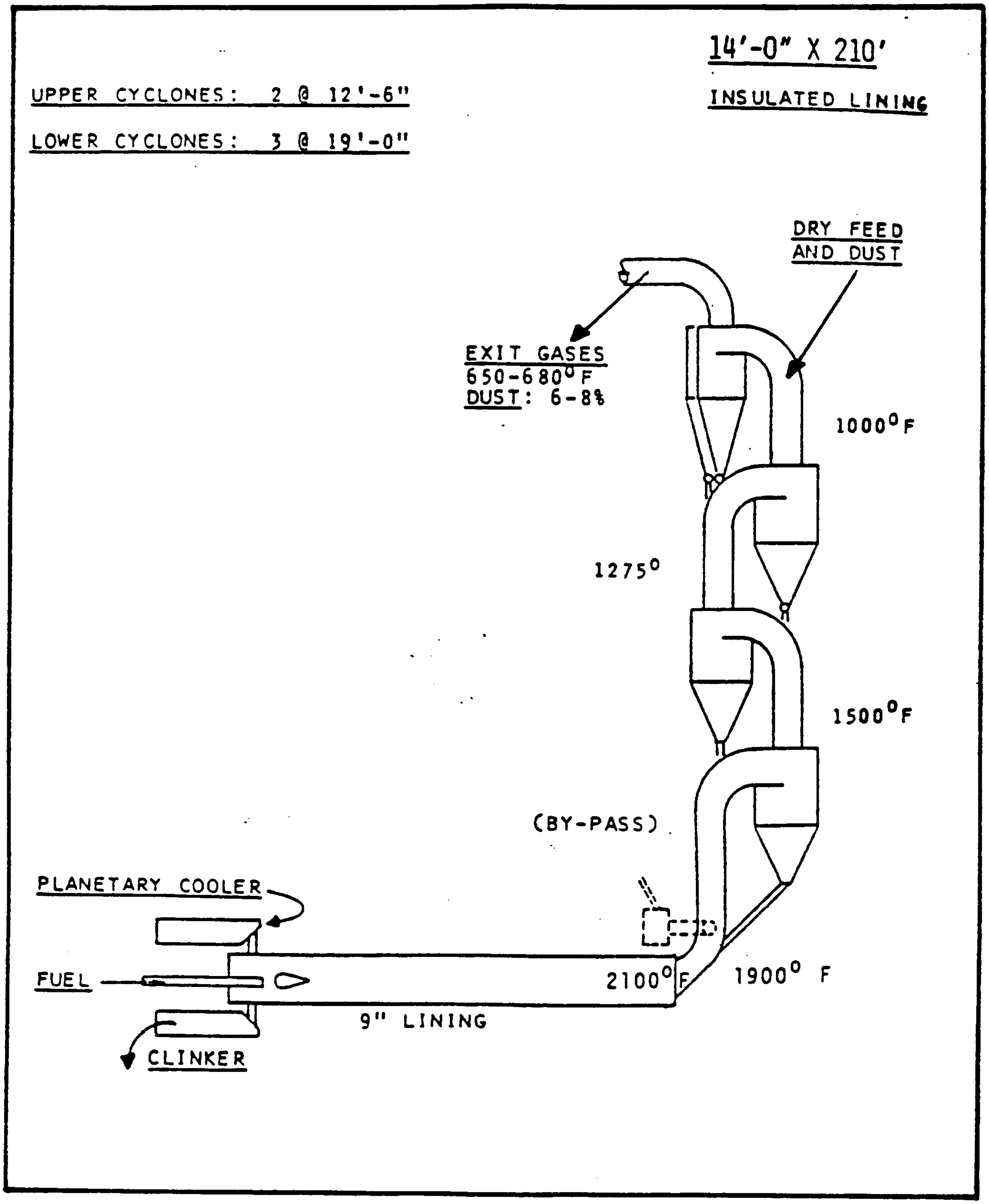

FIGURE III.B-4

FOUR-STAGE SUSPENSION PREHEATER KILN

Source: I.E.E.E. Cement Industry Technical Conference 1976.

suspension preheater design may include a system which bypasses about 5 to 10% of the kiln gases and removes the alkali components.

The idea of using the thermal energy of the hot kiln exit gases to preheat the raw meal has been also applied in the semi-dry processing by the introduction of grate preheater systems. The raw meal in the form of pellets is discharged on to a travelling grate which conveys it toward the kiln inlet. At the same time, the kiln exit gases are passed through the bed of pellets which effects efficient heat exchange to dry, preheat and partially calcine the feed before entry into the kiln. Similar systems are used in the semi-wet processing.

The advent of preheater equipment, either grate or suspension, has allowed the development of two-point fuel firing or precalcining. Precalciner systems or New Suspension Preheater (NSP) systems have one common basis - the degree of calcination of the raw mix entering the rotary kiln is increased by burning a substantial portion (up to two-thirds) of the total fuel requirements in a precalciner vessel which is part of the grate or suspension preheater. In a conventional preheater system, 50% of the heat transfer occurs in the preheater and the raw mix enters the kiln 20-30% decarbonated. With the addition of precalcination, decarbonation is increased to 85-90% and as a result a higher kiln capacity is attained with given kiln dimensions, or for a new installation, the required kiln volume can be reduced by as much as 50%. Since a substantial part of the fuel is burnt outside the kiln, precalciner systems have the major advantage of being able to use low-grade fuels. Other advantages claimed for precalciner systems are: improved brick life for the kiln lining; reduced alkali and sulphate build-up; improved control and kiln stability; more efficient alkali bypass; and reductions in dust emissions. A comparison of production capacity by kiln dimension and processes is shown in Table III.B-1.

III.B.2.3 Clinker Processing

The temperature of clinker discharged from the kiln is reduced in a clinker cooler, serving the dual purpose of lowering the clinker temperature and recuperating the clinker heat for reuse as combustion air inside the kiln. In the United States, most clinker is air-quenched in a travelling or reciprocating grate cooler where cooling air passes through a slowly moving bed of hot clinker.

Finally, clinker is fine ground with gypsum (2-5%) in the case of portland cement, plus other additives such as pozzolan, fly ash, slag, etc., when a different type of cement is being produced.

III.B.3 Energy Consumption in Cement Production*

Cement is a highly energy intensive product, generally requiring between 1,000 and 2,000 megacalories of energy (both fuel and electrical) per metric ton, depending upon the specific manufacturing process. While some other industrial products like steel (7,000 mcals/ton), plastics (20,000 mcals/ton) and aluminum (42,000 mcals/ton) have higher specific energy consumption

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Source: Fog, M.H., and Nadkarni, K.L., "Energy Efficiency and Fuel Substitution in the Cement Industry with Emphasis on Developing Countries", World Bank Technical Paper, 1983.

TABLE III.B-1

COMPARISON OF PRODUCTION CAPACITY BY KILN DIMENSION AND PROCESSES

Process	Kiln Diameter		
	5 m	6 m	7 m
Wet Long	1,000–1,300 tons/day	1,700–2,200 tons/day	3,000–3,500 tons/day
Dry Long	1,500–2,000 tons/day	2,500–3,000 tons/day	4,000–4,500 tons/day
SP	2,500–2,800 tons/day	4,000–4,500 tons/day	5,500–6,000 tons/day
NSP	4,810–5,200 tons/day	8,000–10,000 tons/day	—

SP = Suspension Preheater

NSP = New SP

Source: Three "I" Publications Ltd., "Cement Technology and Plant Engineering. Guide to Japanese Processes and Profile of Firms", 1980.

per ton of product, the total energy consumption for cement manufacture is higher than for most other industries (with the exception of steel and chemicals), on account of the high tonnages of cement produced (the world's cement production in 1981 was about 883 million tons). It has been estimated that in developing countries the cement industry consumes between 2 and 6% of the total fuel and electrical commercial energy consumption, while in some cases this share can be as high as 10%.

In many uses, however, concrete, the end product of cement, is more energy efficient than other building materials (refer to Table III.B-2), and in this aspect the energy consumed in the manufacturing of cement becomes more acceptable. One cubic meter of concrete represents an energy consumption of 450 to 500 mcals.

Table III.B-3 shows the energy consumption at each major manufacturing stage. The two most energy-intensive phases in a cement plant are the pyroprocessing (kiln) and grinding. Pyroprocessing consumes mainly thermal energy in the form of oil, coal or gas, while grinding consumes mainly electrical power. Total thermal energy requirements in pyroprocessing of clinker normally range from about 750 to 2,100 Kcals/Kg of clinker depending on the specific process used and the operating efficiencies of the concerned cement plants. The required electrical power typically ranges from about 80 to 160 kWh per ton of cement, from which about 42% is consumed by clinker grinding. The overall fuel consumption typically accounts for about 75 to 90% of the total primary energy used in a cement plant, and electrical power for the remaining 10 to 25%.

TABLE III.B-2

COMPARISON OF ENERGY INTENSITIES IN END PRODUCTS OF ALTERNATIVE BUILDING MATERIALS

	Unit Energy Consumption (mcals) Using			
	Concrete	Steel	Asphalt	Brick
Building wall (per m^2)	90-100			130-150
Bridge (per m^2)	900	1,900		
Roadway (per m^2)	200		750	

Source: Fog, M.H., and Nadkarni, K.L., "Energy Efficiency and Fuel Substitution in the Cement Industry with Emphasis on Developing Countries", World Bank Technical Paper, 1983.

TABLE III.B-3

ENERGY CONSUMPTION BY MANUFACTURING STAGE

	FUEL			ELECTRICITY			TOTAL	
	Normal Range	Average		Normal Range	Average		Average	
	kcals/kg of clinker	kcals/kg of clinker	toe/ton of cement	kwh/ton of cement	kwh/ton of cement	toe/ton of cement	toe/ton of cement	% share
Quarrying	5-15	10	.0010	2-6	4	.0010	.0020	1
Raw Material Grinding & Preparation				20-40	30	.0075	.0075	6
Pyroprocessing	750-2,100	1,100	.1100	15-30	22	.0055	.1155	82
Clinker Grinding				35-64	50	.0125	.0125	9
Miscellaneous	—	—	—	10-16	13	.0033	.0033	2
Total	755-2,115	1,110	.1110	82-156	119	.0298	.1408	100
% Share in Total			79			21		100

Notes: Averages include weighted averages as appropriate. Average clinker to cement conversion ratio assumed, 1.00:1.04.

Energy equivalents assumed: 1 kwh = 2,500 kcals (based on energy conversion efficiency in modern power plants, though, in specific cases, the conversion efficiency may be as low as 3,500 kcals per kwh); 1 toe = 10^7 kcals.

Source: Fog, M.H., and Nadkarni, K.L., "Energy Efficiency and Fuel Substitution in the Cement Industry with Emphasis on Developing Countries", World Bank Technical Paper, 1983.

The comparative advantages and disadvantages of the different cement technologies discussed in previous sections are summarized in Table III.B-4, while Figure III.B-5 shows the weighted average of thermal energy consumption in the various systems. In general, the dry process consumes substantially lower thermal energy than the wet process, particularly with the preheater/precalciner systems. On the other hand, the dry process entail a higher consumption of electrical power, as the homogenization and pyroprocessing areas in this process contain a large number of fans operating at high pressure drops. However, the significant thermal energy savings in the preheater/precalciner systems offset the increased electrical power consumption several times over. This fact explains the recent switching of cement industry from the wet to the dry process. In 1979, 98.9% of the total Japanese cement output was by the dry process, and only 1.1% by the wet process, while twenty years earlier the wet process had a production share of 38%. Nevertheless, the physical and chemical characteristics of raw materials and fuel, and a variety of other operational factors must be considered in the designing of a cement plant.

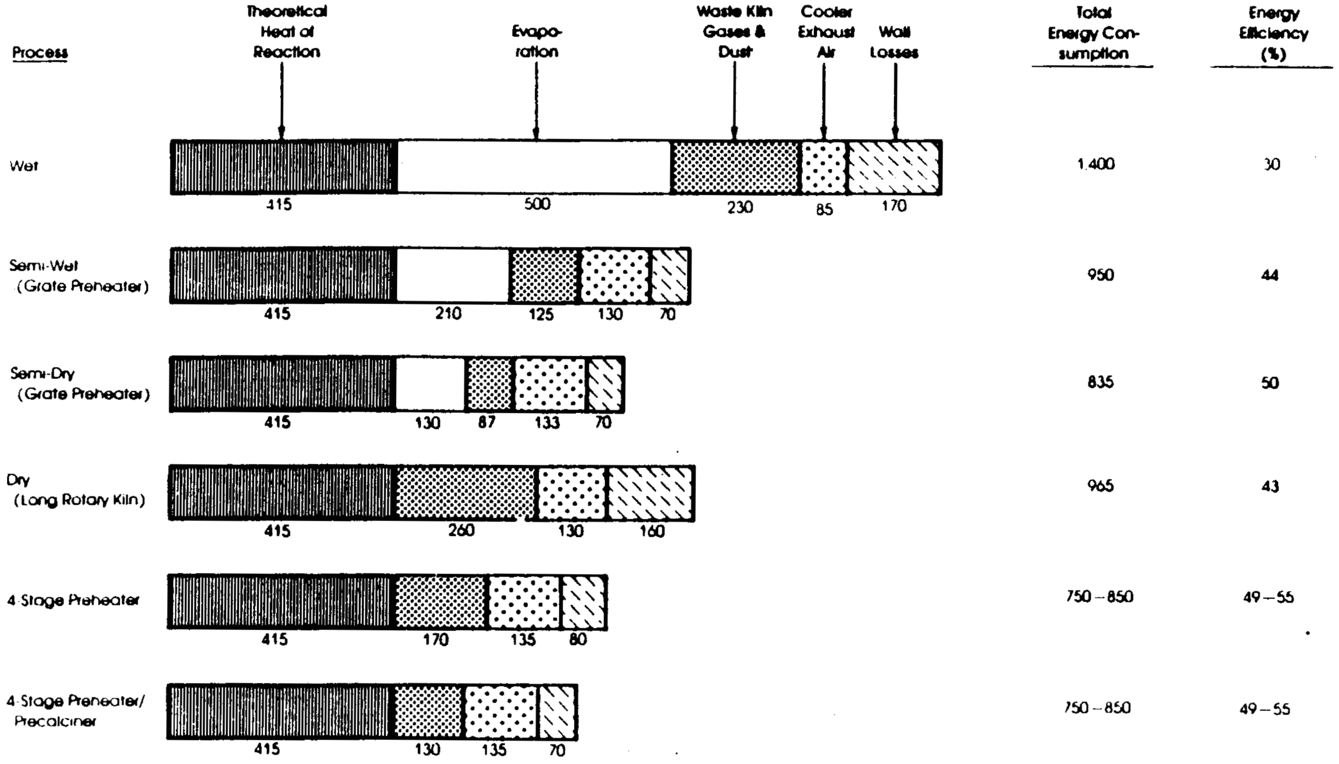
Oil, coal, and gas are the sources of primary energy required by a cement plant. Secondary sources may include low grade fuels such as industrial waste, shredded tires, wood chips, etc., but they can be used only in preheater/precalciner systems. In the last decade, the higher rate of increase in prices of oil and gas has led to a substitution of these two fuels by coal in a number of plants with access to low cost coal. Most of the changes in fuel sources have occurred in industrial countries, where capital and technology for conversion from oil-firing to coal-based systems were available.

TABLE III.B-4

COMPARATIVE FEATURES OF DIFFERENT CEMENT PRODUCTION TECHNOLOGIES

		Kiln Process						
Evaluation feature		Wet	Grate (pellets)	Grate (filtercake)	Long Dry	One stage preheater	4 stage preheater	4 stage preheater w. precalciner
Thermal energy consumption	kcal/kg	1,400	800-900	940-1,060	880-1,000	860-950	750-850	750-850
Electric power consumption in kiln system	kwh/ton	18-27	18-28	18-28	20-22	22-24	27-31	30-34
Availability of secondary heat	Maximum percentage moisture in raw material which can be handled by secondary heat	N/A	4%	N/A	10%	9%	7-8%	7-8%
Sensitivity to raw materials characteristics	(desirable	-	high nodule strength	filterability	-	-	low alkalies low chloride	low alkalies low chloride
	(undesirable	high plasticity	-	-	-	-	-	-
	(critical (area	chain system	preheater grate	filter	-	-	preheater	preheater

Source: Fog, M.H., and Nadkarni, K.L., "Energy Efficiency and Fuel Substitution in the Cement Industry with Emphasis on Developing Countries", World Bank Technical Paper, 1983.



Note Energy efficiency is the percentage ratio of the theoretical heat of reaction to the total energy consumption

FIGURE III.B-5

THERMAL ENERGY CONSUMPTION IN VARIOUS PYROPROCESSING SYSTEMS
(Kcals/Kg of clinker)

Source: Fog, M.H., and Nadkarni, K.L., "Energy Efficiency and Fuel Substitution in the Cement Industry with Emphasis on Developing Countries", World Bank Technical Paper, 1983.

Table III.B-5 shows the significant changes in fuel sources that have occurred since 1974 in selected industrial countries. In oil-fired plants, energy costs usually range between 65 and 75% of the direct operating costs, while in coal-fired plants of similar size, energy costs represent about 60% of the direct operating costs.

III.B.4 Environmental Impact*

Cement plants can result in pollution of air, water, and land resources. The major environmental threat is dust emissions, as particulate matter can originate at most of the cement manufacture operations. The main source of dust is the kiln. Dust removed from kiln gases is primarily a mixture of raw material, and clinker particles. These gases also contain significant quantities of water soluble alkalies, carbon monoxide, sulphur oxides, nitrogen oxides, and lesser quantities of hydrocarbons, aldehydes and ketones.

Larger dust particles can be removed by cyclones or other mechanical devices. Small dust particles can be removed by electrostatic precipitators, bag filters, or wet scrubbers. In most cases, collected dust is recycled to the process for reuse as raw material. However, there are plants where recycling is not feasible, and in these cases, the dust disposal is a serious plant problem.

In some plants, dry dust is mixed with water to make a slurry ("leaching"), which then flows to a clarifier. Clarifier underflow, containing 40 to 60% solids returns to the kiln, while overflow is discharged as waste. Disposal

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*Source: "Environmental Guidelines", The World Bank, Office of Environmental Affairs, 1984.

TABLE III.B-5

SHARES OF DIFFERENT FUELS IN THERMAL ENERGY CONSUMPTION OF CEMENT PLANTS IN SELECTED INDUSTRIAL COUNTRIES (%)

	1974			1980		
	Oil	Coal	Gas	Oil	Coal	Gas
USA	12	44	44	5	75	20
FR of Germany	74	6	20	49	41	10
France	85	4	11	67	20	13
UK	6	80	14	2	97	1
Canada	40	10	50	34	30	36

Note: The shares are based on the oil-equivalents of the different energy sources.

Source: Fog, M.H., and Nadkarni, K.L., "Energy Efficiency and Fuel Substitution in the Cement Industry with Emphasis on Developing Countries", World Bank Technical Paper, 1983.

of either the clarifier overflow, or the entire wet dust slurry with no recovery or reuse, and the aqueous effluents from wet scrubbers are the major wastewater sources in cement manufacture. Large amounts of water are also used for process cooling and other auxiliary activities, but from the environmental standpoint, this water is normally of minor significance.

In all wet process plants, except those leaching collected dust, wastewaters can be used to prepare slurry feed to the kiln, and thus no water effluent is produced. In leaching plants, waste water treatment is effected by neutralization and carbonation. Although removal of dissolved solids is generally not practiced for leachate streams, methods such as evaporation, precipitation, ion exchange, reverse osmosis, and electrodialysis can be quite effective. In dry process plants, recycling of liquid effluents is possible if cooling towers or ponds are used.

Solid materials, including wastes, are generally stored in piles on plant property. These can be contained or treated in order to prevent rain runoff into adjacent waters and contamination of groundwater sources.

III.B.5 Seaborne Cement Transport and Handling

Seaborne cement trade was about 42 million tonnes in 1982 including substantial short-haul exports. Cement products can be shipped in the form of bulk clinker, bulk finished cement, or bagged cement. The physical form of shipment determines the ship type used to carry the product. Bagged cement has traditionally been shipped in general cargo or multi-purpose ships of up to 15,000 DWT or when unitized, in small handy-sized bulk carriers of up to about 30,000 DWT.

Handling of cement clinker, apart from the need to keep it reasonably dry, presents no major problems. It is shipped in small or handy sized bulk carriers, say up to 35,000 DWT, and is loaded or discharged by grab. Clinker is shipped in as large a volume as possible because freight costs frequently exceed cargo value.

Bulk cement, however, requires special treatment. End users are generally very particular about the quality of the product which is sensitive, by its desired properties, to moisture. It also has a natural angle of repose of 45 degrees so that the ship's hold has to be constructed steeply raked to clear it completely when discharging. As cement has a stowage factor of 1.5 t/cu m, the hold has limited capacity for less dense cargoes. In consequence, a specialized fleet of "cement carriers" has developed.

Cement carriers use special purpose loading and discharging equipment to protect the cement from the elements while efficiently conveying the material between quayside silos and the ship's hold. This equipment may be either mechanical or pneumatic and installed at quayside or on board the ship.

Cement is a traditional short-haul trade due to its low unit value. The longest regular voyage in the cement trade is between Japan and the Middle East. In consequence, a very high proportion of bulk cement shipments are made in small (usually self-unloading) cement carriers of less than 10,000 DWT.

However, the increase in demand for cement imports in the last decade, especially from the oil producing nations, initiated mid- and deep-sea routes. The economies of scale encountered in these longer voyages in conjunction with the sharp rises in shipping costs caused shipping of larger volumes of cement. Thus, investments in bulk terminal facilities became financially viable, especially as a significant share of the trade has always been controlled by the cement manufacturers, and larger cement carriers of up to 45,000 DWT were built.

Of the larger vessels, some are conversions and others are newbuilds designed for the bulk cement trade. Two 44,800 DWT combination carriers delivered in 1981, the Castillo de Javier and the Castillo de Monterrey, are the largest purpose built cement carriers in the world. They are also designed to allow carriage of cargoes other than cement. Two of six holds are equipped with pneumatic bulk screw systems and have a capacity of nearly 40,000 tons cement between them. The remaining four holds are left empty if cement is carried or else are loaded with standard bulk cargoes such as coal, grain, pellets, etc. on backhaul voyages.

The deadweight distribution of the world cement carrier fleet is given in Table III.B-6, and the growth of the 10,000 DWT fleet between 1972 and 1982 is shown in Table III.B-7. As shown in Table III.B-6, about 50% of the cement carrier fleet capacity is composed of ships less than 10,000 DWT. These ships, engaged in domestic and short-haul shipments, are usually self-unloaders, vessels with their own discharge equipment installed on board so that they can operate independently of handling gear offered at the discharge port. Employment of such ships in cement transport is often advantageous, particularly in cases where

- cargo is to be discharged at a new location where no adequate shoreside equipment is available

TABLE III.B-6

VESSELS IN THE CEMENT CARRIER FLEET (ABOVE 1,000 DWT) 1982

DWT	No. of Vessels	%	'000 DWT	%
1,000 - 4,999	111	46	408	17
5,000 - 9,999	84	35	564	31
10,000 - 14,999	20	8	242	13
15,000 - 19,999	7	3	118	6
20,000 - 24,999	5	2	107	6
25,000 - 29,999	4	2	103	6
30,000 - 34,999	1	-	34	2
35,000 - 39,999	5	2	192	10
40,000 +	4	2	176	9
TOTAL	241	100	1,844	100

Source: H.P. Drewry Ltd., "World Seaborne Cement Trade, Transport and Handling", 1983.

TABLE III.B-7

VESSELS IN THE CEMENT CARRIER FLEET (ABOVE 10,000 DWT) 1972-1982

	1972		1977		1982	
DWT	No.	000 DWT	No.	000 DWT	No.	000 DWT
10,000 - 14,999	8	92	13	147	20	242
15,000 - 19,999	6	101	8	132	7	118
20,000 - 24,999	3	62	6	127	5	107
25,000 - 29,999	-	-	2	51	4	103
30,000 - 34,999	-	-	1	34	1	34
35,000 - 39,999	-	-	-	-	5	192
40,000 +	-	-	-	-	4	176
TOTAL	17	255	30	491	46	972

Source: H.P. Drewry Ltd., "World Seaborne Cement Trade, Transport and Handling", 1983.

- volumes are too small to warrant installing shoreside equipment;
- multiple discharge ports would require several shoreside installations, versus one for a self-unloader;
- large vessels are excluded from port by draft restrictions and can be loaded or unloaded offshore by small self-unloaders plying between shore and large vessels; and
- dust pollution and climatic conditions require enclosed unloading systems.

Today's self-unloading systems offer high capacity loading up to 1,200 tonnes/hour and discharging up to 1,000 tonnes/hour.

In recent years, with the rapid expansion of some economies and high investment construction projects, floating transhipment terminals have found increasingly wide use in the cement trade. In some cases, they also incorporate bagging plants. While some of these are specially constructed vessels, others are converted bulk carriers. The major advantages of these facilities are the speed of installation (a bulk carrier can be converted into a floating terminal within as little as three months), and the ability to be moved to other location if the facility is no longer required at that port.

III.C Plant Descriptions

III.C.1 New Cement Works in Indonesia

Location: Lho'nga, northern Sumatra (see Figure III.C-1)

Owner: Semen Andalas Indonesia Co.

Start-up: 1983

Output: 1 million metric tons per year

Logistics: Plant is located in a previously undeveloped coastal area in the vicinity of limestone and shale deposits. Present roads and bridges in the area allow local distribution of 100,000 tons product/year. The remainder is transported in bulk form from the plant's marine terminal to Belawan, a port near Medan, which is capital of northern Sumatra and the major market area. Reportedly, two ships of 5000 tons deadweight will be operating a five-day shuttle service between Lho'nga and Belawan.

Site: Since the soil in the flat central area did not have adequate bearing capacity for a heavy plant, a hill adjacent to the quarry had to be levelled to obtain a site with adequate projected area to locate all heavy equipment foundations on rock. Excavation material (450,000m^3) was used for sitefill and for harbor breakwater construction. In addition to the cement works, a captive power plant had to be built at the site. Total area is about 25 hectares, including expansion capability for another kiln and power station.

Plant layout: See Figure III.C-2.

Raw materials delivery: An 800 tph single rotor hammer crusher feeds limestone to an in-works stockpile. Shale is trucked along a 3.5 Km road to an in-works double rotor roll crusher with a capacity of 450

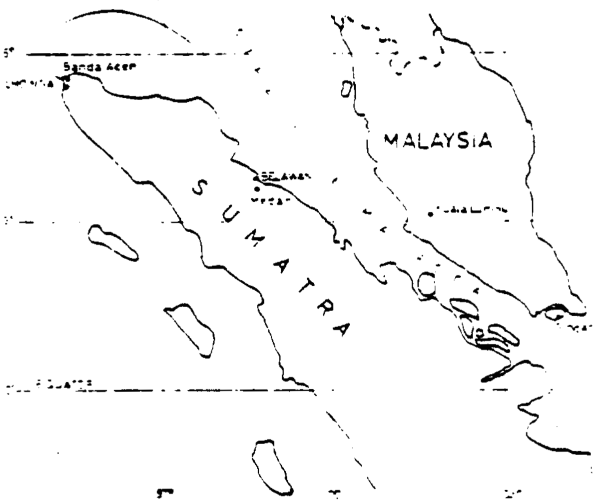


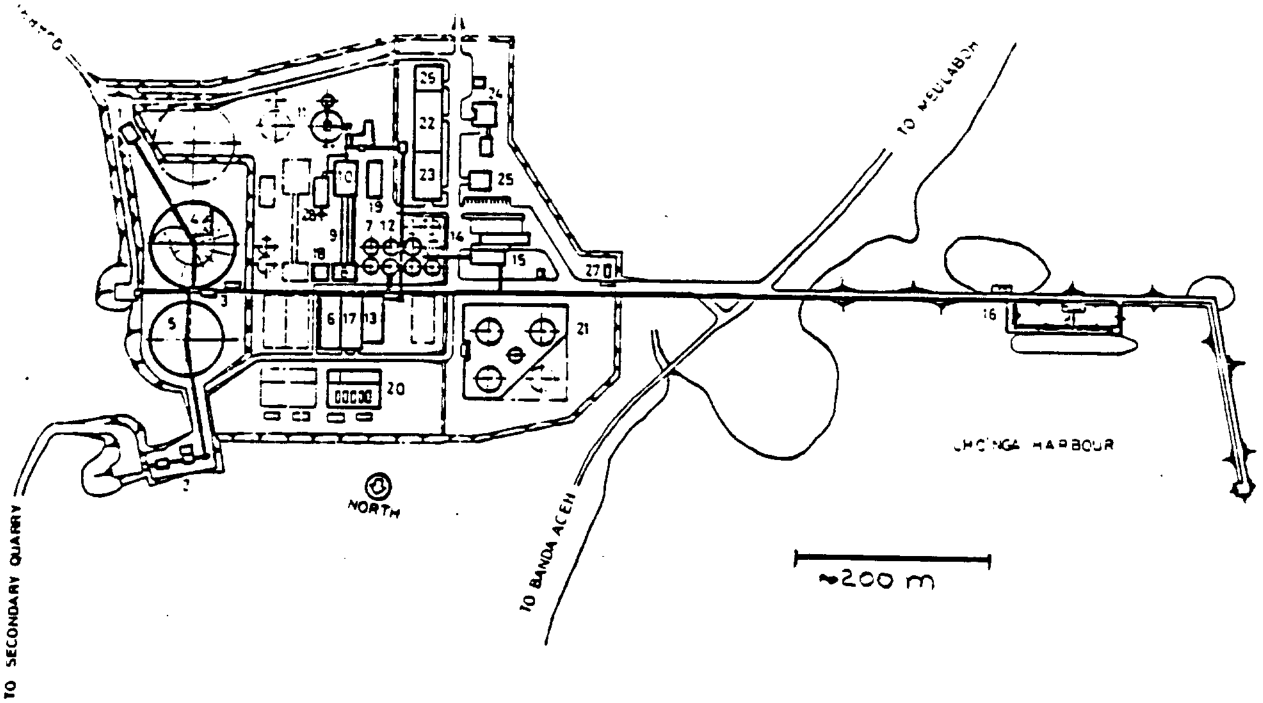
FIGURE III.C-1

LOCATION OF THE SEMEN ANDALAS WORKS

LHO'NGA AND BELAWAN

Source: P. Byland and B. de Quervain

Zement-Kalk-Gips, Nr. 7/1982



1 Limestone crusher
2 Siltstone shale crusher
3 Additive storage
4 Limestone stockpile
5 Siltstone shale stockpile
6 Raw mill
7 Raw meal blending and storage silos
8 Suspension preheater
9 Rotary kiln
10 Burner building
11 Clinker silos
12 Gypsum silos
13 Cement mills
14 Cement silos
15 Packing plant
16 Cement, gypsum and fuel oil transport
17 Electro-static precipitator, cooling tower
18 Compressor room
19 Technical centre
20 Power station
21 Oil tanks
22 Workshop
23 Store
24 Office
25 Utility building
26 Garage
27 Gate house
28 Stationary gravel bed filter
— · — · — Extension

1 Kalksteinbrecher
2 Brecher für Schluffmergel
3 Lager für Zusatzmaterialien
4 Lager für Kalkstein
5 Lager für Schluffmergel
6 Rohmühle
7 Rohmehl-Misch- und Lagersilos
8 Schwebegaswärmetauscher
9 Drehofen
10 Brennerhaus
11 Klinkersilo
12 Gipssilo
13 Zementmühlen
14 Zementsilos
15 Packanlage
16 Zement-, Gips- und Schweröl-Transport
17 Elektrofilter, Kühlturm
18 Kompressor-Raum
19 Leitstand
20 Kraftwerk
21 Öltanks
22 Reparaturwerkstatt
23 Lager
24 Büro
25 Nutzgebaude
26 Garage
27 Pfortnergebaude
28 Stationares Kiesbettfilter
— · — · — Erweiterung

FIGURE III.C-2

LAYOUT OF THE LHO'NGA CEMENT WORKS

Source: P. Byland and B. de Quervain

Zement-Kalk-Gips, Nr. 7/1982

tph.

Raw materials storage: The crushed limestone stockpile is uncovered. It is circular, with an 80 meter rail diameter and 30,000 ton capacity. Stacker and reclaimer handling rates are 1200 and 240 tph respectively.

The crushed shale stockpile has a 72 meter rail diameter, is covered, and holds 20,000 tons. Stacking capacity is 600 tph and reclaiming is 110 tph.

Reclaimed limestone and share are weighed at the discharge from their respective stockpiles and directly fed to the raw mill without the use of intermediate hoppers.

Raw mill: The raw material mill has the following characteristics:

- type - double compartment tube mill
- maximum feed size - 15.39 m shell
  24.35 m total including drying chamber
- diameter - 4.98 m inside shell
- drive - 2 x 2500 KW twin pinion girthgear
- circulation fan - 5200 m^3/min at 110°C, 30 mbar
- bucket elevator - 1200 t/h, 40 m height

Raw meal homogenization/storage silos: Two homogenizing concrete silos with a capacity of 2 x 1800 t and a diameter of 13 meters are used. The homogenized meal is stored in concrete storage silos with a capacity of 2 x 5200 t and diameters of 13 meters.

Calcination: The unit is equipped with a 4 stage double string cyclone type preheater with a precalciner. The rotary kiln has a 4.4 meter inside diameter, is 68 meters long, and lies at 3.5% incline. Its rated output is 3000/3300 t/d.

Dust emission control: The total cost of all the dust collection equipment is $12 million (US) or 12% of the cost for the entire turnkey package.

Clinker storage: Clinker is cooled to 80°C above ambient temperatures on a 102 m^2 horizontal grate cooler and then conveyed to a storage silo of 30,000 ton capacity, 30 meters in diameter, and 40 meters high.

Cement grinding/storage: The cement grinding plant consists of two three-compartment air-swept ball mills with a capacity of 80 t/h each and drives rated at 2900 KW each. The mills have shell lengths of 13.6 m and inside diameter of 4.0 m. From the mill, cement is conveyed pneumatically to two concrete silos of 6000 t capacity each. They have an inside diameter of 13 m and are 35.5 m high.

Product dispatch: Most of the cement is conveyed to the marine terminal by means of a 6000 tph belt conveyor (also reversible for 360 t/h gypsum unloading) which is 692 meters long, 1.05 m wide, and travels at 2.44 m/sec. From hoppers located at the harbor, cement is pumped into bulk cement ships which supply the required compressed air from on-board compressors. Ships are loaded by 4 screw pumps of 150 t/h capacity (80 tph discharge) each.

Belawan Silo Station: Eight silos of 2300 ton capacity (each). Silos are 10 meters in diameter and 26 meters high. The four cement packers have a capacity of 2000 bags per hour each, and the bags are loaded onto trucks by means of 4 automatic and 4 manual loaders. The station also has a mobile loader for bulk shipments.

Power Station: The power station is equipped with five diesel generator sets, including one stand-by. The generators burn heavy oil or diesel oil and have an output of 7750 KVA (6200 KW at 0.8 power factor). They are cooled by a semi-closed circuit type with seawater/treated water heat exchanger.

Voltage distribution is 6.6 KV, 50 Hz, 3-phase 3-wire. Transformers for main low voltage distribution are 6.6 KV/.38KJ with ratings between 1000 and 1500 KVA.

Lho'nga Harbor: The landing jetty is designed to accommodate 10,000 ton BRT ships. A main breakwater of 200 meters total length was positioned normal to the prevailing south-west winds. A 1:60 scale model morphologically representing about 1.7 Km^2 of harbor area was constructed at Hanover University (Franzius Institute) to determine the probable availability for vessel loading/offloading given the layout and wave characteristics. With a maximum ship movement of 50 cm, the evaluation showed that the critical wave heights and directions would affect the mooring and loading/unloading work on the jetty for a total of only 9 days per year.

Another test at 1:30 scale-down was carried out to determine breakwater stability. A covering of 32-ton tetrapods laid on a slope of 1:1.5 along the breakwater and 1:2 at the breakwater head, with packing density of 19 units per 100 m^2 was required for achieving adequate stability.

Belawan Harbor: Belawan lies at the mouth of several estuaries and as a result has very poor soil conditions: a water-saturated silt layer about 15 meters thick lies on a 2-3 meter thick sand layer, under which is a 30-meter thick water-saturated clay layer. Large unpredictable settlements would be expected at specific loads greater than 30 KN/m^2. Since ground pressures under the storage silos were calculated at 120 KN/m^2, soil consolidation operations were required. Water extraction was carried out on the top silt layer over a surface of 88 m x 54 m, on which a sand layer was deposited to a height of 13 meters.

Plant erection: Cargo was delivered by liner to Singapore, where it was loaded onto barges, transported to the site, and offloaded at a temporary jetty built in a nearby river mouth. The 150-ton crawler cranes being used in construction were also used to lift pre-assembled plant parts. The erection weight of steelwork, machines, and electrical parts totalled 15,000 tons.

Construction costs:

1.	turnkey portion, with a supplier credit of US$60 million (including power plant, harbor, silo stations, packing plant, paper sack factory)	US$135.0 million
2.	mobile quarry equipment	US$ 6.0 million
3.	landrights, housing development	US$ 10.0 million
4.	duties, taxes, finance, working capital	US$ 23.0 million
5,	engineering and pre-operational management	US$ 11.0 million
6.	contingencies	US$ 15.0 million
		US$200.0 million

The letter of intent was issued on 14 March 1980 and the contract awarded on 9 June 1980, with a contractual construction period of 33 months.

III.C. 2 Cement Plant

Location: Tilbury Island, in the south arm of the Fraser River (see Figure III.C-3), approximately 34 Km south of Vancouver.

Owners: Genstar Cement Limited

Start-up: 1978

Output: 1 million tons/year

Flowsheet: See Figure III.C-4

Raw materials: All major raw materials are delivered by barges ranging in capacity from 4000 tons to 11,000 tons.

Discharging: Front-end loaders move the materials onto a conveyor system at rates up to 1000 tph. Self-unloading barges are recommended, however, to avoid the need for skilled front-end loader operators.

Product shipment: Cement barges and ocean-going vessels of up to 10,800 tons are handled at the dock with loading rates of 250-500 tph. Clinker is shipped by a specially designed self-unloading barge, which is loaded via conveyor at rates up to 700 t/h.

Raw material storage: All raw materials except those for masonry cement are stored separately in a covered A-frame storage building which is 59 m x 215 m, with a capacity of about 100,000 t. Material is individually reclaimed using a portal reclaimer of 650 t/h.

Electrical power connections: See Table III.C-1. If all systems were allowed to operate together, a peak load of 23 MWs would result.

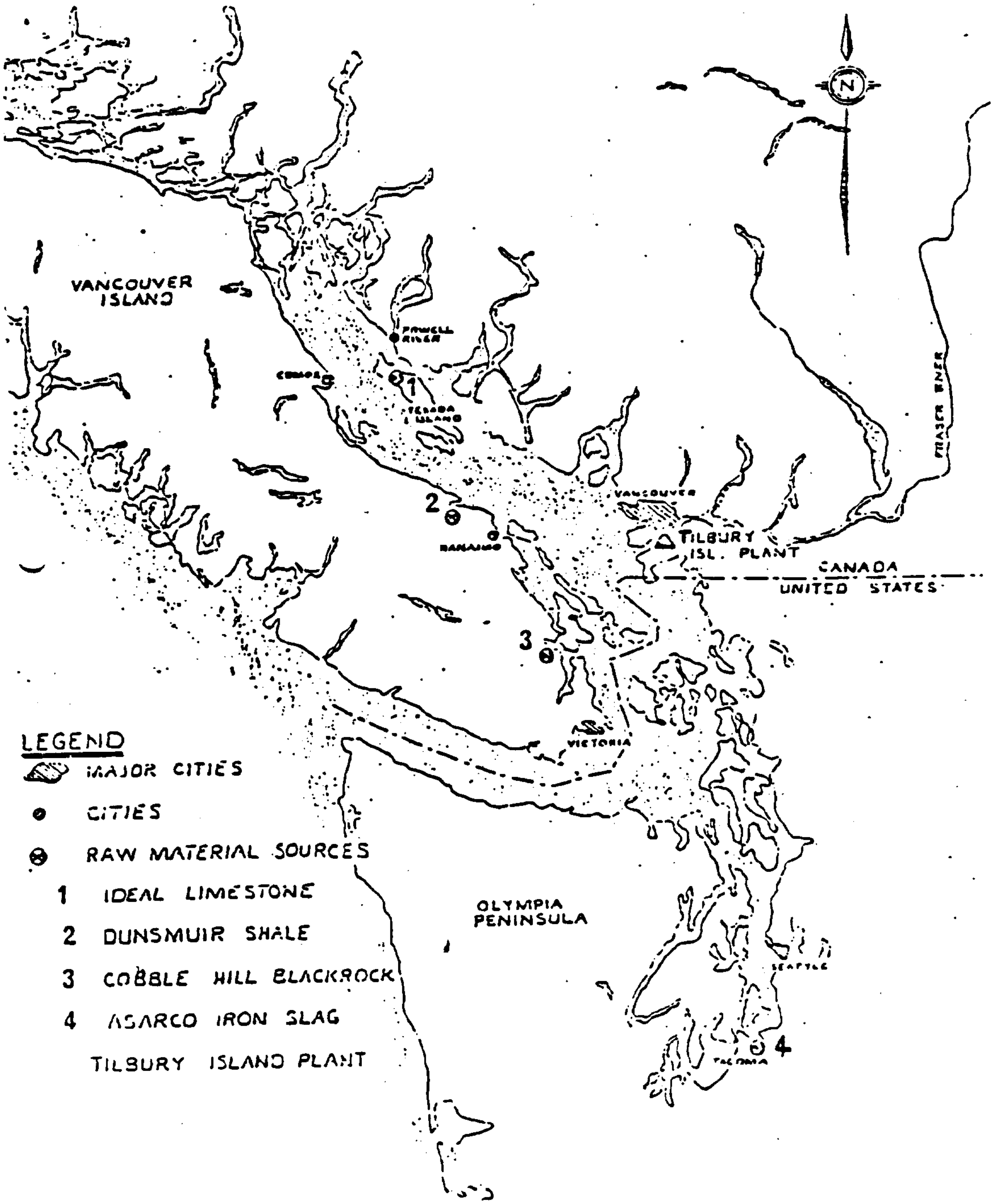
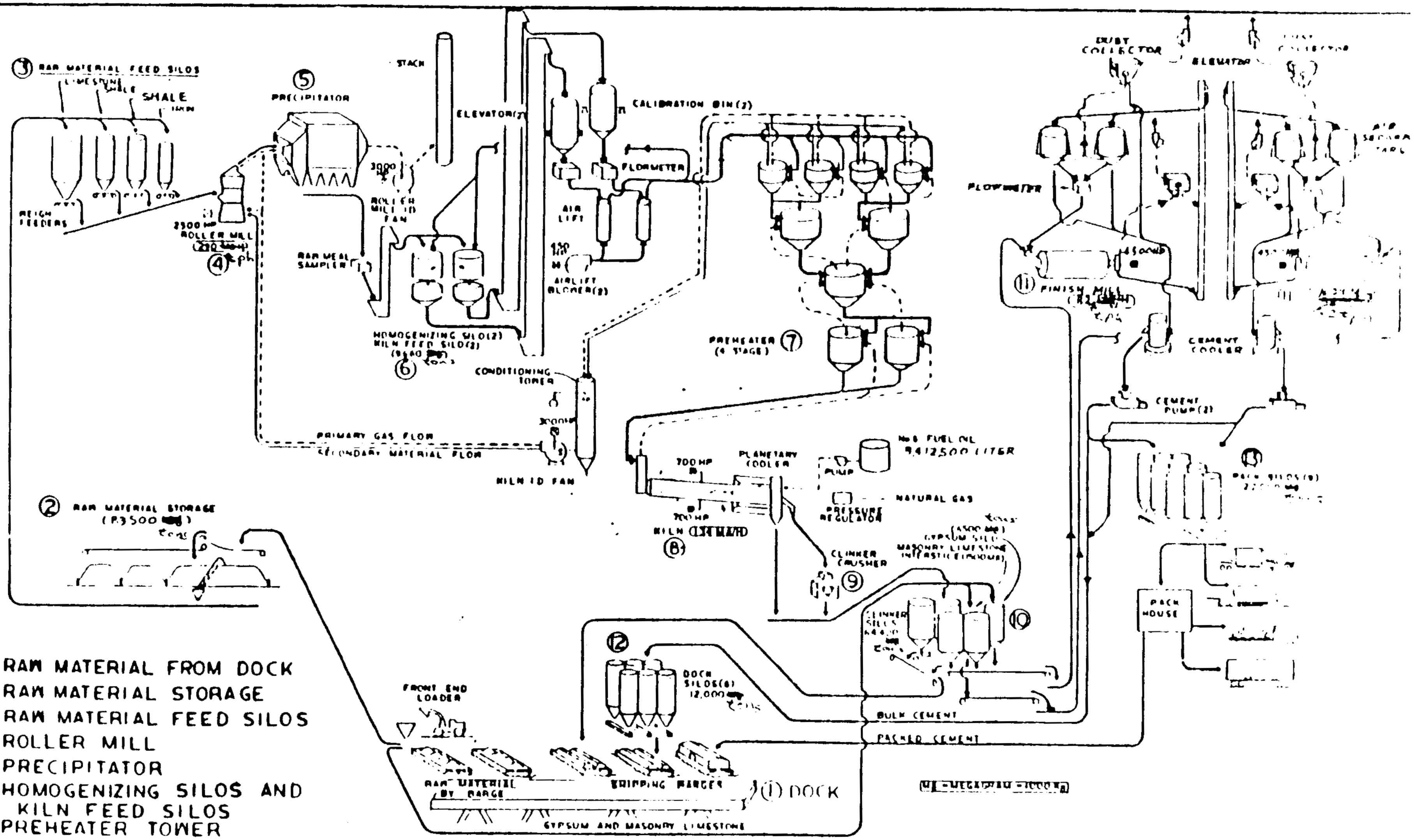


FIGURE III.C-3

LOCATION MAP OF THE GENSTAR CEMENT LTD.

PLANT AT TILBURY ISLAND, CANADA

Source: I.E.E.E. Cement Industry Technical Conference, 1979.



① RAW MATERIAL FROM DOCK
② RAW MATERIAL STORAGE
③ RAW MATERIAL FEED SILOS
④ ROLLER MILL
⑤ PRECIPITATOR
⑥ HOMOGENIZING SILOS AND KILN FEED SILOS
⑦ PREHEATER TOWER
⑧ KILN
⑨ CLINKER CRUSHER
⑩ CLINKER SILOS, GYPSUM SILO, AND MASONRY LIMESTONE SILO
⑪ FINISH MILLS
⑫ DOCK SILOS
⑬ PACK HOUSE AND PACK SILOS

FIGURE III.C-4 FLOW SHEET - GENSTAR CEMENT LTD. - TILBURY PLANT

Source: I.E.E.E. Cement Industry Technical Conference, 1979.

TABLE III.C-1

APPROXIMATE HORSEPOWER AVAILABLE AND IN USE FOR TILBURY ISLAND CEMENT PLANT OPERATION

Activity	Connected HP	HP in Use
1. Raw material unloading - three separate materials are conveyed on this system to different locations. One material is transported at a time.	475	360
2. Reclaiming	425	314
3. Roller mill	6180	4635
4. Homogenization/kiln feed	2360	1760
5. Kiln drive	5490	4120
6. Finish mill 1	6200	5890
7. Finish mill 2	6200	5890
8. Clinker barge loading	250	165
9. Packing and truck loading	500	160
10. Cement barge loading (pneumatic, 2 lines with 1250 HP per line)	2500	2375
TOTAL	30580	25669

Source: I.E.E.E. Cement Industry Technical Conference, 1979.

III.C.3 Cement Plant

Location: Sandchok, Korea

Owners: Tong Yang Cement Co.

Start-up: 1938, expanded by addition of two 900,000 MT/yr kilns in 1975.

Output: 2.8 million tons per year

Layout: See Figure III.C-5

Plant features: Before the latest expansion, the plant totalled 1 million tpy porduction, using three kilns and several raw and finish grinding mills. The 1975 addition provides 1.8 million tons per year using twin preheater-type kilns, electrostatic precipitators, two 5000 hp raw grinding mills with air separators and rotary driers, and three 5000 hp finish grinding mills.

Quarries: Two new quarries were developed. One has a 1000 tph primary gyratory crusher. After secondary crushing, raw material is conveyed to the limestone storage area. The other quarry includes a new 500 tph jaw crusher and a relocated 500 tph supplementary jaw crusher. Ten overland belt conveyors transport the limestone and other crushed raw materials to the stacking area. These belts provide 76 to 470 meters of transport across a mountainous terrain to the plant site.

Principal equipment: See Table III.C-2.

Power distribution: The total plant (old and new section) includes 90,000 HP of connected load, served from three 154 KV transformers. Transformer ratings are given in Table III.C-3.

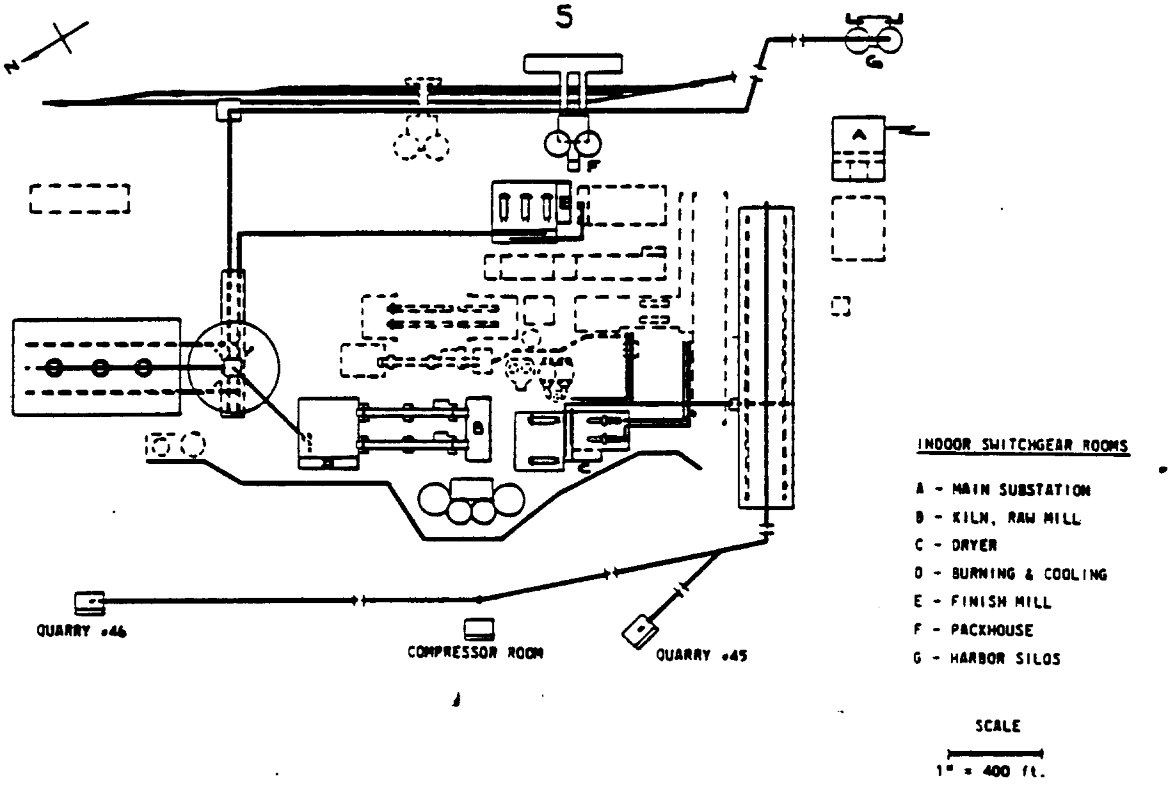


FIGURE III.C-5

PLOT PLAN - SAMCHOK PLANT

Source: I.E.E.E. Cement Industry Technical Conference, 1976

TABLE III.C-2

PRINCIPAL EQUIPMENT AND DRIVES AT THE SAMCHOK PLANT

EQUIPMENT	SIZE, EACH	DRIVE, hp
Quarry 45 Gyratory Primary Crusher	1000 MT/h of 6" rock	250
Quarry 46 Jaw Primary Crusher	500 MT/h of 6" rock	200
Quarry 46 Jaw Primary Crusher	500 MT/h of 6" rock	200
Quarry 45 Hammermill Secondary Crusher	500 MT/h 6" rock to 90% -1"	400
Quarry 45 Hammermill Secondary Crusher	500 MT/h	600
Quarry 46 Hammermill Secondary Crusher	500 MT/h	600
Quarry 46 Hammermill Secondary Crusher	500 MT/h	600
1 Limestone Storage Pile	136,000 MT	-
20 Limestone Storage Reclaiming	200 MT/h Underpile Vibrating Feeders	
2 Rotary Driers	55 MT/h	125
2 Raw Air Separators	240 MT/h	500
2 Raw Ball Mills 2 Comp't., 13'6" x 45'		5000 Syn.
2 Blending & Storage Silos	18600 MT	-
2 Preheater Kilns	2200/3000*MT/d	500
2 Grate Coolers	2200/3000*MT/d	3-30
4 Preheater (ID) Fans	272000M^3/HR @ 343°C & 940 mm H20.	1500
1 Clinker Storage Pile	217000	
22 Clinker Reclaiming	200 MT/h Underpile Feed Gates	
3 Finish Air Separators	100 MT/h	500
3 Finish Ball Mills 2 Comp't., 13'6" x 45'	100 MT/h at 3200 Blaine	
2 Cement Silos	10000 MT	-

* Future rating when flash calcining is added.

Syn = Synchronous motor with clutch.

Source: I.E.E.E. Cement Industry Technical Conference, 1976.

TABLE III.C-3

SUBSTATION TRANSFORMER RATINGS AT THE SAMCHOK PLANT

		VOLTAGE kV	TRANSFORMER MVA	% IMPEDANCE
Main Substation	(2)	154-13.8	30/33.6	12.5
	(1)	154-66	25	12
4160V by departments				
Raw mills. blending and kilns	(2)	13.8-4.16	7.5-8.4	4.5
Finish mill separators	(1)	13.8-4.16	3/3.6	4.5
Quarries, crushers, compressors	(3)	13.8-4.16	3.0	4.5
Relocated crushers	(1)	4.16-3.3	1.5	4.5
480V by departments	(6)	13.8-0.48	2.0	5
	(3)	13.8-0.48	1.5	5
	(1)	13.8-0.48	1.0	8
	(6)	13.8-0.48	0.75	5
Kiln Drives	(2)	4.16-0.48	0.75	5.75
Harbor	(1)	13.8-0.48	0.75	5
	(1)	13.8-0.48	1.0	8

Source: I.E.E.E. Cement Industry Technical Conference, 1976.

III.D Cement Industry Statistics

List of Tables

TABLE III.D-1

CEMENT PRODUCTION AND CONSUMPTION IN SELECTED COUNTRIES

	Production (Million Tons)				Consumption (Million Tons)				Per Capita Consumption (Kg)		
	1950	1973	1981	% Share of World Prod. in 1981	1950	1973	1981	% Share of World Cons. in 1981	1950	1973	1981
Industrial Countries (ICs)											
- France	7.2	31.9	29.5	3.4	6.4	28.9	27.0	3.0	155	573	501
- FR of Germany	10.9	40.9	30.2	3.4	9.6	39.7	29.3	3.3	200	640	475
- Italy	5.0	36.7	43.1	4.9	5.2	35.7	42.7	4.8	111	648	746
- Japan	4.5	77.7	84.4	10.2	4.0	77.7	77.9	8.8	48	715	659
- USA	38.0	73.9	65.0	7.4	38.0	78.4	66.5	7.5	251	374	289
- Spain	2.1	22.6	30.5	3.5	2.0	21.6	18.5	2.1	73	619	491
- Others	26.9	85.1	63.4	6.5	21.9	88.7	69.5	8.1			
Subtotal	94.6	368.8	346.4	39.3	87.1	370.7	331.4	37.5			
Centrally Planned Economies (CPEs)											
- USSR	10.2	109.4	127.0	14.4	10.2	106.7	124.6	14.1	53	427	465
- Czechoslovakia	1.8	8.3	10.6	1.2	1.6	9.1	10.7	1.2	132	624	702
- Poland	2.5	15.5	14.2	1.6	2.4	17.0	13.9	1.6	95	510	388
- Others	2.1	16.1	21.6	2.4	2.1	15.8	19.5	2.2			
Subtotal	16.6	149.3	173.4	19.6	16.3	148.6	168.7	19.1			
High Income Oil Exporting Countries (HIOECs)											
- Kuwait	-	0.3	1.5	0.2	-	0.7	1.9	0.2	-	769	1,300
- Saudi Arabia	-	1.0	3.4	0.4	-	1.5	15.6	1.7	-	178	1,670
- Others	-	0.2	5.0	0.6	-	2.6	8.0	0.9			
Subtotal	-	1.5	9.9	1.2	-	4.8	25.5	2.9			
Developing Countries (DCs)											
Oil Importing DCs (OIDCs)											
- Argentina	1.6	5.2	6.7	0.8	2.0	5.2	6.5	0.6	120	215	240
- Brazil	1.4	13.4	26.0	2.9	1.8	13.5	26.0	2.9	34	133	204
- Burma	-	0.2	0.4	-	-	0.2	0.3	-	-	7	7
- China	-	40.8	82.0	9.3	-	39.8	81.1	9.2	-	49	80
- Greece	0.4	6.5	13.1	1.5	0.4	6.1	6.5	0.7	52	581	670
- Hungary	0.8	3.4	4.6	0.5	0.8	4.6	5.1	0.6	84	444	480
- India	2.6	15.0	20.1	2.3	2.7	14.8	22.3	2.5	7	26	33
- Korea	-	8.2	15.6	1.8	-	7.2	12.4	1.4	-	215	321
- Morocco	0.3	1.6	3.6	0.4	0.6	1.7	3.6	0.4	63	102	176
- Pakistan	0.4	2.7	3.7	0.4	0.4	3.4	4.1	0.5	6	53	49
- Philippines	0.3	4.0	4.0	0.4	0.3	2.8	3.5	0.4	17	71	71
- Portugal	0.6	3.2	6.0	0.7	0.5	3.2	6.4	0.7	63	368	636
- Romania	1.0	9.8	14.8	1.7	1.0	8.1	12.0	1.4	60	387	532
- Thailand	0.2	3.7	6.3	0.7	0.2	3.1	6.1	0.7	10	77	126
- Togo	-	0.1	0.4	-	-	0.1	0.2	-	13	56	82
- Turkey	0.4	9.2	15.1	1.7	0.5	8.3	11.8	1.3	25	216	259
- Yugoslavia	1.2	6.2	10.1	1.1	0.9	6.7	10.0	1.1	56	321	444
- Others	n.a.	33.5	53.6	6.2	n.a.	31.0	54.7	6.4			
Subtotal	n.a.	166.7	286.7	32.4	n.a.	159.8	272.6	30.9			
Oil Exporting DCs (OEDCs)											
- Algeria	0.3	1.0	4.5	0.5	0.5	2.2	5.5	0.6	56	162	279
- Ecuador	0.1	0.5	1.2	0.1	0.1	0.6	1.6	0.2	20	96	181
- Egypt	1.0	3.6	3.4	0.4	1.0	3.0	6.9	0.8	47	86	159
- Indonesia	0.1	0.8	6.8	0.7	0.2	2.1	6.7	0.7	3	17	44
- Mexico	1.4	9.7	18.0	2.0	1.4	9.6	18.1	2.0	54	171	255
- Nigeria	-	1.2	2.5	0.3	0.2	1.9	7.2	0.8	5	32	91
- Tunisia	0.2	0.5	2.0	0.2	0.2	0.7	2.1	0.2	56	125	319
- Others	n.a.	13.9	28.1	3.2	n.a.	13.5	36.6	4.1			
Subtotal	n.a.	31.2	66.5	7.5	n.a.	33.6	84.7	9.6			
Subtotal for all DCs	n.a.	197.7	353.2	39.9	n.a.	193.4	357.3	40.5			
World Total	133.0	717.5	882.9	100.0	133.0	717.5	882.9	100.0	55	188	190

Source: Fog, M.H., and Nadkarni, K.L., "Energy Efficiency and Fuel Substitution in the Cement Industry with Emphasis on Developing Countries", World Bank Technical Paper, 1983.

TABLE III.D-2

CLINKER CAPACITY BY TYPE OF PROCESS IN DEVELOPING COUNTRIES - 1979[a]

	Rotary Dry			Rotary Semi-Dry			Rotary Wet			Vertical Shaft			Total		
	No. of Kilns	Type of Fuel	Capacity ('000 tons)	No. of Kilns	Type of Fuel	Capacity ('000 tons)	No. of Kilns	Type of Fuel	Capacity ('000 tons)	No. of Kilns	Type of Fuel	Capacity ('000 tons)	No. of Kilns	Type of Fuel	Capacity ('000 tons)
A) AFRICA															
- Algeria	10	G	3,850	-	-	-	5	G	1,100	-	-	-	15	G	4,950
- Angola	-	-	-	-	-	-	4	0	900	-	-	-	4	0	900
- Cameroon	1	0	70	-	-	-	-	-	-	-	-	-	1	0	70
- Congo	1	0	80	-	-	-	-	-	-	-	-	-	1	0	80
- Egypt	-	-	-	3	0	840	18	0,G	6,900	-	-	-	21	0,G	7,830
- Ethiopia	2	0	130	1	0	38	-	-	-	-	-	-	3	0	168
- Gabon	-	-	-	-	-	-	1		350	-	-	-	1		350
- Kenya	2	0,C	750	-	-	-	2	0	350	6	0,C	500	10	0,G	1,600
- Libya	9	0	3,930	-	-	-	-	-	-	-	-	-	9	0	3,930
- Madagascar	-	-	-	-	-	-	1	C	115	-	-	-	1	C	115
- Malawi	1	C	70	1	C	70	-	-	-	-	-	-	2	C	140
- Mali	-	-	-	-	-	-	1		45	-	-	-	1		45
- Morocco	4	0	1,870	4	0	960	8	0	1,600	-	-	-	16	0	4,430
- Mozambique	1	C	600	1	C	90	1	6	300	-	-	-	3	C	990
- Niger	1	0	37	-	-	-	-	-	-	-	-	-	1	0	37
Nigeria	6	0	1,570	2	0	430	8	0	2,700	-	-	-	16	0	4,700
- Senegal	3		380	-	-	-	-	-	-	-	-	-	3		380
- Sudan	3	0	600	-	-	-	-	-	-	-	-	-	3	0	600
- Tanzania	2	0	545	-	-	-	-	-	-	-	-	-	2	0	545
- Togo	2	0	1,200	-	-	-	-	-	-	-	-	-	2	0	1,200
- Tunisia	6	0	3,430	-	-	-	3	0	470	-	-	-	9	0	3,900
- Uganda	4	0	300	-	-	-	-	-	-	-	-	-	4	0	300
- Zaire	3	0	710	1	0	105	3	0.C	115	-	-	-	7	0,G	930
- Zambia	2	C	270	-	-	-	3	C	200	-	-	-	5	C	470
- Zimbabwe	1	C	427	3	C	250	-	-	-	-	-	-	4	C	675
Sub total for Africa	64		20,817	16		2,783	58		15,235	6		500	144		39,335
Distribution by Type of Process (%)															
- No. of kilns	45			11			40			4			100		
- Capacity			53			7			39			1			100

0 = Oil; C = Coal; G = Gas.

[a] Capacity refers to rated capacity and includes plants under construction in 1979.

TABLE III.D-2 (Cont'd)

	Rotary Dry			Rotary Semi-Dry			Rotary Wet			Vertical Shaft			Total		
	No. of Kilns	Type of Fuel	Capacity ('000 tons)	No. of Kilns	Type of Fuel	Capacity ('000 tons)	No. of kilns	Type of Fuel	Capacity ('000 tons)	No. of kilns	Type of Fuel	Capacity ('000 tons)	No. of kilns	Type of Fuel	Capacity ('000 tons)
B) AMERICA															
- Argentina	28	O,C,G	7,830	3	O,G	300	11	O,G	1,995	-	-	-	42	O,C,G	10,025
- Bahamas	-	--	-	-	-	-	2	O	690	-	-	-	2	O	690
- Bolivia	4	O	610	-	-	-	-	-	-	-	-	-	4	O	610
- Brazil	43	O,C	18,265	3	O	755	51	O,G	7,965	-	-	-	97	O,C	26,985
- Chile	5	C	920	-	-	-	2	C	430	-	-	-	7	C	1,350
- Colombia	6	O	955	-	-	-	36	O,C,G	5,415	-	-	-	41	O,C,G	6,370
- Costa Rica	3	O	985	-	-	-	-	-	-	-	-	-	3	O	985
- Dominican Republic	1	O	540	-	-	-	6	O	760	-	-	-	7	O	1,300
- Ecuador	6	O	940	-	-	-	2	O	120	-	-	-	8	O	1,060
- El Salvador	1	O	290	-	-	-	3	O	610	-	-	-	4	O	900
- Guatemala	4	O	1,020	-	-	-	-	-	-	-	-	-	4	O	1,020
- Haiti	-	--	-	-	-	-	2	O	270	-	-	-	2	O	270
- Honduras	4	O	450	-	-	-	-	-	-	-	-	-	4	O	450
- Jamaica	-	-	-	-	-	-	3	O	400	-	-	-	3	O	400
- Mexico	68	O,G	23,050	-	-	-	4	O	490	-	-	-	72	O,G	23,540
- Nicaragua	-	-	-	-	-	-	5	O	330	-	-	-	5	O	330
- Panama	1	O	120	-	-	-	3	O	330	-	-	-	4	O	650
- Paraguay	-	-	-	-	-	-	2	O	200	-	-	-	2	O	200
- Peru	8	O	2,835	-	-	-	4	O	235	-	-	-	12	O	3,070
- Puerto Rico	-	-	-	-	-	-	8	O	2,030	-	-	-	8	O	2,030
- Trinidad and Tobago	-	-	-	-	-	-	3	O	425	-	-	-	3	G	425
- Uruguay	1	O	255	-	-	-	7	O	470	-	-	-	8	O	725
- Venezuela	9	O,G	3,400	-	-	-	14	O,C	4,400	-	-	-	23	O,G	7,800
Subtotal for America	192		62,465	6		1,055	168		27,465	-			365		90,985
Distribution by Type of Process (%)															
- No. of kilns	53			2			46			-			100		
- Capacity			68			1			31			-			100

TABLE III.D-2 (Cont'd)

	Rotary Dry			Rotary Semi-Dry			Rotary Wet			Vertical Shaft			Total		
	No. of Kilns	Type of Fuel	Capacity ('000 tons)	No. of Kilns	Type of Fuel	Capacity ('000 tons)	No. of Kilns	Type of Fuel	Capacity ('000 tons)	No. of Kilns	Type of Fuel	Capacity ('000 tons)	No. of Kilns	Type of Fuel	Capacity ('000 tons)
C) **ASIA**															
- Afghanistan	-	0	-	-	-	-	3	C	860	-	-	-	3	C	860
- Bangladesh	-	-	-	-	-	-	1	G	120	-	-	-	1	G	120
- Burma	1	-	240	-	-	-	3	0	300	-	-	-	4	0	540
- China	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	90,000
- India a/	35	0,C	10,160	6	0,C	1,828	95	C,G	12,464	-	-	-	136	0,C,G	24,452
- Indonesia	9	0	7,020	-	-	-	10	0,C	1,450	-	-	-	19	0,C	8,470
- Iran b/	34	0,C	11,890	-	-	-	10	0	4,455	-	-	-	44	0,C	16,345
- Iraq	3	0	1,250	-	-	-	24	0	5,825	-	-	-	27	0	7,075
- Jordan	1	0	440	-	-	-	3	0	660	-	-	-	4	0	1,100
- Korea	21	0	24,790	7	0	2,200	4	0	570	-	-	-	32	0	27,560
- Lebanon	-	-	-	-	-	-	10	0	2,330	-	-	-	10	0	2,330
- Malaysia	3	0	1,100	2	0	450	4	0	1,640	-	-	-	9	0	3,190
- Nepal	-	-	-	-	-	-	1	C	44	-	-	-	1	C	44
- Pakistan	-	-	-	5	G	495	21	C,G	2,865	-	-	-	26	C,G	3,360
- Philippines	20	-	5,075	12	0	1,620	2	0	205	-	-	-	34	0	6,900
- Sri Lanka	4	0	915	-	-	-	-	-	-	-	-	-	4	0	915
- Syria	4	0	1,360	-	-	-	9	0	1,020	-	-	-	13	0	2,380
- Taiwan	21	0,C	11,460	10	0,C	1,910	-	-	-	-	-	-	31	0,C	13,370
- Thailand	7	0	3,990	2	0	400	9	0	2,710	-	-	-	18	0	7,100
- Yemen Arab Republic	-	-	-	-	-	-	1	0	65	-	-	-	1	0	65
Subtotal for Asia - Excluding China	163		79,690	44		8,903	210		37,583	-		-	417		126,176
- Including China	n.a.		n.a.	n.a.	n.a	n.a.	n.a.	n.a.	n.a	n.a	n.a	n.a	n.a.		216,176
Distribution by Type of Process (%)															
- No. of Kilns) Excluding	39			11			50			-			100		
- Capacity) China			63			6			31			-			100

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a/ Does not include mini-cement plants and some new plants under construction.

b/ Cement capacity.

TABLE III.D-2 (Cont'd)

	Rotary Dry			Rotary Semi-Dry			Rotary Wet			Vertical Shaft			Total		
	No. of Kilns	Type of Fuel	Capacity ('000 tons)	No. of Kilns	Type of Fuel	Capacity ('000 tons)	No. of Kilns	Type of Fuel	Capacity ('000 tons)	No. of Kilns	Type of Fuel	Capacity ('000 tons)	No. of Kilns	Type of Fuel	Capacity ('000 tons)
D) **EUROPE**															
- Cyprus	2	0	385	-	-	-	3	-	780	-	-	-	5	0	1,165
- Greece	24	0	10,953	-	-	-	-	0	-	2	0	515	26	0	11,468
- Hungary	5	0,C,G	2,500	5	0	740	14	0,C	1,130	-	-	-	24	0,C,G	4,360
- Portugal	11	0	4,150	1	0	70	6	0	1,750	-	-	-	18	0	5,970
- Romania	n.a.		n.a.	n.a.		n.a.	n.a.		n.a.	n.a.		n.a.	n.a.		n.a.
- Turkey	50	0,C	17,400	-	-	-	8	0,C	2,150	-	-	-	58	0,C	19,550
- Yugoslavia	31	0,C	9,945				6	0,C	860	22	0,C	725	59	0,C	11,530
Subtotal for Europe	123		45,333	6		810	37		6,660	24		1,240	190		54,043
Distribution by Type of Process (%)															
- No. of Kilns	65			3			19			13			100		
- Capacity			84			1			12			2			100
TOTAL FOR ALL DEVELOPING COUNTRIES															
- excluding China	542		208,305	72		13,551	473		86,943	30		1,740	1,117		310,539
- including China	n.a		n.a	n.a		n.a	n.a		n.a	n.a		n.a	n.a		400,539
Distribution by Type of Process (%)															
- No. of Kilns) Excluding China, Romania	49			6			42			3			100		
- Capacity) Excluding China, Romania			69			4			28			1			100

Source: Fog, M.H., and Nadkarni, K.L., "Energy Efficiency and Fuel Substitution in the Cement Industry with Emphasis on Developing Countries", World Bank Technical Paper, 1983.

TABLE III.D-3

CEMENT TYPES AND PRODUCTS

1. Clinker. - Heating a properly proportioned mixture of finely ground raw materials containing calcium carbonate, silica, alumina, and usually iron oxide in a kiln to a temperature at which partial fusion occurs produces a substance called clinker. Chemically, clinker comprises four main phases of various proportions of tricalcium silicate (C_3S), dicalcium silicate (C_2S), tricalcium aluminate (C_3A), tetracalcium aluminoferrite (C_4AF), minor amounts of calcium sulphate ($CaSO_4$), and usually, but not necessarily magnesia (MgO), lime (CaO), and various alkalies, depending on raw materials used and type of cement manufactured. Clinker, ranging in particle size from fine sand grains to walnut size, is ground with a small amount of calcium sulphate, usually gypsum or anhydrite (2% to 5%), to make portland cement.

2. Portland Cement. - Portland cement is produced by pulverizing clinker consisting essentially of hydraulic calcium silicates and usually containing one or more of the forms of calcium sulphate as an interground addition. ASTM specifies five types of portland cement, based mostly on the proportions of C_3S, C_2S, and C_3A in the cement: Type I, for use when special properties specified for any other types are not required; Type II, for general use, more especially when moderate sulphate resistance or moderate heat of hydration is desired; Type III, for use when high early strength is required; Type IV, for use when a low heat of hydration is desired; and Type V, for use when high sulphate resistance is required. ASTM specifications include three additional types of portland cement designated Type IA, Type IIA, and Type IIIA that are respectively air-entraining cements for the same uses as

TABLE III.D-3 (Cont'd)

Type I, Type II, and Type III. Air-entraining portland cement is produced in essentially the same way as portland cement but with the addition of an interground air-entraining agent.

3. White Cement. - White cement is made from iron-free materials of exceptional purity, usually limestone, china clay of kaolin, and silica. Clinker is burned with a reducing flame in the kiln and rapidly quenched in a water spray to keep any iron in the ferrous state to avoid coloration by ferric ions. Clinker is ground with high-purity white gypsum using ceramic balls and liners in grinding mills; recently high-chromium alloys have been used for liners and grinding media. White cement conforms to portland cement specifications for the various types and is used in decorative concrete including terrazzo, highway lane markers, and architectural concrete.

4. Masonry Cement. - Masonry cement is a hydraulic cement for use in mortars for masonry construction, containing one or more of the following materials: Portland cement, portland-pozzolan cement, slag cement, or hydraulic lime, usually with hydrated lime,limestone, chalk, calcareous shale, talc, slag, or clay interground for plasticity.

5. Portland-Blast Furnace Slag Cement. - This type is essentially an intimately interground mixture of portland cement clinker and granulated blast furnace slag, or an intimate and uniform blend of portland cement and fine granulated blast furnace slag in which the amount of the slag constituent is between 25% and 65% of the total weight of blended cement. Type I S

TABLE III.D-3 (Cont'd)

portland-blast furnace slag cement is for general concrete construction.

6. Slag Cement. - Slag cement is a finely divided material consisting essentially of an intimate and uniform blend of granulated blast furnace slag and hydrated lime in which the slag constituent is at least 60% of the total weight of blended cement. Type S-slag is for use in combination with portland cement in making concrete and in combination with hydrated lime in making masonry mortar.

7. Portland-Pozzolan Cement. - Pozzolan is a siliceous or siliceous and aluminous material that in itself possesses little or no cementitious value but that will, in finely divided form and in the presence of moisture, chemically react with calcium hydroxide at ordinary temperatures to form compounds possessing cementitious properties. Fly ash is a pozzolanic material, and is the finely divided residue collected from flue gases produced from combustion of ground or powdered coal. Natural pozzolans are materials occuring in natural state such as some diatomaceous earths, opaline cherts and shales, tuffs, volcanic ash, and pumicites. Calcined pozzolans are produced by calcination of natural siliceous or alumino-siliceous earths for the purpose of activation of pozzolanic properties. Portland-pozzolan cement, an intimate and uniform blend of portland cement or portland-blast furnace slag cement and fine pozzolan, is produced by integrinding portland cement clinker and pozzolan, by blending portland cement or portland-blast furnace slag cement and finely divided pozzolan or a combination of intergrinding and blending in which the amount of the pozzolan constituent

TABLE III.D-3 (Cont'd)

is between 15% and 40% of the total weight of blended cement. Type I P portland-pozzolan cement is for use in general concrete construction, and type P is for use in concrete construction where high strengths at early ages are not required.

8. Pozzolan - Modified Portland Cement. - The constituents in this type of cement are the same as those for portland-pozzolan cement, and the methods of production are also the same. However, the amount of pozzolan constituent is less than 15% of the total weight of blended cement. Type I (PM) pozzolan-modified portland cement is for general concrete construction.

9. Oil-Well Cement. - Oil-well cement was developed to seal oil and gas wells under pressures up to 18,000 pounds per square inch and temperatures up to 350°F. These cements are required to remain fluid up to about 4 hours and then harden rapidly. Setting time is controlled by reducing C_3A to nearly zero or adding to portland cement some retarder such as starches or cellulose products, sugars, and acids or salts of acids containing one or more hydroxyl groups.

10. Expansive Cement. - Expansive cement is a hydraulic cement that tends to increase in volume after setting during the early hardening period, due to the formation of chemical substances such as calcium sulpho-aluminate hydrate, which causes expansion equal to or greater than the shrinkage that would normally occur during the hardening process.

11. Regulated-Set Cement. - Regulated-set cement is a hydraulic cement, the setting time of which can be controlled from a few minutes to 30 minutes or

TABLE III.D-3 (Cont'd)

more. The rapid-hardening modified portland cement develops very high early strengths. Promising applications include highway resurfacing and paving patching, underwater patching, manufacturing concrete pipe, blocks, and prestressed precast forms, as well as use in slip form structures.

12. Aluminous Cement. - Sometimes known as calcium aluminate cement, high-alumina cement, or "Ciment Fondu", aluminous cement is a hydraulic nonportland cement containing monocalcium aluminate (CA) as the predominant cementitious compound that sets at about the same rate as portland cement but hardens very rapidly, attaining high strength in 24 hours. Aluminous cements are produced mainly from relatively high-purity bauxite and limestone with very low silica and magnesia content within the temperature range of 2,700° to 2,900°F. Special applications of aluminous cement are based on its rapid-hardening qualities, resistance to sulphate action, and refractory properties when used as" castable refractories" and mortars for furnaces and kilns.

13. Concrete. - A proportioned mixture of inert mineral aggregates of sand and gravel or crushed stone, concrete is bound together by a paste of hydraulic cement and water into a monolithic mass when the binder sets and hardens through the chemical action of cement and water. A mixture of cement, water, and fine aggregate is called mortar; concrete contains coarse aggregate in addition.

Source: U.S. Bureau of Mines, "Mineral Facts and Problems", edition 1980.

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IV.

FERTILIZERS

IV.A Data Sheet

IV.A.1 General

Fertilizers may be graded either by the elemental rating (Nitrogen, N; Phosphorus, P; Potassium, K), or by the nutrient rating (Nitrogen, N; Phosphorus pentoxide, P_2O_5; Potassium oxide, K_2O). Both systems are in use today. The above nutrients are important singly, but also as combination products for shipment.

Fertilizer raw materials are generally unsuitable without processing. The type and location of the processing are important for determining sea transportation requirements: in particular the concentration of nutrient in the product and whether location is at raw material source, destination or intermediate location.

IV.A.2 Phosphatic Fertilizers

Phosphates are the largest volume of fertilizers in international trade. They tend to be shipped in low nutrient concentrations, which means high volumes. The principal commodity is phosphate rock, which has a nutrient rating of between 0.12.0 and 0.32.0. Phosphate rock is used to produce phosphoric acid (nutrient rating: 0.54.0). Large volumes of waste gypsum are generated as by-product of the phosphoric acid production process.

For phosphoric acid production of 120,000 t/a (using phosphate rock with 33% P_2O_5), the requirements per ton of output are:

Phosphate rock	3.22 t
Sulphuric acid	2.78 t
Water	150 t

Electricity	150 kWh
Steam	1.9 t
Labour	0.0003 (3000 t/m/a)

Phosphoric acid together with other commodities such as sulphur is used to produce a variety of fertilizers, the most important being triple superphosphate (TSP) in granular and non-granular form with nutrient rating 0.45.0; single superphosphate with rating 0.18.0; and the multinutrient fertilizers monoammonium phosphate (MAP) with rating 11.55.0, and diammonium phosphate (DAP) with rating 18.46.0.

Phosphate complexes producing several products may, in addition to the requirement for phosphoric acid production, require the following to produce either (a) 250,000 t/a of DAP or (b) 357,000 t/a of TSP (when produced in conjunction with phsophoric acid manufacture) per ton of product:

	DAP	TSP
Sulphur	0.45 t	0.33 t
Phosphate rock	1.52 t	1.65 t
Ammonia	0.22 t	nil

The production of one ton of SSP with 20% available P_2O_5 content requires:

Phosphate rock (34% P_2O_5)	0.626 t
Sulphuric acid (93% H_2SO_4)	0.39 t
Water	0.09 t
Electricity	
Production process	3 KWh
Rock grinding	7-25 KWh
Labor	0.15 man-hours

Phosphate rock is shipped in bulk carriers, typically between 20,000 and 40,000 dwt, or as "bottom cargo" in multi-decked conventional cargo vessels. Phosphoric acid is carried either in a limited fleet of dedicated tankers with rubber lined, steel tanks (capacities vary between 5,000 and 25,000 dwt), or in the stainless steel tanked parcel fleet with ships of up to 30,000 dwt.

The phsophatic fertilizers TSP, SSP, and the compound fertilizers MAP and DAP, may be shipped in bagged or bulk form with bulk being particularly popular. The USA is the largest exporter of MAP and DAP and these exports may be in bulk shipments to China, for example, of about 54,000 dwt although the average is about 31,000 dwt. For other trade routes shipments may typically be between 10,000 and 20,000 dwt.

IV.A.3 Nitrogenous Fertilizers

The key material for nitrogenous fertilizer manufacture is synthetic ammonia (NH_3), which can be applied directly as a fertilizer itself or used as a feedstock for manufacture of other nitrogenous fertilizers. Ammonia is produced by catalytic reaction between nitrogen from air, and hydrogen from "synthesis gas", which is prepared from steam and various hydrocarbon raw materials, mostly natural gas. For a 330,000 t/a ammonia plant, the following are required per tonne of product:

Natural gas	36 GJ or 1100 cu m
Electricity	20 - 35 kWh
Water	200 t (which may be reduced by recirculation)
Land	0.2 - 0.3 sq m
Personnel	0.0005 (say 2,200 t/m/yr)

Ammonia (nutrient rating: 82.0.0) is shipped as liquified ammonia gas in specially constructed cryogenic carriers of up to 50,000 cu m.

Urea with a nutrient rating of 46.0.0 is the most popular nitrogenous fertilizer. It is a downstream product of ammonia gas, and its manufacture requires per tonne of product:

Ammonia	0.58 t
Carbon Dioxide	0.76 t
Water	75 t
Steam	1.2 t
Electricity	125 kWh
Personnel	0.0005 (say 2,200 t/m/yr)

Urea may be shipped either in small bulk carriers as bulk cargo, or in conventional'tweendeckers in bagged form. Ships used in urea trade are rarely over 20,000 dwt.

Nitric acid is a strong oxidizing agent, which in its anhydrous form HNO_3 does not normally exist in the liquid state. It is used for the production of ammonium nitrate, and is not a significant commodity in international trade.

Ammonium nitrate, ammonium sulphate, and a variety of compound fertilizers are solid materials, often moved in bags by'tweendeckers. Their shipment is usually in very small lot sizes.

IV.A.4 Potassic Fertilizers

The largest source of potassium is potassium chloride, muriate of potash, which yields 85% of all potash produced. Most potash is produced in the developed countries of North America and Europe, and in the USSR. Potash is shipped in bulk or bagged form. A quarter of the output of the largest exporter Canada is in panamax ships but generally shipments are in vessels of 7 to 25,000 dwt.

IV.A.5 Sulphur

Of the secondary macronutrients, sulphur is the most important in international trade. Sulphur is only economically produced in quantity in a few countries. It may be produced from mined deposits which are melted in water by the Frasch process, which is the major source, but sulphur may also be recovered from sour natural gas or petroleum in the form of granules. Both forms of sulphur are called brimstone. The Frasch derived sulphur is shipped in dedicated molten sulphur carriers comprising about twenty ships of between 750 and 29,000 dwt. There is a limited trade in sulphuric acid in ships of 5,000 to 20,000 dwt. Granule sulphur being dry cargo may be shipped as conventional bagged, or as bulk cargo.

IV. B. Fertilizer Types

Chemical fertilizers are usually classified and graded on the basis of their plant nutrient content. They may be classified as:

(a) macronutrients which include carbon, hydrogen and oxygen that are available from air and water; "primary" nutrients (nitrogen, phosphorus and potassium); and "secondary" nutrients (calcium, magnesium and sulphur)

(b) micronutrients which include boron, chlorine, copper, iron, manganese, molybdenum and zinc.

The macronutrients are those required in the largest quantities and of these only nitrogen, phosphorus and potassium are of major importance in international bulk trades. Sulphur is also shipped but the volume of trade is not great.

Straight fertilizers contain only one of the primary nutrients and are termed:

(1) nitrogenous (N-type)
(2) phosphatic (P-type)
(3) potassic (K-type)

Multinutrient fertilizers (for example, NP and NPK-types) are classified in either of two groups, according to how they are prepared: mixed types are mechanically blended combinations of straight constituents, while complex types require chemical processing and granulation facilities.

There are two systems of fertilizer grading in use today. The first is based on elemental content, expressed as the percentage by weight of nitrogen (N), phosphorus (P), and potassium (K). The second system is based on primary nutrient content, expressed as the percentage by weight of nitrogen (N), phosphorus pentoxide (P_2O_5), and potassium oxide (K_2O). For example, a 20·10.10 multinutrient fertilizer is a product with 20 percent nitrogen content, 10 percent P_2O_5, and 10 percent K_2O by weight. Table IV.B-1 rates fertilizers by elemental and nutrient grading.

High analysis fertilizers provide a relatively high percentage of total nutrients, usually more than 40 percent, while medium-analysis types have 25 to 40 percent nutrient contents and low-analysis types are in the 15-25 percent range.

The major raw materials, intermediate products, and production processes used in manufacture of high-volume fertilizers are indicated in Figure IV.B-1.

TABLE IV.B-1

THE NPK RATING FOR MAJOR FERTILIZER PRODUCTS*

	NUTRIENT RATINGS IN COMMON USE			ELEMENTAL RATING		
	N	P205	K20	N	P	K
NITROGEN FERTILIZERS (N)						
Anhydrous Ammonia	82	0	0	82	0	0
Urea	46	0	0	46	0	0
Ammonium Nitrate	35	0	0	35	0	0
Ammonium Sulphate	21	0	0	21	0	0
Sodium Nitrate	16	0	0	16	0	0
PHOSPHATE FERTILIZERS (P)						
Phosphate Rock	0	32	0	0	14	0
Superphosphate (SSP)	0	18	0	0	8	0
Triple Superphosphate (TSP)	0	45	0	0	20	0
Phosphoric Acid	0	54	0	0	24	0
Superphosphoric Acid	0	70	0	0	31	0
POTASH FERTILIZERS (K)						
Potassium Chloride	0	0	60	0	0	50
Potassium Sulphate	0	0	50	0	0	42
COMBINATION FERTILIZERS						
Mono-ammonium Phosphate (MAP)	11	55	0	11	24	0
Di-ammonium Phosphate (DAP)	18	46	0	18	20	0
NPK, PK and NK Fertilizers		Various			Various	

* Ratings may vary slightly with source

Source: H.P. Drewry Ltd., "The Organization and Structure of the Deep Sea Fertilizer Trades"

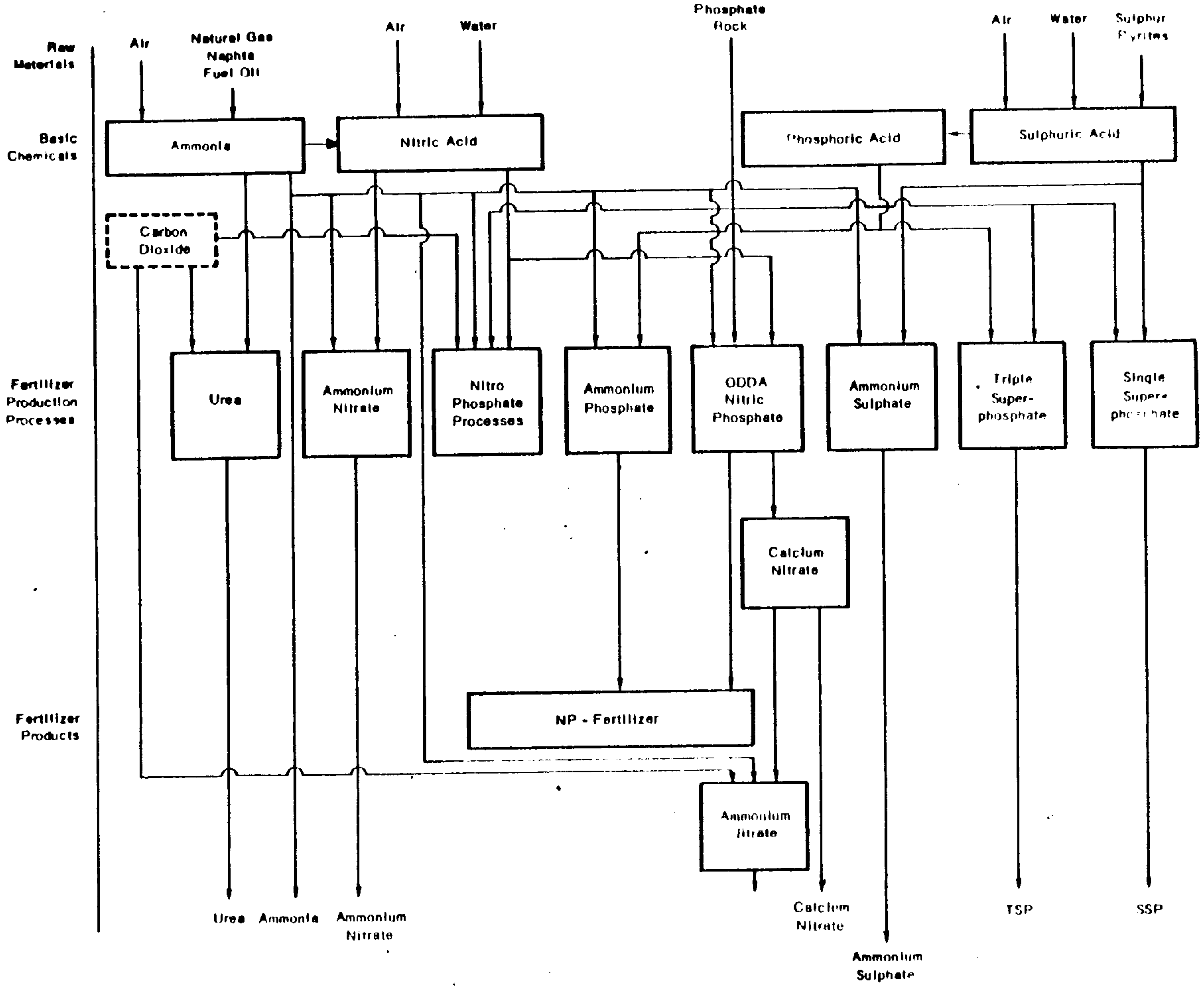

FIGURE IV. B-1

PRINCIPLES FOR PRODUCTION OF FERTILIZERS

Source: OECD, "Emission Control Costs in the Fertilizer Industry", July 1977

IV. C Phosphatic Fertilizers

The ultimate source of most fertilizer phosphorus is phosphate rock, which consists of one or more phosphate minerals such as fluorapatite ($Ca_3(PO_4)_3F$) or tricalcium phosphate ($Ca_3(PO_4)_2$) along with various impurities. Phosphate deposits are usually found mixed with clay and sand, which are separated by washing, classification, and flotation processes.

The phosphate content of rock is reported as percent phosphorus pentoxide (P_2O_5) or as percent tricalcium phosphate, also referred to as bone phosphate of lime - BPL - (1.0 percent BPL is equivalent to 0.458 percent P_2O_5). Commercial rock is sold based on its BPL content, with downward price adjustments made if iron oxide and alumina contents exceed certain limits. Grades sold range from 77 BPL to 64 BPL. The rock is sold on a bone dry basis, but actual moisture content is guaranteed not to exceed 3.5 percent for all but the lowest grades, which have a 5 percent maximum moisture limit.

The phosphate rock consumption pattern shown in Figure IV.C-1 indicates that agricultural (fertilizer) manufacture accounts for the highest percentage use by far. The figure also shows that phosphoric acid is a key intermediate in production of phosphatic fertilizers. Accordingly, the tendency until recently has been to build a phosphoric acid plant in conjunction with plants producing phosphate fertilizers. Since phosphoric acid manufacture consumes large quantities of sulphuric acid, the latter is often manufactured within the fertilizer complex as well.

During the past decade, however, bulk phosphoric acid transportation has developed to the point where the potential consumer can choose between purchase and production. With no nearby sources of phosphate rock, some plants may realize lower transport costs by importing acid instead of considerable quantities of rock and sulphur. High capital

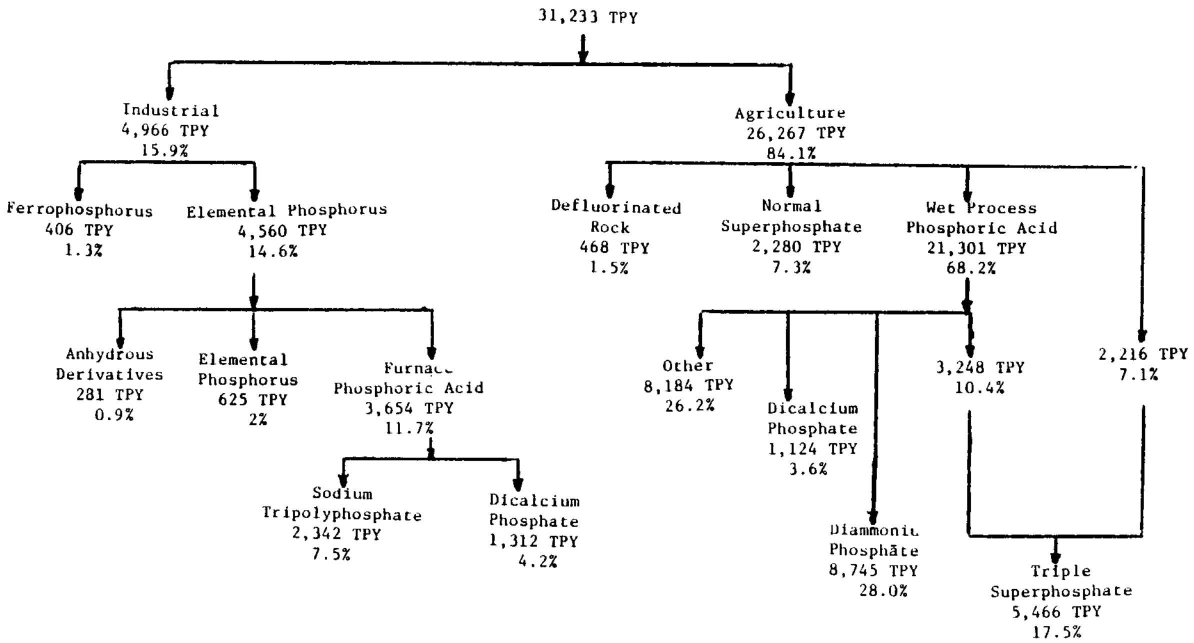

FIGURE IV.C-1

U.S. PHOSPHATE ROCK DEMAND
(Estimated in Thousand Short Tons per Year)

Source: U.S. Bureau of Mines, Mineral Commodities, 1980.

investments and trouble-some environmental regulatory obstacles can also be avoided.

IV.C.1 Phosphoric Acid Manufacture and Raw Material Requirements

Phosphate rock and sulphuric acid are the two major raw materials for manufacture of phosphoric acid. Several commercial wet-process routes to phosphoric acid manufacture are available, but all are based on reacting phosphate rock and sulphuric acid in liquid slurry form. The reaction produces phosphoric acid and by-product calcium sulphate (gypsum). The latter is removed by filtration of the acid/gypsum slurry. A typical flow sheet and material balance are given in Figures IV. C-2 and IV.C-3, indicating that 0.88 tons of 98 percent concentrated sulphuric acid are consumed for each ton of 30 percent phosphoric acid produced. In addition, about 5.3 tons of gypsum are formed per ton of phosphoric acid for the process indicated. Heavy sulphuric acid consumption and corresponding large volumes of by-product gypsum are two key characteristics of phosphoric acid manufactured by the wet process. Gypsum disposal, in particular, presents major environmental and land-use problems at large plants where the common practice has been to impound the gypsum in a self-contained pond-and-pile area. The world's largest gypsum piles are more than 60 meters high and still growing.

For phosphoric acid production of 120,000 t/a, using phosphate rock with 33% P_2O_5, the requirement per ton of output is:

Phosphate rock	3.22 t
Sulphuric acid	2.78 t
Water	150 t
Electricity	150 kWh
Steam	1.9 t
Labour	0.0003 (3000 t/m/a)

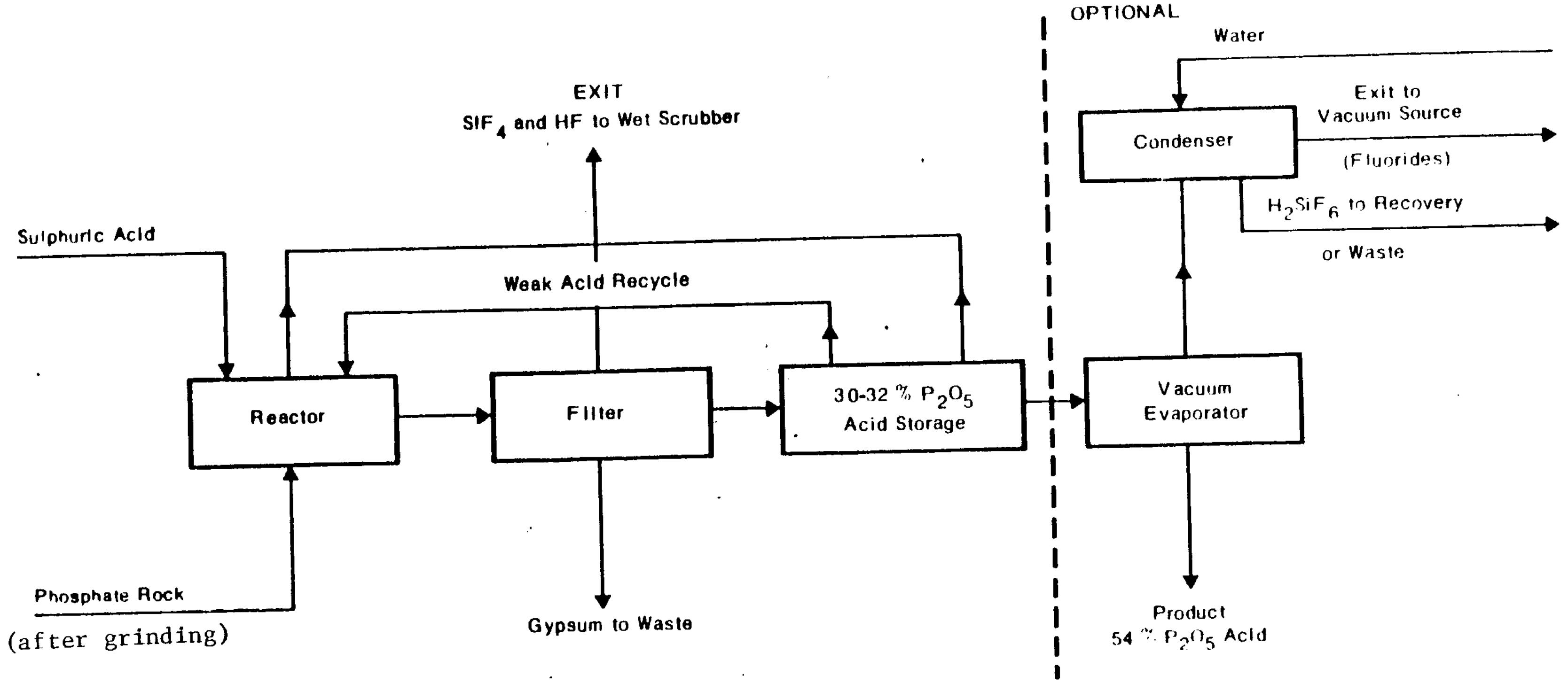

FIGURE IV.C-2

FLOW DIAGRAM OF WET PROCESS PHOSPHORIC ACID PLANT

Source: OECD, "Emission Control Costs in the Fertilizer Industry", July 1977

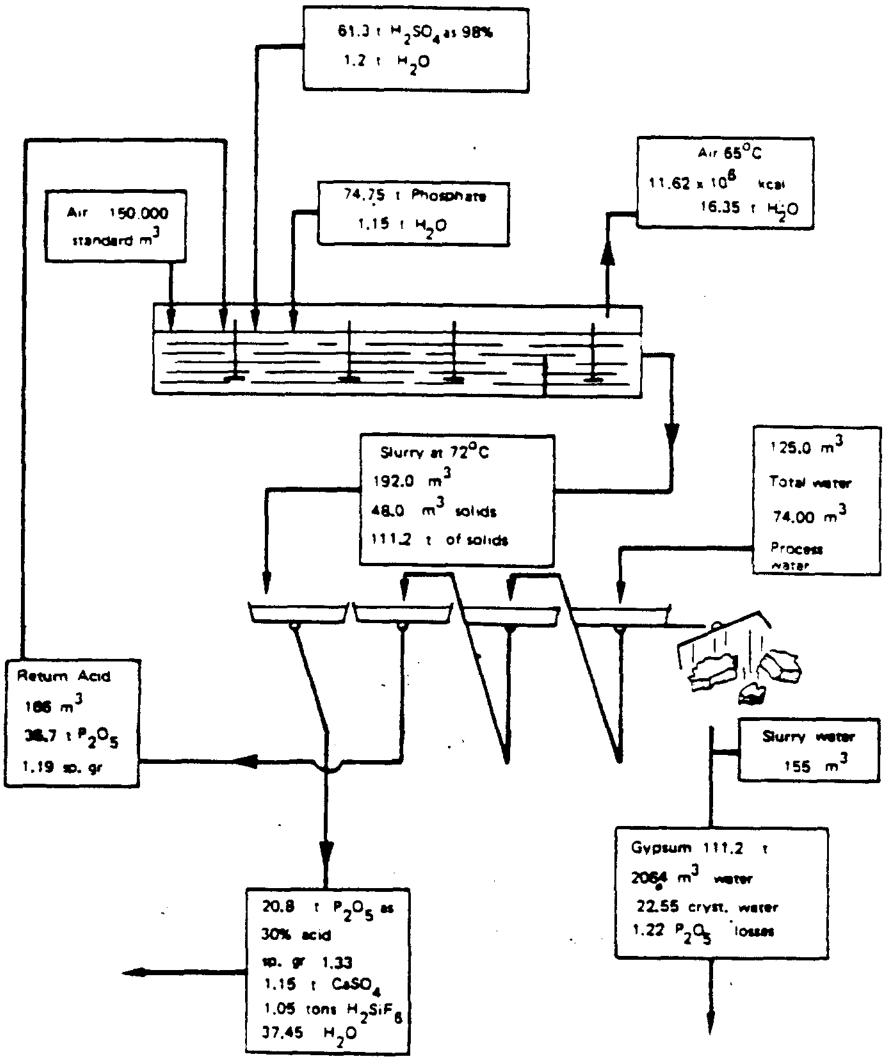

FIGURE IV.C-3

Material balance in tons and cubic meters per hour for a 500-ton/day P_2O_5 unit (20.84 tons of P_2O_5 per hour) with 94.5% yield of total recovery using a phosphate rock with 29.5% P_2O_5, 49.0% CaO, 3.0% SO_3, 5.5% CO_2, 3.5% F, and 1.5% H_2O.

Source: Becker, P., "Phosphates and Phosphoric Acid", 1983

IV.C.1.1 Phosphoric Acid Process Alternatives

Commercial wet processes are characterized by the chemical form of the calcium sulphate (gypsum) precipitate and by the strength of the acid produced in the reactor. So-called hemihydrate (HH) processes yield gypsum in the form $CaSO_4 \cdot 1/2H_2O$, whereas dihydrate (DH) processes yield $CaSO_4 \cdot 2H_2O$. Characteristics of HH and DH processes and their hybrids in commercial use are given in Table IV.C-1.

The most important characteristics of these processes is the P_2O_5 concentration of the product acid as it leaves the reactor. The relatively high concentrations achieved with the hemihydrate processes eliminate the need for an evaporative concentration step (see Figure IV.C-2), resulting in lower capital and operating costs. The main disadvantages of the HH process are the higher reactor temperatures, which increase corrosion, and the more elaborate process control requirements. Hybrid hemihydrate-dihydrate processes have been developed in Japan that yield a gypsum by-product suitable for industrial use without extensive treatment.

Despite these and other advantages of the hemihydrate processes, straight dihydrate facilities remain the most widespread, because of their relative simplicity and their ready adaptability to a wide variety of rock grades.

IV.C.1.2 Phosphoric Acid Process Equipment

Major equipment items correspond to the processing steps identified in Figure IV.C-2:

(1) phosphate rock mill

(2) reactor

(3) slurry filter

(4) vacuum evaporator

TABLE IV.C-1

CHARACTERISTICS OF COMMERCIAL PROCESSES FOR PHOSPHORIC ACID MANUFACTURE

Type	Number of Separation Steps	P_2O_5 Concentration %	Temperature, °C	
			Reactor	Recrystallizer
Dihydrate	1	26-32	70- 85	na
Hemihydrate	1	40-50	85-100	na
Hemihydrate-dihydrate	1	26-30	90-100	50- 60
Hemihydrate-dihydrate	2	40-50	90-100	50- 65
Dehydrate-hemihydrate	2	35-38	65-70	90-100

Source: Becker, P., Phosphates and Phosphoric Acid, 1983.

IV.C.1.2.a Grinding

The grinding operation is required to produce the desired particle size distribution in the reactor feed. Grinding equipment selection depends on many factors, including rock characteristics, degree of phosphate recovery required, acid process employed, and process operating variables. In phosphate operations, approximately 40 percent of the total electrical energy consumed is utilized for grinding, so another important aspect of mill selection is the energy required.

Grinding is characterized as "dry" or "wet" depending on whether rock moisture is removed from or left in the ground product. Wet grinding eliminates all fuel consumption for rock drying and requires no dust emission control equipment. There are disadvantages in terms of reduced product yields and operating factors, but these have been outweighed by tremendous savings in fuel costs.

Table IV.C-2 indicates sizes and operating data for a number of ball mill installations at U.S. phosphoric acid plants.

IV.C.1.2.b Slurry Reactor

Phosphoric acid reactor technology uses many different designs to suit the varying properties of phosphate ores. For the dihydrate process, reactors tend to be rectangular or circular tanks provided with large mechanical agitators or slurry circulation pumps. Reactor volumes vary, but traditional dihydrate systems operate with a specific reaction volume of 1.5-2.0 cubic meters per ton of P_2O_5 produced daily. Agitation energy varies from 20 to 50 KWH per ton of P_2O_5, depending on the rock reactivity and reactor cooling method employed (air-swept or vacuum flash cooling.)

TABLE IV.C-2

PHOSPHATE ROCK GRINDING INSTALLATIONS AT SELECTED U.S. PHOSPHORIC ACID PLANTS

Type*	Size (ft.)	HP	Capacity (tons/hr)	Feed	Product
C, CC, WG	16½ x 23	4000	200	-½ in. 85% -35 mesh	0.8% +35 mesh
CO, CC, DG	10 x 84	500	31	-½ in.	60% -200 mesh
C, OC, WG	17 x 38	6000	240	6.2% +¼ in. 51.3% +30 mesh 65.8% +40 mesh 85.4% +70 mesh	1.6% +40 mesh 9.8% +70 mesh 90.2% -70 mesh 78.3% -100 mesh 47.9% -200 mesh
CO, CC, DG	10 x 72	450	23	-½ in.	90% -100 mesh
C, OC, DG	14 x 24	3000	110 87	-½ in.	2% +35 mesh 0.8% +35 mesh

* C, cylindrical; CC, closed circuit; CCS, closed circuit screen; CO, conical, DG, dry grinding; OC, open cycle; T, tricone, WG, wet grinding.

Source: Becker, P., "Phosphates and Phosphoric Acid", 1983

IV.C.1.2.c Filtration

A 1000 ton/day P_2O_5 plant sends about 350 cubic meters of slurry per hour to the filter, where phosphoric acid is removed from calcium sulphate crystals by passing the slurry on to a filter cloth and applying a vacuum to the underside.

The filter and associated acid and vacuum pumps/piping represent about half of the investment cost of a phosphoric acid dihydrate unit. Three types are in common use: travelling belt, tilting pan, and rotating table filters. The first type consists of an endless reinforced perforated rubber belt which supports a filter cloth. A vacuum box provides suction to draw the acid through the filter cloth. Surface areas up to 100 square meters are available with some belt filters.

The rotating table filter is a large rotating disk, up to 15-20 meters in diameter. The disk consists of a series of troughs bolted together and covered with perforated metal plates that support the filter cloth. Each trough is connected to a vacuum control valve timed to provide vacuum during the appropriate interval on each rotation. A rotating screw conveyor scrapes off the accumulated cake.

IV.C.1.2.d Vacuum Evaporation

In dihydrate processes, phosphoric acid exits the filter with a concentration of 27-30% P_2O_5, which must be concentrated to 50-54% in the final product. Acid concentration is accomplished by evaporation under vacuum, usually using low-pressure by-product steam generated in sulphuric acid manufacture (in an adjacent unit). The concentration step consumes 1.8-2.0 tons of low-pressure steam per ton of P_2O_5.

The concentration unit consists of a heat exchange boiler chamber, condenser, vacuum pump, acid circulation pump, and piping. Since the reactor capacity generally exceeds the evaporator capacity, two or three units are generally installed in multi-stage arrangement.

Unit inputs for the concentration step depend on process equipment and the degree of concentration. For concentrating 30% acid (as P_2O_5) to 54% acid, 1.9 tons of low-pressure (105°C, 1.24 bar) steam and 15-50 KWh electricity are consumed.

IV.C.1.3 Gypsum Disposal and Cooling Water Treatment

IV.C.1.3.a Gypsum Disposal

Between 4 and 6 tons of by-product phospho-gypsum are produced for every ton of P_2O_5 produced by a phosphoric acid plant. Large plants, with outputs of 1000 tpd P_2O_5 therefore have 4000-6000 tons of solid by-product generated daily. The gypsum produced is often of low quality and far exceeds market demands, even for commercial grade gypsum. Consequently, acid manufacturers are often forced to dispose of the by-product as a solid waste. In Japan, where there are no natural domestic gypsum supplies, phosphogypsum has long been used for plaster and cement additive.

Gypsum disposal is generally achieved by impounding on land or by pumping into rivers or seas. Obviously, marine disposal requires sites where tidal and current movements bring about adequate dispersion and suspension of the gypsum, in order to avoid a build-up in the vicinity of the discharged point. Environmental regulations in some areas may prohibit this type of disposal or make it economically unattractive.

In the U.S., the common practice for gypsum disposal is land impoundment in a self-contained pond and pile. In this method, the gypsum is slurried and sluice transported to a large settling pond, where the overflow is collected and recirculated to the plant for reuse in gypsum sluicing. After three or four cycles, the reclaimed sluice water is fed to the plant for process use, which permits recovery of 1-2% P_2O_5 dissolved from the waste product.

As the solids settle in the pond, its level gradually elevates. After the bottom level has elevated by 2-3 meters, the slurry is fed to an alternative pond and the first is left to dry up. After drying, the first pond is provided with reelevated dikes and otherwise prepared for subsequent reuse in settling sluiced gypsum.

The surface of a single operating pond for a 1000 ton P_2O_5 per day plant is at least 20-30 hectares. The total settling area approaches 100 hectares, with a yearly elevation of about 1.2 meters per year (based on 1.2 meters annually per 1000 square meters per ton of P_2O_5 per day).

Supra, a Swedish firm, disposes of phosphoric acid gypsum by using the material to build an artificial island in the Baltic Sea. The pile base is lined with a 0.3 mm polyethylene film. The film is covered by a gravel/collecting pipe drainage system on which rests a filter cloth. Drainage pipes empty the collected water into a peripheral ditch fitted with a 1 mm hypalon lining.

IV.C.1.3.b Cooling Water Treatment

Cooling water from the reactor flash cooler and the phosphoric acid concentration systems is recycled, because of the large quantities required and because this water contains fluorides, which should be contained in a closed-circuit system (due to environmental considerations). In the range of 300-400 squares meters per daily metric ton of P_2O_5 are required for the cooling pond surface. A 1000 ton P_2O_5 per day plant will require on the order of 40 hectares for a cooling pond to handle up to 65,000 cubic meters of evaporator condenser water and 34,000 cubic meters of reactor flash cooler condenser water per day. Cooling pond surfaces are calculated based on local climatic conditions. Daily heat release rates of 3500-9000 Kg/cal per square meter have been reported in the southeastern U.S.

IV.C.2 Phosphatic Fertilizer Manufacture and Raw Material Requirements

Most phosphatic fertilizers are produced by reacting ground phosphate rock with either sulphuric or phosphoric acid. Depending on the type of acid used and the rock-to-acid ratio maintained in the reactor a variety of products can result. The two most important, high volume straight phosphatic fertilizers are the following.

- single superphosphate (SSP), 16-21 percent P_2O_5, produced by reacting ground phosphate rock and sulphuric acid
- triple superphospate (TSP), 43 to 48 percent P_2O_5, produced by reacting ground phosphate rock and phosphoric acid

The production of one ton of SSP with 20% available P_2O_5 content requires:

Phosphate rock	(34% P_2O_5)	0.626	t
Sulphuric acid	(93% H_2SO_4)	0.39	t
Water		0.09	t
Electricity		3	kWh
Labor		0.15	manhours

The electricity consumption given above does not include the consumption for rock grinding, which requires 7-25 kWh/ton of rock depending on hardness and desired particle size distribution.

A phosphate complex producing 357,000 t/a of TSP (in conjunction with phosphoric acid prodution) requires the following per ton of product (in addition to the phosphoric acid production requirements as stated in section IV.C.1):

Sulphur	0.33 t
Phosphate rock	1.65 t

Phosphoric acid is also used for the production of multinutrient fertilizers, the most common being the NP products monoammonium phosphate (MAP) and diammonium phosphate (DAP). A complex producing 250,000 t/a of DAP in conjunction with phosphoric acid production, may require the following (per ton of product):

Sulphur	0.45 t
Phosphate rock	1.52 t
Ammonia	0.22 t

in addition to the requirements for phosphoric acid production.

IV.C.2.1 Triple Superphosphate

TSP has the advantage of being the most highly concentrated straight phosphate fertilizer available. Further, about 25 to 30 percent of P_2O_5 in TSP is derived directly from rock, a relatively low-cost source. TSP is prepared in either granular or non-granular form, the latter for use as an intermediate in production of compound fertilizer and the former for a direct application fertilizer or for blending.

IV.C.2.1.a Non-granular TSP

Figure IV.C-4 provides a schematic illustration of the process for manufacturing non-granular TSP, also called "Run-of-Pile" TSP. As shown, the rock and acid are metered and then combined in a cone mixer from which the material is fed onto a conveyor belt. The TSP sets (hardens) on the conveyor belt and passes through a disintegrator before being deposited on a storage/curing pile where the reaction proceeds to completion and the material further hardens and cools. After 2-6 weeks' storage curing, the TSP is reclaimed with a power shovel and ground in a cage mill to pass a 6-mesh screen (3.3 mm). The ground TSP is then used for making compound fertilizer by granulation processes, or it is granulated into product TSP.

IV.C.2.1.b Granular TSP

The granular form can be produced by processing cured non-granular

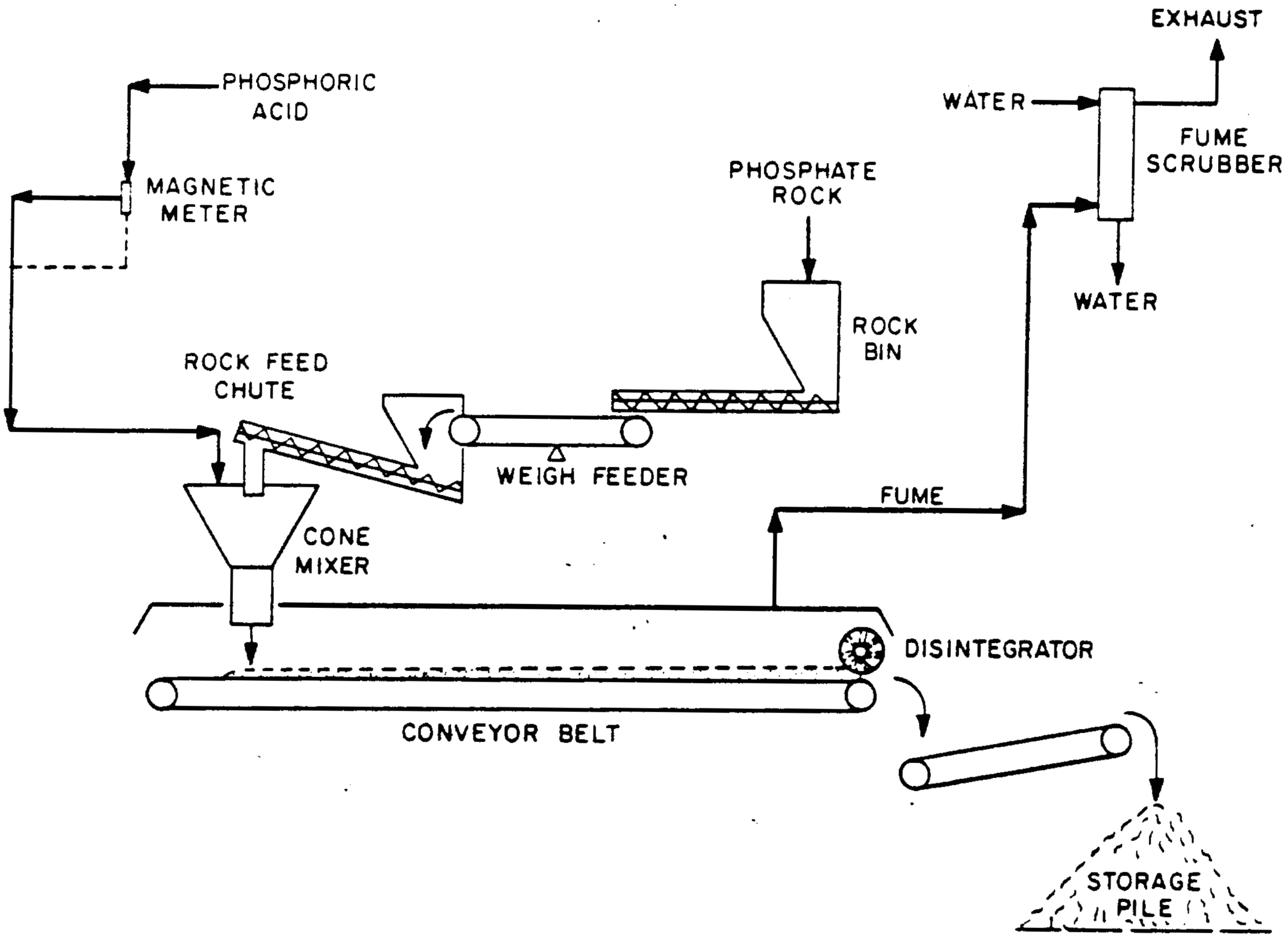

FIGURE IV. C-4

MANUFACTURE OF RUN-OF-PILE TRIPLE SUPERPHOSPHATE

Source: U.N., " Fertilizer Manual", 1980.

TSP or by direct granulation, which is usually preferred because of lower operating costs and improved product properties.

There are two different types of direct granulation processes in use: slurry granulation and ex-den granulation. The ex-den process is similar to the method described above for non-granular TSP, except the rock is more finely ground and the fresh product goes directly to a granulator rather than to storage. Following granulation, the product is dried, screened, and conveyed to storage.

A simplified flow diagram for the slurry-type granulation process is shown in Figure IV.C-5. In this process a thick slurry formed by reaction of ground rock and phosphoric acid in a series of steam-heated reactors is fed to a blunger or rotary drum granulator together with recycle material. The granules are dried, sized, and recycle or sent for cooling and storage.

Approximate utility requirements per ton of product are 40 KWh of electrical energy (including phosphate rock grinding), 125,000 Kcal of fuel oil for drying, and 20 Kg of steam (mainly for providing heat to the reactors).

IV.C.2.2 Single Superphosphate (SSP)

SSP use accounts for about 20 percent of the fertilizer phosphates. The relative share of SSP continues to decrease, however, primarily due to the disadvantage of low analysis (16-22% P_2O_5) and consequent high P_2O_5 distribution costs compared to costs of TSP (43-48% P_2O_5) phosphate.

SSP is still preferred over TSP in situations where both P_2O_5 and sulphur are deficient in the soil, where demand is insufficient to justify an economical scale of TSP production or TSP importation, and where SSP can utilize deposits of phosphate rock that are too small to justify a large plant.

The process for producing SSP is relatively simple and requires a small capital investment; in fact, many SSP plants operate on a planned seasonal

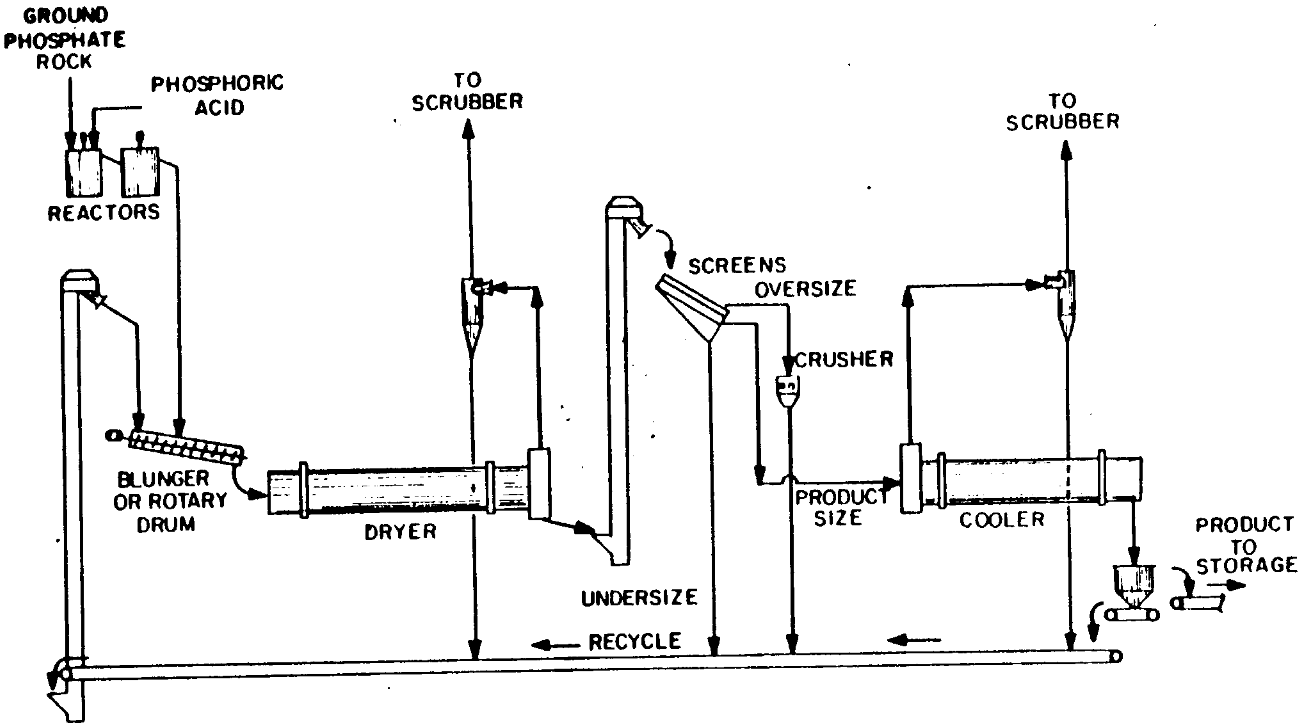

FIGURE IV. C-5

SLURRY PROCESS FOR THE MANUFACTURE OF GRANULAR TRIPLE SUPERPHOSPHATE

Source: U.N., "Fertilizer Manual", 1980

schedule.

The following operations are performed (Figure IV.C-6):

(1) finely ground phosphate rock (90% 100-mesh) is mixed with 68-75% sulphuric acid in a ratio of 0.58 Kg acid (100% basis) per kilogram of rock

(2) the mixer material is fed to a slat conveyor in a reaction den, where solidification takes place due to continued reaction and crystallization of monocalcium phosphate

(3) after 30-60 minutes retention time in the den, the material passes through a disintegrator and is conveyed to storage piles for a final curing period of 2-6 weeks. The cured product is reclaimed from storage piles and fed to a hammer or cage-mill for grinding to pass a 6-mesh screen

(4) for granular forms, the process line includes a granulator, which can treat cured or uncured superphosphate.

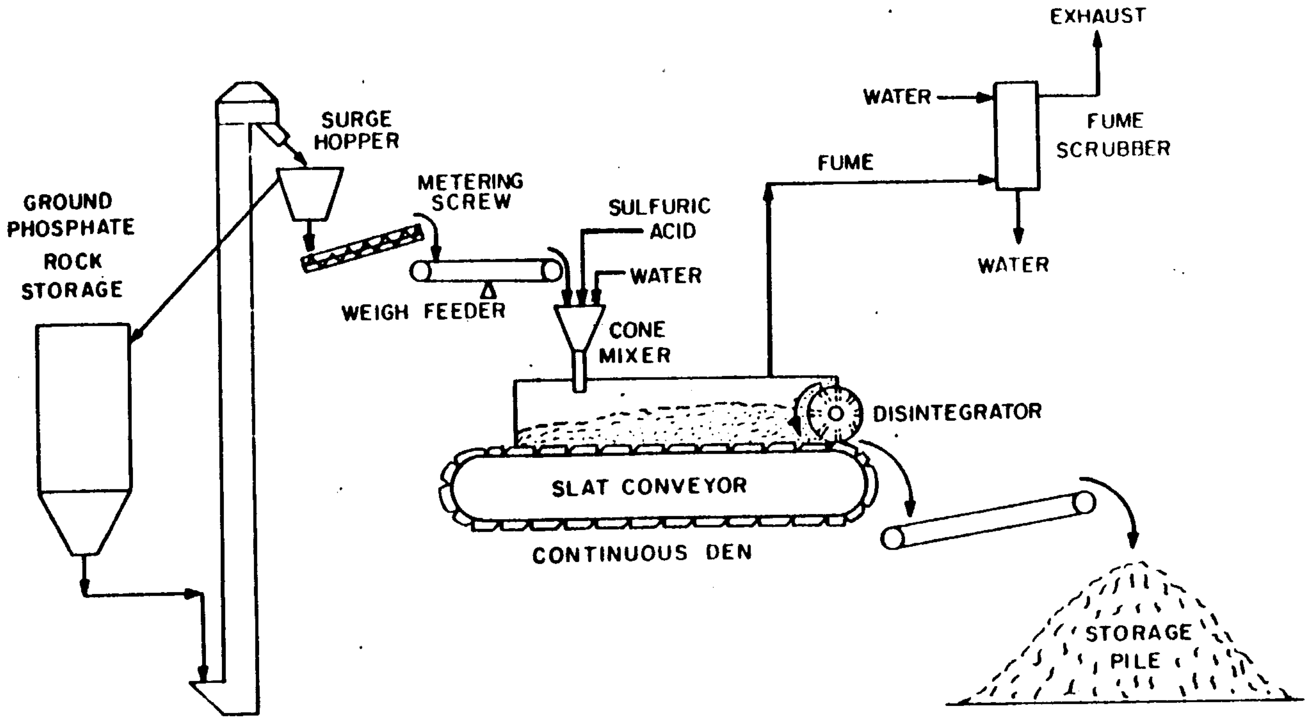

FIGURE IV. C-6

CONTINUOUS MANUFACTURE OF SINGLE SUPERPHOSPHATE

Source: U.N., "Fertilizer Manual", 1980

IV.D. Nitrogenous Fertilizers

Nitrogen, an essential plant nutrient, is supplied to cultivate soils in the form of certain water-soluble nitrogenous chemical compounds that can be absorbed in solution by plant roots. Natural deposits of these compounds are too scarce for commercial fertilizer use, so almost all nitrogenous chemical fertilizers are derived from gaseous nitrogen, which is abundant in the earth's atmosphere.

The key material for nitrogenous fertilizer manufacture is synthetic ammonia, a compound of nitrogen and hydrogen (NH_3) that can be applied directly as a fertilizer itself or used as a feedstock for manufacture of other nitrogenous fertilizers. At present, over 95 percent of all commercial fertilizer nitrogen is supplied by or derived from synthetic ammonia, which is produced by catalytic reaction between nitrogen from air and hydrogen from "synthesis gas". The latter is prepared from steam and various hydrocarbon raw materials (natural gas, coal, naptha, etc.), so ammonia is considered a petrochemical.

The major straight nitrogen fertilizers are

(1) anhydrous ammonia
(2) aqua ammonia
(3) nitrogen solutions
(4) ammonium nitrate
(5) urea
(6) ammonium sulphate

In addition to the straight nitrogen fertilizers, over half of all fertilizer nitrogen is applied as compound NP and NPK types. The relationship between these nitrogenous products was outlined in Figure IV.B-1.

IV.D.1 Ammonia

Synthetic ammonia is the world's largest volume petrochemical, with a worldwide production of 94 million metric tons in 1981. New plants have outputs in the range of 1000 to 1200 tons NH_3 per day, requiring on the order of one million cubic meters of natural gas to supply daily fuel and feedstock consumption in natural gas-based plants. Most new plants today use natural gas technology and are located in sites with ample supplies of gas, either from crude oil-associated sources or gas deposits.

Most ammonia plants use the same hydrocarbon material for both feedstock and process fuel. The main alternatives are natural gas, naptha, fuel oil, and coal. Natural gas remains the preferred feedstock, despite recent changes in relative prices. Regardless of the type of feedstock used, there are four major processing steps in ammonia manufacture:

(1) reaction of steam and hydrocarbon at high temperature (800°C) to yield "synthesis gas", a mixture of hydrogen and carbon monoxide

(2) treatment of synthesis gas with more steam at higher temperature (900-1200°C) to produce additional hydrogen by reaction of carbon monoxide and steam. This step is called "shift conversion".

(3) purification of the hydrogen by removing remaining CO and CO_2. This is a two-stage process.

(4) catalytic reaction at high pressure (150-350 atmospheres) between hydrogen and nitrogen (added as air in step (1)), forming ammonia.

Figure IV.D-1 indicates the flow chart and chemical reaction for ammonia synthesis, and Figure IV.D-2 indicates the process operations and related

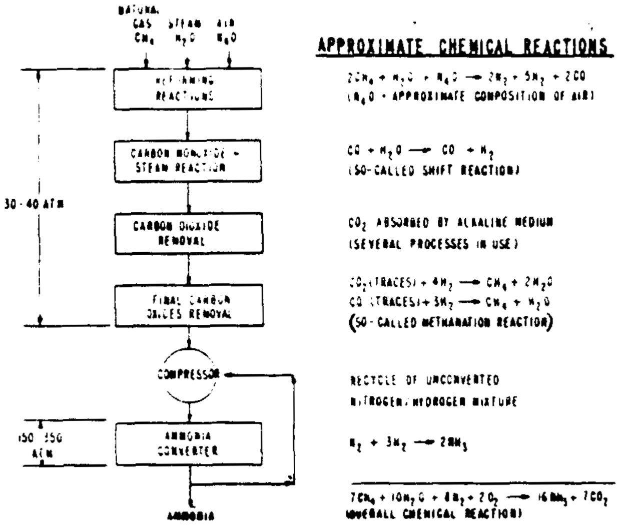

FIGURE IV.D-1

FLOW CHART OF AMMONIA SYNTHESIS
(Steam Reforming of Natural Gas)

Source: U.N., "Fertilizer Manual", 1980.

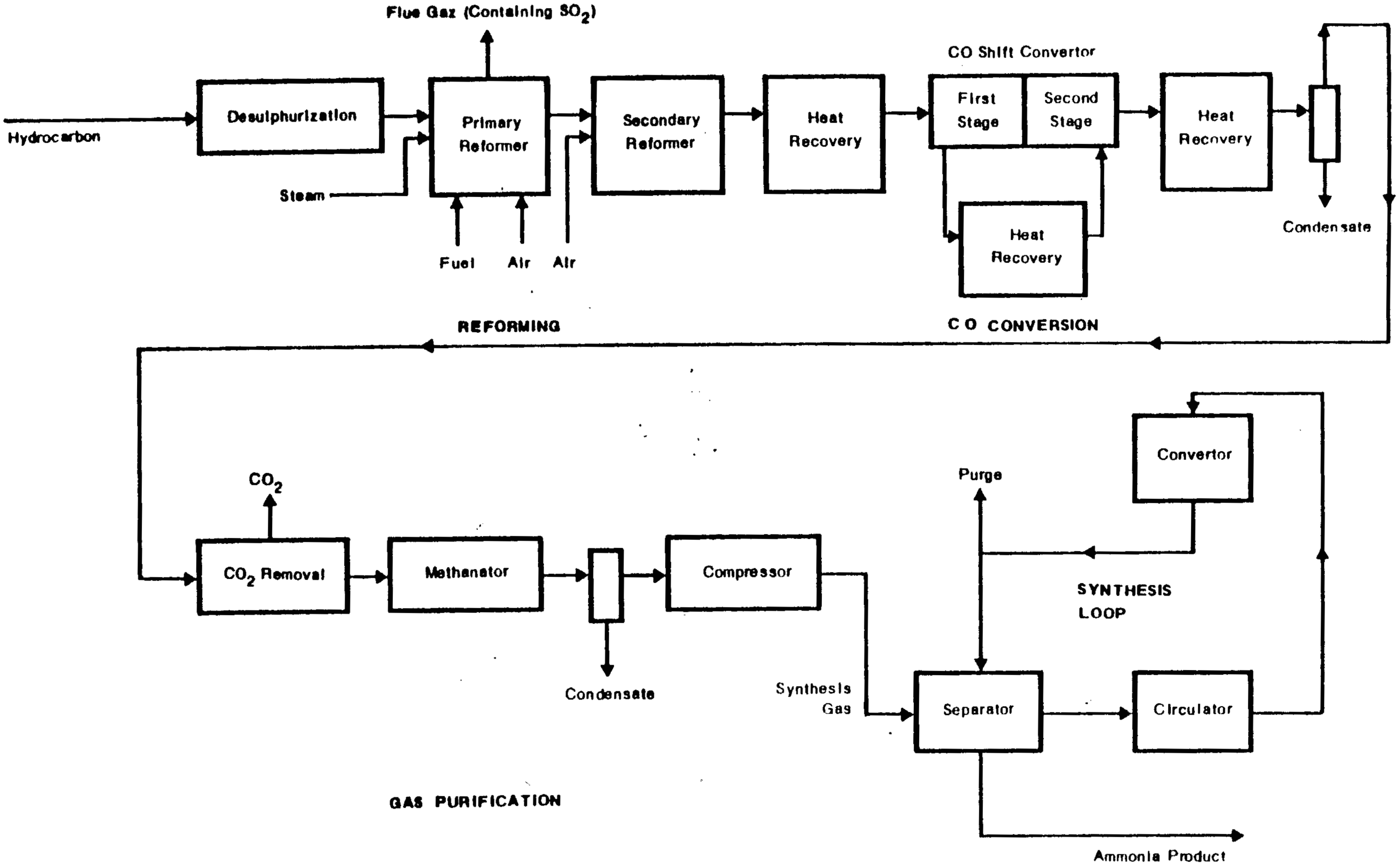

FIGURE IV.D-2

TYPICAL FLOWSHEET FOR AMMONIA PRODUCTION

Source: OECD, "Emission Control Costs in the Fertilizer Industry", July 1977.

equipment.

IV.D.1.1. Synthesis Gas Preparation

Synthesis gas is prepared from natural gas or naptha feedstocks by a process known as "steam reforming". Hydrocarbons heavier than naptha, such as fuel oil, are converted into synthesis gas by means of the "partial oxidation" process.

Steam reforming of natural gas or naptha is usually carried out in two stages (see Figure IV.D-2), using primary and secondary reformers. The first step in the process, however, is desulphurization of the feedstock to prevent poisoning of the reformer catalyst. The primary stage then converts the bulk of the feedstock to hydrogen and carbon monoxide by reaction with steam over a nickel catalyst. The remainder of the reaction occurs in the secondary reformer at higher temperatures with heat available from the introduction of air, which burns part of the synthesis gas and supplies the required amount of nitrogen for ammonia synthesis.

The primary reformer contains a large number of catalyst-packed tubes which are externally heated by combustion of a fuel which is usually, but not always, the same as the feedstock. The reformer tubes are high-strength, stainless steel, ranging from 7.5 to 20 cm in diameter and 3 to 14 meters in length. To provide 800-900°C exit temperatures, the tube walls may be 900-1000°C or more, and therefore require expensive construction materials and careful design and operation to withstand such severe conditions. Heat energy in the combustion exhaust gases leaving the reformer is used to produce steam, to preheat the incoming feedstock-steam mixtures, and to preheat the combustion air.

The typical secondary reformer is a cylindrical refractory-lined vessel. The upper part serves as a combustion chamber for preheated air and primary reformer exit gas. Combustion raises the temperature to 1200°C and the hot gas descends through the lower part of the reformer, which is filled with a catalyst. As it exits the secondary reformer, the gas has cooled to about 950-1000°C and contains about 56% hydrogen, 12% carbon monoxide, 8% carbon dioxide, and usually less than 0.5% methane.

IV.D.1.2 Shift Conversion

The CO shift conversion is usually carried out in two steps, at a considerably lower temperature than the reforming reactions. Gas from the secondary reformer is cooled to about 375°C prior to entering the converters. The reformed gas heat content is recovered by generating steam in a heat exchanger.

Shift converters contain catalyst beds to promote the conversion of CO and steam to hydrogen and CO_2. After leaving the shift converter, the CO content of the gas is less than 0.3% and the CO_2 content is 18% or more, depending on the feedstock composition.

IV.D.1.3 Gas Purification

Gas exiting the shift converter is cooled to about 100°C and passed to an absorption tower where CO_2 is removed by dissolution into a liquid in which it is highly soluble. Most new plants use potassium carbonate solutions to absorb the CO_2.

While the gas contains only 0.3% CO and 0.2% CO_2, after leaving the CO_2 absorption step, these traces must be removed before the final ammonia synthesis step because even in such small amounts they interfere with the synthesis catalyst and the synthesis reaction. Their removal is achieved by "methanation" which is the reverse of the reformer reactions. A nickel-based catalyst is used to react hydrogen with CO and CO_2 to produce methane.

A preheater is required to raise the gas temperature to 300-350°C prior to entering the methanator. Synthesis gas leaving the methanator contains about 74% H_2, 24% N_2, 0.8% methane, and 0.3% oxygen.

IV.D.1.4 Ammonia Synthesis

The synthesis step achieves the actual object of the ammonia plant: all operations described above merely prepare a suitable raw material, which is a 3:1 mixture of hydrogen and nitrogen.

An important factor in the design and operation of the synthesis section is that the reaction of hydrogen with nitrogen to produce ammonia can only be partially completed in a single pass through the reactor. This is quite different from the reforming step, where the methane-steam reaction can be driven almost to completion in one pass through the reformer reactors.

Since there is no combination in ammonia synthesis that will give more than about 20% conversion under practicable operating conditions, the operation is of the loop type, in which a stream of makeup gas is added at one side of the loop, and a stream of product removed at the other (see Figure IV.D-2). Both the incoming and product stream are small compared to the loop recirculation stream. Product ammonia is separated from the circulating loop gas by cooling, which causes the ammonia to condense to a liquid that is readily separated from the unreacted nitrogen and hydrogen.

Major equipment items in the ammonia synthesis loop are indicated in Figure IV.D-3. A large compressor is required to raise the pressure of loop makeup gas to loop pressure, which is in the range of 150-250 atmospheres.

Large plants use two or three-stage centrifugal compressors driven

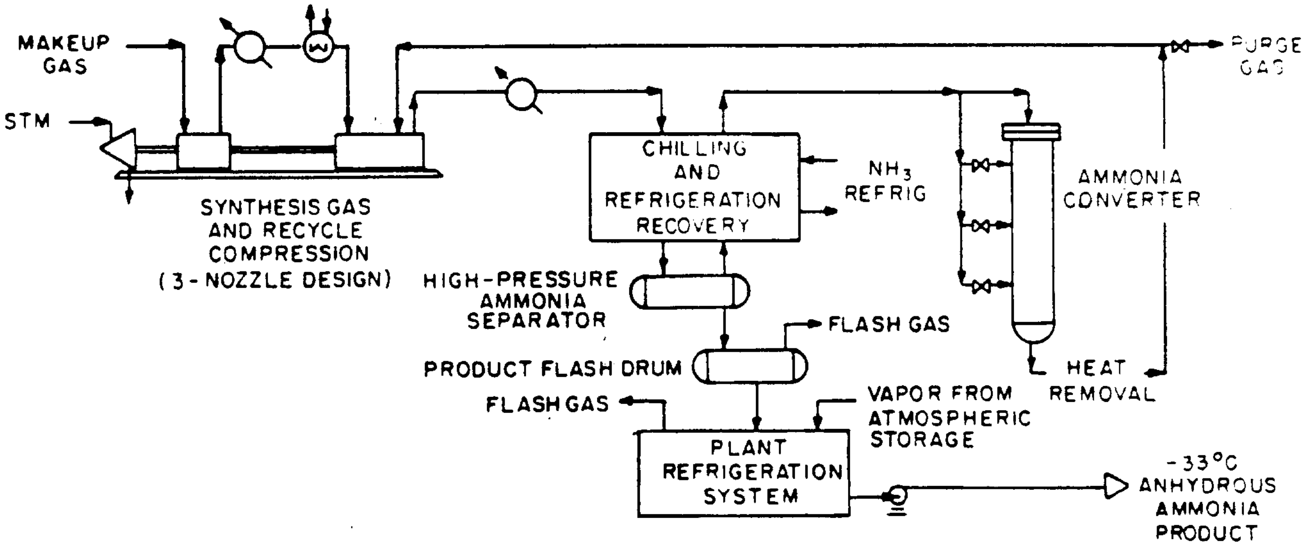

FIGURE IV.D-3

TYPICAL AMMONIA SYNTHESIS LOOP

Source: U.N., "Fertilizer Manual", 1980.

by steam turbines run on high-pressure steam generated mainly from hot process gas leaving the secondary reformer. Gas turbines are used in many plants in place of steam turbines. Even though capital costs are higher for the former, their thermal efficiency is higher because hot exhaust gases provide ready-made preheated reformer air.

The centrifugal compressor for a 1000 tpd ammonia plant is a large equipment item. For suction and outlet pressures of 30 and 245 atmospheres respectively, a steam turbine developing about 23,000 horsepower is required. Large units have three compression stages and operate at speeds of 15,000 rpm. Typical overall dimensions for such a unit are 32 ft. long by 9 ft. wide. Gas cooling between compressor stages is necessary, but many plants cool the gas by refrigeration rather than by water to reduce power requirements.

It should be noted that synthesis gas compression is only part of the compression load in an ammonia plant, as natural gas and air compression before reforming, plus ammonia vapor compression to supply refrigeration in the synthesis loop may require more total horsepower than the main compressor. However, the outlet pressure levels required for these services is relatively low. Typical compressor services in a modern centrifugal ammonia plant are shown in Table IV.D-1.

Ammonia synthesis is carried out at 400-500°C over a special catalyst. Two types of converters are in use: (1) those having a multiple catalyst bed with provision for "quenching" the gas between beds by injecting cool feed gas, for removing heat by steam generation, or for preheating the incoming feed gas, and (2) those having a continuous catalyst bed with a heat exchange for removing heat of the ammonia synthesis reaction.

TABLE IV.D-1

TYPICAL CENTRIFUGAL COMPRESSOR SERVICES IN A MODERN AMMONIA PLANT

SERVICE	PRESSURE RANGE	APPROXIMATE HP FOR 1000 STPD
Natural Gas	100-600 psi (6.8-41 atm)	1500
Air	atm-600 psi (0-41 atm)	8500
Synthesis gas	400-2300 psig (27-150 atm)	17500
Refrigeration	0-275 psig (0-18 atm)	10500
		38000

Source: U.N., "Fertilizer Manual", 1980.

The gas entering the converter contains nitrogen and hydrogen in a 3:1 ratio plus 10-14% inerts and about 2% ammonia, while gas leaving the converter contains 12-18% ammonia.

IV.D.1.5 Input Requirements

The economic capacity of an ammonia plant is between 200,000 and 550,000 t/a and may be associated with methanol production. At such integrated plants the ratio of product is 2:1, ammonia to methanol.

Outputs for a 330,000 t/a ammonia plant requires, per ton of product

Natural gas	36 GJ or 1100 cu m
Electricity	20 - 35 kWh
Water	200 t (which may be reduced by recirculation)
Land	0.2 - 0.3 sq m
Personnel	0.0005 (say 2,200 t/m/a)

Table IV.D-2 shows the required unit inputs for a 1000 short ton per day plant, on a comparison basis for different feedstock.

IV.D.1.6 Ammonia Storage

Ammonia is a gas at atmospheric pressure and ambient temperatures, but it is almost invariably transported and stored in the liquid stage. Liquefaction of gaseous ammonia requires compression or refrigeration, or a combination of the two, with the following conditions in use for bulk storage and transport.

(1) fully refrigerated - atmospheric pressure and a temperature of -33°C

(2) semi-refrigerated - gauge pressure of 3-4 atmospheres and a temperature of 0-5°C

TABLE IV.D-2

COMPARISON OF AMMONIA PRODUCTION INPUTS (330,000 SHORT TONS PER YEAR; 330 OPERATING DAYS PER YEAR) THAT RESULT FROM USING A FEEDSTOCK OF NATURAL GAS, NAPTHA, FUEL OIL, OR COAL

	Natural Gas Steam Reforming	Naptha Steam Reforming	Heavy Fuel Oil Texaco Partial Oxidation	Pittsburgh Seam Coal Texaco Partial Oxidation
Raw Materials				
Coal				2 tons
Natural gas	31 MM Btu			
Naptha		0.8 ton/ton		
Heavy fuel oil			0.96 ton/ton	
Utilities				
Power	20 kWh/ton	22 kWh/ton	110 kWh/ton	136 kWh/ton
Steam				5 tons/ton
BFW	4,000 lb/ton	4,000 lb/ton	5,000 lb/ton	6,000 lb/ton
Cooling Water	2,500 gal/ton	2,700 gal/ton	6,000 gal/ton	3,000 gal/ton
Labor + Supervision (4 shifts)	6 men/shift	7 men/shift	8 men/shift	15 men/shift

Source: Strelzhoff, S., "Hydrocarbon Processing", October 1974.

(3) pressurized - guage pressures up to 18 atmospheres and ambient temperatures.

IV.D.1.6.a Fully Refrigerated Storage

Most large ammonia storage tanks are maintained at fully refrigerated conditions (i.e. at atmospheric pressure) and have capacities up to 45,000 tons. In these tanks, ammonia is used as a refrigerant, being withdrawn as a vapor from the tank, compressed, cooled with water to liquify it, and then returned to the storage tank where it vaporizes and thereby cools the tanks' liquid contents (see Figure IV.D-4).

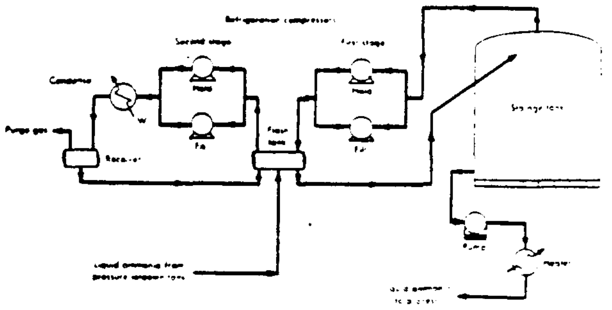

FIGURE IV.D-4

SIMPLIFIED DIAGRAM OF REFRIGERATED STORAGE FACILITY

Source: U.N., "Fertilizer Manual", 1980.

IV.D.1.6.b Semi-refrigerated and Pressure Storage

The regrigeration system is similar in principle to fully refrigerated storage, but much less elaborate in design and relatively inexpensive. The advantage of semi-refrigeration over full pressure storage is that much lighter steel can be used to fabricate the tanks. Pressure or semi-refrigerated storage is economical for quantities up to 2000 tons. Tanks in the upper portion of this range are usually spherical, while horizontal cylindrical tanks with hemispherical ends are used for smaller quantities.

IV.D.2 Nitric Acid

The principal use for nitric acid is in fertilizer production. Ammonium nitrate is the primary end product used straight or in compound fertilizers, nitrophosphates, nitrogen solutions, or mixed salts. Nitric acid also has many industrial uses, including the manufacture of explosives.

Virtually all nitric acid manufactured today is obtained by catalytic oxidation of an ammonia and air mixture. This reaction produces nitric oxide (NO), which in turn is oxidized to higher nitrogen oxides (NO_2) that form nitric acid when absorbed in water. The following major features are usually found in modern nitric acid plants:

(1) vaporization, superheating, and filtration of anhydrous ammonia
(2) preheating, filtration, and compression of process air
(3) catalytic oxidation of ammonia
(4) cooling of nitric oxide by heat exchange with process air, boiler water, tail gas, etc.
(5) oxidation of nitric oxide to higher oxides
(6) absorption of nitrogen oxides in water to form nitric acid
(7) bleaching of acid by additional air or other means
(8) treatment of tail gas to improve plant efficiency and reduce air pollution
(9) recovery of energy in compressed process gases
(10) catalyst recovery

Classification of commercial processes is often based on the operating pressures used: monopressure systems use a single pressure throughout, whereas dual pressure processes use lower pressure for the ammonia oxidation step than the oxide absorption step. Monopressure plants use either medium (3-5 atmospheres) or high (8-13 atmospheres) throughout, and dual pressure palnts use medium-pressure combustion and high-pressure absorption.

Numerous proprietary processes for nitric acid manufacture are available, one of which is shown schematically in Figure IV.D-5. This process operates at 5 atmospheres throughout the system, and uses the ammonia vaporizer to produce chilled water used to cool the second absorption tower. Nitric acid concentrations with this type of plant are in the range of 65 percent, with overall nitrogen recovery of about 96%.

In most processes, the compressors are driven by expansions of preheated tail gases or by steam generated from heat released by the chemical reaction of acid manufacture. In some cases, however, the compressors are driven by electric motors, and the heat of reaction recovered by steam generation is exported to other plant units.

Approximate operating inputs for a mono-medium pressure plant (5 atmospheres) are as follows:

NH_3 required, Kg/ton acid	284
Platinum loss, milligrams/ton acid	95
Electricity, KWh/ton acid	22
Steam credit, Kg/ton acid	600
Cooling water, cubic meters/ton acid	87
Labor, man-hours/ton acid	0.08

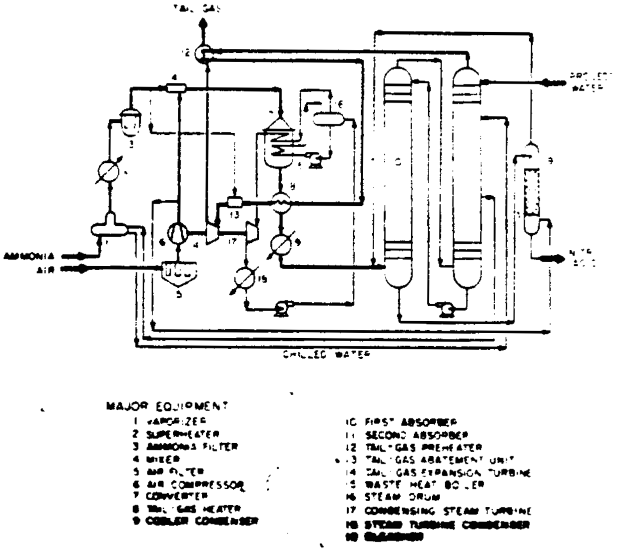

FIGURE IV.D-5

MEDIUM-PRESSURE NITRIC ACID PROCESS (UHDE)

Source: U.N., "Fertilizer Manual", 1980.

Actual values vary widely depending on plant design and operating conditions. Plants built during the 1960s have capacities of 300-400 tons of acid per day (100% acid basis), while newer plants have outputs on the order of 700-900 tons per day.

IV.D.3 Ammonium Nitrate

Ammonium nitrate is a very popular fertilizer in many temperate zone countries. It is produced by neutralizing nitric acid with ammonia, producing a nitrate solution that varies between 80 and 90 percent by weight depending on operating conditions. The solution, known as AN-solution, can either be sold directly or further processed into a dry product.

For a granular or crystal product, the 80-90 percent AN-solution must be concentrated up to 95 percent ammonium nitrate. Concentration to 99-99.5 percent is required in order to produce a prilled product. In the prilling process, concentrated solution is pumped to the top of a tower, up to 50 meters in height, where it is sprayed downward, countercurrent to a stream of air which cools and solidified the droplets. The prills are then further dried to reduce the moisture content to less than 0.5 percent. They are next coated with an anti-caking agent.

Production of dry crystalline ammonium nitrate requires that the solution from the concentrator (95 percent AN) be fed to a continuous vacuum evaporation crystallizer, in which the solution cools and thereby forms AN crystals. Crystal slurry is then fed to a centrifuge for crystal separation. The separated crystals are sent to a drier for water removal to 0.1 percent water content, cooled, and coated with an anti-caking agent.

A schematic flowsheet for a typical ammonium nitrate process is shown in Figure IV.D-6. Production inputs for a large plant (1400 metric tons per day) are roughly as follows:

Input	Per ton AN (prilled)
Ammonia	0.21 ton
Nitric acid	0.77 ton
Stabilizer	4 Kg
Steam	0.2 ton
Water	8 m^3
Electricity	20 KWh
Labor	0.17 manhour

IV.D.4 Urea

Urea is one of the most widely used solid nitrogenous fertilizers, due to its high nitrogen concentration (46%) and favorable production costs compared to other nitrogenous fertilizers. It is also well suited to use in warm climates and for fertilizing of rice plants, and accounts for about 85% of nitrogenous fertilizer capacity in Asia. Urea is also used as a cattle feed supplement and for industrial applications, notably for production of plastics.

The raw materials for commercial production of urea are carbon dioxide and ammonia, both of which are obtained from an adjacent ammonia manufacturing unit. (Carbon dioxide is a by-product of ammonia manufacture.) The reaction between ammonia and carbon dioxide forms an intermediate product, named ammonium carbamate, which decomposes to form urea and water in the second step of the reaction. Conversion of carbamate to urea and water goes to 40-70 percent completion depending on process conditions.

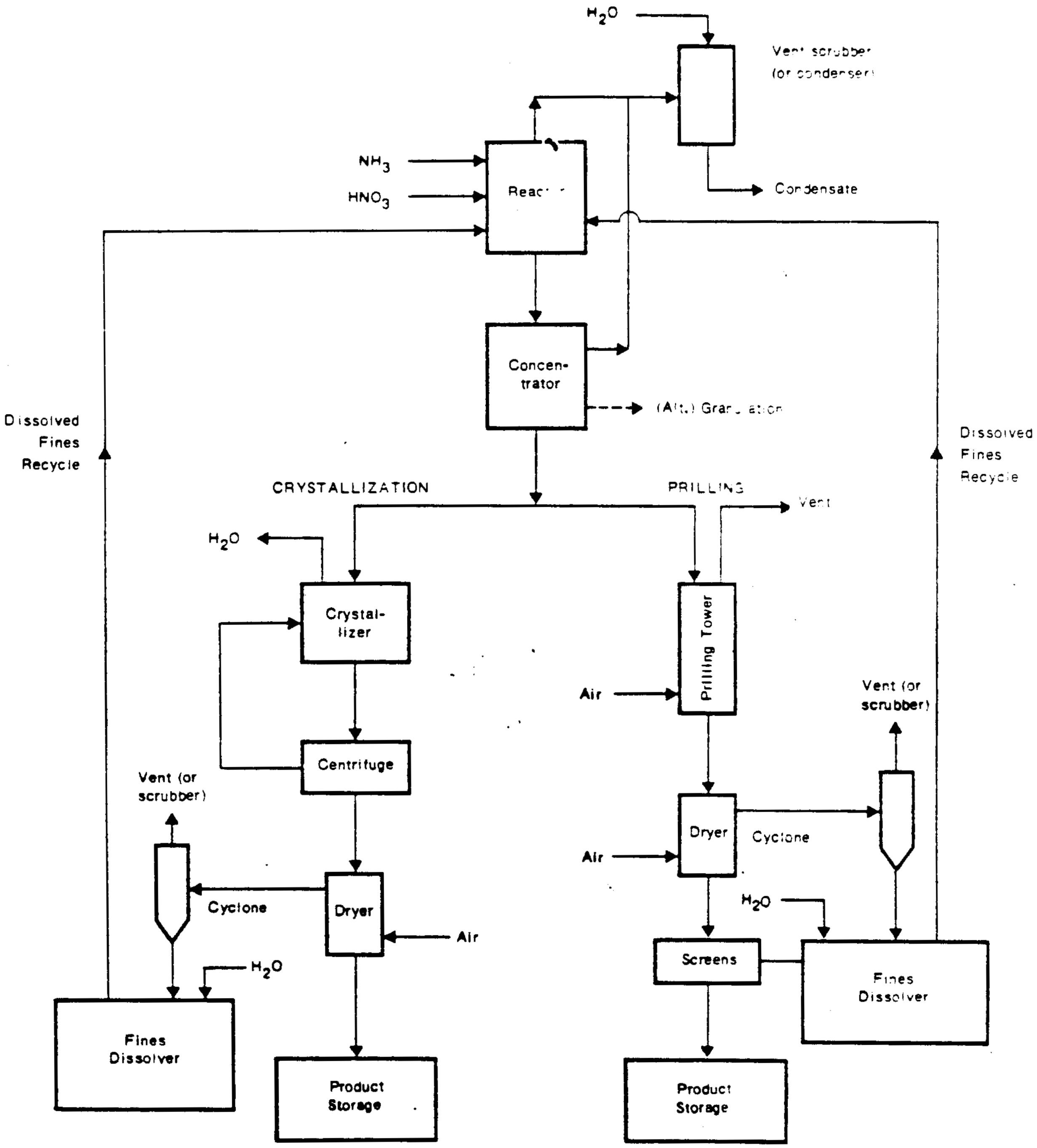

FIGURE IV.D-6

TYPICAL FLOWSHEET FOR AMMONIUM NITRATE PRODUCTION

Source: OECD, "Emission Control Costs in the Fertilizer Industry", July 1977.

Three basic urea production methods are in use, differing primarily in the handling of unreacted ammonia and carbon dioxide in the reactor exit gases:

(1) in the 'once-through process' the unreacted raw materials are not recycled, but used in manufacturing other fertilizers

(2) in "partial recycle" a fraction of the excess ammonia is recycled back to the reactor while other portions are used in production of other fertilizers

(3) the "total recycle" process recycles both ammonia and carbon dioxide back to the reactor.

High-pressure reaction conditions are used in all commercial urea processes. The reaction of ammonia and carbon dioxide to form urea, ammonium carbamate, and water takes place in the reactor at pressures of 130-250 atmospheres and temperatures of 180-210°C. The urea reactor effluent contains urea and water formed by the synthesis reaction, along with unconverted carbamate and excess ammonia. Carbamate is separated by manipulating subsequent process conditions in a "decomposer" where the carbamate dissociates into ammonia and carbon dioxide (reverse of synthesis process). The ammonia and carbon dioxide are removed from the urea solution as gases and recycled back to the synthesis reactor. The urea solution flows to a second decomposer for final carbamate removal and then to a concentrator. The resultant 75% solution can be used as is or further concentrated and transformed into a solid product by prilling or granulation.

Prilling, described for ammonium nitrate manufacture in Section IV.D.3, is still the most widely used process for solid urea finishing, but most new plants in the U.S and Canada are installing urea granulation equipment because of higher demand for the granular form. Granular urea has greater crushing strength and resistance to abrasion than the prilled form, and greater flexibility in particle size determination.

The following raw materials and utility consumptions are reported for one of the many licenses urea (46%) processes, per ton of product:

Ammonia	0.58 t
Carbon Dioxide	0.76 t
Water	75 t
Steam	1.2 t
Electricity	125 kWh
Personnel	0.0005 (say 2,200 t/m/a)

IV. E Other Fertilizers

IV.E.1 Potash Fertilizers

Potash nutrient ratings are often in the oxide K_2O form with 83% rating of elemental potassium. While potash is abundant in the sea and inland brine deposits, extraction costs are high so that most resources are dry mined salts followed by benefication of the ore. The largest of these is potassium chloride, muriate of potash, which yields about 85% of all potash produced. The most common ores are Sylvinite with 10 - 35%, K_2O, Carnallite (10 - 16%), Langbeinite (7 - 12%), Kainite (13 - 18%) and Hartsaltz (10 - 20%). With the exception of Carnallite, produced in the Congo and Brazil, most production is in North America, the USSR or Europe. Thailand has reserves of potash but they are not currently being exploited. The predominant source of potassium chloride is sylvinite. Potash production at the mine is usually accompanied by benefication processes which include froth flotation and fractional crystallization.

Potassium chloride has a high analysis of 0.0.60, but it may be harmful on some plants because of the chlorine content. For this reason, potassium sulphate (0.0.50), although more expensive, may be preferred for some uses. Both potassium chloride and potassium sulphate are normally applied in a mixture with other nutrients.

IV.E.2 Sulphur Fertilizers

Of the secondary macronutrients, sulphur is the most important in international trade, mainly because of its use in processing other nutrients. Sulphuric acid is used in the production of phosphatic fertilizers, but is also required in the synthesis of ammonium sulphate and potassium sulphate.

Sulphur is economically produced in quantity in only a few countries. It may be produced from mined deposits which are melted in water by the Frasch process, which is the major source, but it may also be recovered from sour natural gas or petroleum in the form of granules. Both forms of sulphur are called brimstone.

IV.F Environmental Impact

Fertilizer industry wastes can affect air, water, and land resources of an environment. In this section, the major waste sources and applicable treatment techniques for nitrogenous and phosphatic fertilizer facilities will be shortly discussed. A more detailed analysis can be found in the "Environmental Guidelines", The World Bank, Office of Environmental Affairs (1984).

IV.F.1 Phosphatic Fertilizer Facilities

The principal air pollution problem in phosphatic fertilizer plants is fluoride emission, for which stringent limitations exist. Sulphur dioxide (SO_2) is an important air pollutant generated at the sulphuric acid plants, which are usually part of phosphatic fertilizer complexes. Emissions of SO_2 can be reduced by use of the "double-contact" process or ammonia scrubbing. Other gaseous contaminants include considerable amounts of dust generated at the grinding stage of phosphate rock, and fluorine (as SiF_4) which may evolve in the acidulation process of phosphate rock. Dust and obnoxious fumes result from granular and non-granular TSP production, but these are readily collected and treated.

Wastewaters of limited volume are generated in phosphate fertilizer plants, and may include water treatment plant wastes, cooling tower and boiler blowdowns, make-up water, spills and leaks, surface runoff, and gypsum pond water. Usually all water which has direct contact with process gas or liquid streams is recirculated and there should be no discharge of liquid effluents (other than the rainwater runoff) from these plants.

In addition to the considerable amount of phospho-gypsum produced in the phosphate fertilizer plants, solid materials may be found in storage piles, settled dust, and similar forms.

IV.F.2 Nitrogenous Fertilizer Facilities

In production of nitrogen fertilizers, no air pollution results from ammonia and urea manufacture. However, the tail-gas vented from nitric acid plants contains nitrogen oxides (NO, NO_2, and N_2O_4), which can be harmful to plants, animals, and people, and can produce smog by photochemical reaction in the atmosphere. U.S. emission standards for nitrogen oxides are 100 microgram per cubic meter, about one-tenth the emission rate in plants having no pollution abatment systems. Tail-gas can be handled by extended absorption or catalytic reduction. Overhead vapor resulting from ammonium nitrate production may lead to an air pollution problem, but it can be handled by cyclones or baghouses.

Liquid wastes from the nitrogen fertilizer industry can originate from water treatment plant wastes, cooling tower and boiler blowdowns, compressor blowdown, process condensates, and spills or leaks. Effective methods using air or steam are applied for removing ammonia from process condensates and blowdowns at ammonia, urea, and ammonium nitrate plants. Biological methods and ion exchange units are also used to remove ammonia and nitrates from waste waters. At urea plants, hydrolysis is used to remove urea from waste streams.

IV.G Seaborne Fertilizer Transport

Only the primary nutrients (nitrogen, phosphorus, and potassium) are of major importance in international trade. Among the secondary nutrients, sulphur is the most traded one, mainly because of its use in processing other nutrients. Calcium and magnesium are normally available in local liming materials such as ground limestone and dolomite, and therefore their trade is insignificant. The world's production and exports of fertilizer raw materials and products in 1982 are shown in Table IV.G-1. It should be noticed that only 50% of the world sulphur and sulphuric acid production is used by the fertilizer industry, while the rest is related to entirely different industries.

The international trade of fertilizer raw materials and products depends on the location and degree of integration of the fertilizer industry, which are determined mainly by production and transport economics. The following factors are responsible for the geographical distribution of the fertilizer industry today:

- Minimization of transit distances favors integrated production from raw materials to finished products on a single site located close to either raw material resources or markets.
- Minimization of shipments favors the production of fertilizers at the site of the most bulky raw material especially phosphate rock or ammonia.
- The use of the same raw materials and equipment for the production of several different products favors the production at a single plant. For example, SSP, TSP, MAP and DAP are often produced all at the same integrated phosphate complexes. The same applies for cases

TABLE IV.G-1

WORLD PRODUCTION AND EXPORTS OF FERTILIZER PRODUCTS, 1982

('000 metric tonnes)

PRODUCT GROUP	PRODUCT	PRODUCTION	EXPORT	% EXPORT
RAW MATERIALS AND INTERMEDIATES				
Sulphur	Brimstone	31,488	14,540	46.2
	Sulphuric Acid	130,260	3,250	2.5
NITROGEN	Ammonia	93,570	6,860	7.3
PHOSPHATE	Phosphate Rock	121,850	43,430	35.6
	Phosphoric Acid	36,400	5,430	14.9
POTASH	Potash Salts	45,880	26,340	57.4
		459,440	99,850	21.7
FINISHED FERTILISERS				
NITROGEN+	Urea	42,190	11,900	28.2
	Ammonium Nitrate	39,850	5,220	13.1
	Ammonium Sulphate	13,590	4,220	31.1
PHOSPHATE+	Superphosphate	32,680	1,130	3.5
	Triple Superphosphate	8,600	3,030	35.2
NP	MAP/DAP		5,830	
	Other	60,200*	1,570	24.0
Nk/PK	-		1,090	
NPK	-		5,980	
		196,910	39,970	20.1

\+ Nitrogen and phosphate straight fertiliser figures exclude single nutrient fertilisers other than specified, which are mainly unspecified USSR and Chinese products and USA anhydrous ammonia. They mainly do not enter international trade.

* Estimates of compound fertiliser productions are based on an assumed average of 65% NPK rating. The total nutrient content of compound fertiliser is N - 11,370 tonnes, P_2O_5 - 18,370 tonnes, K_2O - 9,380.

Source: H.P. Drewry Ltd., "The Organisation and Structure of the Deep-Sea Fertiliser Trades", 1984.

where by-products from one process are used in another production process. For example, urea and ammonia plants are usually located on the same site, since CO_2 is a by-product of ammonia synthesis and a raw material for urea production.

- The encountered economies of scale favor production in large units, especially in cases of existing, partly or fully amortized plants.
- Other factors such as earning of foreign exchange, desire for self-sufficiency, and exploitation of national resources may play an important role in locating fertilizer industries, especially in developing countries.

The following sections will discuss the types and sizes of ships used in seaborne fertilizer trade. In general, 'tweendeckers of 10,000-18,000 dwt, and "handy-sized" bulk carriers of 15,000-40,000 dwt and occasionally up to "panamax" size (50,000-80,000 dwt) are used to transport dry fertilizer materials. Specialized acid, gas, or molten carriers are used for shipments of phosphoric and sulphuric acid, ammonia, and molten sulphur respectively.

Almost any bulk carrier can be employed in the trade of dry fertilizer materials, as the only constraints are that the cargo should be kept dry and that the ship should be equipped with cargo handling devices in the cases of inadequate shore-based facilities. However, there are other physical and economic factors which determine the ship selection, such as:

- Physical form of cargo: for a variety of reasons many fertilizers are shipped in bags. This leads to the employment of smaller break bulk 'tweendeckers, since the stowage of bags in vessels with decks is easier.

- Size of shipments: the shipping requirement of relatively small volumes of many, different raw materials and finished products (refer to Table IV.H-5), the need for storage, and the amount of capital tied up in stocks justify for the use of small vessels, except in the case of a few high volume trade routes. Lot sizes of much less than 15,000 tonnes leave very little choice, as only 'tweendeckers are available at very low capacities.
- Port facilities: draft and loading/unloading rates (refer to Table IV.H-6) possess important physical limitations on the size of vessels used.
- Voyage length: long distances allow shippers to take advantage of economies of scale in bulk shipping, while the use of smaller ships is more economical on short haul routes.
- Backhaul opportunities: smaller break bulk ships have more possibilities of backhauling other, usually "general" cargoes, a fact which limits or eliminates the costs of ballasting.

IV.G.1 Phosphate Fertilizers

Although the world's nutrient requirements of elemental phosphorus are far less than those of nitrogen, phosphate is the major fertilizer type in international trade. The reasons are firstly that phosphate is shipped in forms with a low nutrient content, which leads to high volumes of material transported, and secondly that the worldwide distribution of phosphate deposits is more uneven than the hydrocarbons used in ammonia production.

IV.G.1.1 Phosphate Rock

Four countries, the U.S., U.S.S.R., Morocco, and China account for almost 80% of world commercial phosphate ore production. In 1982, 35.6% of all phosphate rock produced was traded internationally, and over 90% of this trade was transported by sea. The seaborne trade volume of 40 million metric tons in 1982 ranked phosphate rock fourth among the major dry bulk commodities.

Phosphate rock as mined contains between 5-10% of elemental phosphorus, but this is usually raised (by benefication processes at mine) to about 14%, giving a nutrient rating of 0.32.0.

Phosphate rock is commonly shipped as bulk cargo, and may either be in bulk carriers, or in multi-decked conventional cargo vessels as "bottom cargo". Specialized vessels are not required, although some ships incorporate conveyor-fed unloaders to speed discharging operations. The size distribution of ships transporting phosphate rock is shown in Table IV.G-2. Small ships, those of less than 20,000 dwt, handle a much higher proportion of total tonnage than in the other major bulk trades. About 35 percent of the seaborne trade in phosphate rock is carried in vessels of less than 18,000 dwt, which are predominantly 'tweendeckers. Relatively short shipping distances and draft limitations, particularly in African and Middle East loading ports, have contributed to the continued use of these smaller ships by many importers. Larger ships, in the 40-60,000 and over 60,000 dwt ranges, account for a growing share of total shipments (refer to Table IV.G-2). Vessels of say 50,000 dwt and above (larger than those indicated in Table IV.H-5) are on time charter on some of the transatlantic trades.

TABLE IV.G-2

SIZE DISTRIBUTION OF SHIPS TRANSPORTING PHOSPHATE ROCK
(% of World Seaborne Trade in Phosphate Rock)

Ship Size (dwt)	1970	1973	1976	1978	1980	1982	1983
Under 40,000	95	89	86	86	84	83	78
40-60,000	5	11	13	11	13	12	11
60,000 +	-	-	1	3	3	5	10

Source of data: H.P. Drewry Ltd., "Outlook for Phosphate Shipping and Trade", 1982; and Fearnleys, "World Bulk Trades", 1983.

In the U.S. domestic trades, large, self-unloading barges are used to move phosphate rock from Florida to fertilizer manufacturing plants on the lower Mississippi (refer to Table IV.G-3).

IV.G.1.2 Phosphoric Acid

Phosphoric acid has increasingly become a commodity in international trade. The volume of seaborne trade in 1982 was 4.68 million metric tonnes. The normal grade of phosphoric acid produced contains 54% P_2O_5. Imports of phosphoric acid are mostly used to meet a temporary shortfall in acid production. However, there are fertilizer process facilities, specifically designed to use the imported material.

Phosphoric acid is carried in bulk by a limited fleet of dedicated tankers, which have mild steel tanks lined with rubber due to product corrosivity. These vessels are totally restricted to this trade, and their capacity varies between 5,000 and 25,000 dwt. In addition, phosphoric acid can be carried in the stainless steel capacity of the parcel tanker fleet. The sizes of these ships vary from 11,000 to 30,000 dwt. To promote development of trade in phosphoric acid, North African producers (Morocco and Tunisia) have invested in their own shipping capacities to deliver acid exports.

IV.G.1.3 Finished Phosphate Products

The most important phosphate fertilizers in the international trade are:

	Analysis
Straight	
Single superphosphate (SSP)	0.18.0
Triple superphosphate (TSP)	0.45.0

TABLE IV.G-3

SELF-UNLOADING PHOSPHATE TUG/BARGE UNIT

Name: Erol Becker (barge), April J. Becker (tug)

Owner: Becker Shipping Co. (USA)

Year of Build: 1982

Barge characteristics:

length, OA	610 ft.
beam	78 ft.
depth, molded	51 ft.
design draft	36 ft.
deadweight	42,000 tons

Tug characteristics:

length	145 ft.
beam	42 ft.
depth	21 ft.
gross tons	197
total horsepower	7,200
crew	8

Discharge rate: 4000 short tons of phosphate rock per hour

Unloading system: A centerline conveyor runs the entire length of the cargo hold (495 ft.) and delivers cargo to a loop belt conveyor, which consists of a double set of conveyor belts pressed together under tension by rollers that sandwich the rock. The loop belt conveyor elevates the cargo to a 105 ft. boom conveyor for discharge off the vessel.

A self-propelled hatch cover gantry crane moves the entire length of the barge and lifts/stacks the 14 hatch covers.

Note: This barge is one of the largest phosphate carriers currently in use.

Source: Marine Engineering Log, January 1983.

	Analysis
Multinutrient NP	
Monoammonium phosphate (MAP)	11.55.0
Diammonium phosphate (DAP)	18.46.0

The ammonium phosphates are most commonly traded, as they have higher nutrient content and hence lower transportation costs per unit of value. In 1982, 5 million metric tonnes of MAP/DAP were shipped, while the volume of SSP/TSP was only 3.03 million mt. Virtually the entire straight phosphate product which enters international trade consists of TSP.

All the above products can be shipped in bulk or in bags, the former being the most common. The size of vessels transporting phosphate fertilizers varies highly depending on the distance and volume of the shipments. While the U.S. exports to China are served by ships well above 50,000 dwt, in the U.S. - South America trade the average lot size is about 10,000 dwct.

IV.G.2 Nitrogen Fertilizers

The main commodities in international trade associated with the production of nitrogen fertilizers are:

	Analysis
Intermediate products	
Ammonia	82.0.0
Finished products	
Urea	46.0.0
Ammonium Nitrate	35.0.0
Ammonium Sulphate	21.0.0

Ammonia plants are almost always located either close to cheap source of feedstock, or close to major markets where natural gas is commonly pipeline fed (over 80% of synthetic ammonia is produced from natural gas), and therefore no raw material shipments for nitrogen fertilizer plants are required.

IV.G.2.1 Ammonia

The high corrosivity of ammonia along with the requirement for low temperature or high pressure, if it is to be carried as a liquid, counter balance the advantage of the high elemental content (82%) of this product. Total world international trade in anhydrous ammonia amounted to 4.81 million metric tonnes in 1982. This trade results mainly from a short-fall in its synthesis capacity on the site of fertilizer processing. However, the recent low ammonia pricing in some cases has favored the imports rather than investments in expensive ammonia synthesis facilities.

The ammonia trade is serviced by a worldwide network of maritime ammonia terminals with storage capacities ranging from a few hundred tons to over 100 thousand tons, and a fleet of specialized ocean-going vessels and inland waterway barges.

Vessels utilized in deepsea or coastal shipments of ammonia have well-insulated tanks or holds to contain liquid ammonia at slightly above atmospheric pressure and a corresponding temperature of $-33^{\circ}C$. These ships have refrigeration facilities similar to those used for onshore storage tanks and also are equipped with high-capacity pumps to ensure rapid cargo discharge.

Vessels capable of transporting ammonia are designed to accept low temperature liquefied petroleum gases (LPG) as well, at minimum temperatures ranging from $-34^{\circ}C$ to $-48^{\circ}C$. Dedicated LPG carriers cannot be used for ammonia shipments because of ammonia corrosivity, unless if their tanks are constructed of special metals. Liquid gas carriers range in capacity from 2,000 to 50,000 cubic meters, the majority being less than 20,000 dwt (30,000 cu m).

To minimize port time, ships must be loaded or unloaded rapidly and with minimum vaporization of refrigerated ammonia. This requires, in addition to large pumping capacity, large diameter cryogenic pipelines suitable for transport of ammonia between ship and terminal. The high per-meter cost of these pipelines normally requires short distances between storage tanks and berths.

Terminal size depends mainly on the capacity of ships serving it. Capacity is usually 25-50% greater than the average shipment size, to allow for flexibility in scheduling and to provide a buffer for delays due to storms, strikes, etc.

Barge shipment of anhydrous ammonia is extensively used in Europe and the United States, where inland and coastal waterways transportation is found to be economical compared to other modes. European inland waterways are often narrow and/or shallow, and better suited to single, self-propelled barges, while in the U.S. towed barges fastened in groups of 6 or 8 are typical on the Mississippi River and Gulf coastal waterways. The barges are usually fully refrigerated and have capacities in the range of 1500 to 2500 tons depending on draft restrictions. A typical terminal served by barges has 60,000 tons of ammonia storage capacity in two 30,000-ton tanks.

IV.G.2.2 Finished Nitrogenous Products

The seaborne exports of nitrogenous fertilizers amounted to 15.42 million mt in 1982.

Urea is the most popular product of this type, with a nutrient rating of 46.0.0, which is the highest analysis among nitrogenous fertilizers. It may be shipped either in bulk or in bags. Bulk urea is coated to prevent caking, while bagged urea is usually moved in tough woven polypropylene sacks with polythene liners and can be stored in the open without loss or deterioration. Urea is mostly transported in 'tweendeckers and rarely in ships over 20,000 dwt.

Ammonium nitrate, ammonium sulphate, and the compound fertilizers are often moved in bags and in 'tweendeckers, the shipments being in very small lot sizes.

IV.G.3 Potash

Potash is an important element in the total seaborne trade in fertilizer materials, accounting for 12.02 million mt in 1982. The high volume of potash trade can be explained by the following reasons:

- The worldwide distribution of potash reserves are extremely uneven, as virtually the entire world supply emanates from North America, Europe, and the U.S.S.R.
- Beneficated potash can be applied directly to the soil.
- Total requirements for potash are much smaller than for the other primary nutrients, and hence when it is incorporated in multinutrient fertilizers, it is potash the raw material which is transported to the fertilizer plants, usually located close to sources of more bulky raw materials.

Potash is shipped bagged or in bulk. The largest exporter of potash is Canada, a quarter of such shipments being in Panamax ships for long hauls, e.g. to China or Brazil. Generally, however, bulk shipments are in smaller vessels of 7 to 25,000 dwt.

IV.G.4 Brimstone and Sulphuric Acid

The total seaborne brimstone trade accounted for 10.33 million mt in 1983, from which 1.99 million mt was in molten form (Frasch derived). The remainder was in granular form (recovered from sour natural gas or petroleum). Since fertilizer plants using sulphuric acid usually have an associated sulphuric acid facility, this product is normally required to meet temporary shortfalls in process capacity, usually occurring during an expansion phase in the fertilizer industry. The seaborne sulphuric acid trade in 1982 was of 1.72 million mt. Only 50% of the brimstone and sulphuric acid traded volume is used by the fertilizer industry.

Molten sulphur is shipped in dedicated tankers with heating coils and insulation in order to keep temperature in the range 135°C - 158°C. There is a fleet of about twenty ocean-going molten sulphur carriers with capacities varying between 750 and 29,000 dwt.

High-grade chemical tankers are required for the shipments of sulphuric acid, as this substance is highly corrosive. The sizes of ships used in this limited trade are between 5,000 and 20,000 dwt.

IV.H Fertilizers Industry Statistics

List of Tables

TABLE IV.H-1

WORLD PRODUCTION OF PHOSPHATE ROCK (tonnes)

Country	1978	1979	1980	1981	1982
France	24 500	* 24 000	25 400	28 700	24 400
Finland	4 218	2 690	137 950	200 927	233 053
Soviet Union	* 24 800 000	* 24 500 000	* 24 700 000	* 25 400 000	* 26 600 000
Sweden	83 000	58 000	88 000	124 000	128 000
Turkey	32 205	37 571	82 655	103 129	35 400
Algeria	1 124 000	1 132 000	1 025 400	857 700	947 000
Egypt	638 734	645 000	658 300	720 300	707 600
Morocco	19 273 200	20 030 768	18 824 243	18 562 162	17 753 600
Senegal					
Phosphate rock	1 460 000	1 523 000	1 289 543	1 792 000	837 000
Aluminium phosphate (a)	356 723	390 963	83 060	199 218	400 000
Seychelles					
Guano (b)	6 089	6 383	4 285	1 440	–
South Africa	2 699 100	3 221 000	3 282 000	3 033 500	3 173 000
Togo	2 826 614	2 915 811	2 932 845	2 215 363	2 035 000
Tunisia	3 712 338	4 056 960	4 501 907	4 924 000	4 729 391
Zimbabwe	106 639	136 238	130 337	122 235	121 608
Mexico	322 076	274 428	396 646	251 000	415 000
Netherlands Antilles	81 000	49 000	–	–	–
USA	50 037 000	51 611 000	54 415 000	53 624 000	37 414 000
Brazil	1 050 118	1 628 193	2 611 641	2 710 604	2 732 000
Chile					
Guano	240	–	–	1 100	* 1 000
Colombia	1 320	6 776	8 370	15 000	18 000
Venezuela	11 000	–	–	–	–
China	* 4 400 000	8 517 000	10 726 000	10 862 000	11 228 000
Christmas Island (b)(c)	1 378 046	1 360 852	1 638 315	1 358 572	1 342 032
India	789 270	681 486	543 004	565 902	* 569 000
Indonesia	6 071	5 323	* 5 000	* 5 000	* 5 000
Israel	1 553 900	2 085 500	2 307 100	1 918 700	2 710 600
Jordan	2 328 700	2 825 823	3 911 166	4 243 643	4 460 795
Korea, Dem. P.R. of	* 500 000	* 500 000	* 500 000	* 500 000	* 500 000
Philippines					
Phosphate rock	1 074	2 495	17 679	8 380	* 10 000
Guano	821	3 158	24 836	2 051	* 3 000
Syria	800 000	1 170 000	1 319 000	1 320 500	1 455 000
Thailand	3 485	4 542	5 570	2 610	4 265
Vietnam	* 1 600 000	* 400 000	* 500 000	* 500 000	* 500 000
Australia	248 328	7 557	6 621	21 997	235 000
Banaba (b)	468 400	(d) 445 700	–	–	–
Nauru (b)	1 998 900	1 828 420	2 086 676	1 479 900	1 333 300
World total	125 000 000	132 000 000	139 000 000	137 000 000	123 000 000

(a) Including lime phosphates
(b) Exports
(c) Including phosphate dust
(d) Figure is for 11 months only; mining ceased in November 1979
* Estimated

Source: British Geological Survey, "World Mineral Statistics", 1984.

TABLE IV.H-2

EXPORTS OF PHOSPHATE ROCK (tonnes)

Country	1978	1979	1980	1981	1982
Belgium-Luxembourg	14 203	18 433	11 291	14 779	10 379
France	16 503	26 017	15 498	3 441	3 804
Germany, Federal Republic of	1 230	952	1 555	1 959	1 602
Netherlands	66 605	71 427	64 064	26 250	23 926
Soviet Union (c)	* 6 025 000	* 6 025 000	* 4 525 000	* 5 025 000	* 5 025 000
Sweden	65 045	43 816	60 675	92 575	81 414
Algeria	614 450	836 122	807 829	791 000	704 000
Egypt	64 093	...	25 945	55 817	
Morocco	17 284 372	17 856 090	16 527 145	15 635 480	13 976 076
Senegal					
Calcium phosphate	1 569 492	1 429 308	1 483 273	1 206 539	) * 1 250 000
Aluminium phosphate	170 151	101 830	77 430	50 819	)
Seychelles					
Guano	6 089	6 383	4 285	1 440	–
South Africa	–	5 321	2 841	21 521	124 180
Togo	2 801 507	2 692 710	2 818 806	2 212 495	2 055 000
Tunisia	1 669 010	1 598 246	1 317 125	951 028	...
Western Sahara	441 000	...	...	...	...
Netherlands Antilles	78 800	* 48 000	18 373	...	...
USA	13 692 646	14 786 811	14 320 352	10 553 611	9 735 025
Christmas Island (a)	1 378 046	1 360 852	1 638 315	1 358 572	1 342 032
Israel (b)	479 401	474 653	601 887	1 215 523	664 339
Jordan	2 159 920	2 754 615	3 623 069	3 529 381	3 569 701
Singapore	13 019	12 465	18 653	29 988	23 791
of which: Re-exports	13 016	10 911	14 702	27 812	20 374
Syria	919 804	1 253 389	744 034	955 497	722 000
Australia	* 284 300	104	116	...	...
Banaba	468 400	445 700	–	–	–
Nauru	1 998 900	1 828 420	2 086 676	1 479 900	1 333 300

(a) Including phosphate dust

(b) Figures may be incomplete as value only given in Israeli trade return for exports to some countries

(c) Including apatite ore

* Estimated.

... Figures not available.

– Nil.

Source: British Geological Survey, "World Mineral Statistics", 1984.

TABLE IV.H-3

WORLD PRODUCTION OF POTASH
(tonnes of K_2O content)

Country	1978	1979	1980	1981	1982
United Kingdom					
Chloride	157 342	277 684	321 469	294 150	252 936
France					
Potassic salts	1 928 000	2 075 000	2 039 000	1 969 000	1 824 000
Germany, Federal Republic of					
Potassic salts	2 470 000	2 616 000	2 737 000	2 610 000	2 057 000
Italy					
Potassic salts	248 310	182 429	130 164	141 780	146 023
German Democratic Republic					
Potassic salts	3 323 000	3 395 000	3 422 000	3 460 000	3 434 000
Soviet Union	8 193 000	6 635 000	8 064 000	8 449 000	9 000 000
Spain					
Potassic salts	722 301	780 632	791 498	860 891	822 696
Canada					
Chloride	6 109 555	6 704 728	7 302 901	7 146 629	5 197 238
USA					
Potassic salts	2 253 000	2 225 000	2 239 000	2 156 000	1 784 000
Chile					
Nitrate	* 14 900	* 21 600	* 25 300	* 21 400	* 20 600
China	* 21 000	* 16 000	* 12 000	* 11 000	* 25 000
Israel					
Chloride	695 000	730 000	797 000	839 000	* 1 000 000
World total	26 100 000	25 700 000	27 900 000	28 000 000	25 600 000

* Estimated

Source: British Geological Survey, "World Mineral Statistics", 1984.

TABLE IV.H-4

EXPORTS OF POTASH (tonnes)

Country	1978	1979	1980	1981	1982
United Kingdom					
Sulphate	326	40	473	1 237	1 093
Chloride	62 951	164 700	200 240	91 216	76 552
Potassic chemicals	549	1 742	1 745	1 758	2 159
Belgium-Luxembourg					
Fertiliser salts (a)	138	566	729	713	112
Sulphate (a)	274 416	297 668	325 076	291 287	
Chloride (a)	8 551	5 138	6 060	5 849	15 367
Potassic chemicals	1 651	1 389	1 700	2 113	3 279
France					
Fertiliser salts	11 533	18 453	13 293	8 807	11 892
Chloride	492 681	412 820	311 855	345 239	447 959
Other potassic fertilisers	30 621	33 937	23 553	21 825	17 604
Potassic chemicals	14 819	20 189	18 981	21 655	22 152
Germany, Federal Republic of					
Fertiliser salts	32 280	49 296	35 585	39 882	38 562
Sulphate	485 992	569 272	2 503 623	2 348 198	1 996 789
Chloride	1 891 526	1 863 298			
Potassic chemicals	33 628	34 132	32 413	38 012	37 656
Italy					
Sulphate	106 804	105 194	72 040	40 426	39 789
Potassic chemicals	301	303	214	20 656	25 941
Netherlands					
Chloride (a)	473	1 504	3 423	3 456	2 330
Potassic chemicals	1 719	1 738	1 351	1 912	1 505
German Democratic Republic					
Fertiliser salts (a)	2 744 000	2 745 000	2 817 000	2 860 000	2 834 000
Potassic chemicals	1 412	• 1 980	• 2 400		
Poland					
Potassic chemicals	8 342	6 762	14 000		
Portugal					
Sulphate	1 315	–	100		
Other potassic fertilisers	–	100	1 295		
Soviet Union					
Fertiliser salts	5 771 093	4 773 334	6 604 707	5 244 747	4 956 288
Spain					
Sulphate	64 466	80 369	78 485	95 436	
Chloride	340 268	597 132	495 867	512 038	
Potassic chemicals	12 771	19 473	13 478	6 299	
Sweden					
Chloride	3 371	441	1	–	56
Potassic chemicals	3 128	3 643	3 714	3 696	4 818
Yugoslavia					
Potassic chemicals	1 073	2 349	2 115	2 611	
Canada					
Chloride	9 275 810	10 630 584	10 565 401	10 067 852	7 221 375
USA					
Sulphate	183 531	227 805	147 731	99 363	99 758
Chloride	1 126 000	891 378	1 174 548	712 887	717 969
Other potassic fertilisers	227 239	310 483	324 265	279 607	288 074
Potassic chemicals	22 457	27 323	34 155	27 206	8 900
Hong Kong					
Potassic chemicals (Re-exports)	206	772	1 012	846	891
India					
Potassic chemicals (c)	1 518	705	794		
Israel (b)					
Potassic chemicals	3 413	2 435	3 938	3 991	4 400
Japan					
Sulphate	4 149	2 002	3	4 300	1 020
Chloride	4	4	3	3 918	55
Potassic chemicals	5 617	5 415	7 096	5 433	6 421

TABLE IV.H-4 (Cont'd)

Country	1978	1979	1980	1981	1982
Singapore					
Sulphate	...	524	468	737	2 005
of which: Re-exports	...	524	468	737	1 979
Chloride	...	2 413	2 349	4 553	5 354
of which: Re-exports	...	2 406	2 098	3 852	5 054
Other potassic fertilisers	203 616	231 230	185 837	261 224	182 649
of which: Re-exports	203 490	231 172	185 736	261 090	182 539
Taiwan					
Potassic chemicals	1 110	1 082	1 172	685	516

Note: So far as possible the term 'potassic chemicals', as used in this table, relates to items 522. 54,523. 1 and 2 of the Standard International Trade Classification (Revision 2) and includes caustic potash, carbonate, chlorate, nitrate and sulphate

(a) K_2O content
(b) Figures may be incomplete as value only given in Israeli trade return for exports to some countries
(c) Years ended 31 March following that stated

* Estimated.
... Figures not available.
\- Nil.

Source: British Geological Survey, "World Mineral Statistics", 1984.

TABLE IV.H-5

FERTILIZER SHIPMENT SIZE BY ROUTE AND COMMODITY ('000 DWCT)
(Taken from Recorded Spot Fixtures & Enquiries Dec. 83-Sept.84)

DISCHARGE / LOAD	INDIA			CHINA			N.W. EUROPE			MED/BLACK SEA/ W. AFRICA			CENTRAL/ SOUTH AMERICA			E.C. US/ CANADA/CARIBS			FAR EAST/ SOUTH EAST ASIA		
	AV. SIZE	NO.	RANGE	AV. SIZE	NO.	RANGE	AV. SIZE	NO.	RANGE	AV. SIZE	NO.	RANGE	AV. SIZE	NO.	RANGE	AV. SIZE	NO.	RANGE	AV. SIZE	NO.	RANGE
PRODUCT : SULPHUR																					
Arabian Gulf/Red Sea	14	23	6-30	-	-	-	30	1	30	21	20	10-25	-	-	-	-	-	-	-	-	-
W.C. US/Canada																					
Vancouver	20	9	16-25	25	1	25	38	12	15-55	25	12	13-35	27	4	18-40	16	4	6-21	16	2	2-30
California	16	4	15-18	11	2	7-15	-	-	-	16	3	12-19	-	-	-	-	-	-	-	-	-
E.C. US/Canada/Caribs																					
Galveston	15	2	12-18	-	-	-	52	3	50-55	20	7	15-35	-	-	-	-	-	-	-	-	-
Others	-	-	-	-	-	-	-	-	-	-	-	-	4	2	2- 6	3	1	3	8	1	8
N.W. Europe/Baltic	17	4	12-21	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
PRODUCT : PHOSROCK																					
Arabian Gulf/Red Sea																					
Aqaba	14	18	5-22	-	-	-	20	15	20	12	4	4-15	30	1	30	-	-	-	33	5	30-40
Med/W. Africa	14	22	8-21	15	2	15	23	17	5-46	-	-	-	30	1	30	-	-	-	25	2	20-30
E.C. US/Canada/Caribs																					
Tampa	23	2	23	-	-	-	30	5	20-38	11	4	3-16	-	-	-	23	7	20-30	22	4	17-26
Others	-	-	-	-	-	-	39	1	39	21	1	21	-	-	-	-	-	-	-	-	-
PRODUCT : POTASH																					
Med/W. Africa	-	-	-	-	-	-	20	1	20	-	-	-	14	2	13-15	-	-	-	-	-	-
W.C. US/Canada																					
Vancouver	23	2	20-25	-	-	-	-	-	-	-	-	-	15	7	5-45	-	-	-	19	6	2-30
E.C. US/Canada/Caribs	-	-	-	-	-	-	17	10	10-25	-	-	-	12	2	8-15	18	2	15-21	-	-	-
N.W. Europe																					
Hamburg/Wismar	15	13	7-18	-	-	-	-	-	-	-	-	-	13	4	9-16	13	3	6-18	-	-	-

TABLE IV.H-5 (Cont'd)

LOAD \ DISCHARGE	INDIA			CHINA			N.W. EUROPE			MED/BLACK SEA/ W. AFRICA			CENTRAL/ SOUTH AMERICA			E.C. US/ CANADA/CARIBS			FAR EAST/ SOUTH EAST ASIA		
	AV. SIZE	NO.	RANGE	AV. SIZE	NO.	RANGE	AV. SIZE	NO.	RANGE	AV. SIZE	NO.	RANGE	AV. SIZE	NO.	RANGE	AV. SIZE	NO.	RANGE	AV. SIZE	NO.	RANGE
PRODUCT : MAP, DAP(BULK)																					
Med/W. Africa																					
Aqaba	19	5	13-23	-	-	-	16	2	4-28	8	2	6-10	10	1	10	-	-	-	28	2	25-30
Others	-	-	-	-	-	-	47	2	44-50	-	-	-	-	-	-	-	-	-	-	-	-
N.W. Europe/Baltic																					
Antwerp	-	-	-	-	-	-	-	-	-	-	-	-	10	1	10	-	-	-	-	-	-
E.C. US/Canada/Caribs																					
Tampa	-	-	-	31	15	23-54	22	7	18-26	20	10	14-20	8	9	2-23	-	-	-	26	6	15-48
Others Gulf	18	22	13-25	20	2	20	23	2	8-38	22	7	18-35	12	10	15-20	-	-	-	-	-	-
E.C.	20	2	18-23	25	1	25	-		8-38	-	-	-	-	-	-	-	-	-	-	-	-
W.C. US/Canada																					
Vancouver	17	2	16-17	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
S. Africa																					
Richards Bay	-	-	-	-	-	-	-	-	-	-	-	-	10	1	10	-	-	-	19	1	19
PRODUCT : UREA(Bulk)																					
Arabian Gulf/Red Sea	12	26	2-20	-	-	-	-	-	-	-	-	-	16	1	16	-	-	-	11	3	8-15
Med/W. Africa	15	17	10-18	10	1	10	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Black Sea	16	6	10-20	27	3	20-30	-	-	-	-	-	-	-	-	-	18	2	15-20	18	2	15-20
N.W. Europe/Baltic	14	8	10-18	38	2	25-50	-	-	-	-	-	-	10	1	10	13	1	13	10	1	10
W.C. US/Canada																					
Vancouver	15	2	15	-	-	-	-	-	-	-	-	-	12	1	12	5	1	5	25	1	25
Kenai	22	3	20-25	-	-	-	-	-	-	-	-	-	11	1	11	7	3	3-12	18	2	5-30
E.C. US/Canada/Caribs	18	5	11-25	-	-	-	-	-	-	-	-	-	7	7	2-15	-	-	-	-	-	-

TABLE IV.H-5 (Cont'd)

DISCHARGE	INDIA			CHINA			N.W. EUROPE/ BALTIC			MED/BLACK SEA/ W. AFRICA			CENTRAL/ SOUTH AMERICA			E.C. US/ CANADA/CARIBS			FAR EAST/ SOUTH EAST ASIA			E.C. AFRICA			ARABIAN GULF/ RED SEA		
LOAD	AV. SIZE	NO.	RANGE	AV. SIZE	NO.	RANGE	AV. SIZE	NO.	RANGE	AV. SIZE	NO.	RANGE	AV. SIZE	NO.	RANGE	AV. SIZE	NO.	RANGE	AV. SIZE	NO.	RANGE	AV. SIZE	NO.	RANGE	AV. SIZE	NO.	RANGE
PRODUCT : NPK + UNSPECIFIED BULK FERTS																											
Med/Black Sea																											
Constantza	-	-	-	-	-	-	-	-	-	-	-	-	12	2	11-12	-	-	-	-	-	-	-	-	-	-	-	-
N.W. Europe/Baltic	10	2	8-12	20	2	20	-	-	-	-	-	-	16	3	10-23	13	1	13	10	4	4-13	-	-	-	-	-	-
W.C. US/Canada																											
Vancouver	-	-	-	-	-	-	-	-	-	-	-	-	4	2	3-5	5	1	5	-	-	-	-	-	-	-	-	-
E.C. US/Canada/Caribs																											
Tampa	-	-	-	-	-	-	27	2	20-34	-	-	-	10	5	4-20	22	1	22	19	5	14-30	7	2	7	-	-	-
Other Gulf	-	-	-	50	1	50	22	4	14-35	17	3	15-18	14	1	14	-	-	-	-	-	-	-	-	-	-	-	-
E.C. US (Hopewell/ Norfolk)	17	1	17	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	20	1	20	-	-	-	-	-	-
PRODUCT : AMM. SULPHATE/ NITRATE/CALCIUM NITRATE																											
N.W. Europe/Baltic																											
Heroya	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	9	2	6-12	-	-	-	-	-	-	-	-	-
A/R/A	15	1	15	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Central/S. America																											
Mexico	-	-	-	-	-	-	-	-	-	-	-	-	12	1	12	-	-	-	-	-	-	-	-	-	-	-	-
USEC/Gulf/Caribs	17	1	17	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
US Gulf	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	20	1	20	-	-	-	-	-	-
EC (Hopewell/ Norfolk)	-	-	-	-	-	-	-	-	-	20	2	15-25	16	9	4-27	-	-	-	21	4	20-21	25	1	25	-	-	-
PRODUCT : BAGGED FERTILISERS																											
Arabian Gulf/Red Sea	8	8	4-15	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	10	1	10
Med/W. Africa	14	4	12-16	14	8	10-18	-	-	-	-	-	-	5	1	5	-	-	-	13	1	13	-	-	-	-	-	-
Far East/S.E. Asia																											
Ulsan, S. Korea	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	17	3	15-20
Black Sea																											
Varna	11	8	10-12	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	11	1	11
Constantza	-	-	-	-	-	-	-	-	-	-	-	-	17	1	17	-	-	-	-	-	-	-	-	-	-	-	-
Ploce	-	-	-	10	1	10	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
N.W. Europe/Baltic																											
Heroya	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	7	4	5-8	-	-	-

Source: H.P. Drewry Ltd., "The Organisation and Structure of the Deep-Sea Fertiliser Trades", 1984.

TABLE IV.H-6

FACILITIES AT FERTILIZER LOADING PORTS

	MAX DRAFT (FEET)	MAX SIZE SHIP (DWT)	ACTUAL AVERAGE LOADING RATES (from Spot Fixtures) (Tonnes/Day). ( ) = Estimate
PHOSPHATE ROCK			
Algeria			
Annaba	33	30,000	4,500
Indian Ocean			
Christmas Island	35	35,000	(8,000)
Israel			
Ashdod	36	40,000	1,800
Jordan			
Aqaba	50	100,000	3,500
Morocco			
Casablanca	32	50,000	(8,000)
Safi	30	25,000	(3,000)
Nauru Island	No limit	35,000	5,000
Senegal			
Dakar	36	38,000	(2,000)
South Africa			
Richards Bay	55	165,000	(3,000)
Syria			
Tartous	35	35,000	4,500
Togo			
Kpeme	38	45,000	(8,000)
Tunisia			
Sfax	33	30,000	(6,000)
La Goulette	32	30,000	(2,000)
USA			
Jacksonville	38	36,000	8,000-15,000
Morehead City	40	40,000	6,000
Tampa	34	35,000	10,000-15,000
USSR			
Murmansk	39		(3,000)
POTASH			
Belgium			
Antwerp	45	80,000	4,000
Canada			
St. John	30	40,000	8,000
Vancouver	60	150,000	6,000
Germany (East)			
Wismar	27	25,000	2,500

TABLE IV.H-6 (Cont'd)

	MAX DRAFT (FEET)	MAX SIZE SHIP (DWT)	ACTUAL AVERAGE LOADING RATES (from Spot Fixtures) (Tonnes/Day). ( ) = Estimate
Germany (West)			
Bremen	30	30,000	2,500-3,000
Hamburg	38	45,000	6,000
Rostock	37	40,000	3,500
Israel			
Ashdod		(see above)	
Jordan			
Aqaba		(see above)	
USA			
Houston	39	45,000	5,000
USSR			
Ventsplis	24	20,000	2,000
SULPHUR (DRY)			
Canada			
Vancouver		(see above)	
France			
Bayonne	26	25,000	(5,000)
Germany (West)			
Brake	37	36,000	(2,000)
Kuwait			
Shuaiba	41	45,000	2,000
Mexico			
Coatzacoalcos	37	40,000	(4,000)
Poland			
Gdansk	33	35,000	(5,000)
Saudi Arabia			
Jubail	43	45,000	5,000
USA			
Galveston	46	80,000	8,500
Los Angeles	35	35,000	5,000
Stockton	32	30,000	8,000
NITROGEN			
Belgium			
Antwerp		(see above)	
Bulgaria			
Varna	31	30,000	1,000
Egypt			
Suez	26.5	25,000	1,000

TABLE IV.H-6 (Cont'd)

	MAX DRAFT (FEET)	MAX SIZE SHIP (DWT)	ACTUAL AVERAGE LOADING RATES (from Spot Fixtures) (Tonnes/Day). ( ) = Estimate
Kuwait			
Shuaiba		(see above)	
Libya			
Marsa el Brega	26	25,000	3,000
Qatar			
Umm Said	36	40,000	3,000
Rumania			
Constanza	36	40,000	2,500-3,500
Saudi Arabia			
Jubail		(see above)	
USSR			
Odessa	38	45,000	(3,000)
UAE			
Ruwais	40	25,000	(3,000)

Notes : - Because of widespread production, only major nitrogen export ports are listed.

- Finished fertiliser loading ports are not listed separately because in many cases they coincide with raw material export ports, and where this is not the case the volume exported is very small.

Source: H.P. Drewry Ltd., "The Organisation and Structure of the Deep-Sea Fertiliser Trades", 1984.

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V

PETROCHEMICALS

V.A Data Sheet

V.A.1 General

Petrochemicals are produced from natural gas and refined petroleum products. They account for 90% of world production of organic chemicals. The only two other sources of any significance, in weight terms, are coal tar and cellulose.

The basic raw materials, petroleum and natural gas, are processed to produce basic petrochemical feedstocks (primary products), the most important of which are:

the lower olefins - ethylene, propylene and the butylenes, butadiene and isoprene
the aromatics - benzene, toluene and the xylenes (BTX), and
the higher olefins - a wide range of petrochemicals in the C_6 to C_{18} range.

With the addition of inorganic feedstocks like oxygen, chlorine and hydrogen, over three thousand petrochemicals are produced from this small number of primary products. The first step is the production of "monomers", which in turn are the building blocks for downstream production of a variety of products, the most important being plastic resins, synthetic fibres and synthetic rubber materials ("polymers").

Petrochemical plants can be sited adjacent to a source of primary hydrocarbons, such as a refinery, or supplied with raw materials via long distance overland or undersea pipelines. Some plants have captive primary hydrocarbon sources and cannot process alternative types of raw materials, while others are highly flexible and utilize various refinery liquids or gas supplies, depending on price and availability.

Petrochemical plants are usually large and elaborate, and they use sophisticated, automated equipment. They are designed with a high emphasis on safety considerations. A fairly large scale of operation is usually necessary to make such plants economically advantageous.

Plant area requirements are highly variable because of the multitude of site, feedstock, operating, and product mix alternatives. However, it has been estimated that the area required for a refinery based petrochemical plant is between 1.5 and 2.0 sq m per tonne of throughput per annum. Such complexes may account for between a third and a half of the overall site.

V.A.2 Olefin Plants

All the lower olefins (ethylene, propylene and butadiene) are co-products, produced in various ratios by the cracking of hydrocarbon feedstocks in an olefin plant. Aromatics are also produced in an olefin plant as by-products. An olefin plant often forms the core of an entire petrochemical complex designed to produce a wide range of products.

All the components of natural gas (methane, ethane, propane, butane) may be used as raw materials for petrochemical manufacture. Methane is primarily used for fuel, but it is also the prime feedstock for ammonia production. Ethane and propane are source materials for ethylene and propylene and may be derived from natural gas or distillation top gas from a refinery. Butane from natural gas or refinery top gas, is used to produce the butylenes which after dehydrogenation and separation yield butadiene, etc.

Naptha, gas oil and crude oil may, however, be "cracked" directly to produce ethylene, propylene and the butylenes. Direct cracking is usually associated with refinery operations to yield higher value products reflecting the lower percentage demand for the heavier products, e.g. gas and fuel oil, from distillation processes.

The following are examples of yields from various feedstocks*:

Feedstock	Products and By-products (% wt)			
	Ethylene	Propylene	Butadiene	Aromatics
Full range naptha	34.4	14.4	4.9	13.1
Light naptha	28.7	14.8	4.8	10.6
Gas oil	25.9	13.3	5.4	13.3
Ethane	84.0	1.4	1.4	0.4

Based on the above yields, approximate feedstock inputs for three different ethylene plant sizes are as follows:

Ethylene, t/a	250,000	500,000	1,000,000
Full range naptha, t/a	735,000	1,470,000	2,941,000
Light naptha, t/a	871,000	1,742,000	3,484,000
Gas oil, t/a	965,000	1,930,000	3,861,000
Ethane t/a	297,000	595,000	1,190,000

---

*Source: Hydrocarbon Processing, November 1980.

It can thus be seen that the highest yield source of ethylene is ethane but that it has a more limited output of the other lower olefins. Nevertheless, ethylene is the most significant petrochemical building block accounting for 30% of petrochemicals.

The following operations are required in an olefin plant:

- Pyrolysis of hydrocarbon feedstock (the process of breaking down hydrocarbons in the presence of steam at temperatures 600-900°C).
- Multi-stage waste heat recovery.
- Compression of pyrolysis gas.
- Cryogenic treatment of pyrolysis gas.
- Multiple fractionation of the cooled mixture.
- Further processing depending on the product (ethylene, propylene, butadiene, aromatics).

Typical end uses for ethylene and propylene are:

Ethylene	%	Propylene	%
Low density polyethylene	39	Acrylonitrile	22
Vinyl chloride monomer	17	Polypropylene	20
High density polyethylene	15	Oxo alcohols	17
Ethylene oxide	13	Propylene oxide	13
Styrene	7	Cumene	10
Others	9	Isopropanol	8
	100	Others	10
			100

V.A.3 Industry Requirements

Olefin production is energy intensive with high process steam, compression, and refrigeration requirements for performance of the various production operations. Between 5 and 7 tons of steam are consumed to produce one ton of ethylene. In addition, the following requirements may be associated with a 450,000 t/a ethylene plant from ethane. From such a source the ethane and other gases may provide the electricity generation feedstock.

Ethylene production	
ethane	535,000 t/a
water	12 - 24 Kt/d
elec. energy installed	2 MW
personnel	300
area	40 ha

Low density polyethelene (160,000 t/a yield)	
ethylene	180,000 t/a
water	80 - 160 kt/d
elec. energy installed	25 -35 MW
personnel	160 - 240
land	5 - 20 ha

Vinyl chloride monomer (160,000 t/a) and polyvinyl chloride (150,000 t/a)	
ethylene	80,000 t/a
rock salt	180,000 t/a
chlorine	96,000 t/a
water	150 - 240 kt/d
elec. energy installed	6 - 14 MW
personnel	300 - 500
area	50 ha

High density polyethylene (60,000 t/a)

ethylene	70,000 t/a
water	25 - 40 Kt/d
elec. energy installed	3 - 7 MW
personnel	140 - 240
land	5 - 10 ha

Styrene (200,000 t/a)

ethylene	60,000 t/a
benzene	160,000 t/a
water	10 kt/d
elec. energy installed	3 - 5 MW
personnel	60 - 180
land	5 - 20 ha

In addition for polystyrene (100,000 t/a)

water	6 kt/d
elec. energy installed	5 MW
personnel	160 - 180
land	5 - 10 ha

For an integrated plant based on 450,000 t/a ethylene from ethane

water	300 - 500 Kt/d (which may be reduced by recycling)
installed electricity	45 - 75 MW
personnel	1,000 - 1,500
area	100 - 200+ ha

V.A.4 Shipping

The plant, of course, need not be integrated. At various stages of processing, different materials are either produced as feedstocks or as by-products.

Gases such as ethane, propane, butane, ethylene, propylene, butadiene, ammonia and vinyl chloride may be shipped by sea in specialized carriers. While there is some flexibility of use of liquefied gas carriers, the pressure/temperature and corrosive characteristics of petrochemicals have to be matched to the vessel characteristics.

The sizes of such ships range widely but typically energy carrying ships are of larger size, with LPG carriers (propane and butane) up to 130,000 cu m. Petrochemical carriers range from a few hundred cu m capacity to 35,000 cu m for ethylene.

Liquid petrochemicals are carried in specialized "chemical tankers", which are characterized by a large number of stainless steel or coated tanks (often as many as 40 or 50). The sizes of such ships vary between a few hundred up to 39,000 DWT. Vessels carrying noxious liquid substances (according to MARPOL Annex II) are built under the provisions of the IMO Bulk Chemicals Code.

Low density and high density polyethylene, PVC and the styrene derivatives are in solid form and shipment is usually in bags. Bulk shipment is also possible but because of demand orientation of these downstream commodities, inland transportation often is of such significance that bulk exports are not justified.

Rock salt imports, if required for VCM production, would be in bulk carriers, the size depending on route and economic considerations.

V.B General Considerations

Petrochemicals is a generic term for the diverse chemical products derived from petroleum and natural gas.

Petroleum occurs in the semi-liquid and liquid phases from asphalts to crude oils. Natural gas comprises methane (CH_4), ethane (C_2H_6), propane (C_3H_8) and butane (C_4H_{10}), which are gases at normal temperatures and pressures.

Natural gas may contain small proportions of the "pentane plus" fractions (C_5+) which are liquids at normal temperatures and pressures. These liquids may be called "condensates", "natural gasolines" or "natural napthas". If the volumes of these are small, say less than 14 cc/(normal) cubic meter, the gas is termed "dry" or "non-associated". In contrast, "associated" or "wet gas" is gas found dissolved in crude oil or in contact with underlying gas saturated crude oil, and contains significant portions of butanes and pentane plus fractions.

Petrochemicals are produced from natural gas and refined petroleum products. They account for 90% of world production of organic chemicals. The only two other sources of any significance, in weight terms, are coal tar and cellulose.

The basic raw materials, petroleum and natural gas, are processed to produce basic petrochemical feedstocks (primary products), the most important of which are:

the lower olefins - ethylene, propylene and the butylenes, butadiene and isoprene the aromatics - benzene, toluene and the xylenes (BTX), and

the higher olefins - a wide range of petrochemicals in the C_6 to C_{18} range.

With the addition of inorganic feedstocks like oxygen, chlorine and hydrogen, over three thousand petrochemicals are produced from this small number of primary products. The first step is the production of "monomers", which in turn are the building blocks for downstream production of a variety of products, the most important being plastic resins, synthetic fibres and synthetic rubber materials ("polymers"). Table V.B-1 identifies a number of high volume petrochemicals and illustrates the flow of feedstocks through successive stages of production to finished plastic, fibre and rubber goods manufactured by a wide variety of industries.

Petrochemical plants can be sited adjacent to a source of primary hydrocarbons, such as a refinery, or supplied with raw materials via long distance overland or undersea pipelines. While the United States, USSR, Europe, and Japan account for over 95 percent of world petrochemical production, many new plants are being built in petroleum-exporting developing countries, such as Saudi Arabia, Kuwait, Indonesia, Mexico, and Nigeria. These countries will be manufacturing petrochemicals for domestic consumption and for export, hoping to benefit from higher financial returns achievable by marketing downstream products.

Petrochemical plants are usually large and elaborate; they use sophisticated, automated equipment. A fairly large scale of operation is usually necessary to make such plants economically advantageous.

TABLE V.B-1

PETROCHEMICAL ROUTES

Primary products		*Intermediate products*		*End products*	
Ethylene →		→			PLASTICS
	+ chlorine →	Vinyl chloride →		Polyethylene	
	+ acetic acid →	Vinyl acetate →		Polyvinyl chloride (PVC)	
	+ oxygen →	Acetaldehyde →	acetic acid	Polyvinyl acetate	
	+ oxygen →	Ethylene oxide →	ethylene glycol		
	+ benzene →	Styrene →		Polystyrene	
Propylene →		→		Polypropylene	
	+ benzene →	Cumene →	phenol acetone		FIBRES
	+ ammonia →	Acrylonitrile →		Acrylic	
Benzene	+ hydrogen →	Cyclohexane →	caprolactam adipic acid →	Polyamide	
p-Xylene	+ methanol →	Dimethyl terephthalate (DMT) →	(+ ethylene glycol) →	Polyester	
Butadiene →		→		Polybutadiene (BR)	ELASTOMERS
	+ styrene →	→		Styrene-butadiene rubber (SBR)	
o-Xylene	+ propylene →	Phthalic anhydride →	(+ alcohols) → phthalate plasticizers		
Sulphur →		Sulphuric acid			
Methanol					
Ammonia					

Source: UNIDO, "The Petrochemical Industry", ID/106, New York, 1973.

New plants can be designed for a narrow product range or as fully integrated complexes comprised of twenty or more production units. Some plants have captive primary hydrocarbon sources and cannot process alternative types of raw materials, while others are highly flexible and utilize various refinery liquids or gas supplies, depending on price and availability.

Petrochemical plants are designed with a high emphasis on safety considerations, including:

(1) containment and operating control

(2) safe release and disposal of liquids and vapors

(3) ignition prevention

(4) incident control and disaster prevention

Provisions must be made to allow emergency shutdowns and automatic isolation of certain plant sections in case of localized fire. Aside from intrinsic design aspects, plant safety also is highly dependent on the competence of the operating and support personnel.

Plant layout and area requirements are highly variable because of the multitude of site, feedstock, operating, and product mix alternatives. However, it has been estimated that the area required for a refinery based petrochemical plant is between 1.5 and 2.0 sq m per tonne of throughput per annum. Such complexes may account for between a third and a half of the overall site.

V.C Olefin Plants

Ethylene, propylene, and butadiene are the three major olefin primary products used for production of downstream petrochemicals. All of three are coproducts, produced in various ratios by the cracking of hydrocarbon feedstocks ranging from ethane to naptha to crude oil in an olefin plant. The key role of an olefin plant in the petrochemical industry is illustrated by Figure V.C-1.

Ethane and propane are source materials for ethylene and propylene and may be derived from natural gas or distillation top gas from a refinery. Butane from natural gas or refinery top gas, is used to produce the butylenes which after dehydrogenation and separation yield butadiene, etc. Methane, the principal component of natural gas, is primarily used for fuel, but it is also the prime feedstock for ammonia production (refer to Chapter IV - Fertilizers).

Naptha, gas oil and crude oil may, however, be "cracked" directly to produce ethylene, propylene and the butylenes. Direct cracking is usually associated with refinery operations to yield higher value products reflecting the lower percentage demand for the heavier products, e.g. gas oil and fuel oil from distillation processes.

Thus petrochemical production is generally associated with gas production, which may be wet or dry, or refinery products. Yields from various feedstocks are shown in Table V.C-1. It can thus be seen that the highest yield source of ethylene is ethane but that it has a more limited output of the other

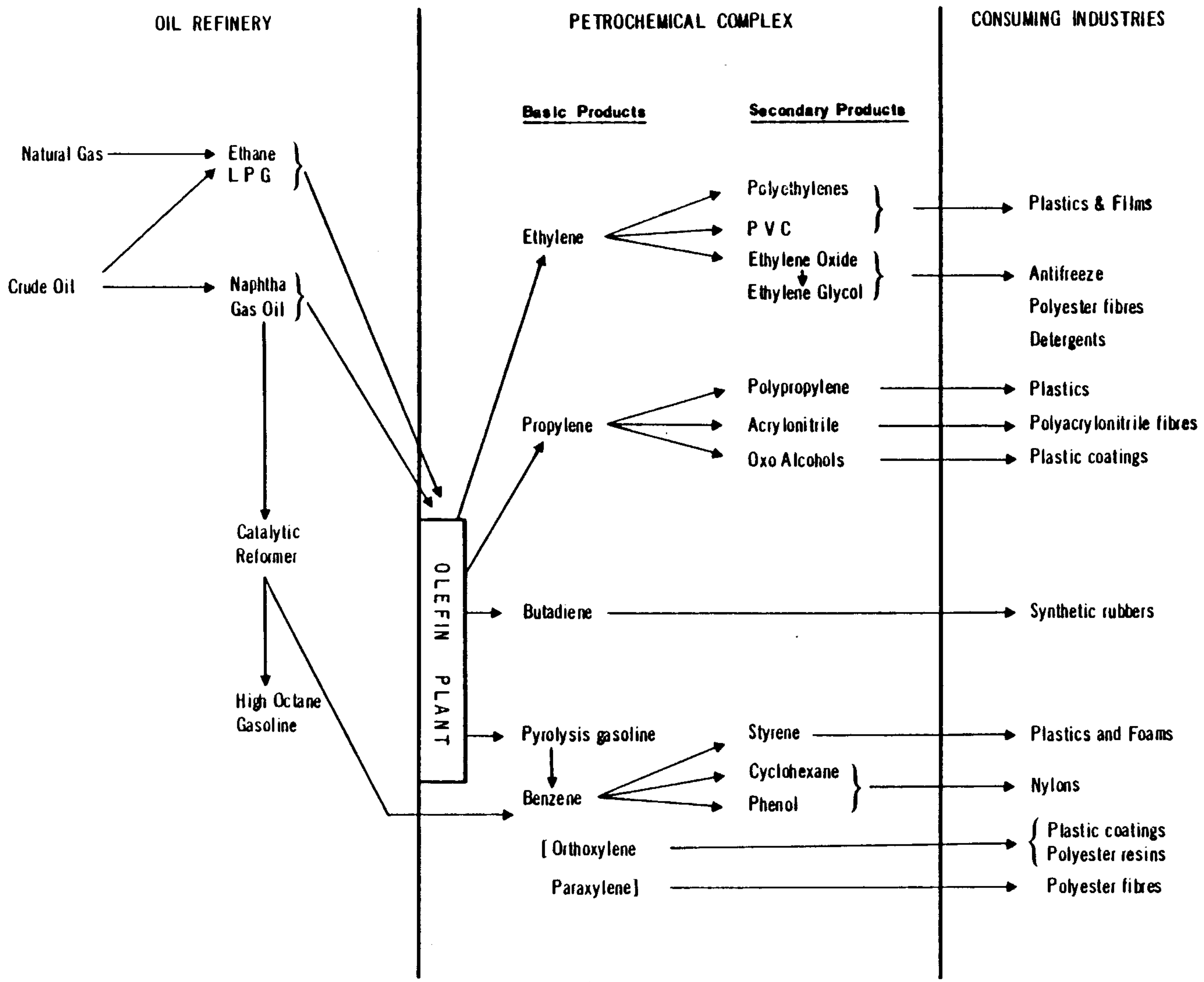

FIGURE V.C-1

CHAIN PRODUCTION OF PETROCHEMICALS

Source: OECD Secretariat, "The Petrochemical Industry", Paris, 1979.

TABLE V.C-1

TYPICAL FEEDSTOCKS AND COPRODUCT RATIOS IN ETHYLENE MANUFACTURE

Feedstock	Products and By-products (% wt)			
	Ethylene	Propylene	Butadiene	Aromatics
Full range naptha	34.4	14.4	4.9	13.1
Light naptha	28.7	14.8	4.8	10.6
Gas oil	25.9	13.3	5.4	13.3
Ethane	84.0	1.4	1.4	0.4

Based on the above yields, approximate feedstock inputs for three different ethylene plant sizes are as follows:

Ethylene, t/a	250,000	500,000	1,000,000
Full range naptha, t/a	735,000	1,470,000	2,941,000
Light naptha, t/a	871,000	1,742,000	3,484,000
Gas oil, t/a	965,000	1,930,000	3,861,000
Ethane t/a	297,000	595,000	1,190,000

Source: Hydrocarbon Processing, November 1980.

lower olefins. In general, the amounts of propylene, butadiene and aromatics formed by cracking increase, at the expense of ethylene yield, as heavier liquid feedstocks are used.

Price, availability, and product yield are the main factors considered in the selection of primary hydrocarbon feedstock for an olefin plant. In general, the higher molecular weight feedstocks are easier to crack, with typical furnace outlet temperature for cracking ethane, for example, at about 800°C, while naptha or gas oil can be cracked at 675-700°C. Nonetheless, plants utilizing heavier feeds are more costly than those designed for ethane, because of the larger separation facilities required with higher ratios of propylene, butadiene, and aromatics.

In the United States, ethane and propane recovered from natural gas processing plants have been the traditional feedstocks for olefin production. Western Europe and Japanese olefin plants are primarily naptha-based, because of the limited availability and higher equivalent price of natural gas-derived ethane. However, large-scale olefin manufacturing facilities based on ethane and propane recovered from North Sea natural gas are presently being designed. New plants being built in the Middle East are based on associated gas gathered as a by-product of crude oil production. These plants have a considerable competitive edge over older units in Europe and Japan that operate on high-priced napthas and gas oils.

V.C.1 Ethylene and Its Derivatives

Ethylene is the most significant petrochemical building block accounting for 30% of petrochemicals. Typical end uses of ethylene are:

	%
Low density polyethylene	39
Vinyl chloride monomer	17
High density polyethylene	15
Ethylene oxide	13
Styrene	7
Others	9
	100

Modern ethylene plants are among the largest, the most complex,and the most expensive facilities of the petrochemical industry. An ethylene unit often forms the core of an entire petrochemical complex designed to produce a wide range of products. In Europe, Japan, and Brazil, large ethylene plant capacities range from 300,000 to 500,000 tons per year. In the U.S., several plants with annual capacities in excess of 500,000 tons are in operation. A new $3 billion petrochemical complex at Jubail, Saudi Arabia will include a 656,000 ton/year ethylene unit. Small and medium-sized plants are in operation and under construction in developing countries to serve smaller local markets.

A complex automation control system is required to operate modern ethylene units. The typical plant contains well over 400 pieces of major equipment (fired heaters and heat exchangers, reactors, fractionating towers, compressors, high capacity pumps), more than a thousand measuring instruments, and hundreds of control loops. Electronic instrumentation has widely supplanted the earlier pneumatic types, and process control computers are playing an increasing role in plant operation.

Olefin production is energy intensive with high process steam, compression, and refrigeration requirements for performance of the various production operations. Between 5 and 7 tons of steam are consumed to produce one ton of ethylene. A 450,000 t/a ethylene production based on ethane with other associated hydrocarbon supplies (e.g. methane) providing fuel for major compressors, etc. would require:

ethane feedstock	535,000 t
water	12 - 24 kt/d
personnel	300
site area	40 ha
installed electricity	2 MW

However, when ethylene production is combined with production of its derivatives, the industry requirements are much higher. A fully integrated plant based on 450,000 t/a of ethylene may require:

installed power	45 - 75 MW
cooling water	300-500 kt/d (may be reduced by recycling)
personnel	1,000 - 1,500
area	100 - 200+ ha

V.C.1.1 Ethylene Manufacturing Process

The following operations are required in ethylene manufacture:

(1) pyrolysis and primary waste heat recovery

(2) secondary waste heat recovery and pyrolysis fuel separation (for naptha and gas oil feedstocks)

(3) tertiary waste heat recovery and heavy gasoline separation (for naptha and gas oil feedstocks)

(4) pyrolysis gas compression, acid gas removal, and drying

(5) cryogenic treatment and demethanizing

(6) deethanizing and acetylene hydrogenation

(7) ethylene-ethane fractionation

(8) purification of propylene and heavier products

Figure V.C-2 shows the major process systems of a naptha or gas oil-based plant designed to produce high purity ethylene and propylene. Plants that process ethane feedstock are much simpler in design because secondary and tertiary heat recovery systems are not required. Further, the condensate deethanizer and the propylene and butane processing facilities are not required since the production rates for these heavier hydrocarbons are low.

V.C.1.1.a Pyrolysis Furnaces

Pyrolysis, also called steam cracking, is the process of breaking down hydrocarbons in the presence of steam at high temperatures (600-900°C). Ethane feedstocks yield mainly ethylene and hydrogen from the pyrolysis reaction, while pyrolysis of naptha and gas oils yields ethylene, propylene, butadiene, aromatics, and gasoline. The pyrolysis yield pattern, feedstock consumption, and fuel efficiency have a great influence on the economic performance of the plant.

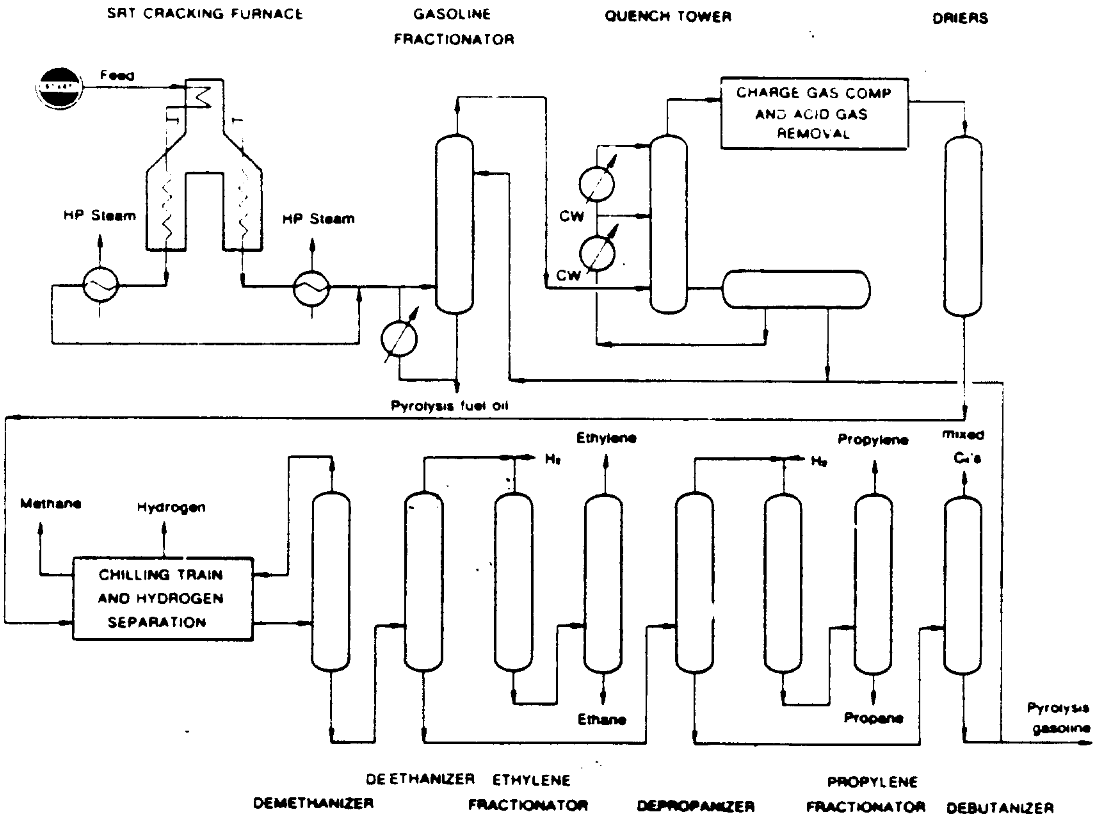

FIGURE V.C-2

FLOW SCHEMATIC FOR ETHYLENE MANUFACTURE

Source: Hydrocarbon Processing, November 1980.

Ethylene plants contain between 4 and 20 pyrolysis furnaces, each of which is fitted with multiple pyrolysis coils made of tubes between 50 and 200 mm in diameter and 50-80 meters long. The typical furnace consists of a rectangular fire box (1200-1300°C) with a row of vertical tubes located in the center plane between two radiating refractory walls. Heat transfer to the tubes occurs mainly by radiation and to a small degree by convection. The convection area of the furnace performs feed and feed water preheating, as well as superheating of steam.

Feedstocks are first preheated externally and then in the uppermost coil of the convection area. Subsequently dilution steam is mixed with the vaporized hydrocarbon in a weight ratio of between 0.5 and 1.0 (steam: hydrocarbon). Dilution steam has the function of lowering the hydrocarbon partial pressure, which later aids the pyrolysis reaction, and preventing carbon deposits on the pyrolysis coils.

After further heating in the convection section to 550-700°C, the steam-hydrocarbon mixture enters the pyrolysis coils (in the radiant section of the furnace), where it is further heated and cracked into products.

The gas has a residence time of 0.2 to 0.6 seconds in the pyrolysis coil and an outlet temperature of 770 to 870°C depending on feedstock and furnace design. The combustion chamber surrounding the reactor (pyrolysis) coils is equipped with numerous (over 100) burners that produce a flat flame, which both avoids impingment on the tube and simulates a uniformly radiating wall.

Furnaces designed to handle light hydrocarbon feedstocks are normally fired with natural gas. Heavier feedstocks, such as naptha and gas oils, are pyrolized in furnaces that fire up to 30 percent of the fuel requirement as fuel oil and the balance as natural gas. Development work is underway toward a capability to use higher proportions of the cheaper oil fuels.

V.C.1.1.b Waste Heat Recovery

Transferline heat exchangers, also known as quench coolers, are required to rapidly cool the gas within milliseconds after it exits the pyrolysis coils, thereby preventing secondary reactions that would degrade the olefin composition of the pyrolysis gas. The temperature of the product gas is rapidly reduced by several hundred degrees in the process of generating high pressure steam, which is subsequently superheated in the pyrolysis section of the superheater before it is used in compressor drives. A mixture of steam and water exits the exchanger and is separated in an elevated drum, the water returning to the exchanger inlet by a thermosyphon effect.

Transferline exchangers are built into the furnace unit, one exchanger serving one or more, often two pyrolysis coils. Pyrolysis gas leaves the exchangers at temperatures ranging from 375 to 500°C for naptha pyrolysis.

Secondary heat recovery is achieved by direct injection of "quench oil" into the pyrolysis gas downstream of the individual transferline exchangers, which reduces the gas temperature to 200-220°C and prevents most product degradation reactions.

Pyrolysis gas and quench oil are separated in the base of the primary fractionator, quench oil heat is subsequently used in the dilution steam generators and in heat exchange with other process steam.

Energy efficiency requires that large amounts of heat be removed from the pyrolysis gas, which in turn requires a large flow of quench oil, typically in the range of 15 to 25 times the flow of feedstock to the pyrolysis section. The temperature difference between hot quench oil and steam generators is also relatively small, so the total heat transfer area of the dilution steam generator is the largest of any service in an ethylene plant.

Following separation of the quench oil, gas leaving the primary fractionator has a temperature of 100-110°C. Tertiary heat recovery from this gas occurs in air- or water-cooled heat exchangers or in a direct contact water-cooled quench tower. The hot quench water is separated from heavy pyrogasoline that condenses along with the dilution steam. This hot water is then used in various process heat exchangers. The net dilution steam is recycled to the dilution steam generators after processing for removal of hydrocarbons and dissolved gases.

V.C.1.1.c Pyrolysis Gas Conditioning

Pyrolysis gas leaves the water quench tower at a temperature of 35-40°C and slightly above atmospheric pressure and must be compressed to about 35-40 atmospheres prior to the downstream low temperature distillation steps. In addition, water vapor, heavy hydrocarbons, acid gas (hydrogen sulphide), and carbon dioxide must be removed.

Radial centrifugal compressors with four or five stages are used in most plants, with interstage cooling by means of cold water or propylene refrigeration. Interstage separators are fitted to remove water and condensed hydrocarbons, while hydrogen sulphide and carbon dioxide are removed in a caustic scrubbing tower between the third and fourth stages of compression. The spent caustic from this operation requires substantial subsequent treatment before it can be safely discharged and is the most troublesome liquid waste of ethylene plants. Acid gases removed from the spent caustic and other gas removal units are either burned and the combustion products exhausted with flue gas, or treated in a Claus unit for conversion of the hydrogen sulphide to elemental sulphur.

Gas compression accounts for a high percentage of total production energy consumption in ethylene manufacture. At one of the world's largest plants, designed to produce 600,000 tons of ethylene per year (8000 operating hours), two parallel compression lines with five stages each are provided. The compressors are rated at 19.95 megawatts each and have expected normal power consumption of 17.9 megawatts each. They are driven by condensing steam turbines with air condensers.

In order to achieve complete removal of water from the pyrolysis gas, most processes employ an absorptive drying system located immediately after the final stage of pyrolysis gas compression. Molecular sieves or dessicant dryers can be used, but the former are preferred because of their selectivity.

V.C.1.1.d Cryogenic Treatment

Conditioned pyrolysis gas is a mixture of light hydrocarbons (ethylene, propylene, hydrogen, methane, ethane, butane, etc.) at ambient temperature and 35-40 atmospheres pressure. Cryogenic separation of the components is achieved by cooling the mixture in stages and performing several fractional distillations of the resulting condensates.

Cryogenic treatment involves staged chilling of the pyrolysis gas by means of heat exchange with boiling refrigerant and with cold process streams that have to be vaporized and/or reheated. Condensate forms as the gas temperature is reduced. Numerous process variations have been developed on the sequence of condensate separation, fractionation, and heat exchange.

Separation of pyrolysis gas through condensation and fractionation at low temperatures involves external refrigeration from ambient temperatures to less than $-100^{\circ}C$. Most plants employ propylene and ethylene as refrigerants because they are suitable and readily available at the plant.

Energy requirements for refrigerant compression are also a main source of power consumption, exceeding that of the pyrolysis gas compressors. For example, in the 600,000 ton/year ethylene plant noted in the previous sections, seven refrigerant levels are provided: three on ethylene and four on propylene. Two ethylene and two propylene compressors are installed. The two propylene compressors operate in parallel while one ethylene compressor is in operation, the second serving as a spare. Each propylene compressor, driven by an extraction-condensing steam turbine, has a rated input of 17 megawatts and an expected consumption of 15.45 megawatts for product ethylene totally produced in the liquid phase. The ethylene compressor is driven by a condensing turbine and has a rating of 6.47 megawatts.

V.C.1.1.e <u>Fractionation</u>

Fractionation of the multicomponent mixture is performed in a series of distillation columns under cryogenic conditions. In one process, the pyrolysis gas is moderately cooled and partially condensed, then fractionated into a heavy and a light fraction. The heavy fraction is sent to another column for propane removal and the lighter fraction, removed as a vapor stream, is first reheated to improve the ethylene yield and then cooled for further condensation and separation into hydrogen, methane, and an ethylene-ethane fraction. The latter is further fractionated into product ethylene and ethane in a "deethanizer", which is a fractionating column with 80 to 120 trays and a recycle ratio of 2.5 to 4.0 depending on operating pressure and product specification.

V.C.1.1.f Ethylene Storage

Ethylene has a boiling point of -104°C and a liquid density of 0.57 Kg/dm^3. Storage of commercial quantities in the gaseous phase at moderate pressures is impractical, common practice being to store it either in the liquid phase in refrigerated above-ground tanks or in the vapor phase at high pressure in underground salt domes or similar reservoirs.

Ethylene can be stored in the liquid phase at any temperature below the critical one, which is 9.2°C. Plant operational holding storage, when required, is normally provided in pressure vessels at -40°C and 13-15 atmospheres. Cylindrical tanks are used for small capacities, while extra holding storage is provided in double spheres in sizes up to 4000 cubic meters.

Large volume reserve or marine terminal storage vessels have capacities on the order of 20-30,000 cubic meters and are usually cylindrical, double-wall tanks at atmospheric pressure, i.e. with ethylene stored at its normal boiling point, -104°C. The inner tank can be made of stainless steel or aluminum and the outer one of carbon steel or concrete. The space between the inner and outer tanks is filled with granulated Perlite as insulation. Newer tanks have suspended roofs over the inner tank, with gas permeable foam glass blankets in the space between roof rim and inner tank. Except for the inner liner material, which may be of a lesser grade for ethylene due to its higher boiling point, tanks to hold ethylene and LNG are alike and present identical design, operational, and safety problems.

Rock-capped salt domes and caverns provide large (up to 1500 meters deep), high-pressure, leak-proof underground ethylene reservoirs for storage of production reserves to supply ethylene pipeline systems in the U.S. and Europe. In these systems, ethylene is stored for transport as a gas, and therefore requires large reservoir volumes. Most of the dome cavities are leached specifically for storage, but some storage domes were originally created in the process of obtaining brine for chemical plants. Salt dome cavity construction requires a plentiful source of water for the leaching operation and an environmentally acceptable means of brine disposal.

V.C.1.2 Ethylene Derivatives

Ethylene derivatives are used for production of plastics (80%), antifreeze (10%), fibers (5%), detergents and solvents (5%). Ethylene is a prime raw material for petrochemicals because of its relatively low cost availability and because it reacts with low cost materials such as oxygen, chlorine, hydrogen chloride, and water under relatively mild conditions and usually with high yields.

V.C.1.2.a Low and High Density Polyethylene

About 55% of ethylene demand is consumed in production of polyethylene, the most extensively used thermoplastic. Among the advantages of polyethylene are the relative low cost and ease of processing, its resistance to chemicals, and its flexibility. The two most widely used grades are "low density" polyethylene, LDPE, which has branched polymer chains, and "high density" polyethylene, HDPE, which is predominantly linear. LDPE is more flexible because of its lower crystallinity, while HDPE is more closely packed due to the absence of branches and therefore less permeable to gases. LDPE is the highest volume thermoplastic, with an expected U.S. production of 8.5 billion pounds in 1984, vs. 6 billion pounds of HDPE.

The following operations take place in a commercial LDPE plant:

(a) Ethylene compression.

(b) Initiator preparation and injection.

(c) Polymerization.

(d) Separation of polymer from unreacted ethylene.

(e) Extrusion of polymer.

(f) Finishing (product degassing, blending, packing and bulk storage).

The ethylene feedstock is compressed up to 3,500 bar with multi-stage compressors, which are fitted with interstage coolers to keep the gas temperature below 110^{o}C, in order to prevent premature polymerization. Low temperature oxygen or air, made up in carrier oil, is used as initiator and is injected into the high-pressure ethylene circuit with an intensifier pump. The quantity of initiator required per metric ton of LDPE varies from 0.05 to 2.0 Kg.

Ethylene passes into the polymerization reactor, where it is heated, and polymerization commences in the presence of the initiator. The reactor consists of a serpentine jacketed tube made of Ni/Cr steel and jacketed with carbon steel. Polymerization rates are generally in the range 20-25% conversion per pass. The mixture of ethylene and LDPE is then fed to a two-stage separator, where pressure drops, temperature rises, and molten polyethylene separates from the gaseous ethylene, which is boosted back into the feed ethylene stream. The molten polymer is extruded, pelletized, and conveyed to the finishing section by a water stream, which is also used to chill the pellets. The pellets are then dewatered, screened and stored in silos, from where they are dispatched either in bulk, or to the bagging plant.

A low density polyethylene plant of about 160,000 t/a output (associated with a 450,000 t/a ethylene plant based on ethane) would require:

ethylene	180,000 t/a
cooling water	80 - 160 kt/d
installed electricity	25 - 35 MW
electricity consumed	1.3 - 2.0 MWh/t
personnel	160 - 240
land	5 - 20 ha

The liquid-phase polymerization process for high-density polyethylene production is carried out in a paraffinic or cycloparaffinic solvent under low pressure. Ethylene, catalyst and solvent are fed continuously to a reactor operating at 125-175^{o}C and 300-450 psig. The reactor product is a slurry of polymer particles in the solvent. Polymer is recovered by flashing off the solvent and drying the polymer, which is then sent to a finishing and pelletizing operation. The use of small amounts of high-activity catalysts (such as chromium oxide on a silica-alumina support) allows for the elimination of the catalyst removal step, as the small amount of residual catalyst in the product does not affect polymer properties.

For a high density polyethylene plant of 60,000 t/a output, the following are required:

ethylene	70,000 t/a ethylene
energy consumption	0.6 - 1 MWh/t
energy installed	3 - 7 MW
water	25 - 40 kt/d
land	5 - 10 ha
personnel	140 - 240

V.C.1.2.b Vinyl Chloride Monomer and Polyvinyl Chloride

About 17% of ethylene demand is consumed in production of vinyl chloride monomer (VCM), an intermediate product, used for the manufacture of polyvinyl chloride (PVC). PVC is another high volume thermoplastic derivative of ethylene, with an expected U.S. production of 7 billion pounds in 1984. Pipe of various kinds accounts for about 40% of PVC consumption, and more than half the PVC pipe market is associated with housing construction, with commercial construction taking most of the remainder. Flexible PVC grades are used in items such as tablecloths, furniture, automobile upholstery, and coatings for wire and cable.

A schematic flow plan for the balanced oxychlorination process, used for the manufacture of vinyl chloride monomer, is shown in Figure V.C-3. Ethylene and chlorine are fed to a direct chlorination reactor, where ethylene dichloride (EDC) is produced. The crude EDC is combined with EDC produced in the oxychlorination step (refer to Figure V.C-3), and purified to remove chlorinated by-products, water, light components and tars. The pure EDC is

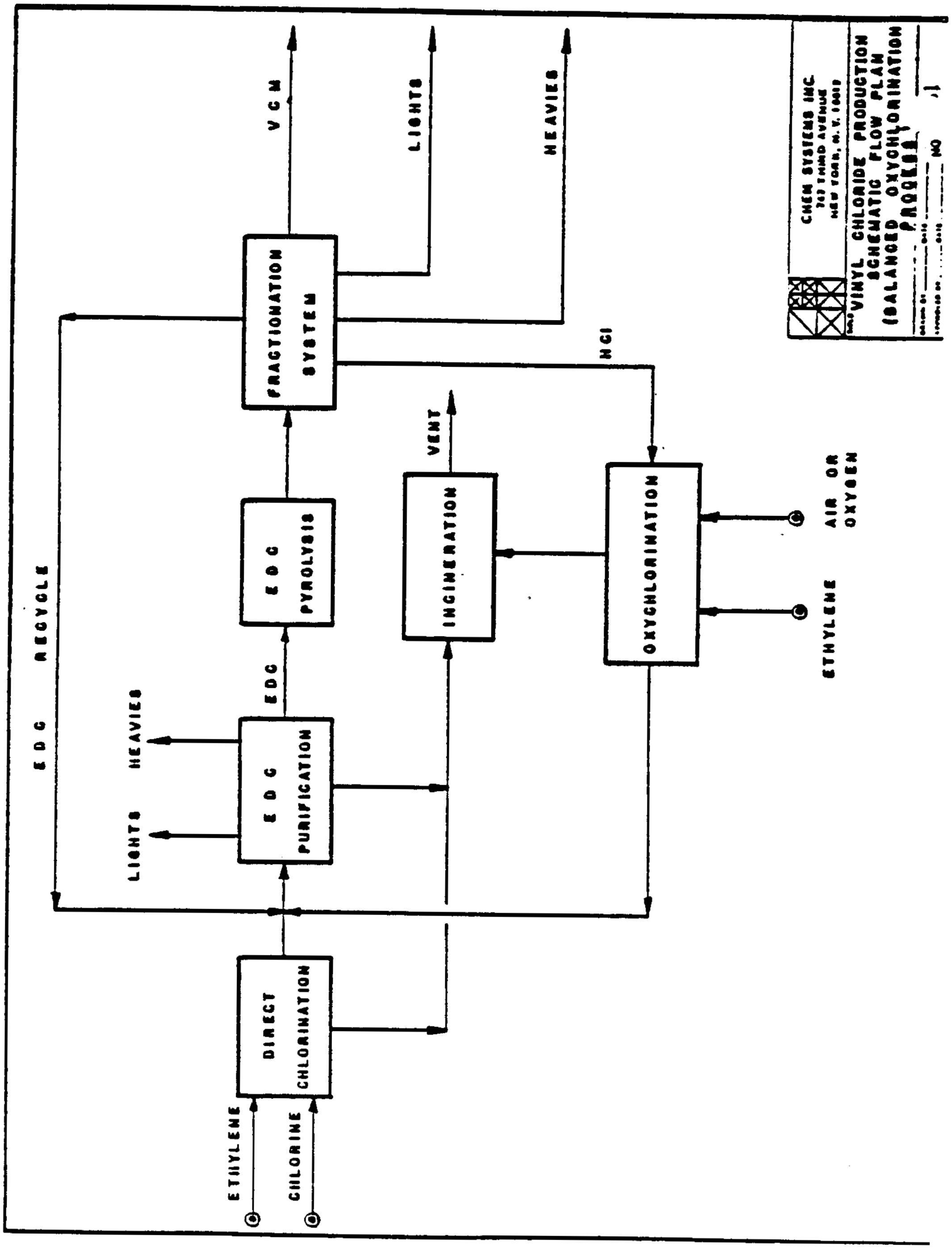

FIGURE V.C-3

VINYL CHLORIDE MONOMER PRODUCTION

Source: Chem Systems Inc., "Natural Gas Valuation in Industrial Applications", New York, 1982.

sent to a cracking reactor which produces vinyl chloride and hydrogen chloride. A fractionation system is then used to recover VCM, to recycle the unreacted EDC, and to send the hydrogen chloride to the oxychlorination reactor. Here, ethylene feed is reacted with oxygen and hydrogen chloride to yield EDC, which is combined with the product of the direct chlorination step. A different process of VCM manufacture uses high-purity acetylene (C_2H_2) and anhydrous hydrogen chloride (HCl) as reactants.

A vinyl chloride monomer plant producing 160,000 t/a of VCM would require:

ethylene	80,000 t/a
chlorine	96,000 t/a which would be supplied by
processing rock salt	180,000 t/a
using electricity	200 - 400 kWh/t
with installed power of	3 - 7 MW
and would yield in addition	
caustic soda	190,000 t/a
carbon tetra-chloride	10,000 t/a

The plant would be able to produce PVC from the VCM in minimum trains of 50,000 t/a and use 200 - 400 kWh/t with an installed power of 1.2 to 2.4 MW.

Land area for a plant producing PVC from ethylene on an integrated site with an output of PVC of 150,000 t/a would be about 25 ha and employ 300 to 500 personnel. 150,000 - 240,000 t/d of water for cooling would be required, which amount may be reduced by recirculation.

V.C.1.2.c Ethylene Oxide and Ethylene Glycol

Ethylene oxide is the basic feedstock for manufacture of antifreeze (ethylene glycol) and polyester. Ethylene oxide is manufactured by direct oxidation of ethylene with high purity oxygen. A schematic flow plan for ethylene oxide production is shown in Figure V.C-4.

Make-up ethylene, oxygen, and methane (the latter aids in controlling the oxidation reaction) are heated to about 220°C and enter the reactor (at 17.2 bar), where oxidation takes place in the presence of a silver catalyst. Ethylene conversion to its oxide is about 11% per reactor pass. Carbon dioxide, water, and some carbon monoxide are the by-products of the reaction. The reactor effluent, after cooling, is passed through an absorber, a desorber, a stripper, and finally enters a purification column, from where pure ethylene oxide is drawn off.

Ethylene glycol is produced from ethylene oxide by liquid-phase acidcatalyzed hydration. Ethylene oxide and water are reacted at about 300 psig and 180°C in the presence of sulphuric acid solution. By selection of the oxide-to-water ratio, it is possible to control the production of the mono-, di-, and higher glycols produced. Reactor effluent is dehydrated in a multiple-effect evaporator system. The effluent from the dehydration section is fed to a series of fractionators. The first tower removes water and traces of the light-ends, the second produces fiber-grade mono-ethylene glycol, and the subsequent towers produce diethylene and higher glycols. A flow sheet of this process is shown in Figure V.C-5.

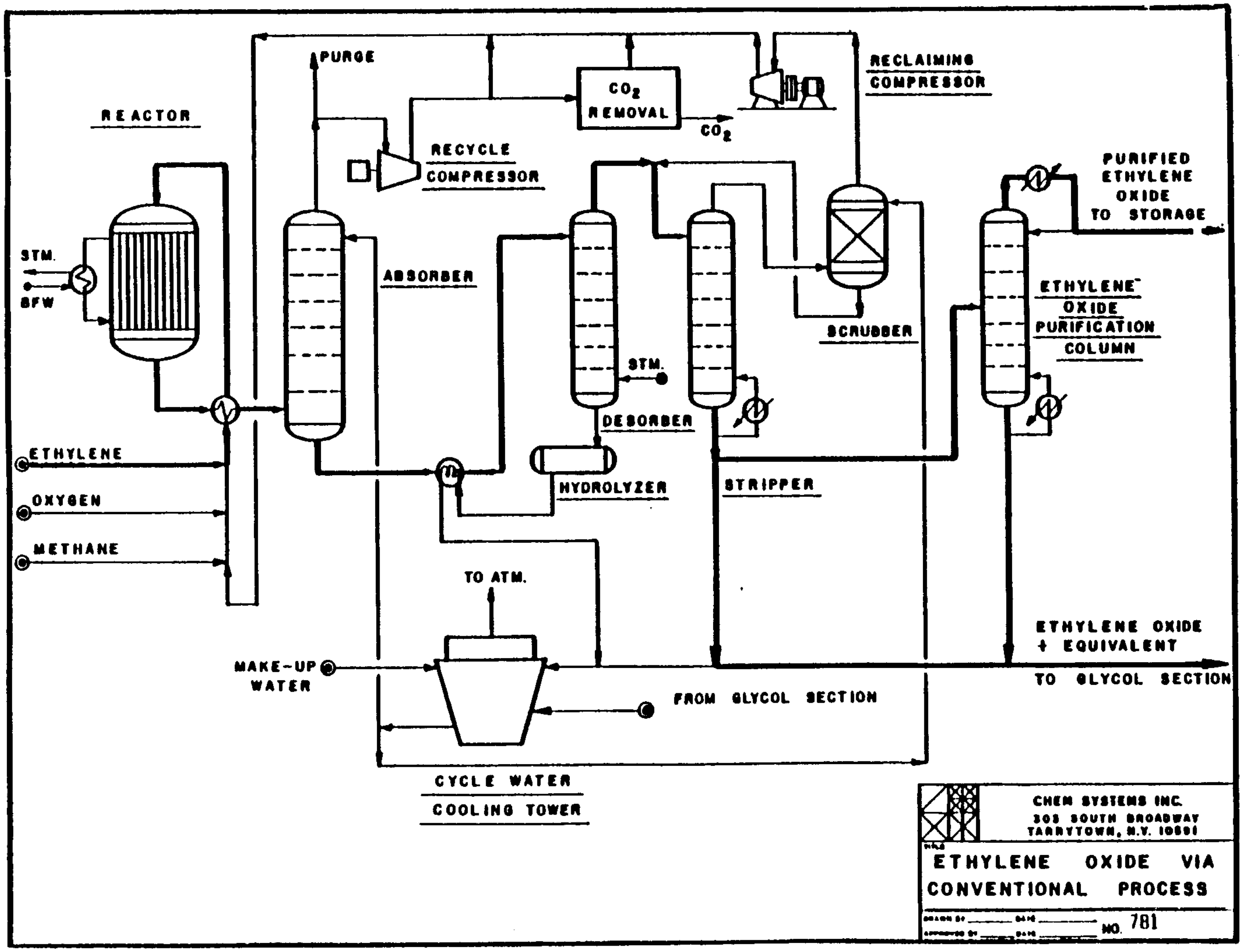

FIGURE V.C-4

ETHYLENE OXIDE PRODUCTION

Source: Chem Systems Inc., "Natural Gas Valuation in Industrial Applications", New York, 1982.

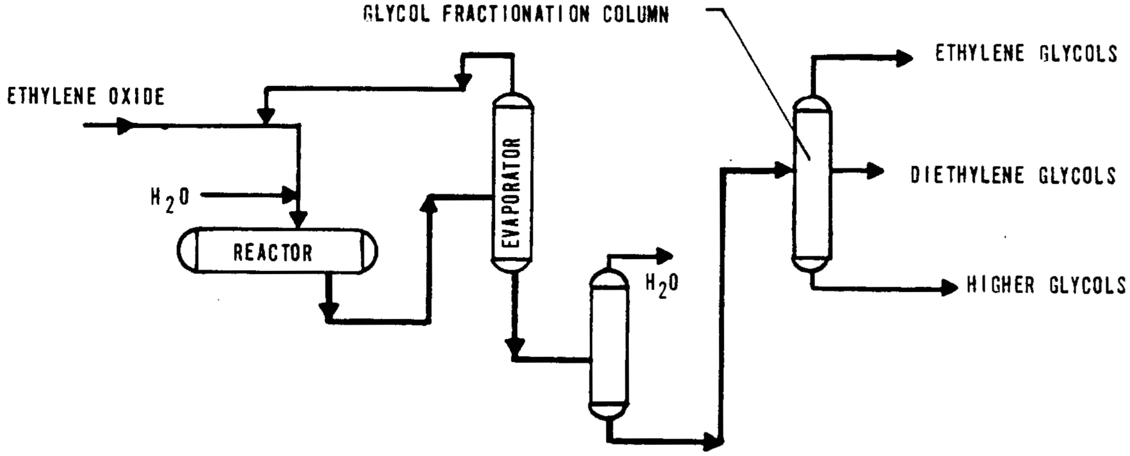

FIGURE V.C-5

PRODUCTION OF ETHYLENE GLYCOLS FROM ETHYLENE OXIDE

Source: U.S. Environmental Protection Agency, "Major Organic Products", EPA-440/1-74-009-a, 1974.

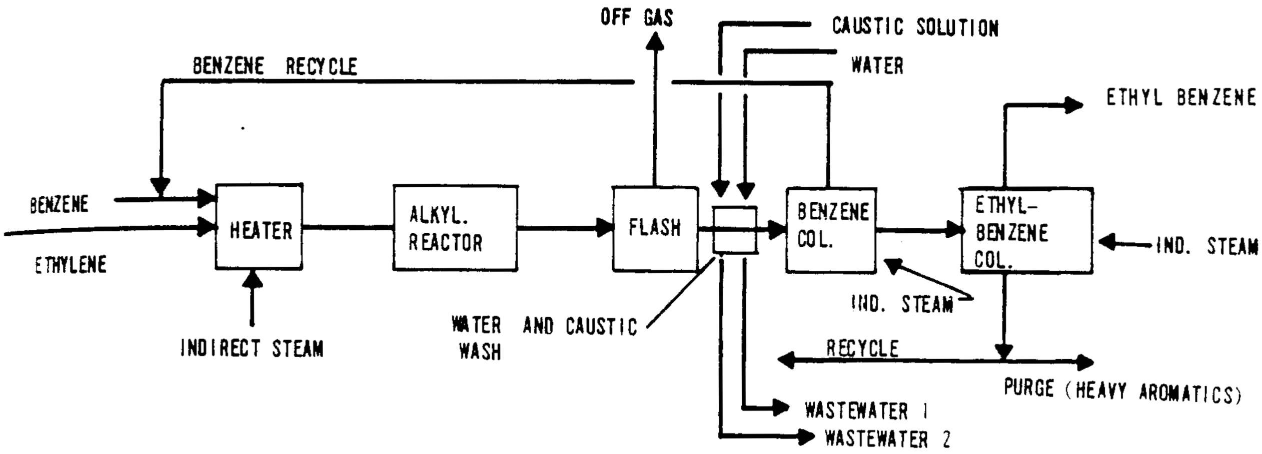

FIGURE V.C-6

ETHYLBENZENE PRODUCTION

Source: U.S. Environmental Protection Agency, "Major Organic Products", EPA-440/1-74-009-a, 1974.

V.C.1.2.d Ethylbenzene - Styrene - Polystyrene

Polystyrene is a thermoplastic produced by polymerization of styrene, which is made from an ethylene derivative, ethylbenzene. U.S. production of polystyrene will approach 4 billion pounds in 1984. The major end uses of polystyrene are packaging and containers, disposable fast food containers, appliance parts, and housewares.

The majority of ethylbenzene is manufactured by the alkylation of benzene with ethylene. A process flow sheet is shown in Figure V.C-6. Ethylene and feed benzene are combined with recycle benzene and polyaromatics, heated to reactor temperature, and introduced to the alkylation reactor. The reactor effluent is washed with caustic solution and water, and is passed to the separation section. Unreacted benzene is recycled, ethylbenzene is drawn off as the product, and polyethyl benzenes are recycled or drawn off as waste effluents.

Styrene is produced by vapor-phase dehydrogenation of ethylbenzene over supported zinc oxide, magnesium oxide, and iron oxide catalysts. Steam is used as the diluent. A schematic flow plan of styrene manufacture is shown in Figure V.C-7. Feedstock ethylbenzene and superheated steam are mixed in a dehydrogenation reactor, which operates at about 60% ethylbenzene conversion. After being condensed, the reactor effluent goes to a separator, where vapors and water-phase components are discharged from the system. The organic dehydrogenated mixture passes to the distillation section, where the unreacted ethylbenzene is separated and recycled. Distillation operates under vacuum to prevent styrene loss due to polymerization. Subsequent controlled polymerization of styrene produces polystyrene.

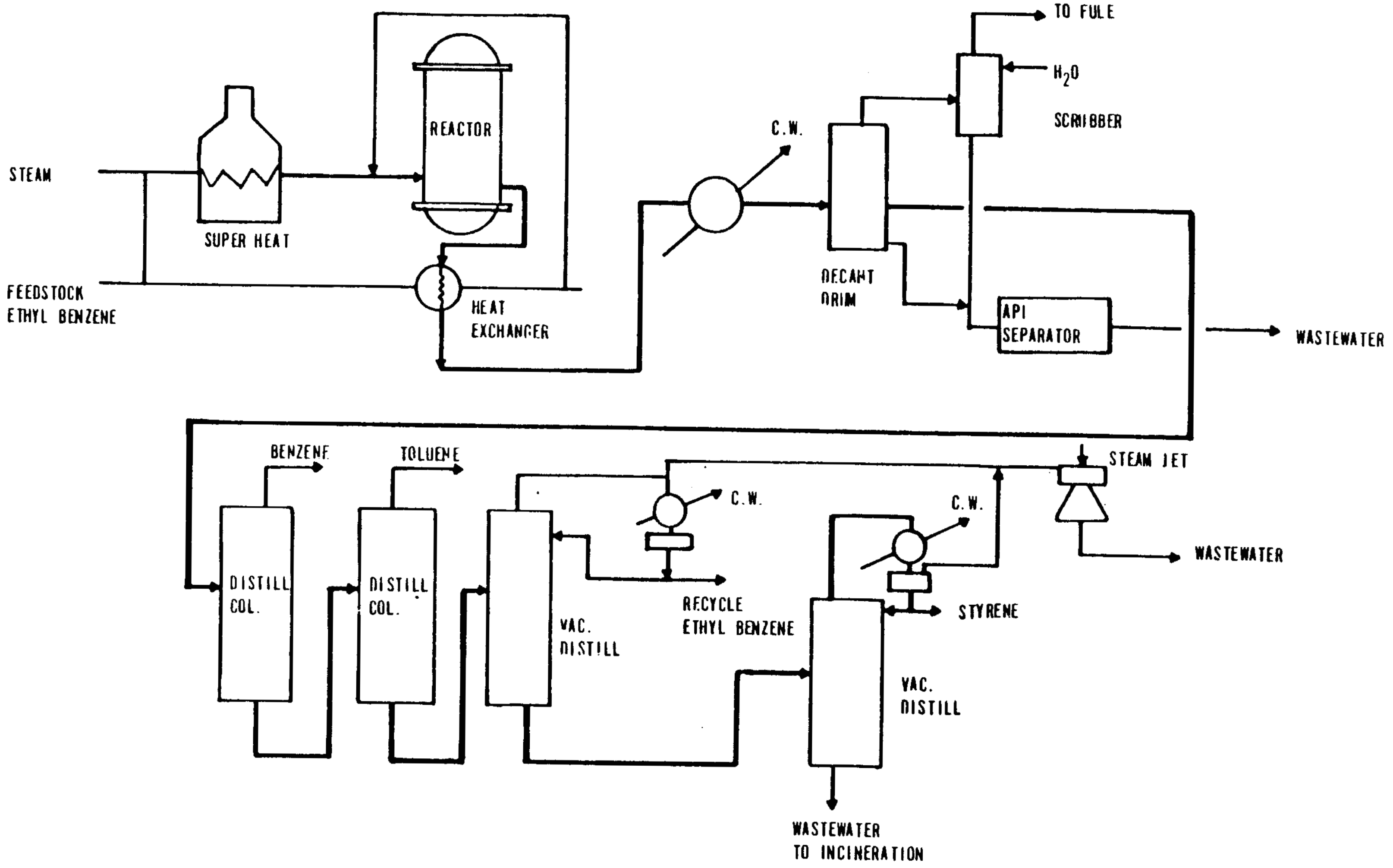

FIGURE V.C-7

STYRENE PRODUCTION

Source: U.S. Environmental Protection Agency, "Major Organic Products", EPA-440/1-74-009-a, 1974.

A styrene/polystyrene plant is normally not smaller than 200,000 t/a in capacity, and requires:

ethylene	60,000 t/a
benzene	160,000 t/a
energy consumed	100 kW/t
energy installed	3 - 5 MW
cooling water	10 kt/d (may be reduced with recycling)
land	5 - 20 ha
personnel	60 - 180

In addition for polystyrene production of 100,000 t/a additional requirements are:

energy consumed	700 kWh/t of product
installed power	5 MW
cooling water	6,000 t/d
land	5 - 10 ha
personnel	160 - 180

V.C.2 Propylene and Its Derivatives

Propylene is another important primary product of an olefin plant, and is used as feedstock for the production of various petrochemicals. Typical end uses of propylene are:

	%
Acrylonitrile	22
Polypropylene	20
Oxo alcohols	17
Propylene oxide	13
Cumene	10
Isopropanol	8
Others	10
	100

V.C.2.1 Propylene Manufacture

Propylene is produced either as a co-product of ethylene manufacture (when feedstocks other than ethane alone are cracked), or by dehydrogenation of propane. In the hydrocarbon pyrolysis process which has been described in section V.C.1.1, propylene is produced from the overhead stream of the depropanizer, after a pass through the C_3 splitter, where propane and propylene are separated.

A flow sheet of propylene manufacture by dehydrogenation of propane is shown in Figure V.C-8. The propane feed is preheated against reactor effluent, further heated to reaction temperature (typically 1000-1400^oF) in a fired heater, and fed to a system of fixed-bed reactors. After fooling, the reactor effluent is compressed and sent to an absorber/stripper system for the removal of fuel gases from the C_3 product. The product stream can be processed further to high purity propylene if necessary.

V.C.2.2 Acrylonitrile

Acrylonitrile, an intermediate product mainly used for the production of synthetic fibres (acrylic), accounts for about 22% of the propylene demand. Acrylonitrile is produced by the propylene ammoxidation process (refer to Figure V.C-9).

A mixture of propylene, ammonia and air is fed to a reactor, where acrylonitrile is formed at a temperature of 420-460^oC, under a pressure of about 14 psig, and in the presence of a fluid catalyst. The major reaction by-products are hydrogen cyanide and acetonitrile. The reactor effluent, containing product, by-products, unreacted feed, catalyst fines and water formed during the reaction, passes through a series of columns, absorbers, strippers

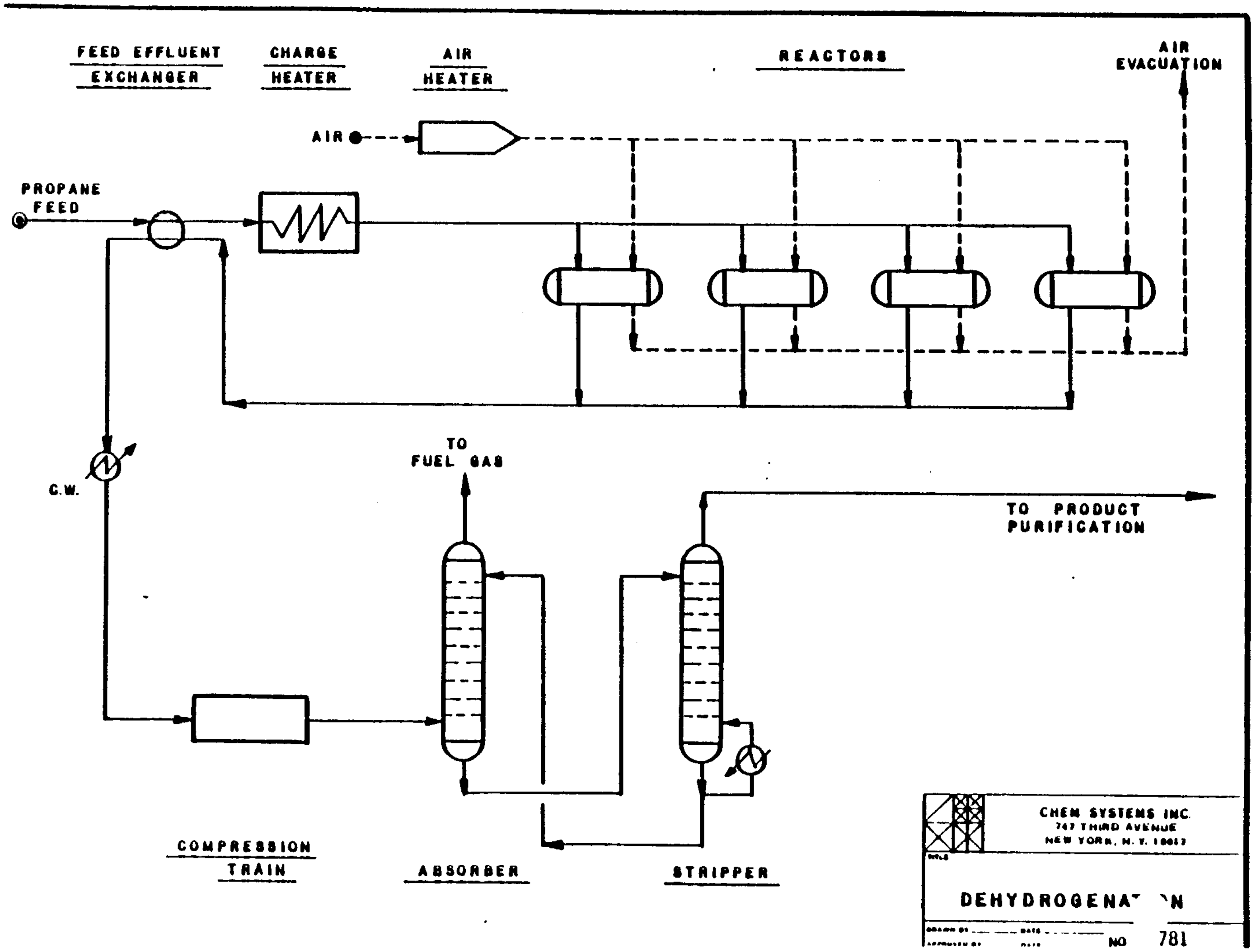

FIGURE V.C-8

PRODUCTION OF PROPYLENE BY DEHYDROGENATION OF PROPANE

Source: Chem Systems Inc., "Natural Gas Valuation in Industrial Applications", New York, 1982.

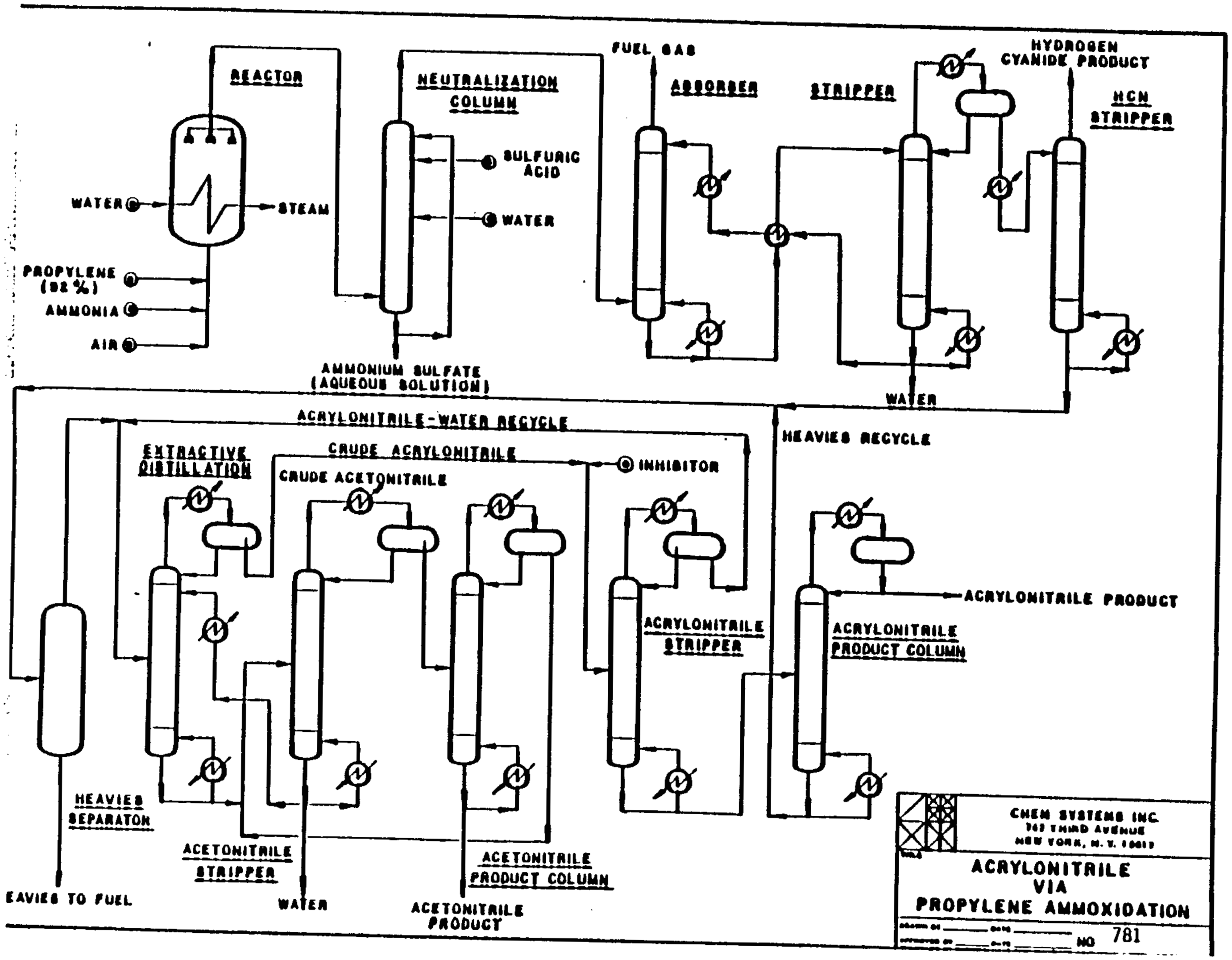

FIGURE V.C-9

ACRYLONITRILE PRODUCTION

Source: Chem Systems Inc., "Natural Gas Valuation in Industrial Applications", New York, 1982.

and separators before pure acrylonitrile product is drawn off. Extractive distillation is used to separate acrylonitrile and acetonitrile, as direct distillation is difficult due to the closeness of the boiling points of these substances.

V.C.2.3 Polypropylene

Polypropylene is a thermoplastic material produced by the polymerization of propylene, and accounts for about 20% of the propylene demand.

Pure propylene (99.8 weight percent) together with a catalyst solution, on inert diluent (usually n-heptane), hydrogen (for molecular weight control) and sometimes ethylene (to produce random or block copolymer) are charged to the polymerization reactors, where about 60% of the propylene is converted to polymer. Four percent of the on-specification polymer output is atactic polymer which must be removed.

The reactor effluent passes through a flash tank, where the unreacted propylene is isolated and recycled to the reactors. The slurry from the flash tank, containing 40 weight percent solids, is pumped to a centrifuge feed tank and then to bowl-type centrifuges, where heptane and atactic polymer are removed and further processed, while polypropylene is taken as a cake. The polymer cake is conveyed to the drying section of the plant, and then to the finishing area, which consists of powder silos, extrusion, pelletizing and product blending, storage and packaging.

V.C.2.4 Oxo Alcohols

The oxo process is a broadly applicable technology which is used to produce aldehydes which are usually converted to the corresponding alcohols.

Two-ethylhexanol, produced from propylene via n-butyraldehyde, is the most important oxo chemical in terms of volume. A process flow sheet of 2-ethylhexanol manufacturing is shown in Figure V.C-10.

Carbon dioxide, natural gas, and steam are passed into a synthesis gas reactor to produce water gas (1:1 ratio of H_2O and CO), which is then mixed with propylene in a liquid-phase reactor in the presence of a cobalt solution. A liquid-gas mixture of aldehydes and unreacted materials is taken overhead from the reactor, cooled, and then separated in successive high- and low-pressure flashing stages, where unreacted synthesis gas is recycled to the oxo reactor. The liquid product, containing n-butyraldehyde, iso-butyraldehyde, and solvent, is separated in two distillation columns. N-butyraldehyde is then sent to a condensation reactor, where 2-ethylhexenal is produced. The unreacted aldehyde is separated from the product by distillation and is recycled to the condensation reactor.

The 2-ethylhexenal is then hydrogenated to 2-ethylhexanol in a pressurized reactor. After being washed with caustic solution and water, the reactor effluent is sent to a fractionator to recover the product 2-ethylhexanol.

V.C.3 Butadiene

Butadiene is the third lower olefin produced in an olefin plant. It is directly suitable for feed to synthetic rubber industries, the end products being the elastomers polybutadiene (BR) and styrene-butadiene (SBR) rubbers. Butadiene is produced either as a co-product of ethylene manufacture, or by dehydrogenation of C_4 hydrocarbons, such as n-butane or butylenes.

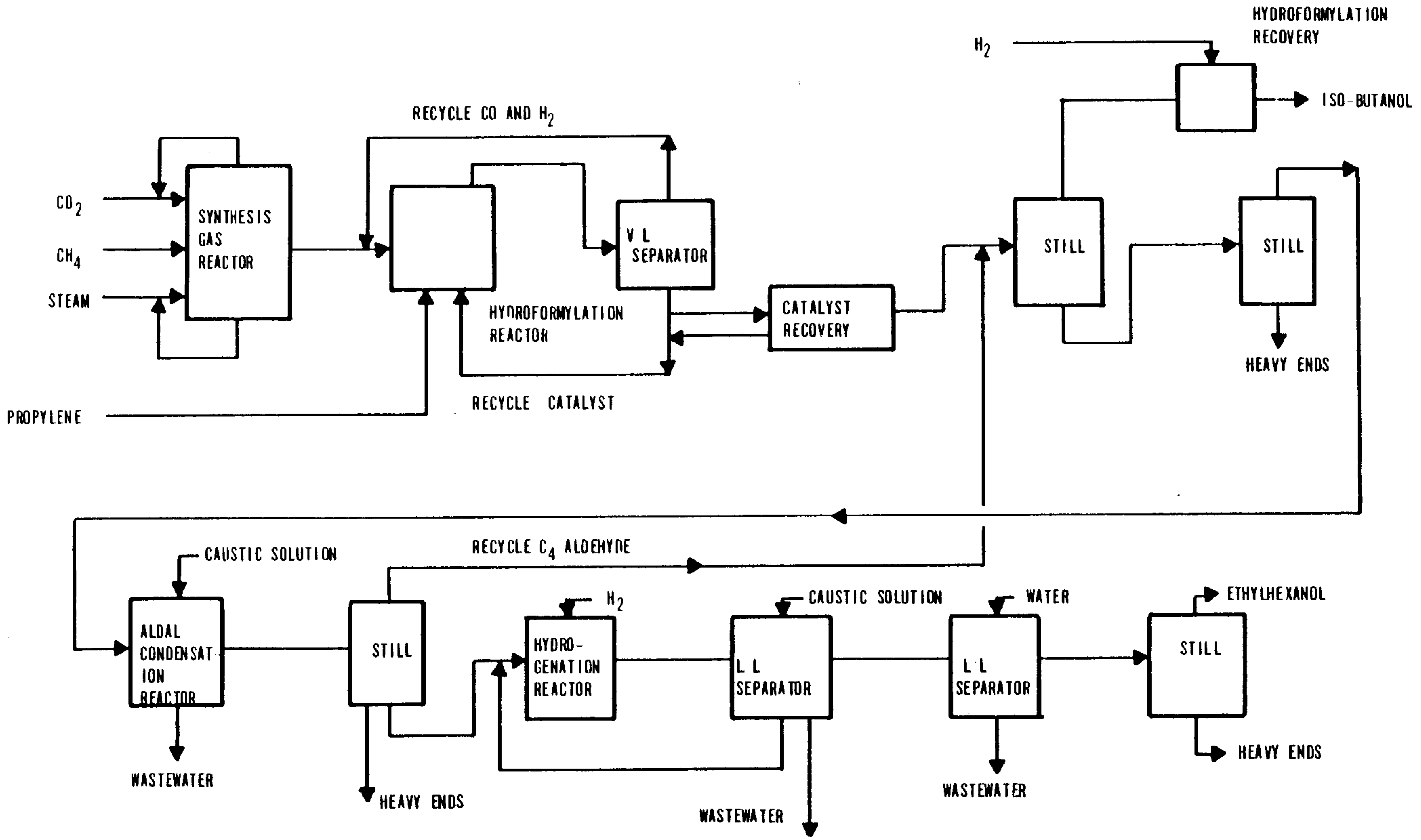

FIGURE V.C-10

2-ETHYLHEXANOL PRODUCTION

Source: U.S. Environmental Protection Agency, "Major Organic Products", EPA-440/1-74-009-a, 1974.

The mixed C_4 stream from the ethylene unit (refer to Figure V.C-2) is vaporized, combined with hydrogen, heated to 450°F, and passed over the C_4 acetylene removal catalyst, which causes the conversion of vinyl and ethyl acetylenes mainly to butenes. The effluent vapor is cooled and passed into an extract tower where the mixture is contacted with an aqueous acetonitrile solution. The butadiene is selectively extracted from the butenes and butanes which are removed overhead. They are washed to recover the solvent. The crude butadiene is fed to a tailing column where heavy ends are fractionated from the product, which is taken overhead and is 99.5 weight percent butadiene.

For an olefin plant producing 65,000 t/a butadiene (along with a 450,000 t/a ethylene output), the butadiene extraction from the cracked gases, would require per ton of product:

Steam,	50 psig	0.5 t
	200 psig	1.55 t
Cooling water (25°F rise)		75 t
Power		15 KWh

The one-step catalytic dehydrogenation of n-butane is another process of butadiene manufacturing (refer to Figure V.C-11). The make-up n-butane, and recycled butane and butenes are fed into a battery of fixed-bed reactors, where dehydrogenation takes place under vacuum and in the presence of solid chromium-on-alumina catalyst. The reactor effluent is oil-quenched, compressed, and sent to an absorption column, where hydrocarbon vapor is absorbed with light oil. The effluent from the absorber is then passed through a series of distillations, where unreacted butane and butene are separated for recycle to the dehydrogenation reactors. Butadiene is separated from the butene splitter overhead by extractive distillation with furfural or cuprous ammonium acetate (CAA) extraction.

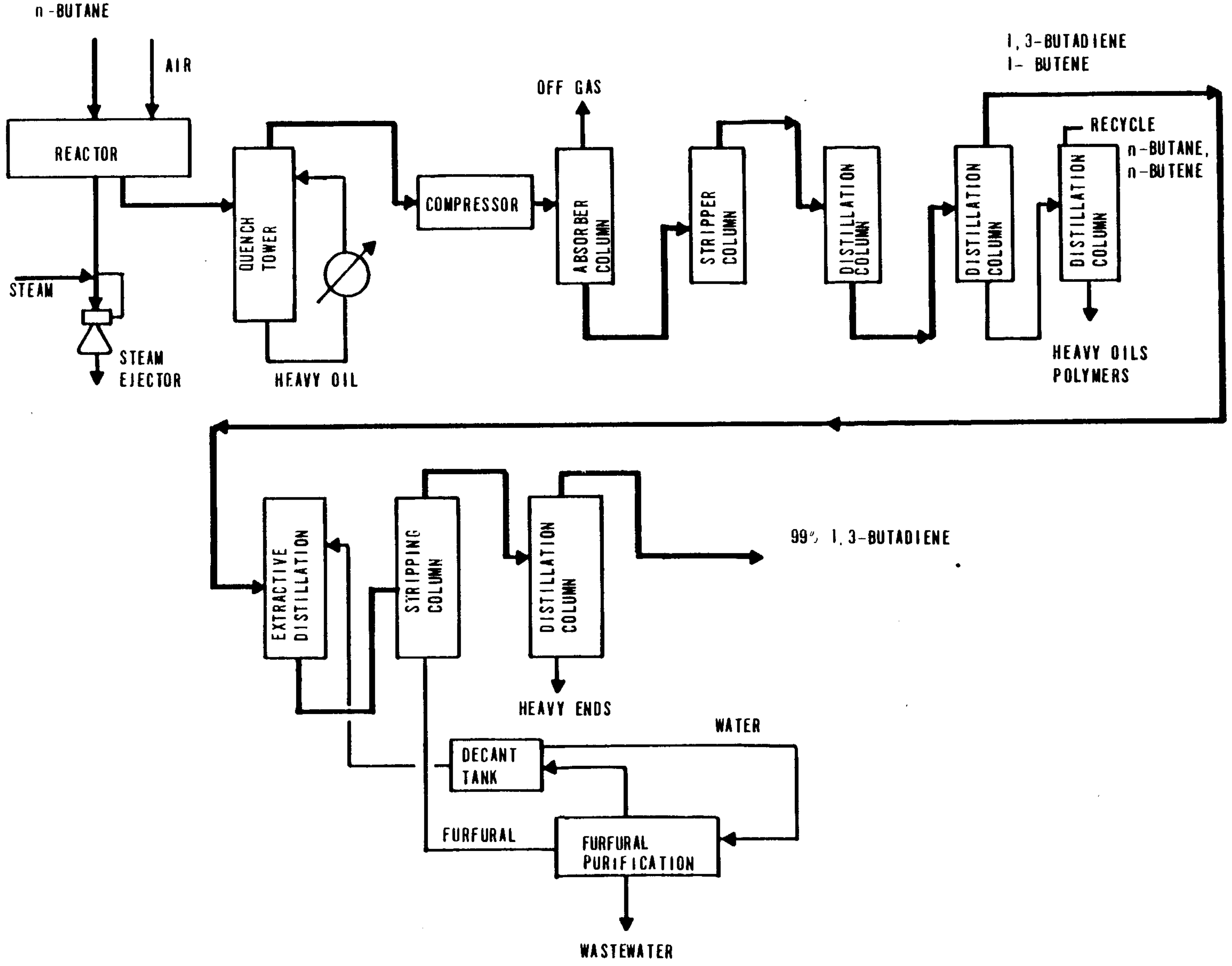

FIGURE V.C-11

BUTADIENE PRODUCTION BY DEHYDROGENATION OF n-BUTANES

Source: U.S. Environmental Protection Agency, "Major Organic Products", EPA-440/1-74-009-a, 1974.

V.C.4 Benzene, Toluene and Xylene (BTX) Aromatics

A mixture of BTX aromatics and saturates may be obtained from an olefin plant as a by-product of ethylene manufacture (by pyrolysis of naptha feedstocks). This mixture must first be stabilized by hydrotreating prior to the recovery of BTX aromatics by solvent extraction. A schematic flow plan of this process is shown in Figure V.C-12.

The feedstock (pyrolysis gasoline from the ethylene plant) is preheated and passed through a series of hydrotreating reactors containing platinum catalyst. The reactor effluent is cooled and then discharged into a separator, where the gas stream taken overhead is recycled back to the reactor after being scrubbed with caustic solution. The liquid phase from the reactor is passed through a coalescer (where water is used to trap coke particiles formed in the pyrolysis reactor), and a stabilizer (where light hydrocarbons are removed).

The stabilized liquid is then extracted with a solvent (di- and triethylene glycol) to recover the aromatics, and the raffinate (containing paraffins) is sent to a cracking furnace to produce olefins. The dissolved aromatics (BTX) are separated from the solvent by distillation, and the solvent-free aromatics are water washed and sent to the fractionation unit. Essentially 100% of the benzene and toluene are recovered in the extract along with 95% of the xylenes. The other 5% of the C_8 aromatics remains in the raffinate.

The extract is first passed through a clay treater to remove trace olefins, and then fractionated in a tower system to produce high purity benzene and toluene, and a mixed xylenes stream.

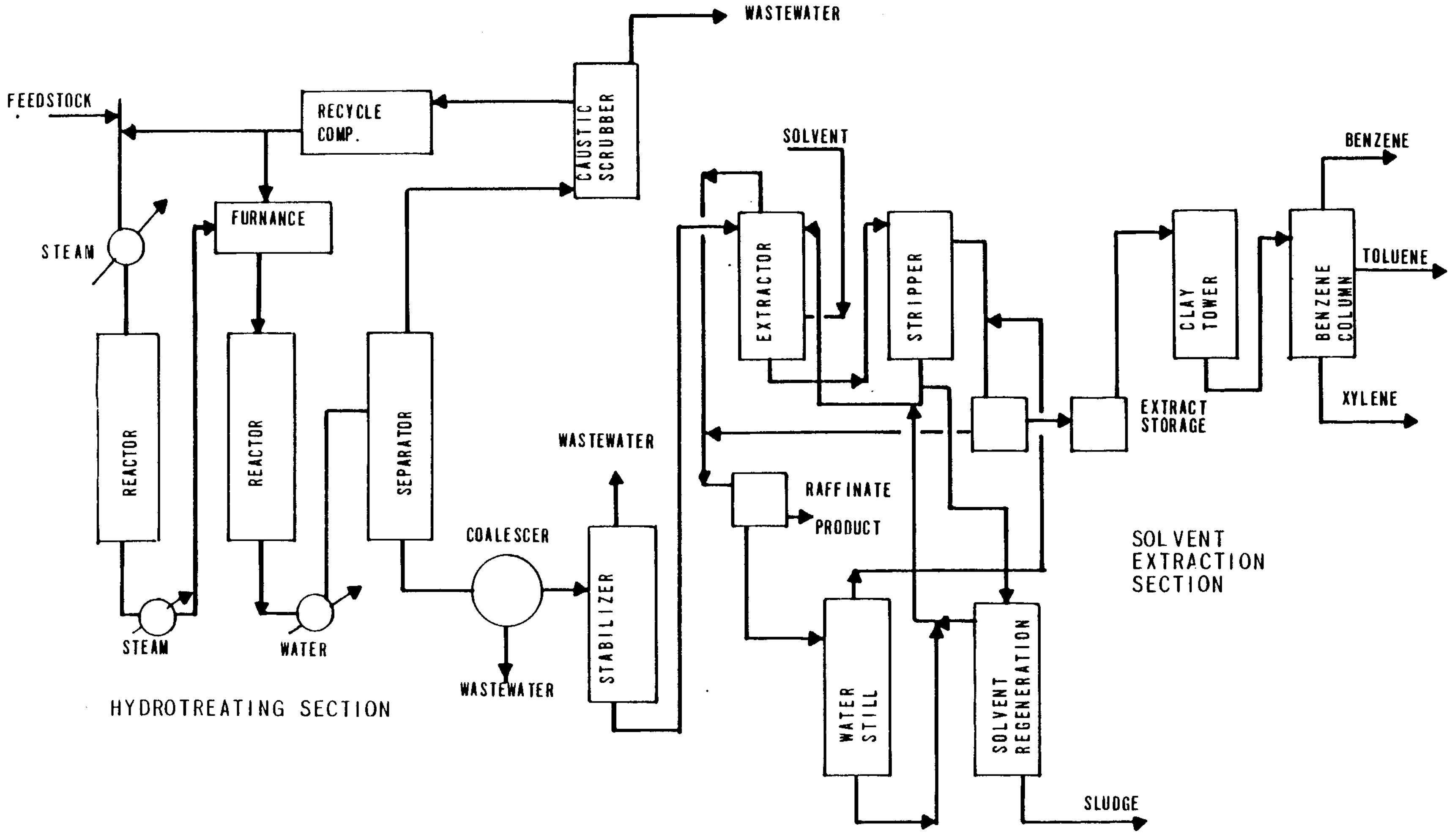

FIGURE V.C-12

BTX PRODUCTION FROM PYROLYSIS GASOLINE

Source: U.S. Environmental Protection Agency, "Major Organic Products", EPA-440/1-74-009-a, 1974.

The BTX extraction and fractionation units together require the following per ton of feed:

Steam, 200 psig	0.88 t
Fuel	0.13 MM BTU
Cooling water	4600 gals.
Power	9.3 KWh

Benzene is the most important aromatic. Its prevailing derivatives are ethylbenzene used for styrene manufacture (refer to section V.C.1.2.d), and cyclohexane used for synthetic fibre (nylon) manufacture. Cyclohexane is produced by hydrogenation of benzene (see Figure V.C-13).

Benzene is combined with make-up and recycle hydrogen, preheated to reaction temperature, and fed into the reactor, where hydrogenation takes place in the presence of nickelpalladium or platinum catalyst. The reaction effluent is cooled and flashed. Part of the vapor is used as recycle hydrogen, while the forward-flow vent gas is chilled by refrigeration to minimize cyclohexane losses and is available as high-pressure fuel gas. The separated liquid is sent to a column where the light-end impurities are taken overhead.

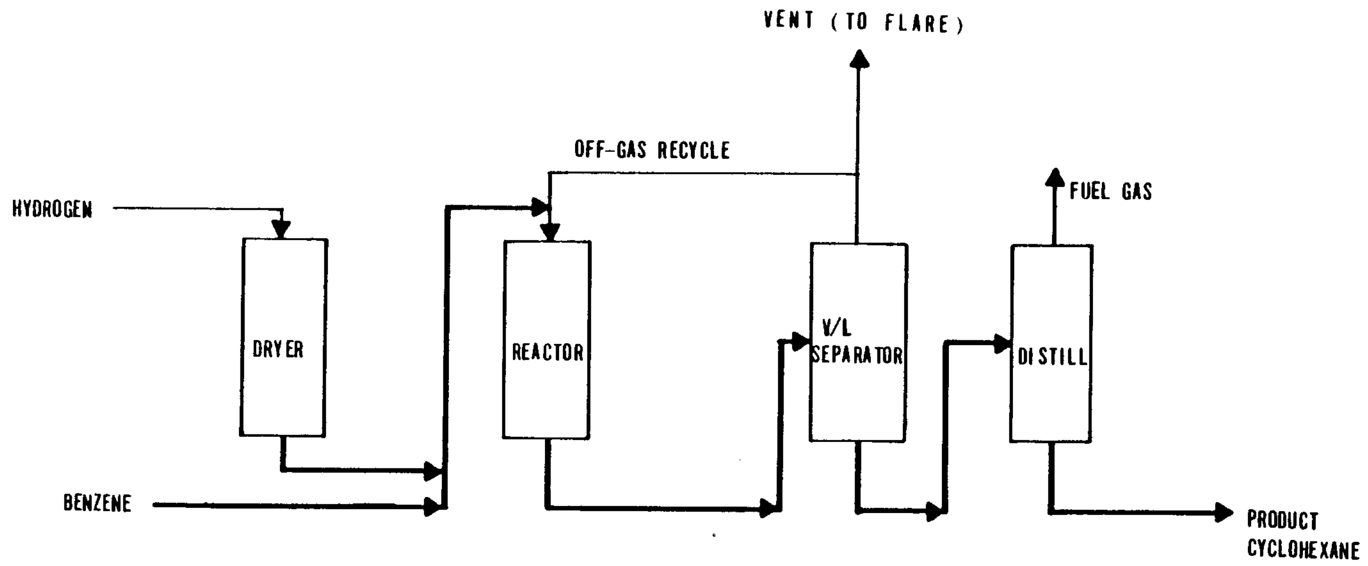

FIGURE V.C-13

CYCLOHEXANE PRODUCTION

Source: U.S. Environmental Protection Agency, "Major Organic Products", EPA-440/1-74-009-a, 1974.

V.D Environmental Impact*

The gaseous emissions and the liquid effluents are of equal importance in a petrochemical complex, and the discharges must be controlled in order to avoid environmental damage. A combination of in-plant control, at-source pretreatment, and end-of-pipe technology can usually be effective in achieving reduction of these discharges to acceptable levels.

It is difficult to categorize gaseous emission sources on the basis of petrochemical operations, since many of them are common throughout the plant. For purposes of emissions control, the petrochemical complex should be considered as an integrated system of storage facilities, process heaters, cooling equipment, pumps, valves and other units and operations.

Sulphur oxides, nitrogen oxides, hydrocarbons, carbon monoxide and odor are the gaseous emissions of greatest concern. Dusts, and other substances coming from catalyst regenerators may also be present but are usually of lesser importance.

Hydrocarbon emissions originate principally from storage facilities, pumps and valves, compressors, cooling towers and process heaters. These emissions can, in most instances be collected by vapor recovery systems or ventilating systems and eliminated by burning through elevated flares, using steam ejection.

Sulphur oxides originate from boilers and process heaters; nitrogen oxides from process heaters, compressors and flares; carbon monoxide from

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*Source: "Environmental Guidelines", The World Bank, Office of Environmental Affairs, 1984.

catalyst regenerators; and odors from treating units and tank vents. The use of waste heat boilers on catalyst regenerators, smokeless flares, and sulphur-recovery systems may reduce emission discharges.

The wastewater flows and characteristics of petrochemical plant effluents can vary considerably according to the type of operations. The following are the pollution parameters of major significance in this industry: 5-day Biochemical Oxygen Demand (BOD_5); Chemical Oxygen Demand (COD); Total Organic Carbon (TOC); Total Suspended Solids (TSS); Oils and Greases (O/G); Phenolic Compounds; Ammonia Nitrogen; Sulphides; Total Chromium; Hexavalent Chromium; and Hydrogen Ion Concentration (pH).

Recycling systems that use water more than once for the same purpose, and the reuse of water from one process to another can greatly reduce the volume of final effluents. Good housekeeping will further reduce waste flows. Examples are minimizing waste when sampling product lines, applying effective maintenance in order to keep the equipment as leakproof as possible, and providing individual disposal for waste streams having special characteristics.

Major at-source pretreatment measures include stripping of sour waters, and neutralization and oxidation of spent caustics. End-of-pipe control technology relies most heavily on a combination of flow equalization and biological treatment methods, such as dissolved air flotation, oxidation ponds, trickling filters, activated sludge, granular media filters, and activated carbon. The selection of the most appropriate techniques depends upon the volume and characteristics of the wastes, availability of land areas and other factors. Sludges produced from biological treatment may be disposed of by land-filling, land farming or incineration.

V.E Transportation of Petrochemicals

It is possible to identify two distinct types of petrochemical trade flows: distributive and balancing movements. Distributive trades involve the movement of a variety of products from a processing plant/area to their final market. Balancing trades emerge when a divergence exists between the supply and demand of a product in a given locality. The major difference between these two types of trade is that, while distributive trades involve a large number of products moving at frequent intervals in relatively small volumes over relatively small distances, balancing movements tend to be relatively large volumes of a few intermediate products between the main producing areas (US, Japan and Western Europe).

Many alternative modes of transport (truck, rail, ship, pipeline) are available for the distributive trade, as small distances are usually involved. Ethylene is one of the most commonly traded products. Pipeline transport of ethylene is made in the vapor phase, while rail, truck, and ship transport is designed for liquid handling at $-104^{\circ}C$ under a pressure slightly higher than atmospheric.

A truck-trailer unit typically has a light weight of about 15 tons and can carry 20 tons of liquid ethylene. Maximum tank operating pressure in these units is 3-4 atmospheres gauge. Rail tank cars capable of carrying ethylene typically weigh 50-55 tons and carry about 65 tons of product liquid. Single rail tankers are not competitive with road tankers over short distances because of their relatively slow speed, but unit trains compare favorably with road transport over longer distances, up to about 1200 Km. A 20-car train could move up to 36,500 tons/year over 1200 Km.

Ocean carriage of ethylene is performed by specialized tankers, which have capacities varying from a few hundred up to 36,000 cu m, and are capable of carrying ethylene at a temperature of -104°C.

Pipeline conveyance accounts for much larger ethylene volumes than the other transport modes combined. Extensive ethylene pipeline grids have been established in Europe and the U.S. in regions with relatively high concentrations of producer, consumer, and producer-consumer plants. In Texas, a group of over fifty manufacturing, consumer, and storage installations is connected to a single grid. Total storage capacity available to this ethylene network exceeds 3 million cubic meters. There are also numerous systems consisting of a pipeline that connects a single producer with a consumer located a few hundred kilometers distant. For example, a 125-Km long, 150-mm diameter pipeline connects a producer at Fawley, England with ICI's Severnside ethylene oxide and glycol plant, providing a capacity of 72,000 tons/year.

For economical transportation over long pipeline distances, ethylene must be transmitted in the vapor phase and preferably at supercritical pressure, where transport capacity is several times that of a subcritical line for the same pressure gradient. Supercritical lines operate at about 53-97 atmospheres pressure, 2 to 20°C, and a density of 400 to 200 kg/cubic meter. A 100-Km line with a 250-mm diameter and ethylene at 10°C has a supercritical capacity of 400,000 tons/year with an initial pressure of 60 atmospheres and a line terminal pressure of about 50 atmospheres.

The balancing trade, on the other hand, occurs mainly between the petrochemical producing countries, and carriage by ships is the only transportation mode available. Undersea pipelines have been installed in some cases, but they are exclusively used for natural gas transport.

V.E.1 Liquefied Petrochemical Gases

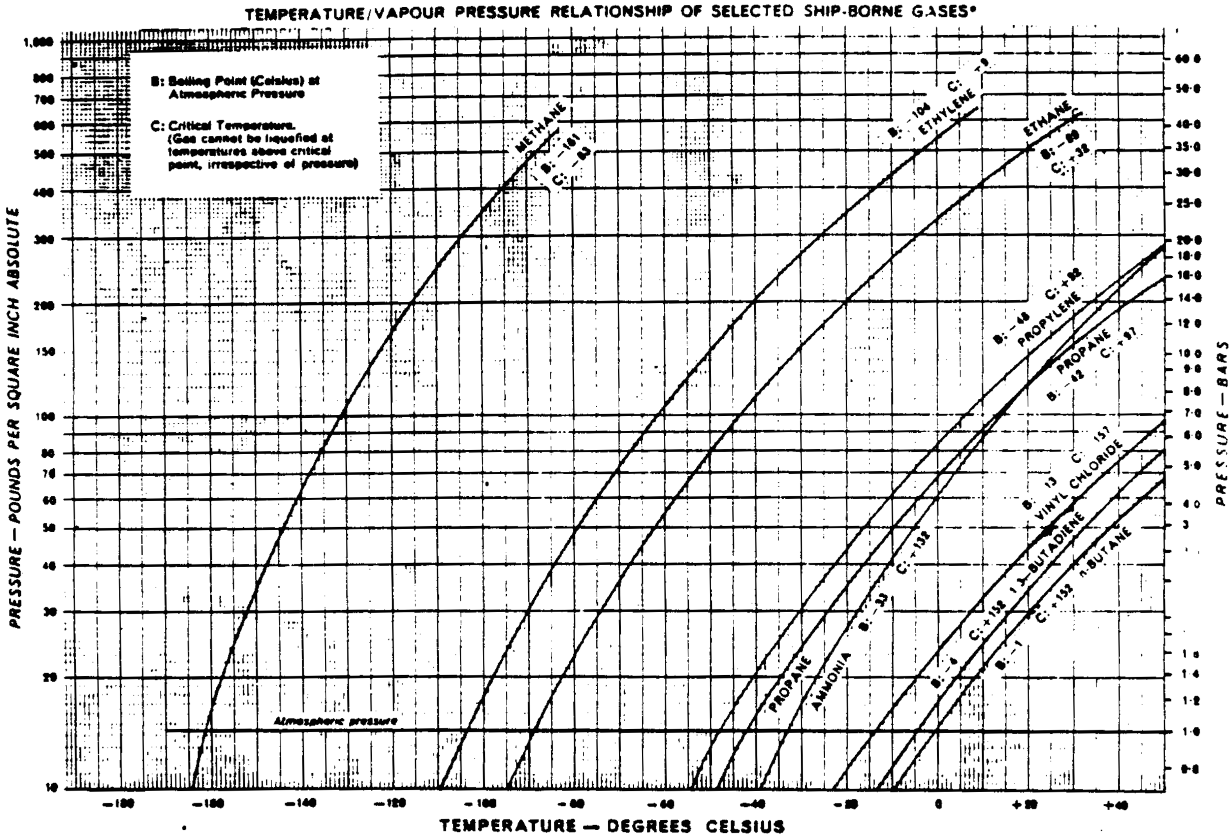
The physical and chemical properties of the various petrochemical products is the main factor determining the type of ships employed.

Gases such as ethane, propane, butane, ethylene, propylene, butadiene, ammonia and vinyl chloride are shipped in liquid phase by specialized carriers. Figure V.E-1 shows the temperature/pressure relationships required for liquefaction of such gases, while the carriage conditions of these cargoes are identified in Table V.E-1.

Liquefied petrochemical gases are carried by vessels which are provided with a refrigeration unit for reliquefaction of the boil-off during transit and while in port because the cargo value warrants recovery rather than venting off. A full complement of spare parts must be carried as refrigeration is vital to the carrier's operation. In addition to the refrigeration compressors, these vessels are equipped with an inert gas generator and load vaporizer as well as a high-capacity, low-head compressor to return displacement vapors generated during loading.

While there is some flexibility of use of liquefied petroleum gas carriers (LPG), the pressure/termperature and corrosive characteristics of petrochemicals have to be matched to the vessel characteristics.

The sizes of ships engaged in liquefied petrochemical trade range widely but, typically, energy carrying ships are of larger size with LPG carriers (propane and butane) up to 130,000 cu m. Petrochemical carriers range from a few hundred cu m capacity to 36,000 cu m for ethylene.


TEMPERATURE/VAPOUR PRESSURE RELATIONSHIP OF SELECTED SHIP-BORNE GASES*

* Curves constructed by application of Antoine equation, using data from "Selected Values of Properties of Hydrocarbons and Related Compounds", American Petroleum Institute Research Project 44, Thermodynamics Research Centre, Texas A. & M. University, and from "Advances in Chemistry Series: No. 22" ([illegible]) published by the American Chemical Society.

FIGURE V.E-1

TEMPERATURE/PRESSURE RELATIONSHIPS FOR SELECTED LIQUEFIED GASES

Source: Clarkson's Liquefied Gas Carrier Register.

TABLE V.E-1

CARRIAGE CONDITIONS FOR SELECTED SHIP-BORNE LIQUEFIED GASES

Properties of Cargoes at Proposed Carriage Conditions

NOTE.—The figures in this table refer to typical qualities of gas likely to be encountered in maritime trade. They are always liable to vary according to the purity of any particular cargo.

PROPERTIES		NATURAL GAS CH_4	ETHYLENE C_2H_4	ETHANE C_2H_6	PROPYLENE C_3H_6	PROPANE C_3H_8	AMMONIA NH_3	VINYL CHLORIDE C_2H_3Cl	BUTADIENE C_4H_6	NORMAL BUTANE C_4H_{10}
Carriage Temperature	°C	−165	−104	−89	−48	−43	−34	−14	−5	−1
	°F	−265	−155	−128	−54	−45	−29	6·8	23	30
Carriage Pressure	kgf/cm^2 Abs.	1·04	1·04	1·04	1·04	1·04	1·04	1·04	1·04	1·04
	lbf/in^2 Abs.	14·7	14·7	14·7	14·7	14·7	14·7	14·7	14·7	14·7
Specific Gravity of Liquid		0·474	0·570	0·547	0·614	0·583	0·683	0·965	0·647	0·602
Viscosity of Liquid (at boiling point, except where otherwise stated)	Centipoise (= ·001 Ns/m^2)	0·142	0·125	0·152	0·160	0·216	0·174	0·265	0·166	0·241
Specific Heat of Liquid		0·465	0·574	0·569	0·519	0·50	1·069	0·380	0·518	0·467
Heat of Vapourisation (Latent heat of boiling)	kcal/kg	124	115	117	105	101	326	79·3	99·0	91·0
	Btu/lb	224	208	211	189	182	588	143	178	164
Vapour Density—Relative to Air at Standard Temperature and Pressure		0·554	0·975	1·048	1·476	1·55	0·597	2·2	1·88	2·9
L.E.L. to U.E.L.*	% by vol.	5·3–14·0	2·7–28·5	3·2–12·5	2–11·1	2·1–9·5	14–28	4–33	2–11·5	1·8–8·5
Flash Point	°C	Very low	Very low	−135	−108	−105	Indefinite	−78	−60	−60
	°F			−211	−162	−157		−108	−76	−76
Ignition Temperature	°C	595	450	530	530	470	652	472	450	406
	°F	1104	842	986	986	877	1207	881	842	763
Maximum Allowable Concentration	Parts per million	Not applicable	5500	Not applicable	Not applicable	Not applicable	25	1·10	1000	Not applicable

* Lower explosive limit to upper explosive limit at atmospheric pressure in air.

Source: Clarkson's Liquefied Gas Carrier Register.

V.E.2 Liquid Petrochemicals

Liquid petrochemicals are carried in "chemical tankers", which are vessels of greater sophistication than conventional petroleum product tankers. The term "parcel tanker" is often used in a narrower sense to describe the most highly sophisticated ships designed for carrying small liquid cargo lots, with a minimum size of about 500 tons, on a worldwide liner-type service on an established framework of routes. These ships are characterized by: a large number of tanks (often as many as 40 or 50), usually in a combination of stainless steel tanks and coated tanks; a separate pump and loading/discharge line for almost every tank; and by double skin/double bottom construction. Simpler ships have less sophisticated cargo handling systems and can accommodate fewer cargo grades.

Table V.E-2 shows the growth of the chemical tanker fleet during the last decade, while the size, type and age distribution of chemical carriers is presented in Table V.E-3. At the end of 1982 the fleet of large chemical tankers (minimum size 10,000 DWT) amounted to 275 vessels totalling 7.0 million DWT. This volume of tonnage represents a considerable increase in the fleet since the early 1970s. The largest chemical carrier has a capacity of 39,000 DWT.

Almost all such vessels are now certified under the IMO Bulk Chemicals Code, as Ships of Type 1, 2 or 3. Table V.E-5 at the end of this section presents the provisions of the Code, covering Ship Type requirements. In addition, according to MARPOL Annex II, noxious liquid substances are divided into four pollution categories (refer to Table V.E-6 at the end of this section). The most commonly traded liquid petrochemicals, their pollution category and the required IMO Ship Type are presented in Table V.E-4. It can be seen from this table that a ship of Type 2 is capable of carrying any liquid petrochemical.

TABLE V.E-2

THE CHEMICAL TANKER FLEET 1973-1982

	NO. OF SHIPS	MILLION DWT
1973	123	2.7
1976	167	3.9
1980	219	5.4
1982	275	7.0

Source: H.P. Drewry Ltd., "The Chemical Carrier Trades", London, 1983.

TABLE V.E-3

THE CHEMICAL TANKER FLEET BY SIZE, TYPE AND AGE
(end-1982 existing fleet)

YEAR OF BUILD	PRE-1968		1968-70		1971-73		1974-76		1977-79		1980-82		TOTAL	
TYPE AND DWT	NO.	'000 DWT	NO.	'000 DWT	NO.	'000 DWT	NO.	'000 DWT	NO.	'000 DWT	NO.	'000 DWT	NO.	'000 DWT
10-14,999														
SS	2	28.8	1	10.6	-	-	-	-	-	-	5	56.9	8	96.3
C	3	42.6	1	14.0	2	21.4	14	182.5	2	27.8	12	138.3	34	426.6
	5	71.4	2	24.6	2	21.4	14	182.5	2	27.8	17	195.2	42	522.9
15-19,999														
SS	-	-	4	73.7	-	-	-	-	-	-	1	18.7	5	92.4
C	11	195.8	4	71.8	-	-	-	-	2	32.3	11	189.9	28	489.8
	11	195.8	8	145.5	-	-	-	-	2	32.3	12	208.6	33	582.2
20-24,999														
SS	4	90.4	2	43.4	3	73.4	2	46.9	2	45.4	4	92.1	17	391.6
C	22	468.0	5	119.4	6	145.0	-	-	5	113.7	6	131.4	44	977.5
	26	558.4	7	162.8	9	218.4	2	46.9	7	159.1	10	233.5	61	1,369.1
25-29,999														
SS	-	-	-	-	6	151.9	12	326.7	7	198.8	-	-	25	677.4
C	4	110.9	2	50.2	6	169.2	3	89.9	-	-	10	291.5	25	711.7
	4	110.9	2	50.2	12	321.1	15	416.6	7	198.8	10	291.5	50	1,389.1
30-34,999														
SS	-	-	-	-	-	-	7	220.8	7	223.5	5	168.6	19	612.9
C	1	34.3	1	32.7	5	164.0	15	486.0	6	194.1	8	256.8	36	1,167.9
	1	34.3	1	32.7	5	164.0	22	706.8	13	417.6	13	425.4	55	1,780.8
35,000+														
SS	-	-	-	-	-	-	-	-	4	151.0	5	189.4	9	340.4
C	4	191.3	1	36.5	1	35.2	2	74.4	2	94.8	15	600.7	25	1,032.9
	4	191.3	1	36.5	1	35.2	2	74.4	6	245.8	20	790.1	34	1,373.3
TOTAL FLEET														
SS	6	119.2	7	127.7	9	225.3	21	594.4	20	618.7	20	525.7	83	2,211.0
C	45	1,042.9	14	324.6	20	534.8	34	832.8	17	462.7	62	1,608.6	192	4,806.4
TOTAL	51	1,162.1	21	452.3	29	760.1	55	1,427.2	37	1,081.4	82	2,134.3	275	7,017.4

SS = vessels known to have some stainless steel cargo tanks

C = vessels with coated cargo tanks and vessels for which tank type is not known

Source: H.P. Drewry Ltd., "The Chemical Carrier Trades", London, 1983.

TABLE V.E-4

POLLUTION POTENTIAL OF MAJOR LIQUID PETROCHEMICALS

SUBSTANCE	IMO SHIP TYPE	POLLUTION CATEGORY
Acetone	-	D
Isopropylbenzene (cumene)	-	C
Ethylbenzene	-	C
Ethylene glycol	-	-
Propylene glycol	-	-
Ethylene dichloride	2	B
Perchloroethylene	-	B
Cyclohexane	-	C
Ethyl alcohol (ethanol)	-	-
Methyl alcohol (methanol)	-	-
Propyl alcohol (propanol)	-	-
Butyl alcohol (butanol)	-	-
Phenol	2	B
Styrene monomer	3	C
Dodecylbenzene	-	C
Benzene	3	C
Toluene	-	C
Xylenes	-	C

N.B. The chemicals listed above which are required to be carried in an IMO-standard ship have all been allocated to integral gravity tanks by IMO.

Source: H.P. Drewry Ltd., "The Chemical Carrier Trades", London, 1983.

V.E.3 Solid Petrochemicals

Rock salt imports, if required for VCM production, would be in bulk carriers, the size depending on route and economic considerations.

Low density and high density polyethylene, PVC and the styrene derivatives are in solid form and shipment is usually in bags. Bulk shipment is also possible but because of demand orientation of these downstream commodities, inland transportation often is of such significance that bulk exports are not justified.

TABLE V.E-5

SHIP TYPE REQUIREMENTS ACCORDING TO THE IMO BULK CHEMICALS CODE

The IMO Code lays down the constructional features for three classes of tanker, and the equipment they should carry with regard to the nature of the products involved. The three IMO Ship Types are related to the hazards of the various chemicals covered by the Code. Each Ship Type is defined by the ability of a ship to survive to a specified degree assumed damage conditions resulting from collision or stranding. The three Ship Types established under the Code cover three degrees of physical protection. The highest level - Type 1 - is required "for substances considered to have the greatest environmental hazard", and there are reduced levels of protection - Types 2 and 3 - for substances "of progressively lesser hazard". Provision 2.2.4 of the Code, covering Ship Type requirements, is shown below (references to other paragraph numbers of the Code are omitted).

(a) Type 1 ship

(i) General

A Type 1 ship is designed to transport products which require maximum preventive measures to preclude escape of such cargo.

(ii) Ship capability

The ship should be capable of sustaining anywhere in her length collision damage or stranding damage and surviving as specified.

(iii) Cargo tank location

Tanks intended for the carriage of cargoes which are required to be transported in a Type 1 ship should be located outside the extent of the damage specified and should nowhere by closer

TABLE V.E-5 (Cont'd)

to the ship's shell than 760 mm (30 inches).

(b) Type 2 ship

(i) General

A Type 2 ship is designed to transport products which require significant preventive measures to preclude the escape of such cargo.

(ii) Ship capability

(1) A ship of 150 m in length or less should be capable of sustaining collision damage or stranding damage anywhere in her length except involving either of the bulkheads bounding a machinery space located aft, and surviving as specified.

(2) A ship of more than 150 m in length should be capable of sustaining collision damage or stranding damage anywhere in her length and surviving as specified.

(iii) Cargo tank location

Tanks containing cargoes which are required to be transported in a Type 2 ship should be located outside the extent of the damage specified and should nowhere be closer to the ship's shell than 760 mm (30 inches).

(c) Type 3 ship

(i) General

A Type 3 ship is designed to carry products of sufficient hazard to require a moderate degree of containment to increase survival capability in a damaged condition.

TABLE V.E-5 (Cont'd)

(ii) Ship capability

(1) A Type 3 ship of 125 m in length and over should be capable of sustaining collision damage or stranding damage anywhere in her length except involving either of the bulkheads bounding a machinery space located aft, and surviving as specified.

(2) A Type 3 ship below 125 m in length should be capable of sustaining collision damage or stranding damage anywhere in her length and surviving as specified with the exception of damage to the machinery space. In addition to the foregoing, the ability to survive flooding of the machinery space should be determined by the Administration.

(iii) Cargo tank location

No special requirements.

In addition to these requirements the Code states that for Type 1 ships the volume of cargo carried in any one tank should not exceed 1,250 cu.m., and in Type 2 the volume of cargo in any one tank should not exceed 3,000 cu.m. (These figures for cargo quantity limitations have been agreed as "holding figures" pending a further study in depth on this subject). The IMO Code lays down additional detailed regulations for pumprooms, cargo pipes and hoses, construction materials, fire and safety precautions, tank venting systems, temperature control, electrical systems, and control and monitoring systems.

TABLE V.E-5 (Cont'd)

Cargo segregation is an important principle of the IMO Code; the regulations state that all cargo tanks should be separated from the machinery, accommodation and stores areas by a cofferdam, or a space such as a pumproom or an empty tank. In addition, cargoes which would react dangerously should be similarly separated. These cargoes should also have separate pumping and piping systems which should not pass through other cargo tanks unless encased in a tunnel. Tanks carrying reactive cargoes should have separate venting systems, and no cargo piping should pass through any machinery or accommodation spaces other than pumprooms. Accommodation should be "all aft", with no accommodation spaces permitted over the cargo tanks or pumprooms.

Source: H.P. Drewry Shipping Consultants Ltd., "The Chemical Carrier Trades", London, 1983.

TABLE V.E-6 (Cont'd)

(d) Category D - Noxious liquid substances which if discharged into the sea from tank cleaning or deballasting operations would present a recognizable hazard to either marine resources or human health or cause minimal harm to amenities or other legitimate uses of the sea and therefore require some attention in operational conditions.

Discharge of Category A substances or any ballast water, tank washings or other residues is prohibited under Regulation 5. Tank washing waters have to be discharged to shore reception facilities but remaining residues below a specified concentration may be diluted (by a volume of water of not less than 5% of the total volume of the tank) and discharged into the sea. Discharge of Category B, C and D substances and residues into the sea is permitted subject to certain provisions covering vessel speed, distance from the shore, depth of water, quantity discharged and concentration of the substances in the wake of the ship.

Special rules apply to the discharge of Category A, B and C substances, or ballast, tank washings or other residues containing these substances in designated Special Areas. These Special Areas are the Baltic Sea and the Black Sea, as defined in Annex I of MARPOL.

Regulation 7 of Annex II states that the Government of each Party to the Convention will provide reception facilities "according to the needs of ships using its ports, terminals, or repair ports as follows:

(a) cargo loading and unloading ports and terminals shall have facilities adequate for reception without undue delay to ships of such residues and mixtures containing noxious liquid

TABLE V.E-6 (Cont'd)

substances as would remain for disposal from ships carrying them as a consequence of the application of this Annex; and

(b) ship repair ports undertaking repairs to chemical tankers shall have facilities adequate for the reception of residues and mixtures containing noxious liquid substances".

Other regulations cover control measures and entries in the Cargo Record Book, surveys, the issue and duration of certificates and requirements for minimizing accidental pollution.

Source: H.P. Drewry Shipping Consultants Ltd., "The Chemical Carrier Trades", London, 1983.

TABLE V.E-6

NOXIOUS LIQUID SUBSTANCES ACCORDING TO MARPOL ANNEX II

The substances listed in Appendix II to the MARPOL Annex II regulations were categorized using a hazard rating system developed in the US by the Group of Experts on the Scientific Aspects of Marine Pollution (GESAMP). The GESAMP system divides noxious liquid substances into four categories and, based on these, Regulation 3 of Annex II sets out four pollution categories:

(a) Category A - Noxious liquid substances which if discharged into the sea from tank cleaning or deballasting operations would present a major hazard to either marine resources or human health or cause serious harm to amenities or other legitimate uses of the sea and therefore justify the application of stringent anti-pollution measures.

(b) Category B - Noxious liquid substances which if discharged into the sea from tank cleaning or deballasting operations would present a hazard to either marine resources or human health or cause harm to amenities or other legitimate uses of the sea and therefore justify the application of spacial anti-pollution measures.

(c) Category C - Noxious liquid substances which if discharged into the sea from tank cleaning or deballasting operations would present a minor hazard to either marine resources or human health or cause minor harm to amenities or other legitimate uses of the sea and therefore require special operational conditions.

V.F Petrochemical Plant Descriptions

V.F.1 Triunfo Ethylene Plant

Plant location: part of an olefins/aromatics petrochemical complex at Triunfo, Brazil.

Startup: 1980

Feedstock: heavy naptha and LPG

Ethylene output: 480,000 tons of polymer grade ethylene per year

Ethylene coproducts:

polymer grade propylene	120,000 ton/year
chemical grade propylene	66,500 ton/year
polymer grade butadiene	67,500 ton/year

Aromatics products:

high purity benzene	150,000 ton/year
nitration grade toluene	60,000 ton/year
solvent grade xylene	42,500 ton/year

Ethylene layout: Figure V.F-1

Design factors:

1. site is an isolated new industrial area without neighboring plants for temporary olefins supplies.
2. energy supply to the complex is based mainly on coal-fired boilers.
3. twin compressor lines were selected for cracked gas and refrigeration compressors.
4. steam is exported to downstream units.
5. the complex is self-sufficient in electricity.

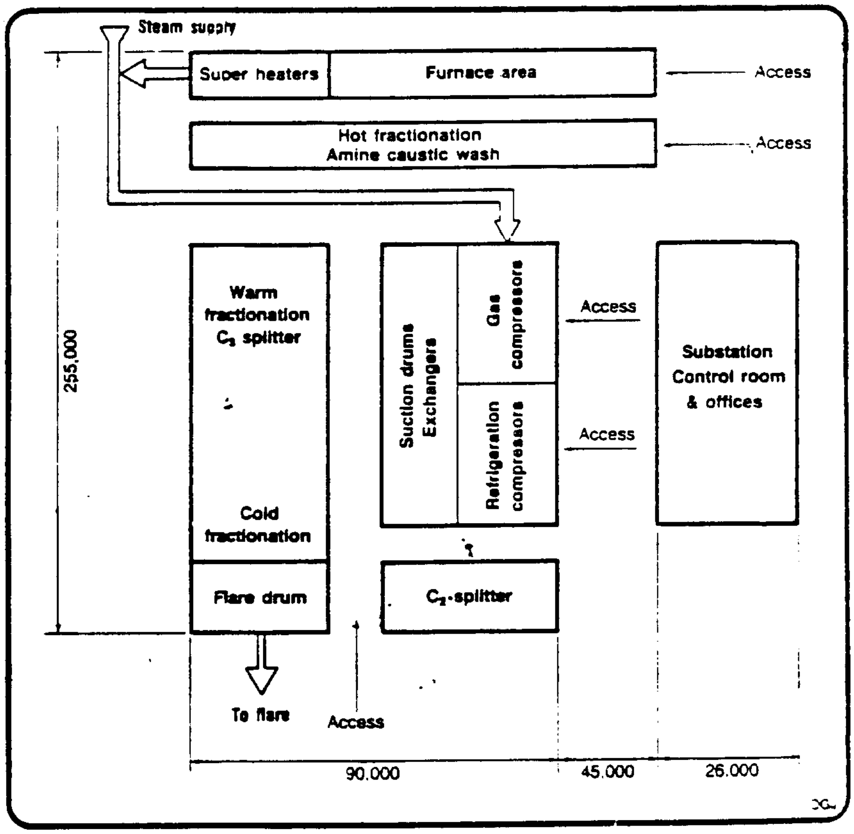


FIGURE V.F-1

TRIUNFO PLOT PLAN

Source: Kaiser, V., Oil and Gas Journal, September 26, 1983.

Storage: above ground tanks at atmospheric pressure.

Offsite storage for the following:

ethylene	2 x 20,000 m^3
propylene (spheres)	3 x 3,200 m^3
butadiene (spheres)	3 x 3,200 m^3
LPG (spheres)	3 x 3,200 and 2 x 1600 m^3
naptha	3 x 31000 m^3

Main boilers: 3 x 280 ton/hr

Alternators: 2 x 15 MV

Cooling towers: 35,000 m^3/hr

Turbines:

pyrolysis gas	2 x 15,673 KW
alternators	2 x 15,673 KW
propylene refrigerant	2 x 15,686 KW
ethylene refrigerant	2 x 2,920 KW

V.F.2 Priolo Olefin Plant

Figure V.F-2 shows the plot plan for an olefin plant producing 600,000 tons/year of polymer grade ethylene from full range naptha or from gas oil. As shown, there are 12 cracking furnaces for production of pyrolysis gas. Each furnace has a capacity of 70,000 ton/year ethylene. Ten are operated at any one time, one is available as a spare, and one is normally undergoing cleaning work. In addition to ethylene (600,000 tons/year), the unit shown

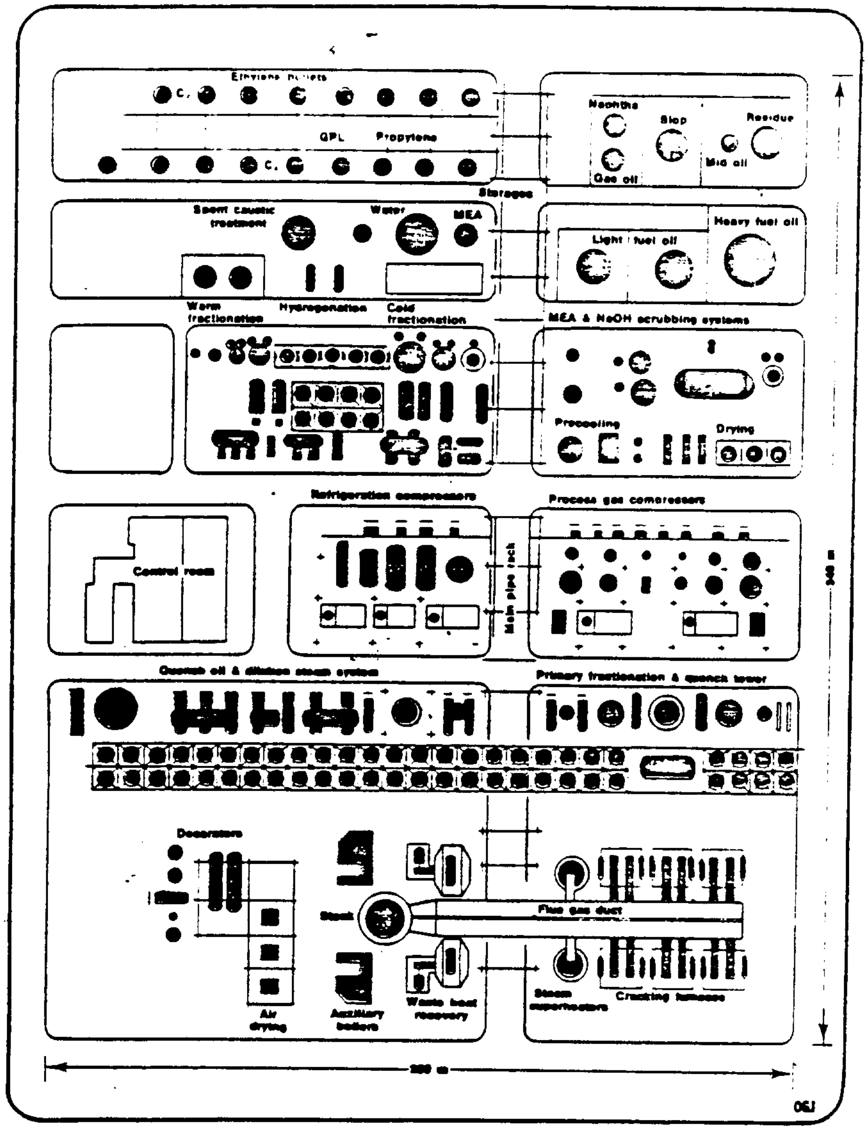


FIGURE V.F-2

PRIOLO PLOT PLAN

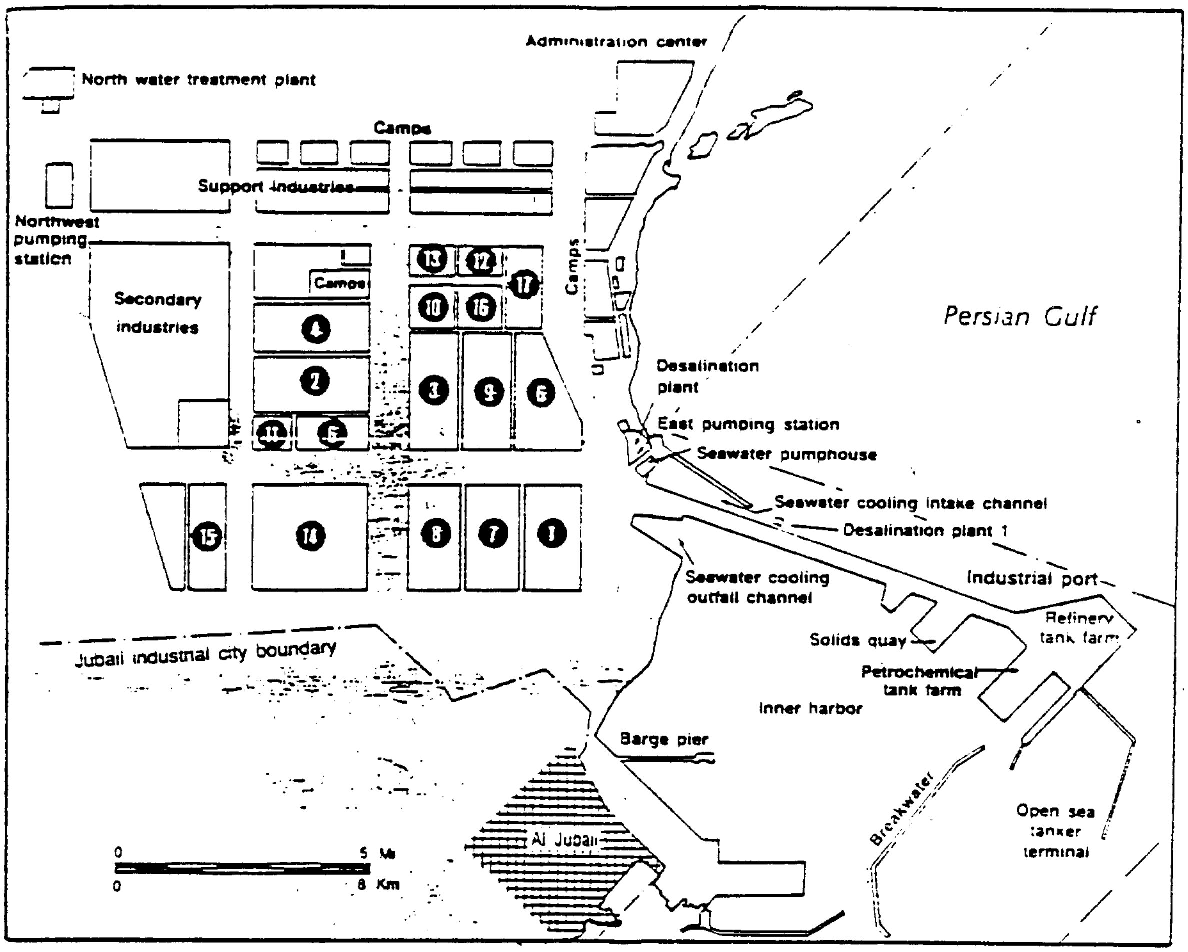
Source: Wett, T., Oil and Gas Journal, April 14, 1980.

produces 350,000 tons/year of propylene and 750,000 tons/year of butadiene, gasoline, and fuel oil. Besides naptha and gas oil, it can crack LPG if required. Total area utilization for this unit is 8.5 hectares.

V.F.3 Jubail Industrial Port

A cluster of very large petrochemical plants provides the nucleus of the industrial zone in Saudi Arabia's new industrial port city, Jubail. As shown in Figure V.F-3, four new petrochemical complexes in addition to two fertilizer plants and two methanol plants are included in the development. The primary raw material for these plants is associated gas (previously flared off) collected and piped from the country's southern oil fields.

The largest of the Saudi petrochemical plants will cost about $3 billion and is scheduled to start production in 1985. This plant alone will produce over 1.5 million tons of basic petrochemicals annually. The plant processing equipment, utilities, and offsite facilities are being prefabricated and assembled in Japan as modules for shipment to the plant site.



Legend

	Designation	Joint venture and name	Nominal capacity	Major products
	Petromin (General Petroleum and Minerals Organization)			
1	Refinery I	Shell, The Hague	250,000 b/sd	Fuel oil, naphtha, kerosine, chemical gas oil, diesel, LPG benzene
2	Refinery II	Delayed to fourth Five year plan	250,000 b/sd	Diesel, chemical gas oils, kerosine, heavy and light fuel oils, naphtha, LPG
3	Refinery III	Chevron/Texaco	76,000 b/sd	12,000 b/d lube oil stock, wax, bunker fuel, asphalt
4	Bulk plant	Petmark	1,050,000 tons/year	Sale of bunkering fuel and diesels, gasoline, and jet fuel
5	Sulfur prilling and export (Site not designated)	Aramco (built and operated for Petromin)	1,500,000 tons/year	Prilled sulfur
	Sabic (Saudi Basic Industries Corp.)			
6	Petrochem I	Shell U.S.A. Saudi Petrochemical Co. (Sadaf)	1,800,000 tons/year	Caustic soda, crude ethanol, ethylene dichloride, styrene ethylene
7	Petrochem II	Dow Europe Arabian Petrochemical Co. (Petrokemya)	700,000 tons/year	High and low density polyethylene
8	Petrochem III	Exxon Al-Jubail Petrochemical Co. (Kemya)	272,000 tons/year	Low density polyethylene
9	Petrochem IV	Mitsubishi Petrochemical Co. Eastern Petrochemical Co. (Sharq)	450,000 tons/year	Ethylene, glycols, low density polyethylenes
10	Methanol I	Celanese/Texas Eastern National Methanol Co.	630,000 tons/year	Methanol (Future, vinyl acetate, acetic acid, and ethylene glycols)
11	Methanol II	Mitsubishi Gas Chemical/C. Itoh Saudi Methanol Co. (Samco)	600,000 tons/year	Methanol
12	Fertilizer I	Delayed to fourth Five year plan	580,000 tons/year	Urea
13	Fertilizer II	Taiwan Fertilizer Co. Al-Jubail Fertilizer Co. (Samad)	500,000 tons/year	Urea
14	DRI/steel and rolling mill	Korf-stahl G.m.b.H. Saudi Iron & Steel Co. (Hadeed)	850,000 tons/year (Future 4,200,000 tons/year)	Steel billets (possibly sponge iron)
			800,000 tons/year	Bar and wire rod mill (Future light shapes)
15	Aluminum	Delayed	210,000 tons/year	Aluminum billets
16	Petroprotein	Delayed	50,000 tons/year	Petroprotein powder
17	Polyisoprene	Delayed	40,000 tons/year	Polyisoprene (or polybutadiene)

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FIGURE V.F-3

PETROCHEMICAL AND OTHER PLANTS AT THE JUBAIL INDUSTRIAL PORT

Source: Oil and Gas Journal, April 12, 1982.

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VI

PAPER

VI.A Data Sheet

VI.A.1 General

A great number of products are produced by the paper industry. These products may be divided into two basic categories: "paper" and "paperboard". Paperboard is generally thicker and heavier than paper, and is used almost exclusively in the construction and packaging industry. Papers are further classified by function into three broad groups: "cultural" papers, which include newsprint, magazine, book and other printing and writing papers; "industrial" papers including wrapping, sack and bag papers, and other special products such as fruit and plant containers; and tissue, towel and similar creped papers.

The principal material from which the various paper products are manufactured is cellulose fibers coming usually from wood. Two kinds of wood species are used in paper manufacture: softwoods (conifers) such as spruce, pine, balsam and hemlock which are characterized by long fibers and are used for the production of strong paper; and hardwoods (broadleaved) such as beech, birch, poplar, eucalypts, etc., which have shorter fibers and lead to weak but smooth papers. Wood residues from sawmilling and other forest industries, and sometimes sawdust, may also be used by some paper manufacturing processes.

Non-wood fibrous materials are also used to a small extent, especially in the developing countries with limited forest resources. Materials included in this group are bamboo; agricultural residues such as sugarcane bagasse and straws; reeds like papyrus and flax; rags and cotton linters; and various grasses. About 25% of the world's production of paper and paperboard comes from collected wastepaper mainly in the developed countries.

The paper manufacturing process involves the following two major steps, which may, but need not be, integrated at the same plant.

(1) Pulp formation. The fibrous raw materials are disintegrated and result in the formation of pulp, a dilute suspension of separated fibers in water. Pulping is accomplished by the treatment of raw materials mechanically, chemically or by some combination of both. Where pulp is to be used for the manufacture of the higher quality papers in which appearance is important, pulp is usually "bleached" to remove discoloring materials.

(2) Paper formation
- (i) A web of entangled fibers is formed by pouring the pulp on a screen.
- (ii) A sheet of paper is formed by pressing and drying the web.

VI.A.2 Pulping Processes

There are five major categories of pulping processes: mechanical, wastepaper, semichemical, chemical and dissolving. The two extremes may be represented as follows:

Pulping Processes

Mechanical processes	Hybrid processes	Chemical processes
Mechanical energy	Combination of chemical and mechanical treatments	Chemicals and heat
Little or no chemicals and heat		Little or no mechanical energy
High yield	Intermediate yields and pulp properties	Low yield
Impure fibers		Pure fibers
Poor strength		Good strength
Good printing quality		
Difficult bleaching		Easy bleaching

Source: U.N., Food and Agriculture Organization, "Guide for Planning Pulp and Paper Enterprises", Rome, 1973.

Some of these processes are allied to a preferred timber source. The typical yield of fiber is given below:

Pulping Class	Typical Processes	Yield of Fiber (%)	Preferred Wood Species
Mechanical	Stone groundwood	95-97	Conifer
	Refiner mechanical	94-95	
	Thermomechanical	92-94	
	Chemimechanical	90-92	
	Chemithermomechanical	90-92	
Wastepaper	Deinking	65-90	Wastepaper and kraft waste
Semichemical	Cold Soda	80	Hardwood
	Neutral-Sulphite-Semi-Chemical (NSSC)	60-85	
Chemical	Sulphate (Kraft)	40-50	Almost any
	Sulphite	50-75	
Dissolving	Sulphite prehydrolyzed sulphate Sirola	33-43	Almost any

It can be seen that mechanical processes have the highest yields but have a preference for conifers. Chemical and dissolving processes can, in general, use any species, although some processes do have preferred species. Sulphate (kraft) is the major chemical process. The minimum economical size of a kraft mill is about 800 air dry tons/day (ADT/d) requiring 1 MT of wood annually but it also requires expensive pollution control facilities to dispose of wastes and recycle chemicals. Thus kraft processes may no longer be economical for modest production levels.

The following data apply to a non-integrated stone groundwood pulp mill producing 100 ADT/d of newsprint-grade pulp, per ton of product:

Wood	2.33 m^3/t
Electricity for grinding	1000 kWh/t
Electricity for screening, drying	500 kWh/t
Water	10-15 m^3/t

A refiner mechanical pulp mill may require about 50% more electrical energy (up to 2,200 kWh/t).

The requirements for a thermomechanical pulp mill, producing 300 ADT/d of pulp, per ton of output are:

Woodchips	2t
Electricity	2000 kWh/t
Power (load)	100 kW
Natural gas for flash drying	3.2 M BTU
Water	12.7 t
Site area (for 300 ADT/d)	16 ha
Manpower (for 300 ADT/d)	100

Chemical pulps are nearly energy self-sufficient, but require very large quantities of water, a factor of major significance in siting a chemical pulp mill. The water requirements of a large bleached kraft pulp mill are in the range of 150 to 200 cubic meters per ton.

Chemical pulp mills are heavy environmental pollutants, mainly because of gaseous and liquid effluents. Sulphur compounds and dust are the major gaseous emissions, while total suspended solids (TSS), biochemical oxygen demand (BOD), and color are the principal parameters for liquid effluents. Recycling and reusing most of the process waters and chemicals, neutralization, settling basins and biological treatment can greatly reduce the environmental impacts. Mechanical pulp mills are characterized by nil air pollution and low water pollution potential.

VI.A.3 Paper-making

At the paper mill the dried pulp is broken up in a hydrapulper, which is a wet process, and is then dispersed in a beating and refinery process. Next come various additives, such as china clay, whiting, rosin (preferably mixed with alum) and other chemical retention aids (to keep the other additives to the fibers after drying). Pigments such as titanum oxide as whitener are also added.

The most common paper-making machine is the Fourdrinier machine. Pulp, containing 99% moisture, emerges as finished paper with about 5-10% moisture a few seconds later. Paper mill requirements vary widely depending on the types of paper produced, the kinds of pulp used, and the degree of integration with pulp mills. The industry is moving towards higher integration between paper and pulp mills.

VI.A.4 Transport

Pulpwood logs, wood chips, pulp and the various paper products are the paper-related commodities which enter the international trade. More than 67% of the traded commodities is in processed form, as process industries tend to be located at or near the main production centers in order to produce a higher-value, more economically transportable product.

Pulpwood logs can be carried as part-cargo by any geared general cargo vessel or bulk carrier. Smaller 'tweendeckers, general purpose bulkers, etc., have gradually given way to the more efficient, more sophisticated, purpose-built specialized "lumber carriers", which are modern bulk carriers with good gear, good cargo access and high deck strength intended to carry packaged or unitized products in the holds and on deck. Ships used for log shipments vary in size from small to medium, depending on the trade route. In general, the major requirement worldwide is for the handy-size ships of 20-35,000 DWT. On the longest deep-sea trades, vessels of up to 45,000 DWT are used.

Specialized bulk carriers are used for the transport of wood chips, as they have a very high stowage factor (100-110 cu ft/long ton). The freeboard of chip carriers generally exceeds that of conventional bulk carriers by over 50%, and their cubic capacity is greater by a similar margin. These vessels are usually equipped with high-capacity belt conveyors and pneumatic trimmers, and can achieve loading rates in excess of 500 tons/hour (discharging rates may be over 300 tons/hour). About two-thirds of the chip carrier fleet consists of medium-sized vessels of 35-50,000 DWT, and larger, "Panamax" vessels in the 50-60,000 DWT range.

Pulp is commonly shipped in bales, and paper in rolls. Unitization has developed and there are many configurations in use today. Pulp and paper products enable high handling rates by consolidating between 15 and 25 tons per lift. The small size of consignments restricts the employment of larger bulk carrier tonnage. Pulp and paper products are shipped as part-cargoes in the smaller 15-20,000 DWT bulkers, and the specialized, geared, open-hatch vessels of 20-35,000 DWT. In some trades (mainly from North America to Europe) other ship types such as containerships, roll-on roll-off (ro-ro) vessels, and barge carriers (LASH vessels) have been used.

VI.B Paper Manufacture

The principal material from which the various paper products are manufactured is cellulose fibers coming usually from wood. However, various non-wood fibrous materials are also used. Higher paper grades use cotton linters or rags as input, while cheaper grades reuse printed matter. Other fiber sources include various grasses, plants and agricultural by-products as sugarcane bagasse.

Cellulose fibers comprise approximately 40 to 50 percent of the dry weight of wood as well as of non-wood plants. The other major components of fibrous materials are the hemicelluloses and lignin which cement the fibers together. The dimensions of cellulose fibers play an important role in determining the quality of the paper produced from a given species of wood or annual plant.

In addition to the above fibrous materials, a variety of non-fibrous raw materials are required for any paper enterprise. The most important are water, fuel, power, and various chemical additives depending on the particular manufacturing process used.

The paper manufacturing process involves the following two major steps:

(1) Pulp formation. The fibrous raw materials are disintegrated and result in the formation of pulp, a dilute suspension of separated fibers in water. Pulping is accomplished by the treatment of raw materials mechanically, chemically or by some combination of both. Where pulp is to be used for the manufacture of the higher quality papers in which appearance is

important, pulp is usually "bleached" to remove discoloring materials.

(2) Paper formation

- (i) A web of entangled fibers is formed by pouring the pulp on a screen.
- (ii) A sheet of paper is formed by pressing and drying the web.

In the next two sections, the types of the end product (paper and paperboard) as well as the kinds of the fibrous raw materials used will be shortly presented before describing the production processes, as both of these factors play an important role in selecting the proper manufacturing process.

VI.B.1 Classification of Papers

Although the pulp and paper industry has access to a relatively limited number of basic fiber types and manufacturing processes, it can nevertheless produce an enormous range of products. This is accomplished by varying the blends of fibers and other additives, the treatment of the fibers in the preparation stage, and the method used to form the sheet on the paper machine. Because of the large number of paper grades made, it is difficult to group and present the grade structure in a brief and concise table. A breakdown effort is presented in Table VI.B-1, together with the U.S. production output of years 1970 and 1980.

In Table VI.B-1, the initial division is made on the basis of the weight of the product, calling the two categories thus distinguished "paper" and "paperboard". There is no precise definition, in quantitative terms, to indicate the line of demarcation between paper and paperboard but, in general,

TABLE VI.B-1

U.S. PRODUCTION OF PAPER AND PAPERBOARD BY GRADE

Type of grade	**1980[p]** (1,000 short tons)	**1970** (1,000 short tons)
PAPER, TOTAL	**29,654**	**23,625**
Printing and writing papers, total	**20,038**	**14,418**
Newsprint	4,545	3,345
Groundwood paper, uncoated, total[1]	1,436	1,215
Publication and printing	1,193	1,070
Other converting and miscellaneous groundwood paper	243	144
Coated printing and converting paper, total[1]	4,749	3,279
Coated one side	481	403
Coated two sides	4,268	2,875
Book paper, uncoated, total[1]	3,903	2,646
Publication and printing	2,269	1,650
Body stock for coating	1,634	24
Other converting and miscellaneous book paper		972
Bleached bristols (excluding cotton fibers), total	971	997
Tabulating card, tag and file folder	472	771
Other bristols	499	226
Writing and related papers, not elsewhere classified, total	4,434	2,937
Writing paper, total	3,798	2,456
Chemical woodpulp	3,674	2,338
Cotton fiber	124	118
Cover and text papers	290	193
Thin paper	345	288
Packaging and industrial converting paper, total	**5,382**	**5,439**
Wrapping paper, total	257	518
Unbleached kraft	141	298
Other	116	220
Shipping sack paper, total	1,134	1,094
Unbleached kraft	1,050	996
Other[2]	84	98
Bag and other sack paper, total	2,313	2,117
Unbleached kraft	2,078	1,898
Other	235	219
Other converting paper, total	915	1,088
Unbleached kraft	434	596
Other	482	492
Glassine, greaseproof and vegetable parchment	262	203
Special industrial paper	488	421
Tissue and other creped paper, total	**4,234**	**3,768**
Sanitary paper, total	4,074	3,548
Toilet tissue	1,555	1,343
Toweling	1,368	1,185
Facial tissue	369	375
Napkin	483	374
Other sanitary stock[3]	298	272
Tissue paper (except sanitary and thin)	160	220

continued on next page

TABLE VI.B-1 (Cont'd)

Type of grade	**1980[p]** (1,000 short tons)	**1970**
PAPERBOARD, TOTAL	**30,861**	**25,477**
Linerboard, total	n.a.	11,436
Unbleached kraft[4]	14,275	10,982
Bleached[4]	(d)	133
Combination furnish[5]	523	321
Corrugating medium, total	n.a.	n.a.
Unbleached kraft[4]	(d)	(d)
Semichemical[4] [6]	4,538	3,416
Combination furnish[5]	1,305	916
Folding carton type paperboard, total[4]	n.a.	n.a.
Unbleached kraft	(d)	(d)
Bleached	2,063	1,395
Tube, can and drum paperboard, total[4]	n.a.	n.a.
Unbleached kraft	207	194
Bleached	(7)	(7)
Other unbleached kraft paperboard[4]	(d)	(7)
Other bleached paperboard, total[4]	1,747	1,856
Milk carton paperboard	1,011	971
Heavyweight cup stock	387	369
Plate, dish and food serving stock	224	317
Bleached paperboard, not elsewhere classified[8]	116	199
Container chip and filler paperboard[5]	264	285
Combination bending board[5]	2,261	2,727
Combination nonbending board[5]	471	1,042
Special combination paperboard[5]	2,174	1,739
Wet machine board	**137**	**139**
Construction paper and board, total	**4,122**	**4,278**
Construction paper	1,399	1,594
Construction board, total	2,723	2,682
Insulating board	934	1,219
Hardboard	1,788	1,463
ALL GRADES, TOTAL	**64,774**	**53,516**

[p] = projected d = withheld to avoid disclosing figures for individual companies

[1] Includes off-machine coated paper produced at mills having primary production facilities. To avoid duplication, off-machine stock is excluded from uncoated groundwood or uncoated book paper, and papers coated at establishments without papermaking facilities are excluded from the coated paper data.

[2] Includes combination kraft and rope bleached and semibleached.

[3] Includes sanitary napkin stock, wadding and wiper stock.

[4] Manufactured with a solid woodpulp furnish.

[5] Manufactured with a combination furnish of woodpulp and paperstock, jute or other fibrous material.

[6] Includes small quantities of other semichemical paperboard.

[7] Bleached tube, can and drum paperboard is included with "Bleached paperboard, not elsewhere classified."

[8] Includes other bleached paperboard for food and miscellaneous packaging; other solid bleached board; and bleached tube, can and drum paperboard.

Source: Kline, J.E., "Paper and Paperboard. Manufacturing and Converting Fundamentals", Miller Freeman Publications Inc., San Francisco, 1982.

a paperboard differs from a paper in two important respects: (a) paperboard is generally thicker and heavier per square meter than paper; and (b) with few exceptions, paperboard is used almost exclusively in the construction and packaging industry.

Papers are further classified by function into three broad groups: "cultural" papers, which include newsprint, magazine, book and other printing and writing papers; "industrial" papers including wrapping, sack and bag papers, as well as special moulded pulp products such as fruit and plant containers; and tissue, towel and similar creped papers. For some grades further distinctions are made on the basis of production process and basic raw materials used.

Paper and paperboard products are characterized by a great number of properties, related to their manufacture and use. These properties are usually grouped into four categories: (a) structural properties such as weight, thickness, volume, density and moisture content; (b) strength properties such as tearing resistance, extensibility, and tensile, mullen and fold strength; (c) optical properties such as color, whiteness, brightness, opacity and ligth reflectance (gloss); and (d) water sensitivity properties such as dimensional stability, curl, water repellency and loss of strength in water contact.

VI.B.2 Fibrous Raw Materials Used in Paper Manufacture*

More than 99.5% of pulp and paper products are produced from the pulp of natural fibrous stems. About 75% of the pulp requirements is virgin pulp produced from wood or non-wood fiber sources, while the remaining 25% is manufactured from recycled material. However, in countries with minimal

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Source: U.N., Food and Agriculture Organization, "Guide for Planning Pulp and Paper Enterprises", Rome, 1973.

forest resources, the percentage of the pulp produced from recycled paper may be as high as 55% of the total pulp production.

The manufacture of virgin pulp is a large-scale international business, with about 70 nations producing approximately 120 million tons each year. The leading pulp producers are the U.S.A., with about 35% of the world's production, and Canada with about 10%. They are followed by the U.S.S.R., Japan, Sweden, Finland, China and Brazil. Approximately 20% of the world's virgin pulp is produced in Asia, South America and Africa, and this proportion is increasing.

Wood is used to produce about 94% of virgin pulp, while non-wood sources are also important, particularly in developing countries, accounting for the remaining 6% of the world's virgin pulp production.

VI.B.2.1 Wood

A great variety of wood species is used satisfactorily in pulp and paper manufacture. Each has its own characteristics, the advantages or disadvantages being largely relative. Fiber length is the most important characteristic of the pulpwood, as longer fibers result in stronger papers. In addition, wood density (that is, the dry fiber weight per unit of green volume), the average tree dimensions, bark volume and other physical characteristics have an important effect on raw material costs. The chemical composition and pulping characteristics determine also the yield of pulp or paper based on wood supply, and affect the annual wood volume requirement. They also affect all other manufacturing costs.

The four major wood supply sources for pulp and paper-making are: (a) natural stands of softwoods (conifers); (b) temperate and tropical hardwoods; (c) plantations; and (d) wood residues from sawmill operations.

VI.B.2.1.a Softwood

Northern conifers, especially spruce (Picea spp.), pine (Pinus spp.), balsam or fir (Abies spp.), and hemlock (Tsuga spp.), are historically preferred by the paper industry. They are characterized by occurrence in natural forests in dense, relatively pure stands, making for economical harvesting, by long fibers which lead to easy processing and strong paper, and by physical characteristics such as density, bark volume and tree size and shape with which the foresters and engineers could cope. In consequence, much procurement practice and most of the wood harvesting, transporting, barking, chipping, digesting and pulp-treating equipment have been designed and have evolved specifically to process these woods and woods with similar characteristics. The average fiber length of the coniferous species is about 3.5 millimeters with relatively little variation, except for a few species with unusually long fibers. The coniferous woods may be pulped by any of the known processes (refer to Section VI.B.3.2). The world's main coniferous forests are found in the U.S.S.R., North America and in Northern Europe.

High-quality packaging papers and paperboards, such as multiwall sack paper, wrapping papers and linerboards for the manufacture of corrugated containers, require high strength because of the rough treatment which they receive in use. Such products usually contain a substantial proportion of long-fiber softwood pulp because of the important role which fiber length plays in providing sheet strength.

VI.B.2.1.b Hardwood

For many years the hardwoods were not highly regarded as raw materials for pulp, due in large measure to the shortness of their fibers, but hardwood pulps are now becoming increasingly important in the paper industry. The fiber length of the useful hardwood species is about 1.2 millimeters on average, the range being from 0.7 to 1.8 millimeters.

Many grades of paper do not require the high strength characteristics for their end-use applications, and to these grades hardwood pulps bring other desirable characteristics. Smoothness, opacity and evenness of sheet formation are important in the printing and writing papers and hardwood pulps offer definite advantages in attaining these characteristics. In many areas in the world where the market is prepared to compromise with reduced strength in paper and paperboard employed for packaging purposes, appreciable amounts of hardwood pulp can be used in the manufacture of these grades, but in most products some proportion of long-fiber pulp is used to attain minimal strength requirements. Thus, hardwood pulp can be used to make most grades of printing and writing papers and tissue, with supplementation of 20 to 35% of long-fiber pulp, or often even less, while linerboard, wrapping and multiwall bag paper may have up to 50% of short-fiber pulp.

The use of hardwoods has both positive and negative effects on wood costs. The higher density usually results in lower cost per unit weight when wood procurement is by volume, and also in a requirement of less digester space for a given pulp-making capacity or, conversely, a higher pulp production from available digester space. Lignin content, the least desirable major constituent of the wood, is generally much less in the hardwoods commonly used for pulping and this results in less chemical and steam consumption in pulping these woods than in pulping softwoods. On the other hand, hardwood pulps are slow-draining and weak, requiring larger washing and sheet-forming equipment. Furthermore hardwood pulping requires more purchased fuel, as less steam and power can be generated than for softwood due to reduced wood solids in the spent pulping liquors.

The hardwood trees most in use include beech (Fagus spp.), birch (Betula spp.), the poplar-aspen-cottonwood family (Populus spp.), the gums (Liquidambar spp. and Nyssa spp.), the eucalypts (Eucalyptus spp.), maple (Acer spp.), oak (Quercus spp.), elm (Ulmus spp.), ash (Fraxinus spp.), alder (Alnus rubra) and wattle (Acacia spp.). Many tropical hardwoods are also employed, such as gewa (Excoecaria agallocha) and many local hardwoods near mill sites in India, Pakistan, Colombia and Brazil. In general, hardwood forests can be found in all temperate and tropical areas such as Southern U.S.A., Central and South Europe, Latin and South America, Africa, Far East, Australia and other Pacific regions.

Utilization of natural forests of tropical hardwoods is of great importance, especially in developing countries. However, these forests often contain a great variety of species, with a wide range of wood density and other properties, and some of them do not pulp by the common processes.

Hardwoods (with the exception of some tropical species) may be used in the chemical* and dissolving pulping processes, as these methods can pulp

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*The pulping processes are described in Section VI.B.3.2.

almost any wood species. For chemimechanical and semichemical pulps hardwoods are preferred, basically because these pulps are used primarily in the manufacture of newsprint and other cultural papers. Neutral sulphite semichemical (NSSC) pulps are made predominantly for corrugating medium and, for this purpose, hardwoods are again preferred. However, the pulping of hardwood by mechanical processes is not commonly employed, since the cellulose fibers of hardwoods are short, and are further shortened in the very harsh grinding process. In the last years, a penetration of hardwoods in the traditionally softwood-using mechanical processes has occurred, especially in areas where resources of long-fiber wood are not available.

VI.B.2.1.c Plantation Wood

Despite the fact that plantation requires both an initial investment, and a lengthy gestation period awaiting returns, significant developments in wood pulp production are based on plantation sources of fibrous raw material. In the colder zones, the essential conifers planted are various species of spruce, pine and hemlock, while in the warmer zones the conifer plantations almost exclusively consist of some pine species. The principal hardwoods planted are the eucalypts and poplars.

Where intensive plantation forestry of suitable species is practised, the results are a homogeneous raw material, high yields per hectare and short rotations. The rates of growth vary enormously according to species, site, rainfall, temperature, length of growing season, and other factors. In very broad terms, conifers in the north temperate zones and in some Mediterranean countries have a mean annual increment of 2 to 5 cubic meters per hectare, and under exceptionally favorable circumstances, 10 to 20 cu m per hectare. In the tropics and subtropics, 15 to 20 cu m/ha is representative. The fastest-growing hardwoods, such as eucalypts and poplars, produce annual increments of 20 to 30 cu m/ha.

For pulpwood, rotations of 12 to 15 years for coniferous species and of 5 to 10 years for broadleaved species are common in the tropics and subtropics, and between 20 to 30 years for conifers and 8 to 15 for broadleaved species in the temperate zones.

VI.B.2.1.d Wood Residues

The utilization of wood residues from sawmilling and other forest industries in pulp-making is of great importance. In 1970, in both the United States and Canada, about 28% of the total wood requirements for pulp production came from wood residues.

The utilization of chips gives rise to certain problems, including the provision of barking and chipping equipment at sawmills, transportation arrangements, and deterioration and loss of wood substance in storage. However, the development of central slashing plants for barking and sorting of wood for various forest industries, the construction of specialized ocean-going "chip carriers", and better inventory control to avoid prolonged storage periods have improved the economy of chip use.

The introduction of greater mechanization in the forests, including barking and chipping equipment, has provided the opportunity for making wider use of logging residues and natural forest thinnings, since they represent a significant volume of fibrous raw material. Furthermore, the successful large-scale manufacture of refiner mechanical pulp from sawdust has added yet another possibility to industrial waste utilization.

VI.B.2.2 Non-wood Plants

All plant material contains cellulose and a number of non-wood plants have proven satisfactory for the establishment of economic pulp and paper mills. Included in this group are bamboo; agricultural residues such as sugarcane bagasse and straws; reeds like papyrus and flax; rags and cotton linters; and grasses like esparto and sabai grass. Table VI.B-2 shows a list of agricultural residues and crops considered suitable for paper manufacture.

About 6% of the world's virgin pulp production is based on these materials. This low percentage is not the result of unsuitability or inferiority of the fibrous material, but can be attributed to the limited supplies and the economics of production.

VI.B.2.3 Wastepaper

Annual world consumption of wastepaper in the manufacture of paper and paperboard is estimated to be about 25% of all fibrous raw material. Wastepaper is assuming added importance as new or virgin fiber becomes more costly and as public opinion shows increasing concern over waste and ecological contamination. Many countries have developed highly organized collection systems for reclaiming wastepaper for fiber reuse. The recovery rate, which is the ratio of the volume of wastepaper collected to the total consumption of paper and paperboard, and the use of wastepaper in the OECD countries, in 1978, are shown in Figure VI.B-1. The United Kingdom heads the list with more than 50% of the fiber furnish from wastepaper.

TABLE VI.B-2

AGRICULTURAL RESIDUES AND CROPS CONSIDERED SUITABLE FOR PAPER MANUFACTURE

Residue or crop	*Paper grade*
Bagasse	Newsprint, writing and printing papers, kraft grades, brown board and other types of board
Straw (wheat, rice, barley, oats)	Writing and printing papers, liner board, corrugating medium and other types of board
Maize stalks	Liner board, corrugating medium and other types of board
Sisal	Hard tissues, cigarette tissue
Sunflower stalks	Liner board grades and corrugating medium
Cotton stalk	Corrugating medium
Date palm leaves	Brown board, bag paper
Banana stems	Hard tissues, speciality grades
Pineapple leaves	Liner board and corrugating medium
Common hemp *(Cannabis sativa)*	Hard tissues, cigarette paper, speciality grades
Sorghum *(Sorghum vulgare)*	Liner board corrugating medium and other types of board
Sun hemp *(Crotalaria junicea)*	Hard tissues, cigarette papers, speciality grades

Source: Jeyasingam, T., "Appropriate Technology for a Low-Cost Paper Project to Stimulate the Rural Economy", UNIDO series: Monographs on Appropriate Industrial Technology, No. 3, New York, 1979.

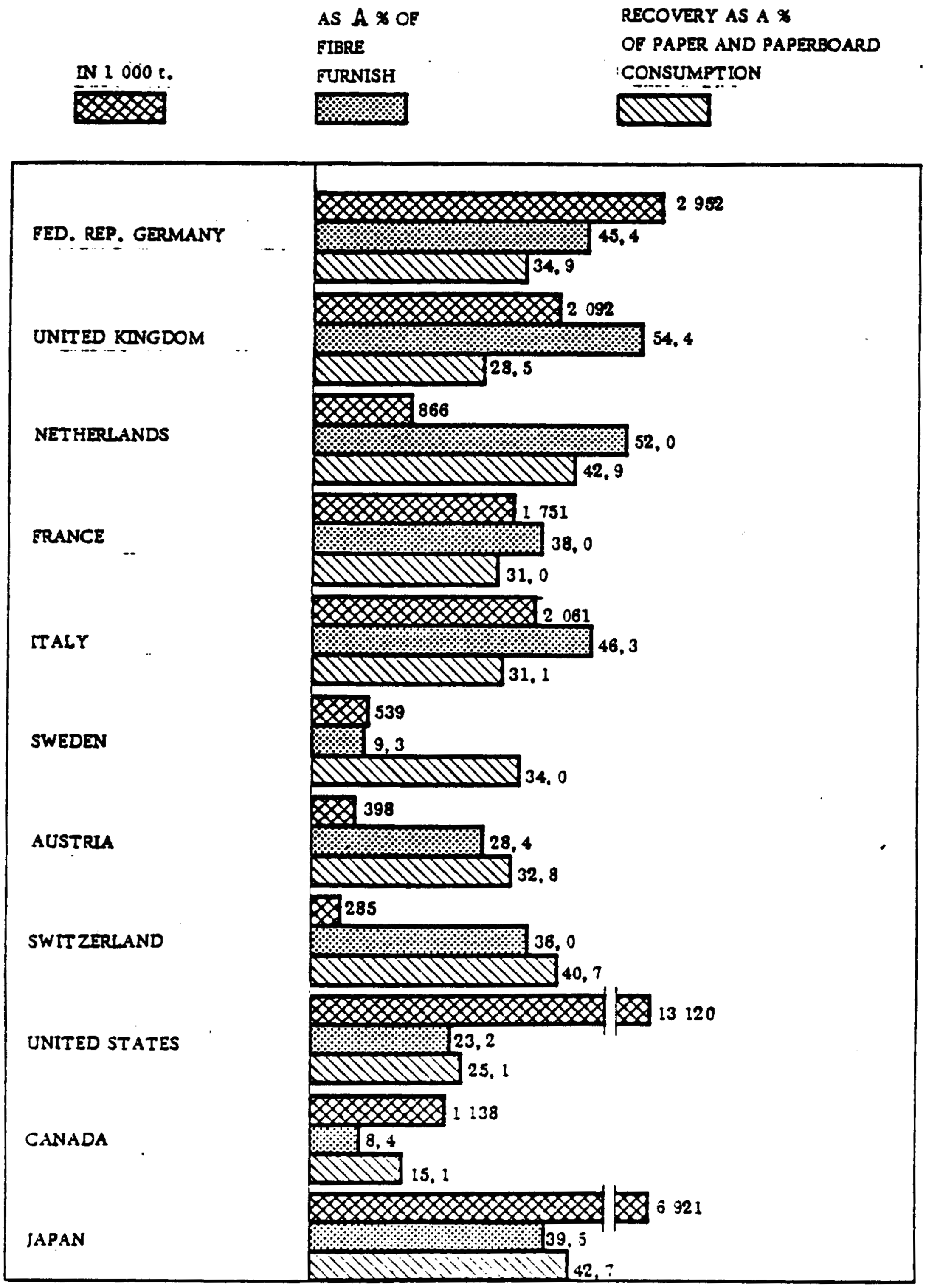

FIGURE VI.B-1

USE OF WASTEPAPER, 1978

Source: OECD, "Integration in the Pulp and Paper Industry in OECD Countries", Paris, 1982.

In the case of the developing countries, more intensive use of paper and paperboard products during their first cycle of utility, and the absence of a paper-making industry able to use wastepaper, result in low recovery rates.

Most fiber obtained from the repulping of wastepaper is not of such high quality as virgin or original fiber produced in a pulp mill, due to contamination by printing ink and impurities, and deterioration of the fiber quality in the repulping process. Nevertheless, pulp fiber obtained from wastepaper is a very satisfactory paper-making substance for certain purposes and large quantities continue to be used even in the more affluent countries having access to comparatively cheap virgin pulp supplies.

Wastepaper pulp has two main uses: the manufacture of printing and writing papers, and the manufacture of paperboard. Wrapping papers, usually coarse, are also made using reclaimed wastepaper.

VI.B.3 Manufacturing Processes*

The paper manufacturing process mainly involves the pulping of raw material inputs and the conversion of pulp to paper. A general process flow of a pulp mill is shown in Figure VI.B-2. Pulp either can be processed to paper in the same integrated mill, or can be dried, packaged and transported to a separate paper mill. Pulp can either be bleached or not, depending on the raw materials used, the desired quality of the end-products, and the kind of pulping process in use. The fibrous raw material preparation, pulping, and papermaking operations will be presented in the following sections.

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*Source: U.N., Food and Agriculture Organization, "Guide for Planning Pulp and Paper Enterprises", Rome, 1973; Gavelin, G., "Pulping Technology and Requirements and Potentialities of Developing Countries", UNIDO series: Monographs on Appropriate Industrial Technology, No. 3, New York, 1979; Kline, J.E., "Paper and Paperboard. Manufacturing and Converting Fundamentals", Miller Freeman Publications Inc., San Francisco, 1982; and various other sources.

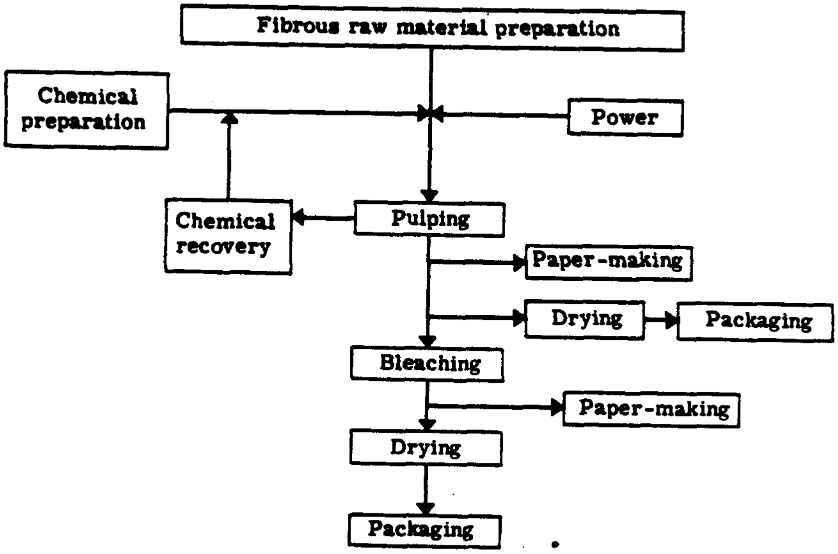

FIGURE VI.B-2

GENERAL PROCESS FLOW IN A PULP MILL

Source: U.N., Food and Agriculture Organization, "Guide for Planning Pulp and Paper Enterprises", Rome, 1973.

VI.B.3.1 Wood Handling and Preparation

There are two major alternative supplies of wood to the pulp mill: roundwood (logs) and chips, and a minor one, sawdust or other waste. Roundwood comes from foresting, while wood chips and sawdust are industrial wastes produced by sawmilling operations. Not all of these physical forms of wood can be used with every type of pulping processes. The requirements of each pulping process will be discussed in the next section.

The wood preparation stage includes some or all of the following operations: debarking, chipping, chip screening and storage. When the wood supply is in the form of roundwood, it can be stored as logs, or chipped and stored as chips. Logs are usually delivered in tree lengths, and can be stored as received or after debarking. They are either stored in piles or, in some cases, in rafts floating in the body of water adjacent to the mill.

Bark amounts to 8 to 25 percent of the volume of rough wood, and it is removed by mechanical or hydraulic action. After debarking, the bark is normally pressed to remove water and burned in auxiliary boilers for its fuel value. After bark removal, the logs are ready for storage, grinding or chipping. In chemical pulp mills, logs are reduced to chips in order to obtain rapid uniform pulping. Chips are usually 15 to 20 millimeters long and a few millimeters thick, the width being in the range of 10 to 30 millimeters. The main functional element of a chipper is a large heavy rotating steel disk on which chipping knives are mounted radially, 4 to 20 knives normally being used. Chippers of this type are the most common today but various new types exist on the market.

Chips are screened to remove undersize "fines", which merely consume chemical in the pulping operation and give low pulp yield. Oversized chips, which would not pulp properly, are also separated and pass through a re-chipper. Accepted chips are stored outside or in silos. Storage is arranged to allow segregation of wood species: hardwoods from softwoods or pine from other softwood species. This permits varying pulp products according to the mill's production program.

The difference between the receipt of logs or chips at the pulp mill is of considerable magnitude, and lies in the fact that the operations of debarking, chipping and primary chip screening have been transferred in whole or in part from the pulp mills to the sawmills or chipping plants. Many sawmills are normally required to supply one pulp mill. There are benefits both to the sawmills, which realize a significant new source of income in exchange for a relatively small capital investment, and to the pulp mill both in capital investment and in wood costs. Recently the use of sawdust has added to these benefits.

VI.B.3.2 Pulping Processes

Pulping may be defined as the separation of fibers

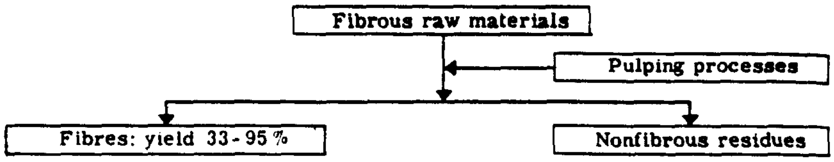

FIGURE VI.B-3

SEPARATION OF FIBERS FROM NONFIBROUS RESIDUES

Source: U.N., Food and Agriculture Organization, "Guide for Planning Pulp and Paper Enterprises", Rome, 1973.

Pulping processes involve the application of mechanical energy or chemicals or both. In Table VI.B-3, a number of representative commercial pulping processes are classified, and arranged in order of the percentage yield of useful paper-making fiber based on a given wood supply. An indication of the principal uses of these pulps is also given.

The two extremes of pulping processes may be represented as follows:

PULPING PROCESSES

Mechanical processes	*Hybrid processes*	*Chemical processes*
Mechanical energy	Combinations of chemical and mechanical treatments	Chemicals and heat
Little or no chemicals and heat		Little or no mechanical energy
High yield	Intermediate yields and pulp properties	Low yield
Impure fibres		Pure fibres
Poor strength		Good strength
Good printing quality		
Difficult bleaching		Easy bleaching

Source: U.N., Food and Agriculture Organization, "Guide for Planning Pulp and Paper Enterprises", Rome, 1973.

On a worldwide basis, approximately one-third of the paper production is from mechanical pulps and two-thirds is from chemical pulps.

VI.B.3.2.a <u>Mechanical Pulping</u>

Mechanical pulp is used in newsprint and, to some extent, in most other printing papers. It is found in many tissue products and sometimes in the center ply of paperboard.

The important market is newsprint. Newspapers are printed with an oil-based ink which is "dried" by absorption of the oil into the paper, and only mechanical pulp can give the newsprint the rapid oil absorption required.

TABLE VI.B-3 PULPING PROCESSES

Class	Mechanical	Wastepaper	Semichemical	Chemical	Dissolving
Typical processes	Stone groundwood Chip refiner groundwood Thermomechanical Chemimechanical Chemithermomechanical	Repulping wastepaper	Cold soda Neutral sulphite semichemical= NSSC	Sulphite Magnefite Sulphate (kraft) Sivola Stora Kopparberg	Sulphite prehydrolyzed sulphate Sivola
Yield of fiber (%)	90-97	65-90	60-90	43-55	33-43
Fiberizing power, (kWh per ton)	800-2200	Low	300-1400	None	None
Preferred species	Conifers (poplars, eucalypts, other hardwoods) Wood residues	Mixed wastepaper Segregated wastepaper Old corrugated boxes Kraft waste Old newspapers	Hardwoods (softwoods)	Almost any	Almost any
Pulping chemicals	None	Alkali, detergents	Sodium sulphite or Ammonium sulphite or Sodium hydroxide	Calcium, magnesium sodium or ammonium bisulphites plus Sulphurous acid or Sodium hydroxide plus Sodium sulphide	Bisulphites plus Sulphurous acid or Sodium hydroxide plus Sodium sulphide
Bleaching chemicals	None or hydrosulphite or peroxide and hydrosulphite	None or hydrosulphite	None or hypochlorite or hydrosulphite	Chlorine Sodium hydroxide and hypochlorite with or without chlorine dioxide or peroxide	Chlorine Sodium hydroxide Hypochlorite and Chlorine dioxide
Uses	Newsprint Printing papers Writing papers Tissue Creped papers Container board Moulded pulp products	Container board Paperboard Newsprint Book paper Construction paper Moulded pulp products	Newsprint Printing and writing papers Coating base Corrugating	All papers and paperboards	Textile fibers Chemicals Plastics

Source: U.N., Food and Agriculture Organization, "Guide for Planning Pulp and Paper Enterpises", Rome,1973, and various other sources.

There are five types of mechanical pulping processes:

1) Stone-ground wood pulp (GWP)
2) Refiner mechanical pulp (RMP)
3) Thermomechanical pulp (TMP)
4) Chemimechanical pulp (CMP)
5) Chemithermomechanical pulp (CTMP)

The GWP is the only pulping method which utilizes roundwood logs as fibrous raw material. It was invented in 1840, when the only alternatives were pulps from cotton and straw. Chemical pulps did not arrive until 1870. However, it was only in the 1960's that fiber morphological mechanisms were sufficiently understood to apply modern technology to the manufacture of mechanical pulp.

Shortly afterwards, interest was drawn to chip-refining processes. This change was conditioned more by scientific advances than by the obsolescence of the GWP process. All the other mechanical pulping methods are based in chip refining. However, if mechanical pulp is to be produced, the GWP process is still one of the alternatives that must be considered.

Stone-ground wood pulp (GWP)

The grinding of logs is carried out by pressing the log against the parallel cylindrical surface of a grinding stone, assisted by water showers. The roughened stone surface removes the fibers. Very large quantities of power are involved, and indeed this is in most cases the largest element of cost in groundwood manufacture in addition to the cost of the wood itself. The availability of adequate supplies of electric power at an acceptable cost is a prerequisite in planning groundwood operations.

Stone grinders are designed for continuous operation, implying that a supply of logs is always available to be held against the stone face, and that pressure of the logs against the stone is constantly maintained. Grinders come in a variety of forms. The Great Northern grinder, illustrated in Figure VI.B-4 is a typical pocket grinder. A pressure foot activated by a hydraulic cylinder holds the logs in each pocket against the stone face. Above each of the two pockets is a magazine storing enough wood to refill the pocket as required. Such an arrangement enables an operator to service more than one grinder.

GWP can be produced from poplar, aspen, some species of eucalyptus, gum and most softwoods. Dense hardwoods are not suitable, giving dark and very weak pulps. Pine with a high pitch content may give too much operating trouble although some improvement can be achieved by alkaline grinding. The wood to be ground must be available as logs, preferably green, from the forest, straight and carefully debarked. Sawmill wastes are not usable.

A 6,000 KW electrical supply and clean water to an amount of 10-15 cubic meters per ton (m^3/t) are the other requirements. The process is simple. The only work requiring specialized training is weekly sharpening of the grinding stone.

To produce one ton of GWP, 2.33 m^3 of solid debarked wood is needed. The wood yield is difficult to determine accurately, but will be in the range of 95 to 97 percent. Depending on the pulp grade made (from coarse paperboard pulp to pulp for addition to fine printing paper) the energy requirement will be 800 to 1,500 kWh/t. These two cost items are the main ones and are almost independent of plant size.

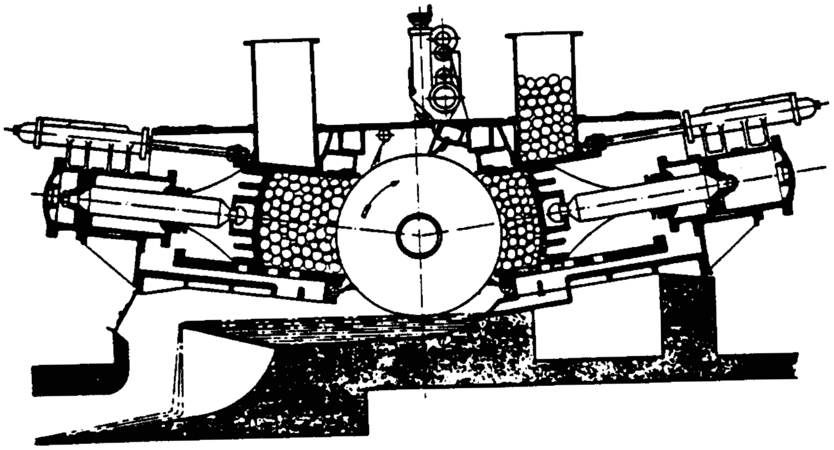

FIGURE VI.B-4

POCKET GRINDER

Source: U.N., Food and Agriculture Organization, "Guide for Planning Pulp and Paper Enterprises", Rome, 1973.

The following data apply to a non-integrated GWP mill producing 100 tons per day (t/d) of news-grade pulp, per ton of product:

Wood	2.33 m^3/t
Electricity for grinding	1000 KWh/t
Electricity for screening, drying	500 KWh/t
Water	10-15 m^3/t

Labor requirements are dependent on the size of the plant, but they are comparatively low.

<u>Refiner mechanical pulp (RMP)</u>

Refiner mechanical pulp is produced by refining wood chips in disk refiners without use of chemicals or steam. The same raw materials are used as for GWP, but the wood can arrive at the mill either as logs, which are then chipped, or as chips, sawdust and other residues from sawmills and wood-processing industries. The process flow is illustrated in Figure VI.B-5.

A chip washer is necessary to remove tramp iron and sand. Defibrizing is accomplished by the action of refiner plates fitted to two vertical disks face to face, with a small clearance between them. One of the disks may be stationary, or both disks may rotate.

The capacity of large double-disk chip refiners, with 1.2-meter (48-inch) disks, is about 50 to 150 tons per day depending on the nature of the fib being fed, and on whether there has been chemical or other pretreatment. With no chemical pretreatment the lower figure is normal. It is customary to carry out chip refining in two or three successive stages, with differing power input in each stage.

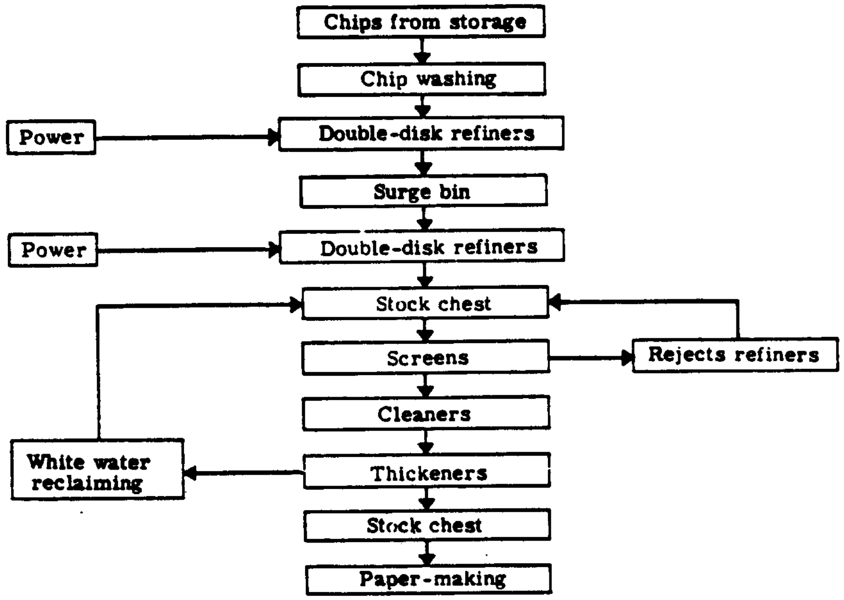

FIGURE VI.B-5

REFINER MECHANICAL PULPING PROCESS FLOW

Source: U.N., Food and Agriculture Organization, "Guide for Planning Pulp and Paper Enterprises", Rome, 1973.

RMP is 50 to 100 percent stronger than GWP from the same wood of equal drainage characteristics, but this high strength has to be paid for by the use of about 50 percent more electrical energy (1,200 to 2,200 kWh/t). To the additional power cost must be added the cost of plates, which have a life of 400 to 500 hours, compared with two to three years for stones. However, the ability to utilize cheaper fibrous raw material, or species not readily pulped by stone grinders, has resulted in the adoption of this process in many mills. In addition, RMP has higher strength than GWP, thereby reducing the requirement of more expensive chemical pulp in the paper-making operation.

Thermomechanical pulp (TMP)

TMP is a further development of RMP, characterized by the addition of a steam treatment of the chips prior to refining. This treatment softens the chips and greatly reduces fiber damage in the initial phase of the fiber separation. As a consequence, TMP will normally have a lower shive content and a higher long fiber fraction than RMP. Dusting and linting will be under better control. Both tensile strength and tear resistance will be higher than for RMP of equal drainage characteristics.

There are many varieties of the RMP and TMP processes adapted to different end-products and to different refiner designs. It is difficult today to draw a strict line between the two processes. Currently, in a typical TMP plant the chips are pre-steamed in a pressurized vessel at 120^o to 130^oC for two to three minutes and then immediately refined at the same pressure. They are then refined in a second stage at atmospheric pressure. Alternatives are pressurized single-stage refining, pressurized refining in two stages, atmospheric single-stage refining and atmospheric steaming followed by pressurized refining.

The wood yield in TMP manufacture may be 1 to 2 percent lower than for GWP. Most published records indicate a yield in the range 92 to 94 percent. Peroxide bleaching will reduce the yield further by 1 to 2 percent.

The energy requirement is 400-500 kWh/t higher than for GWP: about 1,400 kWh/t for a board-grade pulp and 1,900 kWh/t for a news-grade pulp, including screening and cleaning. This difference between the two processes is not significantly affected by steaming the chips.

A TMP mill producing 300 ADT/d (air dry tons/day) of pulp requires the following per ton of output:

Woodchips	2t
Electricity	2000 kWh/t
Power (load)	100 kW
Natural gas for flash drying	3.2 M BTU
Water	12.7 t
Site area (for 300 ADT/d)	16 ha
Manpower (for 300 ADT/d)	100

There is no difference in labor demand between a TMP mill using ground wood and a GWP plant with modern transport and grinder feeding arrangements.

Chemimechanical pulp (CMP)

CMP is an RMP manufactured from chips treated with chemicals at room temperature. The chemicals used mostly are sodium sulphite, sodium hydroxite, sodium carbonate and sodium peroxide, alone or in various mixtures. Only 2 to 6 percent chemicals to the weight of wood are used, and up to 50 percent of the chemicals added may leave the process with the pulp, having reacted with the wood constituents without dissolving them. The wood yield should not be allowed to go below 90 percent if the good optical properties of mechanical pulp are to be retained. Many hardwoods, which cannot give good GWP or TMP, are successfully pulped by the CMP process, now that it is possible to avoid too much loss of capacity.

The manufacturing costs for CMP will differ from those of RMP owing to the chemicals involved. In CMP manufacture both pulp quality and economy are critically dependent on a strict control of the rate of dosage of chemicals. It is also very important to ensure that the chemicals have penetrated the chips before refining. Over-treatment of the chip surfaces will reduce the quality. Therefore, although the process is as simple as the RMP one, more attention should be given to process control.

Physically, the CMP plant will differ from the TMP plant only by the addition of a 10-m^3 tank for the chemical solution, an impregnator, and a somewhat larger pre-heater.

Labor requirements for a CMP mill are the same as for a TMP mill.

Chemithermomechanical pulp (CTMP)

CTMP is a TMP made from chemically pre-treated chips. Lately, a number of articles have been published that report remarkable quality superiorities of CTMP compared to TMP. In particular, higher cleanliness and higher strength are claimed. The energy consumption is not significantly affected by the use of chemicals.

CTMP technology is under rapid development, and it is not yet known which variety of the process will prevail. However, it is advisable to start by steaming the chips at atmospheric pressure, using excess steam from the process. Thereby, air is expelled and the chips obtain uniform temperature and moisture. No chemicals should be added at this stage. The chips should then be washed in 70°C hot-process white water for removal of sand and loose bark and for a more uniform chip moisture. After draining off water from the washed chips one can proceed to impregnation with chemicals. A low temperature at this stage is preferable, but it is not feasible to go much below the white-water temperature of 70°C. The chemicals penetrating into the wood will swell the fiber wall and react with the lignin, making the latter softer and more hydrophilic. A later treatment in the standard TMP pre-heater causes the modified lignin molecules to polymerize so that they are less easily solubilized. Chemicals that have not reacted with the wood will be partly recirculated with the white water back to the CTMP mill. No chemical recovery process is needed.

The CTMP process differs from the CMP process only by the fact that in the former case the impregnator and pre-heater are built as pressure vessels, while in the CMP process, they are atmospheric. This has no effect at all on the plant's labor, area and water requirements.

The choice between the CMP and CTMP processes will depend on pulp quality considerations and on the wood species used. There may be also a desire to produce TMP as well as CMP or CTMP in the same plant. On the other hand, it is possible that, with some wood species, the CMP process will give a better pulp than the CTMP process.

Bleaching mechanical pulps

All mechanical pulps can be bleached to 75 to 80 percent brightness with sodium peroxide. If a brightness level of 70 percent is adequate, bleaching can be done simply by adding 2 percent peroxide to the dilution water going to the first-stage refiner while controlling the pH at close to 8. If a brightness above 75 percent is required, it will be necessary to add a peroxide bleach tower for a two-hour treatment of the pre-bleached pulp after screening and dewatering to 15 percent consistency. It is not usual to wash the pulp after bleaching. Excess perixide will do no harm to the process or the machinery.

While peroxide bleaching of mechanical pulp has been practised for a long time, only recently has the process been developed to a stage where appreciable improvement of strength and cleanliness is obtained. Peroxide is, in any case, only of interest if a high brightness is needed as well as high strength.

VI.B.3.2.b Semichemical Pulping

The two common grades of semichemical pulp are cold soda pulp and neutral sulphite semichemical pulp (NSSC).

The cold soda process

As the name implies, the raw material is treated with alkali at room temperature before refining. Earlier, refining was done in pump-through refiners at 4 to 5 percent consistency, giving pulps of poor cleanliness and strength. The process, which is only applicable to hardwood, was first introduced in 1955, and for some years became quite popular.

Compared with other chemical and semichemical pulping processes, the cold soda process has a very uncomplicated system for liquor recovery. The only difficulty is to obtain economy from it and still avoid water pollution.

However, industry has somewhat lost interest in the cold soda process because higher-quality pulp can be obtained by other processes using sulphur. Still, present experimentation in the area of sulphur-free pulping may lead to improved varieties of the cold soda process.

Neutral sulphite semichemical pulp (NSSC)

NSSC can be produced from most species of hardwood. The chips are steamed at atmospheric pressure, and impregnated with a solution of sodium sulphite and sodium carbonate at a pH of 8 to 9. The wet chips are digested by steaming (vapour phase) in a pressure vessel at 160°-180°C for 15 to 60 minutes. By this process about one half the lignin and one third of the hemicellulose are dissolved. The cellulose, however, is not attacked under normal cooking conditions. The middle lamella, which holds the fibers together, has (especially in hardwoods) high contents of lignin and hemicellulose and is therefore primarily attacked by the cooking process. As a result, a later refining of the digested chips will give comparatively undamaged, strong fibers. Softwood is less suitable for this process because of a lower lignin content of the middle lamella.

The wood yield is in the range 75 to 85 percent, which means that some kind of liquor recovery is necessary in order to limit the pollution of the recipient. Below 75 percent yield, the pulp quality will deteriorate, and other pulping processes become more attractive. A normal level of consumption of chemicals is 8 to 10 percent sodium sulphite and 2 to 5 percent sodium carbonate.

Essentially, the production cost of NSSC depends on the cost of the wood used. Where there is a local surplus of hardwood, conditions will be far more advantageous than where hardwood can also go to a kraft mill.

A cold soda plant or a NSSC plant will always be a department of a paper mill, and thus, its labor requirements can be seen only as the extra personnel needed for pulping. For a Swedish plant producing 150 t/d pulp, this extra personnel would be:

Wood-room operators (two shifts)	9
Pulping operators	10
Extra maintenance (day-shift)	3
Process and quality control	2
Superintendent	1
	25

The important quality characteristic of NSSC is stiffness combined with a certain tensile strength and absorptivity. The pulp is almost exclusively used for fluting, and blended with kraft waste fiber for economy and increased wet strength. It is also possible to mix a little NSSC into the kraft furnish for liner to obtain increased stiffness. In both applications, NSSC will give superior paper characteristics compared to CTMP or kraft waste paper.

The NSSC process would lend itself ideally to manufacture of pulp from mixed hardwoods in small plants located in forests. Instead NSSC plants are generally large and built adjacent to kraft mills. The explanation is that the only practical method of recovering the cooking chemicals is to pump them into a kraft mill black liquor recovery system (cross recovery).

The waste liquor (red liquor) obtained by washing NSSC has a consistency of 8 to 12 percent and holds 400 kg of organic matter per tonne of pulp. It is nowadays seldom permitted to sewer such quantities of oxygen-consuming matter. If the red liquor is evaporated to 50 percent consistency and burnt in an oven, the stack gases can be used for the evaporation process. A regular recovery boiler is generally not economical in this application. The smelt from the oven contains the chemicals, but unfortunately not in a useful form. Several systems have been developed for conversion of the chemicals, but none of them is economically attractive, and all are too complicated for a small, isolated NSSC mill even in a fully developed country. These circumstances seem to rule out the building of small NSSC mills in rural areas.

VI.B.3.2.c Chemical Pulping

The two common chemical pulping processes are the sulphate process and the sulphite process.

The sulphate process

Sulphate pulp is produced by digesting chips in a liquor of mainly alkali and sodium sulphide at 160° to 170°C for 2 to 3 hours. By choosing the appropriate operating conditions, one can manufacture a wide range of pulp grades from high-yield liner pulp to dissolving pulp.*

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*Wood pulp or any other highly purified form of cellulose manufactured for chemical conversion into derivatives is known as dissolving pulp, or special alpha pulp. The manufacture and availability of dissolving pulps have been an important factor in the development of artificial silks of various kinds, of transparent films for packaging and for photography, of nitrocellulose for explosives and lacquers, and of cellulosic plastics. The processes of manufacturing dissolving pulp are generally more complex than those required to make chemical paper pulp, even if the process steps sometimes appear to be similar.

The sulphate process may be represented by the flow chart in Figure VI.B-6. Pulping is carried out in batch or continuous digesters, and the black liquor is recovered, evaporated and burned in a furnace. The furnace ash, which contains mainly sodium carbonate, sodium sulphide and make-up sodium sulphate, is dissolved and treated with lime to regenerate pulping liquor of the proper composition. The continuous digesters are very large pieces of equipment; a single digester can serve the largest modern mills (up to 900 to 1,000-ton per day cooking capacity).

The sulphite process

The other major chemical pulping process is the sulphite process. Sulphite pulp is white enough to be used in newsprint and other printing papers without bleaching, and is historically the main source of pulp for white papers. The process is based on cheap chemicals which could be discarded after use. Because of savings in costs of bleaching and chemical recovery plants, capital investment has been less than for sulphate mills. However, in recent years, the size of new sulphate mills has increased rapidly resulting in a significant economy of scale; and public legislation against stream pollution, where sulphite mills are more offensive than sulphate mills, has become more severe. These developments have diminished the advantages of the sulphite process and, since 1961, bleached and semibleached sulphate pulps have surpassed sulphite pulps in the production of white papers. The extra strength of sulphate pulp is preferred for brown packaging papers, and may also be advantageous for newsprint as chemical pulp furnish. Furthermore, the earlier forms of the sulphite process could not satisfactorily pulp

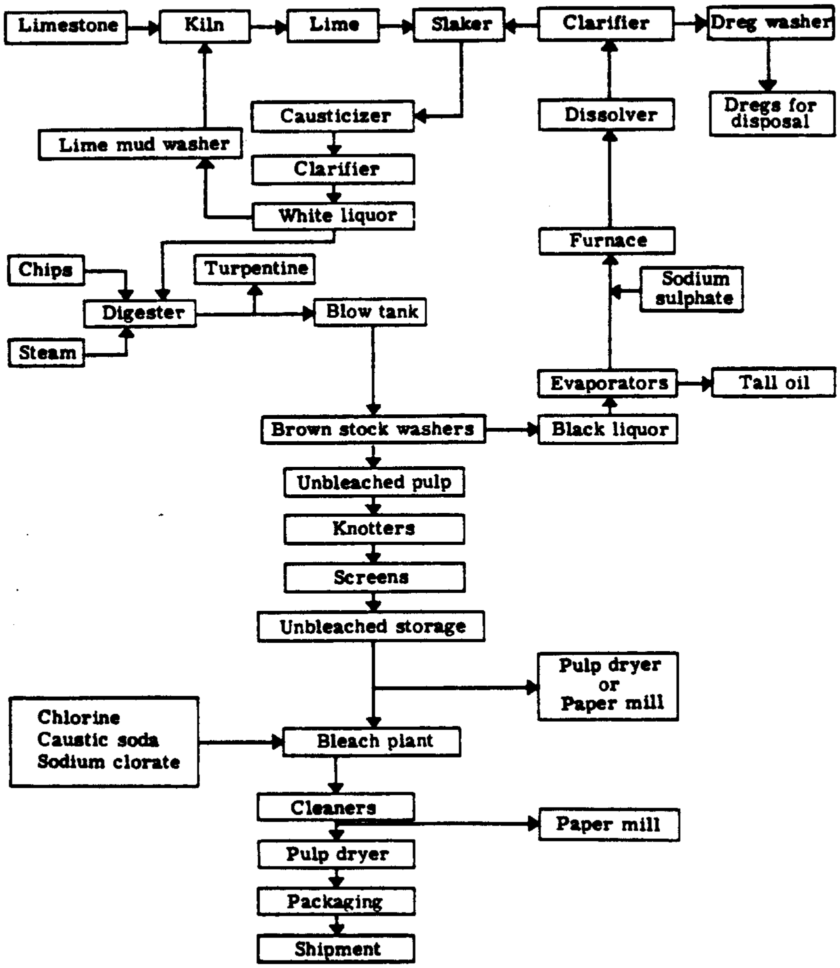


FIGURE VI.B-6

THE SULPHATE PROCESS FLOW

Source: U.N., Food and Agriculture Organization, "Guide for Planning Pulp and Paper Enterprises", Rome, 1973.

pinewood or most of the nonwood fibrous raw materials of the tropics and the developing countries, while these are pulped readily by the sulphate process.

Despite the various developments of the sulphite process, the shares of this method in world pulp production today are low and still diminishing. Figure VI.B-7 represents the sulphite process flow. The various chemicals which may be used to make the pulping liquor are indicated in the figure, which also shows salable by-products. Sulphur and a base, classically limestone but more recently magnesium hydroxide, sodium carbonate or ammonia, are the purchased chemicals.

VI.B.3.3 Paper-making

There are six elementary steps involved in paper-making:

1. A fibrous raw material is pulped, that is, it is so treated mechanically, chemically or by some combination of these, that the individual fibers are more or less completely separated.
2. The fibers are dispersed as a dilute suspension in water.
3. The fibers are filtered from the suspension through a sieve or screen, a "mould", or "wire", in such a fashion as to make a uniform layer of drained pulp, that is, a wet sheet of paper.
4. The screen is separated from the paper, an operation called "couching", in such a way as to leave the wet, and therefore fragile sheet unwrinkled and undisturbed.
5. The couched paper is placed in contact with a woven cloth, a "felt", and pressed to remove excess water.
6. The moist paper is removed from the felt and dried.

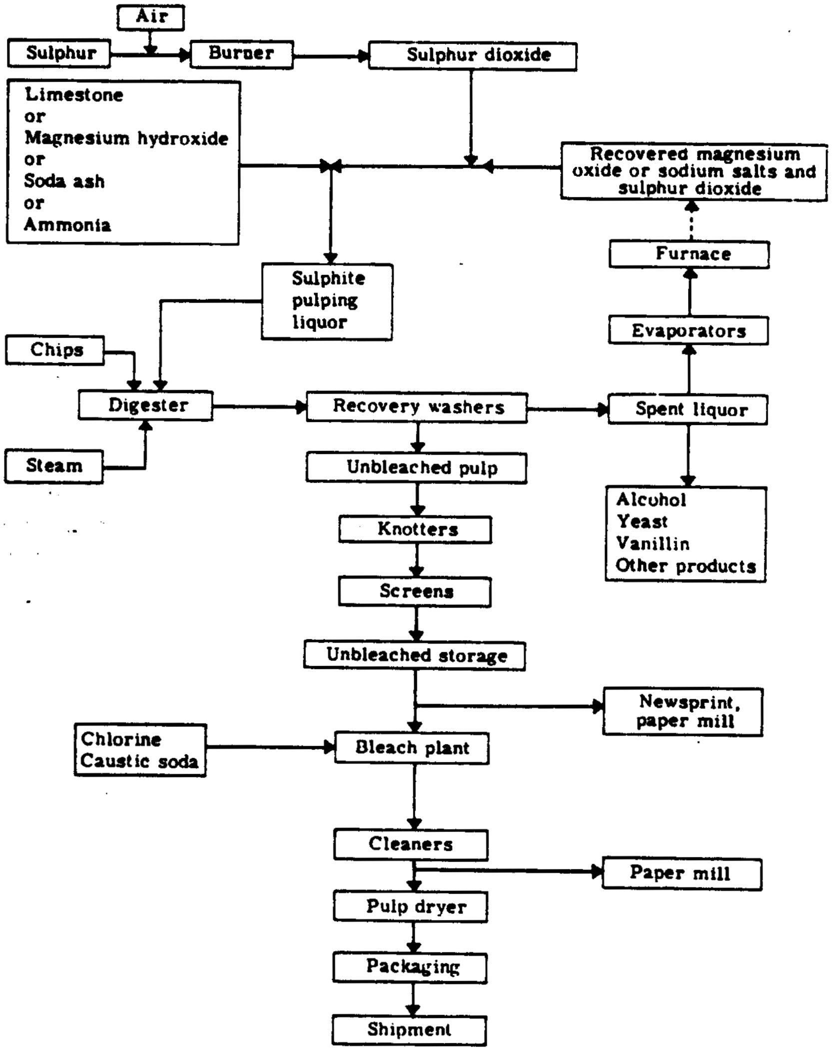


FIGURE VI.B-7

THE SULPHITE PROCESS FLOW

Source: U.N., Food and Agriculture Organization, "Guide for Planning Pulp and Paper Enterprises", Rome, 1973.

The steps in paper-making may be represented by the process flow block diagram in Figure VI.B-8.

There are a great many kinds of paper mills. The appearance and complexity of a paper mill are determined by the degree of integration with pulping or converting, or both; that is, whether the pulping of wood or other fibrous raw materials is carried out on the same site as part of the same operation, and whether the finished paper is converted into multiwall bags, corrugated board, consumer products such as towels or tissues, or other paper products in the same plant.

A second factor which affects the complexity of a paper mill is the raw material supply. For example, the mill may simply import good-quality paper pulp, or it may begin with wastepaper, or other fibrous raw materials.

Another factor in complexity is the product or range of products being made. Obviously, a coated magazine paper mill will be more complex than a linerboard or boxboard mill. Thus, a general description of a paper mill is useful only to the extent that it defines terms common to all or most paper mills. In general, a paper mill must provide for the operations shown in Figure VI.B-9.

The fibrous raw materials for the paper mill may be made on the premises and received in the paper mill as a slurry from a pulp storage chest, as represented in the figure by Pulp No. 1, or the pulp may be purchased. The purchased baled pulp is highly compacted and has to be disintegrated in a pulper to disperse the pulp fibers in water. In the stock preparation department, the pulp suspension is treated in beaters and passed through refiners. Refining (beating) serves to develop improved paper strength. The process of refining also decreases the freeness of the pulp: the rate at which water

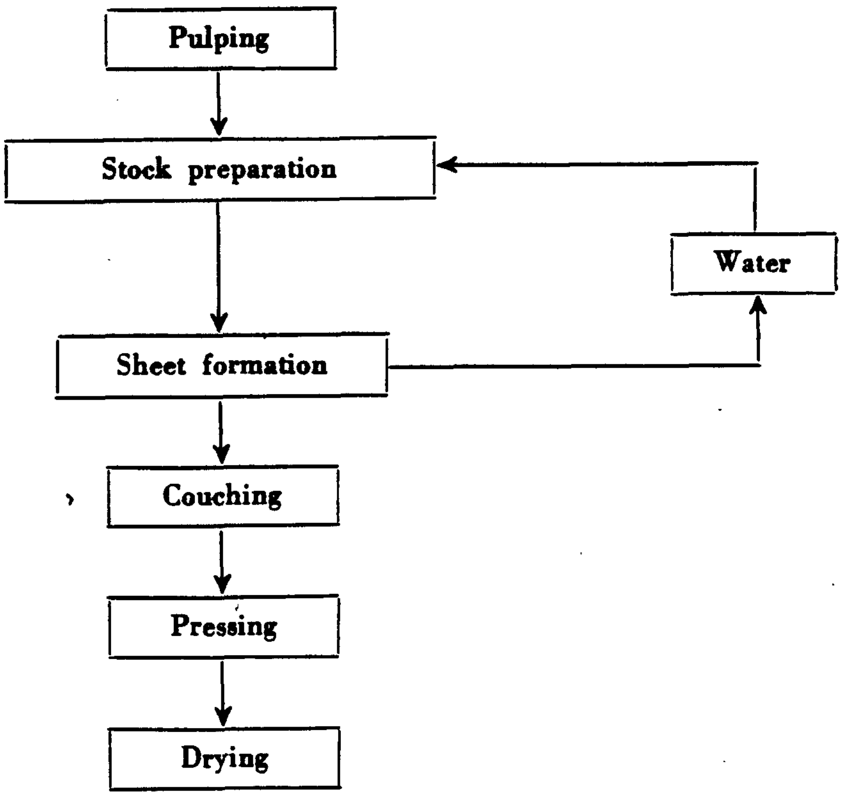


FIGURE VI.B-8

STEPS IN PAPER-MAKING

Source: U.N., Food and Agriculture Organization, "Guide for Planning Pulp and Paper Enterprises", Rome, 1973.

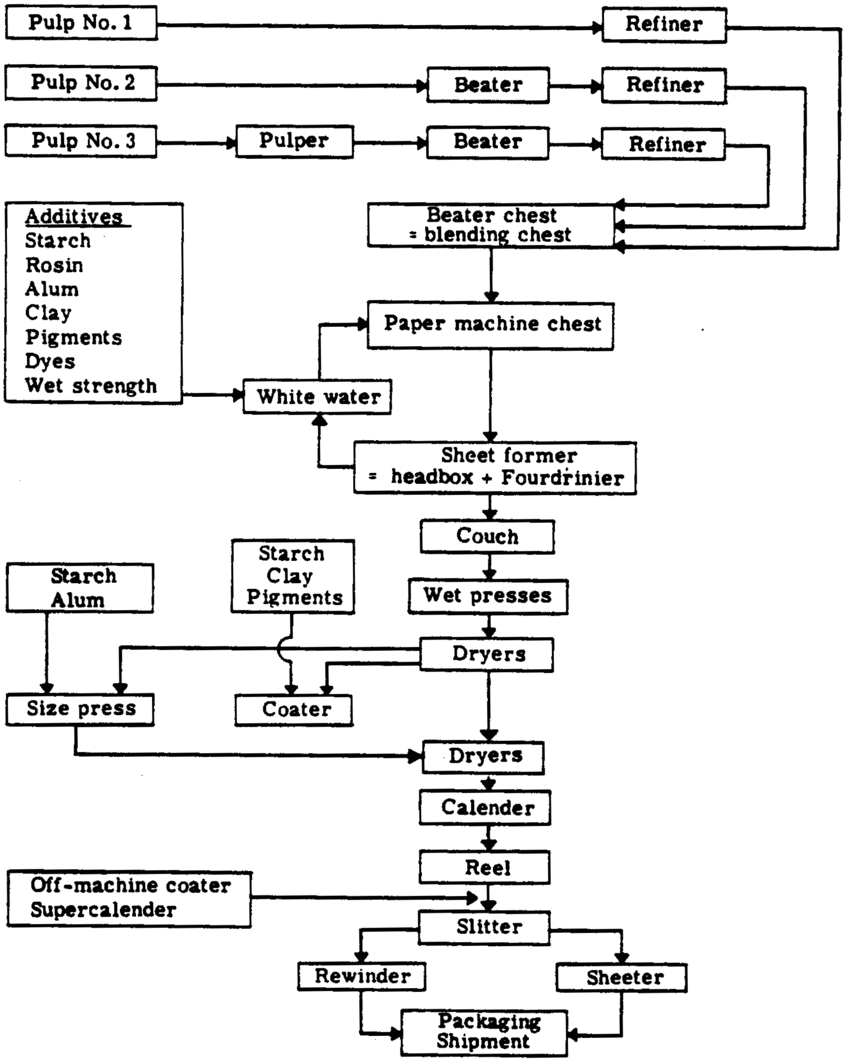


FIGURE VI.B-9

PAPER MILL PROCESS FLOW

Source: U.N., Food and Agriculture Organization, "Guide for Planning Pulp and Paper Enterprises", Rome, 1973.

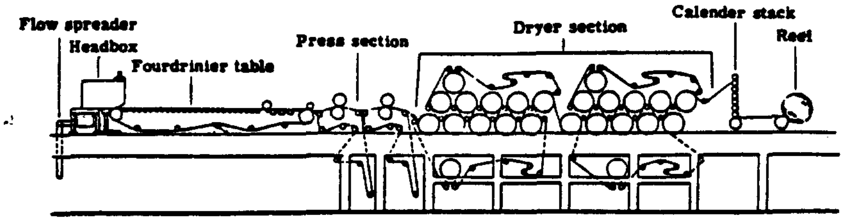
can drain from the pulp suspension. For operation of the paper machine at a fast rate, the pulp suspension must drain freely. Much of the art of papermaking lies in effecting the best compromise between strength and freeness.

Starch, rosin, alum, clay, pigments, dyes and other chemical additives are often added during the stock preparation process, prior to feeding the refined stock to the paper machine headbox (at the fan pump) or during the drying process (for surface sizing). These additives improve paper strength, wet strength, opacity and surface properties. Adhesives are additives to improve fiber-fiber bonding for internal paper strength, while sizes improve surface properties. Surface sizes reduce or prevent the spread of printing or writing inks, increase surface bonding strength and decrease dusting. Starch, which has both adhesive and sizing functions, has been added to paper stock almost since the beginning of the paper-making process.

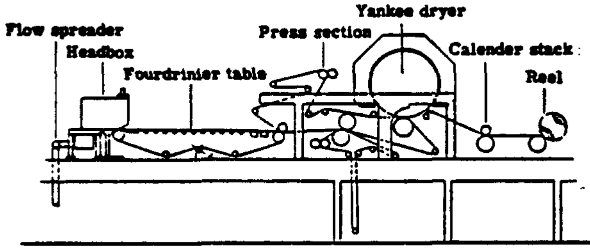
The paper machine and its auxiliary equipment are the most expensive part of the mill. It is therefore normally the item which limits productive capacity. The nature of the paper machine also determines which products the mill is capable of making, since paper machines are usually designed to make a specific product such as newsprint, boxboard or tissue, or a small range of products. Such machines may have quite different appearance, capacity and cost. Nearly all paper machines have certain elements in common, as illustrated in Figure VI.B-10, which shows the three most usual forms of paper machines.

A consistency regulator and a flowmeter ensure exact control of the flow of pulp fiber from the stock preparation department via the machine chest to the paper machine. Protection against foreign matter is afforded by cleaners and screens, and equipment for removing air from the stock to enable better sheet formation is very common. A flow spreader, the stock inlet,

FOURDRINIER PAPER MACHINE



FOURDRINIER TISSUE MACHINE WITH YANKEE DRYER



CYLINDER PAPERBOARD MACHINE

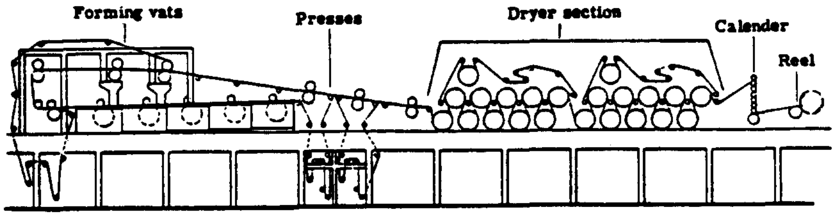


FIGURE VI.B-10

PAPER MACHINES

Source: U.N., Food and Agriculture Organization, "Guide for Planning Pulp and Paper Enterprises", Rome, 1973.

distributes the fiber suspension across the machine and feeds a headbox which, in turn, passes a uniform layer of very dilute fiber suspension through an adjustable slot, the slice, onto the moving wire of the sheet former, where much of the water is drained off.

The wire on which the sheet is formed is continuous, and may be horizontal, cylindrical or even vertical. The Fourdrinier is a flat wire supported on table rolls or water deflectors. It may be up to 10 meters in width and travel at 50 to 1,500 meters per minute. Speeds of about 1,000 meters per minute have been achieved so far only with lightweight tissue papers. In a number of recent instances, dual wires have been installed, horizontal for heavy paper or paperboard formation, or vertical for newsprint, fine papers and, recently, for corrugating medium (fluting).

Various suction boxes and other devices are installed along the wire to assist water removal. At the point of couching, where the sheet leaves the wire, it is still approximately five parts water to one part fiber. In the press section, a combination of mechanical pressure between heavy rolls and vacuum serves to reduce the water content, so that there remain about three parts water (or occasionally as little as two and a half parts) in the sheet before it enters the dryer. Since the remaining water must be removed by heat and evaporation, it is generally cheaper to remove water by mechanical action. This, however, becomes increasingly difficult above 35 percent dryness.

The sheet is carried through the press section by press felts, woven fabrics which assist water removal. There are usually three presses in succession, a transfer press, a main press and a smoothing press. Paper from the press section passes into the drying section, which usually consists of a train of cast-iron steam-heated cylinders, the drying cylinders.

Following the dryer section, the paper passes through a calender which imparts a very smooth surface, and then is wound on a reel. The reel is mounted on the stands of a slitter-rewinder. When newsprint is being made, the rolls produced from the slitter-rewinder are ready for wrapping and conveying to storage or shipment. Other papers require further finishing operations, such as supercalendering, or sheeting, or the paper is converted into paper products such as multiwall bags, packaged towels and tissues, corrugated boxes and a great variety of others.

VI.B.4 Environmental Impact*

Pulp and paper production affects the environment in several ways, since gaseous , liquid and solid wastes are produced from various parts of the operations. The greatest environmental impact comes from the bleaching and pulping of chemical pulp. Mechanical pulping operations usually have less impact on the environment. The environmental impacts can be greatly reduced by recycling and reusing most of the process waters and many of the chemicals back into the process.

VI.B.4.1 Gaseous Emissions

The principal gaseous emissions of concern at chemical pulp mills are sulphur dioxide, total reduced sulphur (TRS) compounds and particulate matter.

Sources: The World Bank, Office of Environmental Affairs, "Environmental Guidelines", 1984; The World Bank, "Environmental Considerations in the Pulp and Paper Industry", 1980; U.N., Food and Agriculture Organization, "Guide for Planning Pulp and Paper Enterprises", 1973.

Principal sources of sulphur dioxide are the recovery furnace, lime kiln, smelt dissolving tanks, and the power plant. Adequate control of this pollutant is possible by proper operations of the liquor recovery furnace, appropriate selection of auxiliary fuels, fuel desulphurization, and flue gas removal.

The TRS group which consists of hydrogen sulphide, methyl mercaptans, dimethyl sulphide and dimethyl disulphide is the major air pollutant of pulp and paper industries, mainly because of its highly odorous nature. In some of the older and overloaded mills, the odor occasionally can be detected 50 to 100 kilometers away. The TRS gases originate in various parts of the mill, especially from the digestor evaporators and the foul condensate stripping. They are commonly collected in headers, scrubbed with an alkali solution to remove a portion of the sulphur, and then burned. Incineration most frequently takes place in the lime kiln, where the TRS is converted to sulphur dioxide which, in turn, is largely recovered by absorption on the lime dust and in the liquid in the kiln exhaust scrubber.

Particulates originate in various elements of the mill operation, such as the recovery furnace, power boilers, lime kiln, exhaust, and others. Control and removal is best achieved by the use of scrubbers, electrostatic precipitation and other similar means.

Chlorine and chlorine dioxide can also occur, but they are not located at any particular point source. They originate as fumes from tank vents, wash filters, sewers, and other similar sources. Generally, their concentrations are not significant.

VI.B.4.2 Liquid Effluents

All pulp and paper mills, whether integrated or nonintegrated, and regardless of product type, discharge water from their operations. This is the water used to wash pulp and convey it through the paper machine. The water contains a number of suspended and dissolved materials which can be detrimental to the rivers, lakes or sea into which they are discharged.

Despite the recycling of the white water in which the fibrous material is suspended, a proportion of the fibers in the form of fines or very small particles cannot be retained. This type of effluent will discolor clear streams, but a more serious effect results from the decomposition or rotting of the fibers. This is a chemical process in which oxygen that is dissolved in the water is consumed (biochemical oxygen demand). The decomposition process therefore takes from the water the oxygen which fish need to survive, and in high concentrations the putrefaction of wood matter produces more obnoxious odors. The same problem occurs in the case of a pulp mill using a wet debarking method, where bark fires can enter the sewage system.

In addition to fiber, a mill may discharge other solids such as clay and fillers which are used in loading the sheet of paper in paper mills. These suspended solids can settle on the bottom of the river, lake, etc., thereby reducing the effective area of the bottom for the growth of plant life valuable as fish feed.

In the various chemical pulping procedures, the spent cooking liquors contain highly colored lignin and lignin derivatives. In spite of recovery procedures, many mills continue to discharge wastes having a high degree of color. Thus, the parameters of principal importance for describing the degree of contamination in liquid effluents from pulp and paper mill operations include:

5-day biochemical oxygen demand (BOD_5); total suspended solids (TSS); and color (for chemical pulping processes only).

Other contaminants found in the pulp and paper-making liquid wastes in minor concentrations are zinc compounds and ammonia nitrogen (for ammonia-based sulphite and dissolving pulping processes).

Liquid wastes can be reduced by in-plant control measures and end-of-the-pipe treatment. In-plant measures include effective pulp washing, chemical and fiber recovery, treatment and reuse of selected waste streams, collection of spills, and other effective housekeeping measures.

End-of-the-pipe treatment includes neutralization, primary treatment to remove the settleable solids, and biological (or secondary) treatment to reduce the effluent BOD_5.

Bleached kraft pulp mill effluent are highly acidic, and some form of lime is used for neutralization. Effluents from mechanical pulp mills and most paper mills are mildly acidic, and a liquid alkali such as caustic soda can be used for pH adjustment.

Large pieces of assorted materials, such as knots and rocks, may be removed by placing screens at strategic locations in the sewer system. Settleable solids are removed in a clarifier, usually a circular tank in which the particles are allowed to settle to the bottom. At some mills settling basins having a detention time of up to 8 hours, either following or in place of clarifiers, are also used.

Biological treatment is now required for effluents from new mills in many industrialized countries. This type of treatment reduces the acute toxicity of the wastewaters and generally creates an effluent suitable for discharge to most surface waters.

Where sufficient land is available, aerated lagoons are most often used to provide extended detention of pulp and paper mill effluents. As a rough guide, one cubic meter of lagoon capacity will be required for each 30 grams of BOD_5 in the effluent. As an average, the system will provide a 90% reduction in BOD_5, with a total detention period of about 10 days. Other methods, such as activated sludge, oxidation ditches and trickling filters, have also been effective.

VI.B.4.3 Solid Wastes

The characteristics of solid wastes from pulp and paper mill operations will vary considerably from one mill to another. For the average integrated mill the distribution of total solid wastes will be as follows:

Wastewater sludges	45%
Ash	25%
Bark, wood waste	15%
Paper, trash	10%
Miscellaneous	5%

Approximately 75% of the solid wastes will be organic in nature, and can be used as a fuel, for agricultural, or other purposes. Fibrous sludges and barks are suitable for manufacturing wallboard and roofing papers. Ash from bark burning boilers is rich in plant nutrients, particularly potash.

Land disposal, by lagooning or dumping, has been used extensively in the past. However, this method is being used less and less because of odors from decomposition of the materials, potential pollution of both surface and ground waters, and the elimination of affected lands from future use. Dewatering and incineration of sludges are now receiving wider usage. Although costs are high, three types of incineration are being practiced: burning in a specially designed incinerator, burning in the bark boiler, and burning in a power boiler utilizing fossil fuels.

VI.B.5 Forest Product Transport*

As shown in Table VI.B-4, the world production of forest products in 1977 was almost 2.5 thousand million metric tons. However, only 7.4% of this entered the international trade (see Table VI.B-5). The great majority was consumed domestically. The explanation for this high rate of domestic consumption is the fortuitous situation that production and consumption are geographically quite closely aligned. The demand for forest products originates, in the main, from industrialized, developed economies; and the major supply areas and/or processing plants are located in these same industrialized, developed nations such as those of North America, Scandinavia and the EEC. Table VI.B-6 illustrates this by apportioning production and consumption figures between developed and developing nations. The only exception is Japan which imports enormous quantities of fibrous raw materials for its own processing industries. For paper products, in particular, consumption per capita varies considerably between different countries. In 1980, for example, world consumption was reckoned to be 85 pounds per year, whilst the figure for the United States alone was 600 pounds per capita (see Table VI.B-7).

Source: H.P. Drewry Ltd., "Deep-Sea Trade and Transportation of Forest Products", London, 1979.

TABLE VI.B-4

WORLD PRODUCTION OF FOREST PRODUCTS 1973 AND 1977 ('000 METRIC TONS)

	1973	1977 OF WHICH:	AFRICA	N & C AMERICA	of which		S.AMERICA	W.EUROPE	of which SCANDINAVIA	E.EUROPE	USSR	ASIA	of which JAPAN	OCEANIA
					USA	CANADA								
FUELWOOD (C)	103,834	101,976	2,643	7,589	1,723	791	7,571	3,854	1,511	1,898	30,062	48,281	4	78
FUELWOOD (NC)	703,541	753,459	220,359	28,202	8,567	1,980	114,491	16,484	5,092	7,746	19,474	341,899	444	4,804
SAWLOGS + VENEER LOGS (C)	415,430	430,555	2,931	200,153	125,874	69,930	9,712	59,759	27,605	17,510	104,192	31,192	12,010	5,106
SAWLOGS + VENEER LOGS (NC)	182,940	187,646	12,834	30,745	24,809	3,588	16,615	16,279	1,584	9,382	23,228	72,434	3,064	6,129
PITPROPS (C)	15,552	16,480	3	308	210	38	-	1,635	21	2,262	7,578	4,686	125	8
PITPROPS (NC)	8,370	8,321	2,146	601	572	-	198	586	134	333	706	3,605	152	146
PULPWOOD AND PARTICLES (C)	155,546	152,495	2,377	72,308	46,753	24,351	3,273	33,664	21,360	7,154	26,386	4,795	1,467	2,538
PULPWOOD AND PARTICLES (NC)	65,329	63,810	1,771	25,977	24,436	1,504	4,511	14,035	4,082	4,325	-	9,576	6,640	3,615
OTHER INDUSTRIAL ROUNDWOOD (C)	72,492	69,930	155	5,890	4,965	881	419	3,992	1,240	3,199	49,255	6,585	599	435
OTHER INDUSTRIAL ROUNDWOOD (NC)	54,082	59,460	12,712	4,818	4,320	-	5,566	3,866	226	3,790	10,231	18,270	235	207
ROUNDWOOD	1,777,116	1,844,132	257,931	376,591	242,229	103,063	162,356	154,154	62,855	57,599	271,112	541,323	24,740	23,066
SLEEPERS	6,244	5,984	209	373	-	124	97	719	59	556	3,408	456	44	166
SAWNWOOD (C)	186,197	184,607	890	64,189	40,263	22,374	4,148	26,659	10,926	8,424	53,352	25,318	15,824	1,627
SAWNWOOD (NC)	69,256	69,446	2,345	11,852	10,153	731	7,336	8,870	562	4,218	9,720	23,313	6,614	1,792
SAWNWOOD + SLEEPERS	261,697	260,037	3,444	76,414	50,416	23,229	11,581	36,248	11,547	13,198	66,480	49,087	22,482	3,585
VENEER SHEETS	2,842	2,944	227	380	-	376	166	926	39	308	358	546	226	33
PLYWOOD	27,464	26,083	284	12,969	11,090	1,727	668	1,741	397	568	1,520	8,253	4,792	80
PARTICLE BOARD	20,755	23,709	205	4,279	3,636	571	532	11,816	1,559	2,310	3,168	998	611	401
FIBREBOARD (COMPRESSED)	7,629	8,169	68	2,268	2,065	176	576	1,707	578	1,114	1,582	707	267	147
FIBREBOARD (NON-COMPRESSED)	2,373	2,383	8	1,447	1,278	153	66	239	149	122	390	78	74	33
WOOD-BASED PANELS	61,063	63,288	792	21,343	18,069	3,003	2,008	16,429	2,722	4,422	7,018	10,582	5,970	694
MECHANICAL WOOD PULP	25,784	24,987	200	10,953	4,069	6,830	308	7,216	4,069	681	2,400	2,520	1,513	709
SEMI-CHEMICAL WOOD PULP	8,388	8,032	128	3,913	3,631	282	206	1,363	661	235	600	1,366	1,336	221
CHEMICAL WOOD PULP	75,373	77,896	481	44,210	33,469	10,362	2,083	13,968	9,236	2,150	6,410	7,812	6,256	782
DISSOLVING WOOD PULP	5,001	4,811	299	1,592	1,319	269	48	1,065	504	348	990	469	330	-
WOOD PULP	114,546	115,726	1,108	60,668	42,488	17,743	2,645	23,612	14,470	3,414	10,400	12,167	9,435	1,712
NEWSPRINT	22,495	22,747	271	11,447	3,188	8,169	255	4,664	2,525	312	1,395	3,919	2,370	483
PRINTING & WRITING PAPER	33,049	35,632	228	14,098	12,644	1,105	908	11,984	2,816	860	1,200	6,189	3,103	166
OTHER PAPER & PAPERBOARD	92,793	93,456	861	40,011	35,928	2,881	2,878	22,233	5,762	3,976	6,505	15,773	10,229	1,219
PAPER & PAPERBOARD	148,337	151,835	1,360	65,556	51,760	12,155	4,041	38,881	11,103	5,148	9,100	25,881	15,702	1,868
TOTAL FOREST PRODUCTS	2,362,759	2,435,018	264,635	600,572	404,962	159,193	182,631	269,324	100,742	83,781	364,110	639,040	78,329	30,925

The suffixes 'C' and 'NC' refer to Coniferous and Non-Coniferous wood, otherwise known as Softwood and Hardwood respectively.

Source: H.P. Drewry Ltd., "Deep-Sea Trade and Transportation of Forest Products", London, 1979.

TABLE VI.B-5

WORLD EXPORTS OF FOREST PRODUCTS 1977
('000 METRIC TONS)

COMMODITY	EXPORTS	EXPORTS AS % AGE OF PRODUCTION
FUELWOOD AND CHARCOAL	817	0.1
SAWLOGS AND VENEER LOGS (C)	19,820	4.6
SAWLOGS AND VENEER LOGS (NC)	35,973	19.2
PITPROPS	934	3.8
PULPWOOD AND PARTICLES	21,839	10.1
OTHER INDUSTRIAL ROUNDWOOD	2,495	1.9
ROUNDWOOD	81,878	4.4
SLEEPERS	679	11.3
SAWNWOOD (C)	33,611	18.2
SAWNWOOD (NC)	8,171	11.8
SAWNWOOD AND SLEEPERS	42,461	16.3
VENEER SHEETS	925	31.4
PLYWOOD	4,025	15.4
PARTICLE BOARD	3,047	12.9
FIBREBOARD (COMPRESSED)	1,383	16.9
FIBREBOARD (NON-COMPRESSED)	175	7.3
WOOD-BASED PANELS	9,555	15.1
MECHANICAL WOOD PULP	1,180	4.7
SEMI-CHEMICAL WOOD PULP	100	1.2
CHEMICAL WOOD PULP	14,142	18.2
DISSOLVING WOOD PULP	1,596	33.2
WOOD PULP	17,018	14.7
NEWSPRINT	10,494	46.1
PRINTING AND WRITING PAPER	5,707	16.0
OTHER PAPER AND PAPERBOARD	11,900	12.7
PAPER AND PAPERBOARD	28,101	18.5
TOTAL FOREST PRODUCTS	179,013	7.4

Source: H.P. Drewry Ltd., "Deep-Sea Trade and Transportation of Forest Products", London, 1979.

TABLE VI.B-6

FOREST PRODUCTS PRODUCTION AND CONSUMPTION BY AREA 1977 (MILLION METRIC TONS)

PRODUCTION	DEVELOPED MARKET ECONOMIES	DEVELOPING MARKET ECONOMIES	USSR	OTHER CENTRALLY-PLANNED ECONOMIES
INDUSTRIAL ROUNDWOOD*	522	154	223	89
SAWNWOOD + SLEEPERS	136	33	66	24
WOOD-BASED PANELS	45	6	7	5
WOOD PULP	96	4	10	5
PAPER AND PAPERBOARD	121	9	9	12
TOTAL	920	206	315	135
% OF TOTAL OVERALL	58.5	13.0	20.0	8.5
CONSUMPTION				
INDUSTRIAL ROUNDWOOD*	555	127	210	91
SAWNWOOD + SLEEPERS	141	32	62	24
WOOD-BASED PANELS	48	5	6	5
WOOD PULP	94	5	10	6
PAPER AND PAPERBOARD	116	14	9	12
TOTAL	954	183	297	138
% OF TOTAL OVERALL	60.5	11.5	19.0	9.0

* Industrial Roundwood = All Roundwood less Fuelwood and Charcoal

Source: H.P. Drewry Ltd., "Deep-Sea Trade and Transportation of Forest Products", London, 1979.

TABLE VI.B-7

WORLD CONSUMPTION OF PAPER, 1980

Country or region	Population (000)	Per capita consumption (lb/yr)
North America	**246,700**	**582**
Canada	24,000	423
USA	222,700	600
Europe	**742,974**	**168**
Total EEC	269,710	269
Belgium	9,900	304
Denmark	5,125	359
France	53,588	256
Germany, Fed. Rep.	61,561	342
Greece	9,200	104
Ireland	3,200	205
Italy	57,042	192
Netherlands	14,144	342
United Kingdom	55,950	269
Scandinavia	17,180	401
Total Other Europe	456,084	99
USSR	260,000	73
Asia	**2,445,769**	**29**
China, People's Rep.	900,000	13
India	660,000	4
Japan	117,057	337
Australasia	**21,531**	**260**
Latin America	**349,662**	**64**
Brazil	120,000	64
Mexico	60,000	88
Africa	**442,198**	**13**

Source: Kline, J.E., "Paper and Paperboard. Manufacturing and Converting Fundamentals", Miller Freeman Publications Inc., San Francisco, 1982.

Among the 179 million tons of forest products exported in 1977, about 30 million tons have been transported inland by trucks and railcars. The remaining 149 million tons entered the seaborne trade. This volume is actually higher than the total of bulk coal shipments recorded in that year by some 22 million tons. The reason why sea transport of forest products continues to be regarded as a minor bulk trade (apart from the five major bulk trades: iron ore, grain, coal, bauxite/alumina and phosphate rock) is that the various commodities of this trade are often shipped as part-cargoes or on small non-bulk vessels and, in addition, the preponderance of short-sea trades means that in ton-mile terms forest products fall some way short of the major bulks.

About two thirds of the total seaborne trade in forest products are shipped along short intra-area routes. A wide range of types and sizes of ships and barges is used for these short-haul trades, with the accent on small general cargo vessels of less than 10,000 DWT.

Less than 40% of the total seaborne trade of forest products in 1977 was related to the pulp and paper industry, the remaining being used mainly in the construction industry. The traded commodities of the pulp and paper industry, their exported volumes in 1977, and their relative percentages are:

Level of processing	Commodity	Volume of exports in 1977 ('000 tons)	Percentage
raw materials	pulpwood and wood chips	21,839	32.6
intermediate products	wood pulp	17,018	25.4
end products	paper and paperboard	28,101	42.0
Total		66,958	100.0

It can, thus, be seen that more than 67% of the traded commodities is in processed form, as process industries tend to be located at or near the main production centers in order to produce a higher-value, more economically transportable product. Based on 1975 prices, the following costs were equivalent for 5 M cu m of wood shipped from the U.S. to Europe:

	$/t	$/t of equivalent wood
roundwood	22.4	20.0
sawntimber	21.8	10.8
newsprint	30.4	10.8
linerboard	29.4	7.7
kraftpaper	30.7	6.1
bleached pulp	23.0	4.6

Thus the advantages of transporting pulp and paper by sea as against the shipment of raw materials are apparent, especially as transportation accounts for roughly 25% of paper cost to the consumer.

Several different types of vessels are employed in the deep-sea forest product trades, ranging from the small, tramping, general cargo vessels carrying goods on a part-cargo basis, to larger, specialized bulk carriers with sophisticated deck facilities and design attributes which, in certain instances, tie them to the trades.

VI.B.5.1 Pulpwood Logs

Pulpwood logs can be carried as part-cargo by any geared general cargo vessel or bulk carrier. Smaller 'tweendeckers, general-purpose bulkers, etc. have gradually given way to the more efficient, more sophisticated, purpose-built specialized "lumber carriers", which are modern bulk carriers with good gear, good cargo access and high deck strength intended to carry packaged or unitized products such as lumber, board, wood pulp, newsprint, etc. in the holds and on deck. More sophisticated ships include gantry-equipped vessels of open-hatch, flush-hold design.

Because of the multiplicity of vessel types which can be characterized as lumber carriers a precise calculation of their number is difficult to achieve, but an estimation of the size of the fleet at the end of 1978 suggests a figure of 401 bulk vessels of over 10,000 DWT amounting to a little over 9.6 million DWT (refer to Table VI.B-8). The largest vessels of this category have a capacity of about 45,000 DWT, are of the open-hatch design, and they can load packaged timber, wood logs, baled pulp, kraft liner rolls, grain, ore, other bulk cargoes, various heavy cargoes or containers. These ships operate on the longest-haul routes from West Coast of North America to Europe, and unitizable sawn timber is the primary commodity carried. Shorter routes, or routes which involve more shipments of logs (less unitizable than sawn timber), such as those from North America to Japan, require less specialized log/timber carriers in the 10-30,000 DWT size range.

Other factors such as limited depth of ports, limited sheltered areas where logs are loaded, and the lack of ponds to accumulate logs, result in the employment of even smaller vessels. As an example, hardwood log movements from South East Asia to Japan are generally effected by geared log carriers ranging from 5,000 to 10,000 DWT.

In general, despite the introduction of several larger bulkers to the longer trades, the major requirement worldwide is still for the handy-sized ships of 20-35,000 DWT. At the end of 1978, the average lumber carrier was about 25,000 DWT.

TABLE VI.B-8

THE LUMBER CARRIER FLEET BY SIZE AND AGE

A. '000 DWT

SIZE RANGE \ BUILT	PRE 1962	1962/63	1964/65	1966/67	1968/69	1970/71	1972/73	1974/75	1976/77	1978	TOTAL
10-14.9	13.3	-	65.1	95.2	12.3	23.8	28.1	230.9	53.5	44.4	566.6
15-19.9	54.2	49.4	127.3	293.1	642.2	229.4	209.9	198.2	268.5	219.7	2,291.9
20-24.9	22.2	71.0	-	-	265.3	259.1	114.1	23.7	251.6	48.8	1,055.8
25-29.9	-	-	-	25.0	446.8	327.9	664.9	486.9	384.0	-	2,335.5
30-34.9	-	33.4	64.2	-	31.6	190.6	531.9	551.7	227.6	66.2	1,697.2
35-39.9	-	-	-	35.9	74.4	37.3	-	565.4	223.5	-	936.5
40+	-	-	-	-	-	-	40.4	-	714.2	-	754.6
TOTAL	89.7	153.8	256.6	449.2	1,472.6	1,068.1	1,589.3	2,056.8	2,122.9	379.1	9,638.1

B. NUMBER OF VESSELS

SIZE RANGE \ BUILT	PRE 1962	1962/63	1964/65	1966/67	1968/69	1970/71	1972/73	1974/75	1976/77	1978	TOTAL
10-14.9	1	-	5	7	1	2	2	18	4	3	43
15-19.9	3	3	8	18	37	13	12	11	15	12	132
20-24.9	1	3	-	-	12	11	5	1	11	2	46
25-29.9	-	-	-	1	16	12	25	18	14	-	86
30-34.9	-	1	2	-	1	6	16	17	7	2	52
35-39.9	-	-	-	1	2	1	-	15	6	-	25
40+	-	-	-	-	-	-	1	-	16	-	17
TOTAL	5	7	15	27	69	45	61	80	73	19	401

Source: H.P. Drewry Ltd., "Deep-Sea Trade and Transportation of Forest Products", London, 1979.

High-capacity handling equipment is installed on these ships. Derricks and cranes with a gear rating between 15 and 30-ton safe working load (SWL) are common in the lumber carrier fleet. High-capacity gantry cranes have also become increasingly popular, due to their high loading/discharging speeds.

VI.B.5.2 Wood Chips

Specialized bulk carriers designed for the carriage of wood chips were developed during the mid-1960's to supply the expanding raw material needs of the Japanese pulp, paper and paperboard manufacturers. Wood chips is a very poor deadweight cargo. The stowage factor of wood chips is 100-110 cubic feet per long ton, while the designed stowage factor of most general-purpose bulkers is 55-60 cubic feet per long ton. Thus, the chip carrying vessels are highly specialized, and their employment in other trades is often precluded for this reason. The freeboard of chip carriers generally exceeds that of conventional bulk carriers by over 50%, while the cubic capacity is generally greater by a similar margin.

The Japanese rationale for transporting large volumes of chips rather than more economically stowed unprocessed logs or processed pulp was the rapid handling rate which can be achieved by the specialized chip carriers and which thus reduces expensive in-port time. Normally chip loading installations employing high-capacity belt conveyors and pneumatic trimmers can achieve rates in excess of 500 tons/hour, and most discharge equipment whether ship or shore based, can offload at rates of over 300 tons/hour.

In 1978, the chip carrier fleet amounted to 76 vessels representing over 2.5 million DWT. The great majority of this tonnage is controlled by Japanese interests. About two thirds of the total tonnage of the specialized chip carrier fleet consists of medium-sized vessels of 35-50,000 DWT, and larger, "Panamax" vessels in the 50-60,000 DWT range. The remaining third of the total tonnage is represented by smaller vessels at between 10 and 35,000 DWT.

Lately, the development of the fleet has been seriously affected by overtonnaging as economic recession has struck at the Japanese paper industry. It has been estimated that as much as 20% of the fleet may have been diverted to the transport of pulverized coal, phosphor ore or bauxite, while some vessels have been converted into car carriers.

VI.B.5.3 Pulp and Paper

Pulp is commonly shipped in bales, and kraft liner in rolls. Unitization has developed and there are many configurations in use today. Pulp and paper products enable high handling rates by consolidating between 15 and 25 tonnes per lift.

While the nature of the trade in pulp and paper products, particularly the small size of consignments, restricts the employment of larger bulk carrier tonnage, part-cargoes are combined with larger volume movements of timber in the smaller 15-20,000 DWT bulkers, and the specialized, geared, open-hatch vessels of 20-35,000 DWT. A few specialized Japanese owned vessels of around 10,000 DWT are also employed in the trade hauling pulp in bulk, often sailing from Alaskan ports to Japan.

Other vessel types have also been used on the North Atlantic routes. For example, the International Paper Company (IPC) has been regularly shipping paper and pulp from the U.S. Gulf to Europe in 400 DWT barges carried abroad the LASH vessels of Central Gulf Lines. Forest products, particularly newsprint, were also reported featuring as part-cargoes on the container/bulk services operated by Cast Lines and Chase International.

Roll-on, roll-off (ro-ro) vessels are particularly suited to the carriage of paper products in that the below deck stowage affords the protection necessary for this relatively high-value product.

The essence of a ro-ro ship is that it loads its cargo not through the employment of cranes and derricks - the lift-on,lift-off (lo-lo) method - but through the use of wheeled transporters, be they road trailers, purpose-built terminal trailers, straddle-carriers, fork-lift trucks, etc. These wheeled units are rolled on and off the ship over a vessel ramp and/or shore ramp. The principal advantage of this system is the ability of the ro-ro vessels to minimize port turnaround time and reduce dependence on shore-side facilities. The ro-ro vessels can load/discharge their cargo in half the time required even for the most efficient of conventional lumber carriers. In addition, ro-ro vessels have the advantage that the tractors and trailers which are off-loading the cargo can take it directly to the storage location which may be well-removed from the quay-side.

The largest ro-ro vessels in the forest products trade have a capacity of about 45,000 DWT, are designed for the transport of all types of trailer units, pallets, containers, cars, agricultural machinery and general cargo, and they operate on the routes from North America to Japan and Europe. Smaller ro-ro vessels have been employed in the North Sea forest products trade between Scandinavia and North Europe.

VI.B.5.4 Ports Handling Forest Products

Of the many influences upon the pattern and structure of the forest products trade, port constraints are of obvious significance. For instance, the deep-draft ports of the West Coast of North America which are orientated towards handling wood chips are fully capable of accommodating larger bulkers, whereas exports from Scandinavia and the Western ports of the U.S.S.R. are generally loaded at shallow-draft ports, these being in the short-sea trades. Restrictions at the loading ports are shown in Table VI.B-9.

In most cases, conventional berths are used for discharging forest products. However, there are few specialized forest products discharging terminals which can give access to large bulk carriers. For instance, the Sodeshi complex in Japan can unload wood chip carriers of up to 45,000 DWT at the exceptional rate of around 1,200 tons/hour. A description of the forest products discharging terminals is shown in Table VI.B-10.

VI.B.6 Major Considerations in Planning Pulp and Paper Industries

After the analysis of the preceding sections, it is apparent that the multiplicity of raw materials, end-products and processing technologies of the pulp and paper manufacture raises critical issues regarding the planning of new investments in this industry. This is particularly true for developing countries which, in addition, face the constraints of a small local market and a limited investing capacity.

The selection of the appropriate manufacturing process as well as siting of a pulp and paper plant are two of the most important issues that planners and analysts have to deal with.

TABLE VI.B-9

FOREST PRODUCT LOADING PORTS

COUNTRY	PORT/OPERATOR	MAX DRAFT		ESTIMATED MAX SHIP SIZE	FACILITIES	LOAD RATE (TPH)	REMARKS
		FEET	METRES				
AUSTRALIA	BUNBURY/(OUTER HARBOUR)	26.3	8.0	30,000	1x50 T Weighbridge	450	-
	(INNER HARBOUR)/	28.5	8.7				
	W.A.CHIP & PULP CO.	38.1	11.6	44,800	1 bulk woodchip loader	1,000	Handles Woodchips only.
	EDEN	41.0	10.7	60,000	1 bulk woodchip loader	-	-
	HOBART	35.1	10.7	50,000	-	-	Loads Japan bound woodchips
	LAUNCESTON/NORTHERN WOODCHIPS PTY. LTD.	38.1	11.6	45,000	-	-	-
	ASSOCIATED PULP & PAPER MILLS LTD.	37.1	11.3	40,000	-	-	-
CANADA	BOTWOOD/PRICE (NFLD) PULP & PAPER LTD. No1 BERTH	32.0	9.8	35,000	20,000 tons (Standard Newsprint) Storage	-	-
	BOTWOOD/PRICE (NFLD) PULP & PAPER LTD No.2 BERTH	34.8	10.6	50,000	-	-	Layberth only.
	CHATHAM/MIRAMICHI LUMBER CO.	30.0	9.1	35,000	-	-	-
	CHEMAINUS/MACMILLAN, BLOEDEL	40.0	12.1	55,000	1 Travelling crane.	-	-
	CHEMAINUS/POWELL RIVER CO.	34.1	10.4	45,000	-	-	-
	CORNER BROOK/BOWATER NEWFOUNDLAND LTD. No.1 BERTH	28.0	8.5	30,000	1 Travelling crane.	-	-
	CORNER BROOK/BOWATER NEWFOUNDLAND LTD. No.2-4 BERTH	32.0	9.8	35,000	1 Travelling crane.	-	-
	COWICHAN BAY/CNR	38.5	9.0	35,000	-	-	-
	CROFTON	35.0	10.7	50,000	-	-	Lumber berth
		35.0	10.7	50,000	-	-	Pulp berth
	DALHOUSIE/NEW BRUNSWICK INTERNATIONAL PAPER CO.	26.9	8.2	30,000	-	-	-
	HALIFAX/NHB	30.0	9.1	35,000	-	-	-
	NANAIMO/HARMAC PULP MILL	37.1	11.3	50,000	-	-	3 berths planned at Duke Head 2 with max draft 44' to be completed by 1980, 3rd by 1995.
	NANAIMO/ASSEMBLY WHARF	36.0	11.0	50,000	Travelling cranes + 5,582 m^2 storage space.		
		33.0	11.6				
	NEW WESTMINSTER/FRASER SURREY DOCKS 5 BERTHS	up to 33.6	up to 10.1	40,000	15,793 m^2 closed storage + 44.5 ha open	-	-
	NEW WESTMINSTER/CROWN ZELLERBACH	30.0			-	-	-
	PORT ALBERNI/MACMILLAN	33.0	10.1	30,000	2 Mobile floating cranes	-	-
	BLOEDEL	39.0	11.0	55,000	-	-	-
	PORT ALBERNI/NEW EXPORT	34.8	10.6	50,000	-	-	-
	BERTHS	40.0	12.2				
	PRINCE RUPERT/NHB	43.0	13.1	65,000	Barge loading ramp	120	-
	SAINT JOHN	34.0	10.4	45,000	-	-	to be completed by 1980.
	VANCOUVER/SEABOARD	40.0	12.2	60,000	-	-	-
	VANCOUVER/NHB	35.1	10.7	50,000	-	-	Also handles ore, concentrates & sulphur
	VICTORIA/NHB 3 BERTHS	35.0	10.7	50,000	-	-	-
	WOODFIBRE/RAYONIER SANADER LTD.	30.0	9.1	35,000	-	-	-
FINLAND	HAMINA	9.8	3.0	10,000	-	-	-
	KEMI/VEITSILUOTO PAPER AND PULP MILL	27.6	8.1	25,000	-	-	-
	KOTKA	30.5	9.0	35,000	Many cranes up to 60 ton capacity	-	-
	MANTYLUOTO	25.9	7.9	25,000	Many cranes up to 200 ton capacity	-	-
	MARIEHAMN	19.7	6.0	15,000	-	-	-
	NAANTALI	23.0	7.0	15,000	Fork lift	1,000M^3	-
	OULU	29.5	9.0	35,000	Mechanical Paper handling facilities	-	-
	PORVOO	45.0	13.5	65,000	-	-	-
GHANA	TAKORADI/GHANA RAILWAY AND PORTS ADMIN.	26.0	7.9	30,000	20x3 ton overhead gantries at sawn timber area, 6x10 ton portal cranes and 1x15 ton derrick at log wharf. 3,000 tons covered storage space.	-	-
INDONESIA	BELAWAN/NHB	23.6	7.2	20,000	1x40 ton floating crane 7x6.10 mobile	-	-
	TANJUNG PRIOK	26.3	8.0	25,000	-	-	-
	TELUK BAYUR	26.3	8.0	25,000	-	-	-
MALAYSIA	KOTA KINABULU	25.0	7.6	25,000	-	-	-
	PORT KELANG	32.0	9.8	35,000	-	-	-

TABLE VI.B-9 (Cont'd)

COUNTRY	PORT/OPERATOR	MAX DRAFT		ESTIMATED MAX SHIP SIZE	FACILITIES	LOAD RATE (TPH)	REMARKS
		FEET	METRES				
NEW ZEALAND	LYTTLETON/CHASIN QUAY No.1	37.7	11.5	55,000	Bulk woodchip loader 30,000 tonnes storage	500	-
NIGERIA	SAPELE/AFRICAN TIMBER AND PLYWOOD CO.	16.1 24.9	4.9 7.6	20,000	Lighterage	-	-
NORWAY	FREDRIKSTAD	33.1	10.1	40,000	Cranage up to 36 ton capacity	-	-
	HEROYA	30'	9.2	20,000	-	-	-
	KRISTIANSAND	33.1	10.1	25,000	-	-	-
	LARVIK/TRESCHOW-FRITZOE PULP QUAY	20.7	6.3	15,000	-	-	-
	MO 1 RANA	36.1	11.0	33,000	-	-	-
	SARPSBORG	24.0	7.3	20,000	-	-	-
PAPUA NEW GUINEA	LAE	32.0	9.8	35,000	-	-	-
	MADANG	32.0	9.8	35,000	Ship's gear	-	-
PHILIPPINES	DAVAO	20.0	6.1	15,000 DWT	Lighterage	-	Berthing facilities limited Vessels normally stand off in deeper water.
	MASINLOK	31.0	9.5	35,000	-	-	-
	ZAMBOANGA	32.0	9.8	15,000 GRT	-	-	-
SINGAPORE	SINGAPORE	34.1	10.4	45,000	-	-	-
SWEDEN	HALLSTAVIK/HOLMENS BRUK A/B	23.0	7.0	20,000	Ships gear + RoRo berth with special equipment for loading newsprint	35-40 for conventional 150 RoRo	-
	NORRKOPING/HOLMENS BRUK A/B	23.0 29.5	7.0 9.0	20,000 35,000	RoRo facilities RoRo facilities	- -	- -
	ORNSKOLDSVIK/MO OCH DOMSJO A/B DOMSJOVERKEN	34.0	10.4	45,000	RoRo Available	60 cbm per gang per day 300 tons per gang and day on conventional vessels	Timber berth
	ORNSKOLDSVIK/MO OCH DOMSJO A/B ALFREDSHEM						
	ORNSKOLDSVIK/MO OCH DOMSJO A/B, HUSUM	34.0	10.4	45,000	RoRo Available	*	See Alfredshem works
	ORNSKOLDSVIK/NORRLANDS SKOGSAGARES CELLULOSA A/B	34.0	10.4	45,000	RoRo Available	*	See Alfredshem works
	PITEA	22.0	6.7	3,000 DWT	Private crane loader.	-	Timber/Paper
	PITEA (HARAHOLMEN)/A/B STATENS SKOGSINDUSTRIER	41.0	12.5		Special forest products loading equipment + RoRo berth.	-	Commenced operations in June 1973.
	SANDVIKEN	24.0 26.9	7.3 8.2	25,000	-	-	Serves seven forest products mills
	SKELLEFTEA/SKELLEFTEHAMN	21.0 24.9	6.4 7.6	20,000	-	-	-
	SODERHAMN/SANDARNE SODERHAMN/STORA ORRSKAR SODERHAMN/STUGSUND	24.0 39.4 20.0	7.3 12.0 6.1	20,000 60,000 15,000	- - Cranage:- 2x3-5, 1x6-10, 1x10.	- - -	- Woodchip terminal. -
	SUNDSVALL	19.0 30.0	5.8 9.1	30,000	-	-	Several berths
	TUNADAL/SUNDSVALL PORT AUTHORITY	30.0	9.1	35,000	2x10 ton cranes. Also accepts RoRo cargoes.	-	-
	UMEA	30.0	9.1	35,000	-	-	-
USA	ANACORTES	30.0	9.1	35,000	-	-	-
	ASTORIA	36.0	11.0	40,000	-	-	-
	BELLINGHAM/NORTHERN TERMINAL	32.0	9.8	35,000	18,560M^2 open storage, 9,290M^2 covered. 2x45 ton rail mounted gantries 1x60 ton floating crane	-	-
	CHARLESTON/WEST VIRGINIA PULP & PAPER CO.	32.0	9.8	35,000	-	-	-
	COOS BAY/CAPE ARAGO LUMBER CO.	24.9	7.6	25,000	No Dock cranes.	600,000 bd.ft. per day	-
	COOS BAY/CENTRAL DOCK CO.	35.1	10.7	40,000	1 bulk woodchip loader	2,000,000 bd.ft. per day	-
	COOS BAY/C.B.P.A.	35.1	10.7	40,000	No Dock cranes	5,000,000 bd.ft. per day	-
	COOS BAY/MCKENNA MILL DOCK	19.0	5.8	10,000	-	500,000 bd.ft. per day	-
	COOS BAY/AL PIERCE LUMBER CO. (MILL 'B') INC.	35.1	10.7	40,000	No Dock cranes available	5,000,000 bd.ft. per day	-
	COOS BAY/AL PIERCE LUMBER CO. (BAYSHORE DOCK)	35.1	10.7	40,000	No Dock cranes available	600,000 bd.ft. per day	-
	COOS BAY/AL PIERCE LUMBER CO (PORTLAND DOCK)	35.1	10.7	40,000	No Dock cranes available	700,000 bd.ft. per day	-

TABLE VI.B-9 (Cont'd)

COUNTRY	PORT/OPERATOR	MAX DRAFT		ESTIMATED MAX SHIP SIZE	FACILITIES	LOAD RATE (TPH)	REMARKS
		FEET	METRES				
USA	COOS BAY/ROSEBURG LUMBER CO.	35.1	10.7	40,000	1 bulk woodchip loader	-	-
	COOS BAY/WEYERHAUSER TIMBER CO.	35.1	10.7	40,000	No Dock cranes Available	2,000,000 bd.ft. per day	Lumber woodchips.
	COOS BAY/DOLPHIN TERMINALS	35.1	10.7	40,000	-	600,000 bd.ft. per day	-
	COOS BAY/FIBREX AND SHIPPING CO. DOCK	35.1	10.7	40,000	1 Pneumatic woodchip loader	-	-
	COOS BAY/GEORGIA PACIFIC LUMBER CO.	35.1	10.7	40,000	1 bulk woodchip loader	-	-
	EUREKA/KRAMER LUMBER SALES CO.	30.0	9.1	35,000	12,000,000 m^2 storage space.	304,800m of timber per day.	-
	EUREKA/OLSON TERMINAL	30.0	9.1	35,000	8,000,000 bd.ft. storage space.	-	-
	EUREKA/HUMBOLDT DOCK & SHIPPING CO.	30.0	9.1	35,000	10,000,000 bd.ft. storage space.	-	-
	EUREKA/LOUISIANA - PACIFIC	30.0	9.1	35,000	2 warehouses.	-	Lumber
	CORP.	35.1	10.7	50,000	Bulk woodchip loader	-	Woodchips
	EUREKA/NORTH COAST EXPORTING CO.	35.1	10.7	50,000	1 bulk woodchip loader	-	-
	EUREKA/CROWN - SIMPSON PULP CO.	35.1	10.7	50,000	RoRo facilities	-	-
	EUREKA/EUREKA FOREST PRODUCTS CO.	30.0	9.1	35,000	-	-	-
	EVERETT/SCOTT PAPER CO.	24.3	9.4	20,000	-	-	-
	EVERETT/WEYERHAUSER TIMBER CO.	30.0	9.1	35,000	-	-	-
	GRAYS HARBOUR/TERMINALS	35.1	10.7	50,000	Lumber cranes stackers, pilers.	-	-
	JACKSONVILLE/JPA	34.1	10.4	45,000	-	-	-
	MOBILE/MPA	40.0	12.2	60,000	-	-	-
	OLYMPIA	35.1 40.0	10.7 12.2	50,000 DWT	2 50 ton cranes	-	-
	PORT ANGELES	28.0 38.0	8.5 11.6	35,000	-	-	-
	PORTLAND/PPA	40.0	12.2	60,000	2 Whirley cranes	-	-
	PORTLAND/GEORGIA	30.0	9.1	-	-	-	-
	PACIFIC LUMBER CO.	35.0	10.7	50,000	-	-	-
	PORTLAND/LINNTON	50.0	9.1	-	Pneumatic bulk woodchip	-	Mainly Fir & Pine.
	CHIP DOCK	35.0	10.7	50,000	loader	-	-
	SAVANNAH/G.P.A.	38.0	9.1	35,000	-	-	-
	SEATTLE	30.0	9.1	35,000	-	-	-
	TACOMA/TPA	40.0 50.0	12.2 15.2	65,000	-	-	-
USSR	ARCHANGEL	26.0	7.9	25,000	Mobile cranes upto 20 tons, floating cranes upto 50 tons.	-	-
	IGARKA	24.0	7.3	20,000	Ships gear	-	A new port capable of exporting 896,000 cu.m. of wood per year is planned
	KLAIPEDA	26.3	8.0	25,000	Mobile cranes upto 45 tons capacity floating cranes upto 50 tons.	-	Extensive re-construction underway.
	LENINGRAD	34.5	10.5	45,000	Fixed & mobile cranage upto 45 tons cap. floating cranage upto 50 tons capacity.	-	-
	NAKHODKA	31.8	9.7	40,000	Cranage upto 45 tons capacity.	-	-
	VOSTOCHNY	39.4	12.0	60,000	Bulk timber loading facilities	-	Capable of loading 375,000 cu.m. of round timber per year.
	VOCTOCHNY	39.4	12.0	60,000	High pressure pneumatic woodchip loader	800	The port began operations during 1978
	VYBORG	21.3	6.5	15,000	Cranage upto 15 tons capacity.	-	-

Source: H.P. Drewry Ltd., "Deep-Sea Trade and Transportation of Forest Products", London, 1979.

TABLE VI.B-10 FOREST PRODUCT DISCHARGING PORTS

COUNTRY	PORT/OPERATOR	MAX DRAFT		MAX SHIP SIZE	FACILITIES	DISCHARGE RATE (TPH)	REMARKS
		FEET	METRES				
BELGIUM	ANTWERP/APA	44.6	13.6	65,000	518,073 sq.m. covered storage	-	-
	GHENT/GPA	40.4	12.3	60,000	-	-	-
FRANCE	DUNKIRK/DPA	32.8	10.0	45,000	2x6 ton, and 2x10 ton cranes	-	-
	MARSEILLES/MPA	34.5	10.5	50,000	-	-	-
	ROUEN/CHARLES BABIN DOCK	29.5	9.0	35,000	2x8 ton cranes	-	Lumber
	ROUEN/AUX BOIS DOCK	24.6	7.5	30,000	12x7.5 ton & 2x6 ton cranes	-	Newsprint
	ROUEN/PAPER MILL	24.0	7.3	30,000	2x3 ton cranes	-	Paper
	ROUEN/SAMS	26.9	8.2	30,000	2x6 ton, 4x5 ton, 2x2 ton cranes 2x8 ton gantries	-	Woodpulp, paper wood
ITALY	GENOA	36.0	11.0	50,000	-	-	-
	VENICE	30.0	9.1	35,000	-	-	-
JAPAN	CHIBA/KEIYO LUMBER	39.4	12.0	40,000	-	-	-
	CHIBA/MITSUBISHI LUMBER	39.4	12.0	40,000	-	-	-
	FUSHIKI	32.8	10.0	35,000	-	-	-
	HACHINOHE	31.2	9.5	40,000	-	10,000 bm	Logs
	HAKATA	39.4	12.0	40,000	486,000 sq.m. storage space.	35	-
	HIMEJI	32.8	10.0	15,000	110 ton level crane, 175,000 sq.m. timber pond 28,000 sq.m. timber yard	-	-
	INNOSHIMA	29.5	9.0	35,000	-	-	-
	ISHINOMAKI	29.5	9.0	35,000	-	-	-
	IWAKUNI/SINMINATO WHARF		5.5	15,000	-	-	New 10m depth wharf under construction.
	IWAKUNI/MURUNOKI WHARF	32.8	10.0	35,000	-	-	-
	IWAKUNI/SANYO PULP CO.	34.5 37.7	10.5 11.5	45,000	Lumber and chip cranes	-	-
	KAGOSHIMA	30.0	9.1	19,000	-	-	-
	KOBE	33.8	10.3	35,000	-	-	-
	NAGOYA/NPA	32.8	10.0	35,000	3,111,524 sq.m. storage space	-	-
	OSAKA/OPA	24.6	7.5	3,000 GRT	-	-	-
	SHIMIZU/SPA FUJIMI	29.5	9.0	35,000	3 bulk woodchip unloaders	-	-
	SHIMIZU/SPA SODESHI	32.8 39.4	10.0 12.0	45,000	2 bulk woodchip unloaders	1,200	-
	SHIMONOSEKI	29.5	9.0	35,000	-	-	-
	TOKYO	30.0	9.1	35,000	7 berths	-	-
	YOKOHAMA/KANAZAWA	32.8	10.0	15,000 GRT	630,256 sq.m. storage space	-	-
	YOKOHAMA/MITSUI & CO./HONMOKU WHARF.	36.1	11.0	30,000 GRT	-	-	-
NETHERLANDS	AMSTERDAM/APA	32.8	10.0	35,000	238,825 sq.m. storage space 15,000 sq.m. warehouse space Cranage upto 35 ton capacity.	-	Automatic timber sorting installation available.
	ROTTERDAM	36.4	11.1	46,000	-	-	-
WEST GERMANY	BREMEN/GEBR ROCHLING KOHLENHAFEN	32.0	9.8	35,000	3x18 ton cranes.	-	Also handles bulk coal, ore and phosrock.
	HAMBURG	30.0 36.0	9.1 11.0	40,000	-	-	-
UK	BRISTOL/BPA	26.6	8.1	30,000	-	-	-
	HARTLEPOOL/HPA	30.0	9.1	18,000	Cranage upto 10 ton capacity 200 acres storage space.	-	Handles over 500,000 tons of forest products per year
	HULL	32.8	10.0	35,000	-	-	-
	LIVERPOOL/LPA	49.9	15.2	66,000	16 acres storage space	-	Packaged forest products
	LONDON/PLA BERTH 34.	42.7	13.0	40,000	Total berth area of 12 acres	-	Handled over 200,000 tons of forest production in 1977
	NEWPORT	33.5	10.2	35,000	40 acre purpose built terminal	-	Monthly hardwood imports from Malaysia
	SHEERNESS/MPA	22.0	6.7	15,000	Cranage upto 6 ton capacity	-	Pulp Paper & Logs.
	SOUTHAMPTON	38.4	11.7	45,000	-	-	Imports over 100,000 Tonnes p.a. of North American newprint and other forest products
	TILBURY BERTH 42 CANADIAN TRANSPORT	38.1	11.6	40,000	Total berth area of 21.5 acres	4,000 tonnes per day	Forest Products trade from Canada.
	TILBURY BERTH 44/SVENSKA TERMINAL	38.1	11.6	40,000	23,000 sq.m. storage space RoRo facility available.	-	Handles 400,000 tonnes of pulp & paper p.a. trades with N.Sweden, US, Canada.
	TILBURY BERTH 46/46A/SEABOARD SHIPPING SERVICES LTD.	38.1	11.6	40,000	3.4 acres covered storage space	-	Handles over 450,000 tonnes of pulp, plywood & paper p.a. trades with WCUS/WC Canada
USA	BALTIMORE	38.1	11.6	45,000	-	-	-
	BOSTON/CASTLE ISLAND TERMINAL/MPA	35.0	10.7	40,000	20 acres storage space.	-	-
	NEW YORK/PORT NEWARK	35.0	10.7	40,000	-	-	-
	NORFOLK	35.C	10.7	40,000	-	-	-
	SAN FRANCISCO/BERTH 15-17	35.0	10.7	40,000	-	-	Newsprint dock.
	SAN FRANCISCO/BERTH 45 A-C	35.0	10.7	40,000	-	-	Newsprint pulp dock.

Source: H.P. Drewry Ltd., "Deep-Sea Trade and Transportation of Forest Products", London, 1979.

VI.B.6.1 Alternative Manufacturing Processes

The applicability of each manufacturing process depends on a variety of factors, the most important being the availability of raw materials and the types of the desired end-products. The advantages and disadvantages of the thermomechanical (TMP) and sulphate (kraft) pulping processes will be presented here with emphasis on their employment for small mills in developing countries. These two processes were selected, as being the most widely adopted.

The major advantages of the TMP process are:

(a) Small production units are feasible for commercial adoption, thus minimizing capital outlay;

(b) Fiber yield is high at about 92-93% of input. High yield reduces the cost of wood material used;

(c) Wood chips and residues from sawmills can be accepted as the only wood raw materials input. Costly procurement systems and chipping operations can be eliminated;

(d) The system generates relatively low waste flow, BOD, and TSS. Thus capital outlay for pollution control is comparatively small;

(e) Both water requirements and wastewater volume are low, making the selection of a mill site comparatively easier than for chemical processes.

However, all mechanical processes are subject to five limitations:

(a) A stable brightness above 80 percent is not obtainable, and any brightness improvement achieved is rapidly lost by exposure of the paper to sunlight;

(b) A paper strength adequate for packaging paper is not obtainable;

(c) Paper containing mechanical pulp will become brittle and yellow after a number of years and is therefore not suitable for books or important documents;

(d) Mechanical pulps are energy intensive, while chemical pulps are nearly energy self-sufficient;

(e) Mechanical processes can pulp only softwood.

For developing countries, on the other hand, the kraft process has the special attraction that almost any wood can be used - hardwood as well as softwood. It is also possible to process a blend of species without great inconvenience. Unbleached softwood kraft pulp is unsurpassed for packaging papers (sack paper, wrapping paper, liner), while bleached hardwood pulp is a soft, opaque, easily refined pulp of high and stable brightness, suitable for printing paper, tissue and paperboard.

Still, especially in developing countries, there are reasons for avoiding this process where possible because of:

(a) The scale factor: Owing to the advanced technology used in kraft pulping which is applicable only to large plants*, a small pulp mill is not competitive with a large one. In 1972, it was computed that a bleached kraft mill for 35,000 tons per annum (t/a) would cost 2.6 times as much per daily ton as one for 350,000 t/a. Today, this ratio is probably higher. For a mechanical pulp mill the capital cost is only 25 percent of that of the kraft mill, and the specific cost increases more slowly as the plant size is reduced;

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*The standard size of new kraft plants, ranges from 500 tons per day (t/d) to 1,000 t/d.

(b) Availability of chemicals: It may sometimes prove difficult to ensure reliable deliveries of the chemicals and raw materials needed in kraft pulping and bleaching;

(c) Technology: Kraft pulping involves a number of chemical processes, all of which must be controlled very strictly. In an isolated small mill it may prove difficult to establish the necessary standard of supervision;

(d) Ecology: In a developed country, even a small kraft mill poses almost insurmountable ecological difficulties because of the exorbitant cost of the required antipollution measures. The difficulties are caused mainly by the use of sulphur in the process, but sulphur is the prerequisite for the favorable quality mix exhibited by kraft pulps. In developed countries small kraft mills are being closed down or rebuilt into large, modern units, and the development of new antipollution technology is geared exclusively to the needs of the latter type of plant. The same goes for the pulping technology.

Thus, it is not likely that a small kraft mill built today in a developing country will ever be able to compete economically with a large kraft mill built in a developed country in the early 1970s or even earlier.

The conclusion seems to be that when small kraft mills are built in developing countries, something which cannot be entirely avoided, one should, from the start, count on their being uncompetitive on the world market. However, such ventures may still be justified because of the effect on the industrial structure of the country, reforestation,and the labor or foreign exchange situations.

The Food and Agriculture Organization of the United Nations has suggested in a 1979 paper* that in cases where small kraft mills in developing countries cannot be avoided, the only effective way to reduce the capital cost is to go back 30 to 40 years in techniques and build the type of simple mills used then, although to do so would result in increased operating costs. The advantages of these simple mills would be increased employment, relatively easy operation of the plants and lower demand of spare parts, which could be partly made locally either in the mill maintenance shop or in local machine works. A very important aspect would be reduced need for highly skilled operators and thus reduced need for training. Countries with cheap labor would be benefited the most. However, these mills should be designed initially so that energy- and chemical-saving equipment can be added later when the enterprise considers it to be economically advisable and can afford it.

VI.B.6.2 Plant Siting

Siting of pulp and paper mills is determined mainly by the following factors: transport economics, water supply, and degree of integration.

As has been shown in Section VI.B.5, transport economics suggest the locating of prime wood processing industries (in this case pulp mills) close to the source of wood in order to produce a higher-value, more economically transportable product. In addition, local processing is preferable in that it encourages industrial development and local know-how, improves employment possibilities and aids the economy as greater value is added to the finished product with a consequent gain in foreign exchange earnings.

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*U.N., Food and Agriculture Organization, "Prospects for establishing viable small-scale pulp and paper industries in developing countries", UNIDO series: Monographs on Appropriate Industrial Technology, No. 3, New York, 1979.

The second important factor in locating a pulp and paper mill is the water supply, as the quantities required can be very high, especially for chemical pulps. For example, in the large bleached kraft pulp mills, water requirements are in the range of 150 to 200 cubic meters per ton, which means that for a 750-ton per day bleached sulphate pulp mill the water requirement would be of the order of 100,000 to 150,000 cu m per day. This is for use in process; a much larger amount is required at the same mill to dilute the effluents in order not to create a pollution nuisance. Such a mill obviously must be situated on a large body of water. The water requirements for mechanical pulp and paper mills are generally much lower. If paper mills are integrated with pulp mills, most of the paper mill process effluent is recycled to the pulp mill process stages.

The problem of water supply is complicated by the fact that the flow in most natural bodies of water is highly variable. This is particularly true of those lakes and rivers affected by the spring runoff of melting snow from the mountains, as in most northern forested areas, or in those tropical regions which are subject to monsoons. In both cases the flow of water available is very variable; it may be a flood proportions during periods of high runoff or heavy monsoons, and may fall to a trickle during other periods of the year. Therefore, water flow records must be kept over a long period of time, and provisions for water supply, storage, intake and outfall must recognize this variability. The variable flow is also normally accompanied by large quality variations. During periods of very high flow the streams are usually turbid and quite unsuitable for use in the raw state, as process water must be very poor and almost colorless especially when making bleached pulp or white papers.

The water, thus, must be completely filtered, because suspended solids in process water not only discolor and add undesirable materials to products but vastly multiply maintenance problems for pumps and other mechanical equipment.

Where other resources are not available, pipelines 5 to as much as 25 kilometers long, or deep wells are used. Where water quality is very poor, such as near the mouths of large rivers in highly industrialized areas, wells may prove to be economically advantageous.

Siting of paper mills is determined basically by the degree of integration of the industry, as well as transport and production economics. Integration of the pulp and paper industry depends mainly on the type of raw materials available and the type of end-products desired. Wastepaper mills and mills using non-wood fibrous raw materials are usually integrated, and the paper and pulp mills are located at the same site. On the other hand, paper mills producing speciality papers are usually non-integrated, as these mills use many kinds of pulps coming from different plants.

An OECD study* reports that newsprint, kraftliner, semi-chemical fluting, sack kraft board, and kraft board are usually manufactured in fully integrated operations. Printing and writing paper is rapidly moving towards a higher degree of integration, too. In the same study it is mentioned that in typical importing countries 20-40 percent of paper production is integrated, while in typical exporting countries similar figures are 85-95 percent. In general, integration in the pulp and paper industry is expected to increase, as it usually reduces the operating costs. Transportation costs, however, increase since shipment of paper products is more costly than that of pulp.

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*OECD Secretariat, "Integration in the Pulp and Paper Industry in OECD Countries", Paris, 1982.

VI.C Pulp and Paper Mill Descriptions

VI.C.1 Bleached Sulphate Pulping Mill

This mill, with a production capacity of 230,000 tons per year, began operations early in 1967. It is owned by Domtar Ltd., and is located in Lac Quevillon, Quebec, Canada, about 640 km north of Montreal, surrounded by extensive stands of timber, predominantly black spruce (Picea mariana). Forest studies have shown that there is sufficient wood available within 40 kilometres of the mill to last the first 25 years. Approximately 30 percent of the mill's pulp production is utilized in Domtar's own paper mills, the balance being sold in North American and world markets.

Pulpwood is brought to the mill from Domtar's timber holdings supplemented by pulpwood purchases from local farmers and chips from local sawmills. Tree-length pulpwood is delivered to the mill on a 24-hour basis the year round. The wood is slashed to 2.4-metre lengths and debarked in one of three barking drums, each 20 metres long by 4 metres in diameter. The barked wood is chipped in a 15-knife chipper, and the screened chips blown either to the digester or to storage. The outside chip storage pile has a capacity of about 220,000 cubic metres.

The single 750-ton per day digester has a shell 5.2 metres in diameter and 57.5 metres high. This includes an internal washing zone where the pulp is washed for 90 minutes. The digester has two chip-feeding lines, each comprising a chip hopper, chip meter, low-pressure feeder, steaming vessel, high-pressure feeder, and a top separator. All heaters are external. Cooked pulp stock is blown to a 125-ton capacity (four hours of production) blow tank from which it is passed through a magnetic trap to four knotters, the knots being recycled to the digester. Accepted unbleached pulp is washed on two drum vacuum washers, 4.26 metres in diameter by 7.9 metres in face length, arranged in series. The pulp then goes through three stages of screening through rotary screens, and four stages of centrifugal cleaners. It is then thickened and fed to a high-density storage tank which holds 225 tons, about seven hours of production.

Filtrate from the unbleached pulp washers, weak black liquor, contains about 16 percent solids. It also contains malodorous sulphur compounds, which are treated with air in an oxidation tower. This step also reduces the requirement of make-up sodium sulphate. The oxidized weak black liquor is evaporated in a six-effect evaporator plant to 50 percent solids. The strong black liquor is further evaporated in a direct contact evaporator, make-up saltcake is added, and the liquor is fired at about 65 percent solids to a furnace. The furnace boiler produces 200 tons of steam per hour at 25 atm and 330^{o}C. The boiler is equipped with scrubbers containing strong black liquor to remove the sodium salts from the flue gases. In the furnace, the organic matter converts the sodium salts in the spent liquor and the make-up sodium sulphate to sodium sulphide and sodium carbonate. Smelt from the furnace bottom is transferred by water-cooled spouts to a dissolving tank, where water is added. The resulting green liquor is first clarified and then treated with reburned lime in a slaker; the causticizing action continues in a series of tanks. In these, by the action of the lime, the sodium carbonate is converted to sodium hydroxide, and this together with the sodium sulphide are the active pulping chemicals. The lime forms a calcium carbonate lime mud which is washed and filtered and burned in a kiln 3.5 metres in diameter and 85 metres long.

Following the high-density storage tank, the pulp is bleached. The bleach plant has six stages arranged in the following sequence: chlorination - caustic extraction - sodium hypochlorite - chlorine dioxide - caustic extraction - chlorine dioxide. There is provision for the future addition of a hydrogen peroxide stage. Each bleaching stage is carried out in a tower; sizes of towers differ from stage to stage - diameters vary from 5 to 6 metres, and heights from 20 to 30 metres. Each stage is followed by a large rotating drum vacuum washer, 4 metres in diameter by 8 metres across the face. Subsequent to the final stage of bleaching, the pulp is treated with sulphur dioxide to neutralize residual bleaching agents. The stock is then pumped to one of two 125-ton high-density storage tanks which together hold eight hours' capacity.

Bleached pulp from the high-density storage tanks is screened by pressurized centrifugal screens, followed by a three-stage centrifugal cleaning system. From the machine chest, the pulp is distributed to an open headbox, from which it flows to a Fourdrinier wire. The wire is 6 metres in width and 32 metres in length, of which the forming section is 10 metres. The speed can be varied from 60 to 150 metres per minute. The basis weight of the sheet can be varied from 650 to 1,000 grammes per square metre, 775 grammes per square metre being standard.

The suction couch is followed by three presses, one suction and two grooved, and includes four predryers between the second and third presses. The airborne dryer is 21 decks high and is equipped with 208 circulating fans to provide the air flow necessary to dry the sheet. The hot sheet leaving the dryer is cooled, also by an air flow, to about 35°C. The pulp then passes directly to a cutter which trims at 5.7 metres, producing seven sheets 81 centimetres wide. The stacked sheets from the layboy are conveyed on two parallel bale-handling lines to two 1,000-ton hydraulic presses for sheet compaction. The pressed bales are wrapped, tied, stamped and automatically conveyed to the warehouse, which has a capacity of 12,000 tons of baled pulp. Rail cars are loaded indoors.

A chemical plant provides all bleaching material. It includes a mercury cell chlorine and caustic soda plant and an electrolytic sodium chlorate plant.

The Lac Quevillon mill uses 200,000 cubic metres of water per day. Of this quantity, about 40,000 cubic metres are treated in a clarifier with lime, a coagulant and alum and passed through sand filters to control the pH and remove colour and turbidity. The bulk of the water intake to the mill is simply fine-screened. A separate potable water system is provided.

Power is purchased from a public utility, stepped down through a substation and a series of transformers to local substations located in the various departments of the mill. In addition to the steam supplied by the recovery boiler, the mill has a power boiler operated on fuel oil and rated at 150 tons of steam per hour. About 90 tons per hour of generated steam are used in turbine drives throughout the mill, on pumps, the emergency power generator, boiler draft fans and air compressors. Air compressors supply 100 cubic metres of air per minute for the mill.

Shops, stores and offices are provided, along with spare parts, mill-operating supplies and machine shops. The office space includes engineering, maintenance, instrument, laboratory and production cost accounting departments, supervisory offices, purchasing, personnel, accounting, plant management and the company's woodlands division management.

Source: Food and Agriculture Organization (FAO) of the United Nations, "Guide for Planning Pulp and Paper Enterprises", Rome, 1973.

VI.C.2 Island Paper Mills, New Westminster, B.C., Canada

While this paper mill is a division of MacMillan and Bloedel Limited, one of the world's largest integrated forest industries, the mill itself is small. It has one paper machine designed for 70 tons per day, planned to serve local markets. It produces printing (bond and book), writing, envelope and other fine papers. It is located on an island at the mouth of the Fraser river, adjacent to the city of Vancouver, B.C., the largest population centre in western Canada.

The mill makes a wide variety of papers and therefore uses a large selection of domestic and imported pulps of west coast softwoods and hardwoods. These are mostly chemical pulps, but some brightened cottonwood (Populus trichocarpa var. hastaia) groundwood is also used. Bales of pulp are pulped batchwise on a 1-ton, 15 to 30 minute cycle; clay filler and dyes are added, as required, at the pulper. Four refiners, each equipped with a 200 hp (149 kW) motor, are available and, when the predetermined "freeness" is obtained, the pulp is added to a blending tank. Alum and rosin are mixed in, and then the blend is dumped into a machine chest. All operations to this point are batch; the fibrous stock is cycled through the refiners until the desired quality is obtained. A central control panel programs and records each batch.

From the machine chest on, the process is continuous. A consistency regulator controls the amount of fibre fed to two 250 hp (186 kW) Jordan refiners which complete the refining process. From the Jordans the stock passes to a fan pump stuff box. The fan pump, rated at 25,000 litres per minute and driven by a 350 hp (261 kW) motor, forces the stock through a bank of centrifugal pulp cleaners and enclosed screens to the stock inlet of the paper machine.

The stock inlet is an air-pressure controlled enclosed type, equipped with two distributor rolls and an auxiliary slice. The hydrostatic head is held constant in order to ensure uniformity of sheet formation on the wire.

The Fourdrinier wire is 3.05 metres (120 inches) wide and has a nominal length of 29 metres (95 feet). It is oscillated from side to side by a shake mechanism. There are 32 rubber-covered table rolls and 7 flat suction boxes. Drainage control deflectors of stainless steel with plastic tops are located between the first 11 table rolls. A driven dandy roll has a spiral wrapped mesh. The suction couch roll is drilled with a special noise-reducing pattern.

White water from the Fourdrinier wire drains from pans into a sump to which the suction of the fan pump is connected. Excess white water beyond that required for stock dilution is cleaned in a saveall. Stock carried by air to the surface of the liquid in the saveall is scraped off and recovered. Clear water from the saveall is used in place of fresh water in a variety of mill operations.

The paper machine has three presses, the first being a straight-through suction press and the second a reversing suction press. The third is a plain smoothing press with a brass bottom roll and a rubber-covered top roll. The suction press rolls are all rubber-covered and are also drilled with a special noise-reducing pattern.

The paper dryer is divided into three sections, the first two having a total of 23 main dryers and 4 felt dryers. High-velocity air hoods assist these dryers. A horizontal size press consisting of a rubber-covered "bottom" roll and a bronze "top" roll is followed by 8 main dryers and 2 felt dryers.

All dryers are 1.5 metres (60 inches) in diameter, 3 metres (118 inches) face and made of cast iron, mounted on antifriction bearings and driven by opencast iron gearing. A central lubricating system serves the presses and calender stacks as well as the dryers.

There are two calender stacks, each with 10 rolls, equipped for hydraulic loading. Loading of the primary and secondary arms of the reel is also accomplished by hydraulic means, and the primary arms return automatically for the next reel bar. The winder operates at 760 metres (2,500 feet) per minute.

The drive for the machine is mechanical, and consists of a steam turbine-driven main line shaft serving the 11 sections of the machine through cone pulleys and belting. Draw is adjusted by belt shifters. All controls for the machine are situated in consoles in front of each machine section. The machine is equipped with an open hood and fresh air, and recirculated air may be proportioned in the building.

From the winder the paper rolls can follow any one of five production lines: they can be split and rewound on a rewinder, stored against future orders, shipped, or they can pass to a supercalender, or to a cutter and layboy for sheeting. There are two trimmers. An automatic sheet counter marks every specified number of sheets.

The supercalender is in the basement and the top roll is just above the machine room operating floor. The stack consists of alternate steel and paper rolls, and the paper can make a maximum of five passes at a maximum loading of 178 kilogrammes per linear centimetre (1,000 pounds per linear inch) between the rolls.

The mill is built on piles. Reinforced concrete columns, beams and floor slabs are used in the paper machine room, and laminated timber roof beams are also extensively employed.

Electric power for the mill is purchased, all drives being electric except for the 500 hp (373 kW) steam turbine, which is the prime mover for the paper machine drive. The turbine uses steam at 28 kilogrammes per square centimetre (400 psig) and 455°C (850°F) and the exhaust steam at 3.5 kilogrammes per square centimetre (50 psig) is used in the paper machine dryers. One gas or oil-fired boiler produces 13,600 kilogrammes (30,000 pounds) of steam per hour.

Water for the mill comes from the Fraser river, which is subject to tidal variations at the mill site and carries much debris. Water is taken from near the surface to avoid salt from the ocean, and is subjected to floccing, settling and filtering of the settled water through pressure sand filters.

The paper machine operates at 45 to 450 metres (150 to 1,500 feet) per minute and produces papers at a basis weight of 40 to 320 grammes per square metre (25 to nearly 200 pounds, 3,000 square foot basis). About 200 grades are made altogether, including different weights, colours, finishes and special treatments. Grades include bond, book, offset, map, tag, bag, envelope, teletype, register, bristol, writing tablet, mimeograph, duplicator, lithograph, stationery and wrapping.

Source: Food and Agriculture Organization (FAO) of the United Nations, "Guide for Planning Pulp and Paper Enterprises", Rome, 1973.

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