Phase 1: marketing, transportation, process technology. v. 2

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EXXON MINERALS COMPANY USA

HOUSTON, TEXAS

CRANDON PROJECT

PYRITE PROCESSING STUDY

PHASE I

MARKETING

TRANSPORTATION

PROCESS TECHNOLOGY

NOVEMBER 1979

2489/0

Davy McKee
ENGINEERS AND CONSTRUCTORS

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ENGINEERS AND CONSTRUCTORS

February 8, 1980

Exxon Minerals Company, U.S.A.
P.O. Box 2180
Houston, Texas 77001

Attention: K. Marc LeVier

Subject: Pyrite Processing Study - DMC 2489
Final Reports, Phase I and Phase II

Gentlemen:

Enclosed herewith is one (1) copy each of the final edition of the Phase I Report and Phase II Report covering the Pyrite Processing Study. Each report is bound in loose leaf form for easy revision. If for any reason, revisions are made we will issue dated revised sheets for easy replacement for the outstanding report books.

Please feel free to candidly comment on the reports and we will revise as necessary.

At this time, only you and Barry Hansen will receive copies of the final reports. Additional copies will be forthcoming as requested.

The Summary Report is in Barry Hansen's hands and we await his comments.

If you have any comments, please advise.

Very truly yours,

Arthur L Raub

Arthur L. Raub
Sr. Project Manager

ALR:lb
Enclosures
cc: B.J. Hansen, Exxon/Rhinelander (w/encl)
C.B. Earl
J.V. Beall
J.P. Dempsey

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EXXON MINERALS COMPANY, USA
PYRITE PROCESSING STUDY

PHASE I

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EXXON MINERALS COMPANY, U.S.A.

PYRITE PROCESSING STUDY

PHASE I

1. Introduction

Exxon Minerals Company, U.S.A., is considering the possibility and viability of developing a large, complex, massive sulfide ore deposit of zinc, copper and lead, situated in the north woods of the state of Wisconsin in the county of Forest near the town of Crandon. The ore deposit contains large amounts of pyrite along with the metal values, which are processed in a flotation mill concentrating the zinc, lead and copper to an acceptable level for final extraction of the metals. The waste product from the mill, called tailings, normally are deslimed with the coarser portion (sands) going back to the mine as fill, and the finer fraction going to a tailings pond for settling and water reclamation.

Due to the pyrite content in the ore, and eventually in the tailings, tailings disposal in this manner not only causes a major public and environmental concern due to the potential acidic nature of the effluents but also is considered by some to be barren, and a natural resource that may be treated to produce other marketable products. Therefore, Exxon is seeking alternatives to surface disposal of these tailings. One alternative is to further treat the tails from the concentrator by making a pyrite flotation, separating the sand from the pyrite and further separating the coarse fraction of the sands and coarse pyrite as mine fill. The fine fraction of the sands would go to a tailings pond, and the fine fraction of the pyrite concentrate would be subject to further processing.

The Pyrite Processing Study has to deal with this portion of the Exxon project:

> In order to recover the natural resources in the pyrite, how can Exxon Minerals Company, U.S.A., dispose of approximately 800 MTPD of pyrite slimes, of -20 micron particle size, in an economically, technically and environmentally sound manner?

In order to answer this question, Exxon Minerals Company, U.S.A., through its study engineers, utilizing the study logic diagram, Figure 1, has objectively related to the following:

a. Feasibility of marketing a separate pyrite flotation concentrate without further treatment.

b. Feasibility of marketing those primary products which could result from the processing of pyrite concentrates.

c. Feasibility of marketing secondary products produced from the further processing of primary products.

d. Technical feasibility of producing these products with commercially proven processes.

e. Will the further processing of the pyrite concentrates create less, equal, or more concern about the environment than the original concern?

The study is divided into three volumes: The Summary, Phase I Report and Phase II Report. Phase I is comprised of three (3) areas of endeavor:

- Marketing (including 320,000 MTPY of sulfuric acid from zinc refinery)
- Transportation
- Process Technology
  - Identification
  - Selection

Phase II is comprised of three (3) areas of endeavor:

- Capital Costs
- Operating Cost
- Revenues

Crandon Pyrite Concentrates

The estimated Crandon material balance indicates a pyrite flotation concentrate of 3128 MTPD (3440 STPD) split up into two fractions of 2364 MTPD (2600 STPD) of +20 micron pyrite sands and 764 MTPD (840 STPD) of -20 micron material (slimes) with a size and chemical analysis as shown in Tables I and II. It is contemplated to utilize the 2364 MTPD (2600 STPD) of +20 micron materials as mine fill and to study the marketing or further processing of the -20 micron material. As an alternate, it is planned to study the marketing or further process the total pyrite flotation concentrate of 3128 MTPD (3440 STPD).

If the market for pyrite concentrates in the United States and North America indicates that it can not be profitably sold due to its limited usage, location and transporation costs, then the study will consider what further processing is necessary to make products that may be marketable.

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Stringer Pyrite Concentrate - Minus 20 Micron Slime

Particle Size	% Retained Individual	% Retained Cumulative	% Passing Cumulative
+ 29.6 micron	0.4	0.4	99.6
22.9	1.1	1.5	98.5
16.0	12.0	13.5	86.5
11.0	23.0	36.5	63.5
8.5	11.9	48.4	51.6
- 8.5	51.6	100.0	-
Total	100.0	-	-

Specific Gravity 3.97

Massive Pyrite Minus 20 Micron Slime

Particle Size	% Retained Individual	% Retained Cumulative	% Passing Cumulative
+ 21.4 micron	0.3	0.3	99.7
14.9	2.2	2.5	97.5
10.3	18.1	20.6	79.4
7.9	19.1	39.7	60.3
- 7.9	60.3	100.0	-
Total	100.0	-	-

Specific Gravity 4.49

TABLE I

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CALCULATED CHEMICAL ANALYSIS OF PYRITE CONCENTRATE

	Assay, %	
Element	Slime (-20 micron)	Sand (+20 micron)
Fe	43.60	42.10
Cu	0.12	0.21
Ni	0.0035	0.0034
Pb	0.123	0.119
Zn	0.66	0.29
Bi	0.010	0.018
Cd	0.0022	0.0010
Cr	0.0034	-
Co	0.017	0.017
Mn	0.019	0.012
Hg	0.0004	-
Mo	0.0004	0.0013
Ti	0.038	0.035
Sn	0.001	0.002
Te	0.0048	0.029
S	49.12	51.34
SiO_2	2.20	4.62
Al_2O_3	0.52	1.13
CaO	0.073	0.030
MgO	0.56	0.40

TABLE II

Products from Pyrite (See Products Logic Diagram, Figure 2)

Pyrite (FeS_2) is considered of commercial value only because of its sulfur content and is some times used as raw material in the manufacture of sulfuric acid. Under certain conditions and special situations elemental sulfur may also be produced.

Other components may play an important part in the commercial use of pyrite. The recoveries of some nonferrous components such as copper, nickel cobalt, gold and silver, etc., may make the operation economical. Low slagging components (SiO_2 and Al_2O_3) in the pyrite might also provide an excellent iron oxide for blast furnace feedstocks. Otherwise, impurities may convert the iron residues into a waste disposal problem.

Using proven commercial technology it is possible to process pyrite under one or more of the following schemes:

Pyrite (FeS_2)	to	S + FeS
	or	S + slag
	or	SO_2 + iron oxide
SO_2	to	Sulfuric Acid
Sulfuric Acid	to	Fertilizers

Some of the products that might be produced from the Crandon pyrites utilizing the routes above are listed as follows:

1.1 CRANDON POTENTIAL PRODUCTS

BASE CASE

Primary Products

Pyrites (slimes)	267,400 MTPY (294,500 STPY)
Sulfur (total pyrites)	134,000 MTPY (147,400 STPY)
H_2SO_4 (100%) - pyrites	400,000 MTPY (440,000 STPY)
H_2SO_4 (100%) - pyrites + zinc(1)	720,000 MTPY (792,000 STPY)
Iron pellets (65.2% Fe)	180,000 MTPY (198,000 STPY)
Liquid Sulfur Dioxide	267.400 MTPY (294,500 STPY)

Secondary Products

Phosphoric acid (54% P_2O_5)	480,000 MTPY (528,000 STPY)
Diammonium Phosphates (18-46-0)	562,000 MTPY (618,000 STPY)
Gypsum	2,400,000 MTPY (2,640,000 STPY)

Supporting Supplies

Phos rock (32% P_2O_5)*	810,000 MTPY (891,000 STPY)
Ammonia (anhydrous)*	125,000 MTPY (137,000 STPY)

*The above major supplies are required to produce the secondary products - phosphoric acid, diammonium phosphate and byproduct gypsum.

(1) 320,000 MTPY from the proposed zinc refinery

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CRANDON POTENTIAL PRODUCTS

ALTERNATE CASE A

Primary Products

Pyrites (slimes and sands)	1,094,000 MTPY	(1,203,400 STPY)
Sulfur (total pyrites)	547,000 MTPY	(601,700 STPY)
H_2SO_4 (100%) - pyrites	1,694,000 MTPY	(1,863,400 STPY)
H_2SO_4 (100%) - pyrites + zinc(1)	2,014,000 MTPY	(2,215,400 STPY)
Iron pellets (65.2% Fe)	718,000 MTPY	(789,800 STPY)
Liquid sulfur dioxide	1,094,000 MTPY	(1,203,400 STPY)

Secondary Products

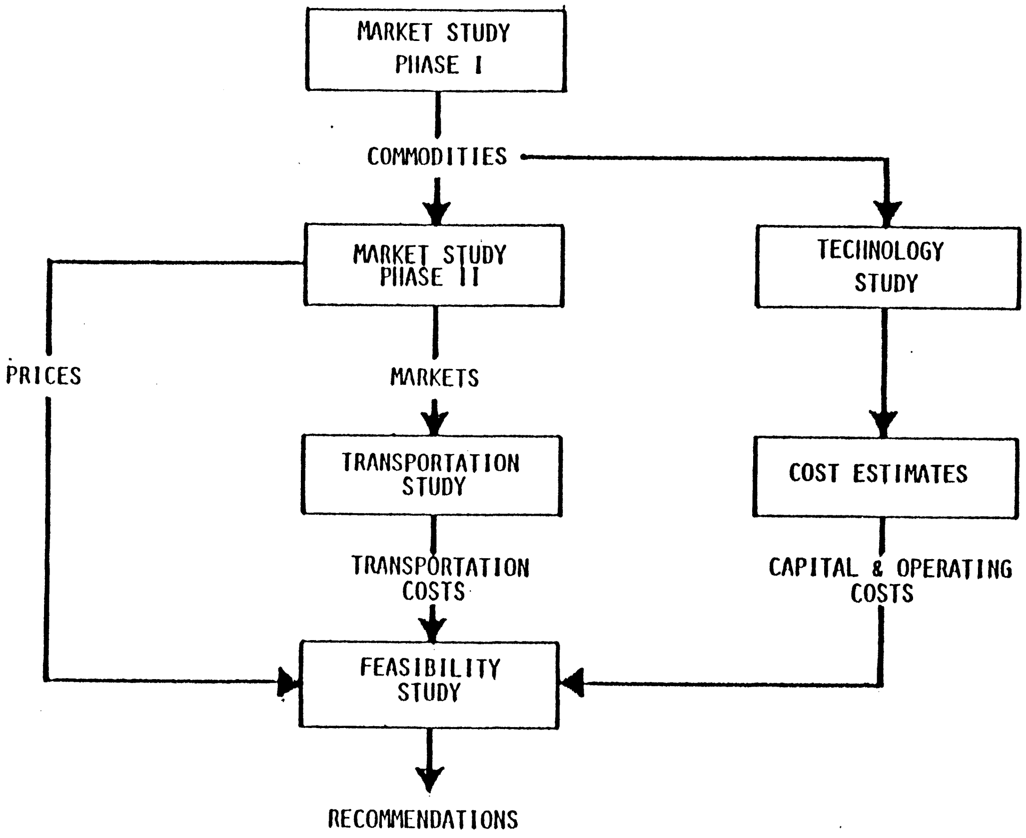
Phosphoric acid (54% P_2O_5)	1,342,633 MTPY	(1,476,200 STPY)
Diammonium phosphates (18-46-0)	1,572,000 MTPY	(1,729,200 STPY)
Gypsum	6,713,168, MTPY	(7,384,500 STPY)

Supporting Supplies

Phos rock (32% P_2O_5)*	2,268,000 MTPY	(2,494,800 STPY)
Ammonia (anhydrous)*	350,000 MTPY	(385,000 STPY)

*The above major supplies are required to produce the secondary products - phosphoric acid, diammonium phosphate and byproduct gypsum.

(1) 320,000 MTPY from the proposed zinc refinery.



STUDY LOGIC DIAGRAM

FIGURE 1

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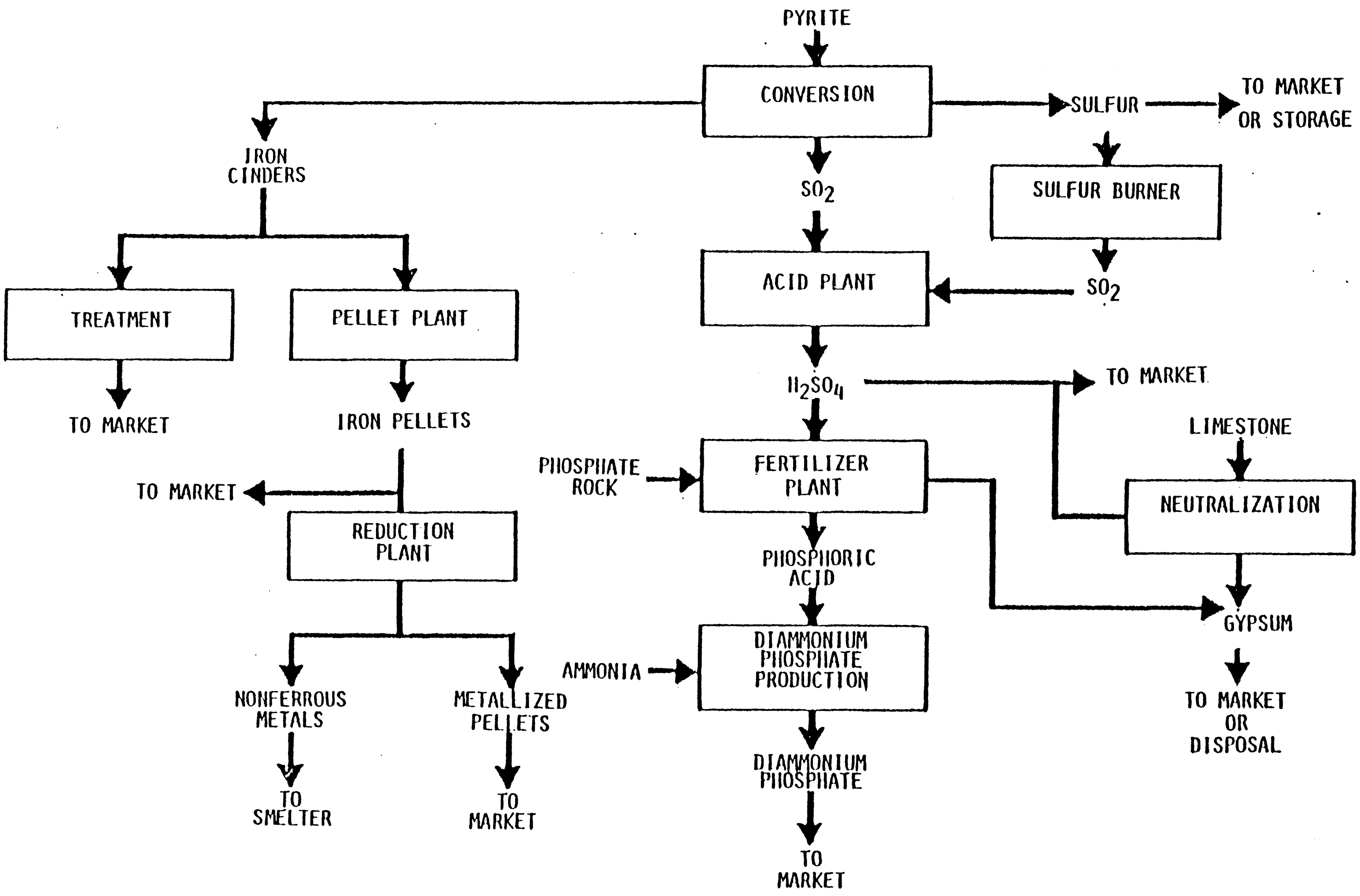
PYRITE PROCESSING STUDY



PRODUCTS LOGIC DIAGRAM

FIGURE 2

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PYRITE PROCESSING STUDY

Numerous other secondary products could be produced from the primary products shown, but the processes may need to be perfected, may be more expensive than current processes using other base products, the markets are dispersed, transportation costs are high and the tonnage requirements are minimal. In certain products the Crandon deposit could supply the total U.S.A. consumption. The marketing section of Phase I and its appendix will cover this lack of market potential for these secondary products in greater detail.

Sulfur and Sulfur Compounds

As pointed out earlier, the consumption of pyrite in the United States and North America is limited in its use, and when it is utilized, it is primarily used to produce sulfuric acid. Other uses are as a soil conditioner for alkaline soils and as a glass coloring agent to make amber glass bottles. The conclusions are that no major market exists in North America for the concentrate product.

The next progression for making a product from the Crandon pyrite concentrate would be to produce sulfur products in the form of elemental sulfur and sulfuric acid.

There are several commercially proven methods to produce both elemental sulfur and sulfuric acid and these methods will be described in detail in Section 4, Process Technology, Phase I of this study.

If elemental sulfur is to be produced, we have found that the domestic production of sulfur by all methods in the years listed was as follows:

Shipments of Sulfur in all forms
Thousand Metric Tons

	1974	1975	1976	1977	1978
Shipments (1)					
Total	11,513	10,220	10,476	10,845	11,289
Frasch	8,025	6,175	5,954	6,030	5,736
Recovered elemental	2,588	2,947	3,196	3,627	4,088
Byproduct sulfuric acid	664	778	957	960	1,103
Pyrites	165	241	291	169	301
Other forms	71	76	78	59	61

Note: (1) Shipments = sold or used.

TABLE III

We have also found that 85% of the sulfur produced was converted to sulfuric acid prior to its end use. It, therefore, seems inconceivable to utilize a high energy demand process to produce sulfur and then convert it to sulfuric acid when processes are available to do it in a single process step. Also, it appears that the production and use of Frasch sulfur is in a declining trend and that sulfur recovered from utilities using high sulfur coals and other sulfur recovery systems installed to protect the environment is on the up trend. The impact from this area, however, is very difficult to assess.

Agricultural chemicals (fertilizers) accounted for approximately 61% of the sulfur demand. Organic chemicals, inorganic chemicals, and other chemical products accounted for 14%, metal mining 6%, and petroleum refining 6% of the sulfur demand. Other uses were very widespread, because most products produced by industry require sulfur in one form or another in some stage of their manufacture. The largest single sulfur use (7,650,000 MT in 1978) is consumed in the production of fertilizers. It includes the manufacture of ammonium sulfate, normal superphosphate, and phosphoric acid. The sulfur remains in the first two products, but in the phosphoric acid production, the sulfur is removed as a calcium sulfate (gypsum), a byproduct which, for the most part, is wasted. Gypsum disposal could pose a problem that must be dealt with if this route is established.

The ammonium sulfate sulfur amounts to about 6% of the total and usually can be considered as a co-product of several industrial operations.

Petroleum refining is a very heavy user of sulfuric acid, but a large percentage of the acid is cleaned and recycled. Therefore, the net use of sulfur only amounts to about two percent of total sulfur consumption. Since sulfur and sulfur compounds are byproducts in oil refineries, the petroleum industry is a net sulfur producer.

The metal mining industries produce their own acid requirements from waste effluents used in electro-refining of metals, but the major quantity is consumed for leaching copper and uranium ores.

Some, but not a large percentage, of the sulfuric acid used in iron and steel pickling, is regenerated for recycling. Hydrochloric acid, due to better conditions for regeneration, is displacing sulfuric acid for this application.

Inorganic pigments, essentially titanium dioxide production, that represented about 5.5 percent of the total U.S. demand for sulfuric acid in 1978, had been declining in its demand. The titanium sulfate process is being displaced by a chloride process which claims a superior product.

Sulfur Consumers

End uses of Sulfur - Sulfuric Acid
Thousand Metric Tons

	1975	1976	1977	1978
Total	9,354	10,038	11,705	11,978
Fertilizers	5,805	5,979	6,969	7,383
Nitrogen	164	146	235	419
Petroleum refining	610	600	780	780
Copper ores	402	542	598	636
Inorganic chemicals	282	232	653	381
Steel pickling	106	965	132	310
Others	2,551	1,730	2,573	

Source: USBM

TABLE IV

The marketing of sulfur and sulfur compounds are further defined in Section 2 of Phase I - Marketing.

Iron Cinder

When roasting the pyrites for the sulfur recovery, the residue is a very fine iron oxide residue with some impurities. If these impurities are removed to acceptable levels, the residue can be considered an iron ore amenable to consumption by the iron and steel industry.

In the Pigment Industry, approximately half of the iron pigments are mined directly as pigments, and the balance, amounting to about 80,000 tons per year, is synthetically or chemically produced. In general, these iron oxides must contain extremely low quantities of heavy metals.

It seems that, due to the amount available and the required removal of the impurities, the iron residue from the sulfur recovery operation has only one viable route for its preparation as an iron and steel feedstock. There are two potential alternates: iron pellets (blast furnace feed) or metallized pellets (electric furnace feed).

Phosphate Fertilizers

Since the production, shipping and handling of sulfur or sulfuric acid to the process consumption areas may not show an economic incentive, it may be judicious to consider the alternative of processing the sulfuric acid into a final marketing product in the same locality where the acid is generated. As phosphate fertilizers utilize over 60% of the sulfuric acid produced in the United States and Exxon Minerals Company may produce over 2000 MTPD (723,000 MTPY) the major consumer might well be a captive fertilizer plant in order to consume the produced sulfuric acid. Below is a brief description of the type fertilizers that might be produced.

Single Superphosphate: Approximately 20% P_2O_5, is the oldest water-soluble phosphate fertilizer, and it still is produced in large quantities. The material is made by reacting ground phosphate rock and 70% H_2SO_4 in a batch den or on a continuous belt. A solid mass of monocalcium phosphate and gypsum is formed, which is cured by storing for several weeks before grinding and shipping. Gaseous compounds of fluorine and silicon are evolved and removed by water scrubbing.

Wet Process Orthophosphoric Acid: This is commercial 30-54% P_2O_5. The addition of H_2SO_4 to phosphate rock in amounts greater than needed to make a single superphosphate produces orthophosphoric acid, H_3PO_4.

This acid is a fertilizer intermediate and also is used to make detergent phosphates after purification. Commercial processes are all based on violent agitation of the rock-acid slurry, followed by removal of $CaSO_4$ via filtration and evaporation of H_2O to obtain the desired concentration, up to 54% P_2O_5. Traditional processes separate the sulfate as impure dihydrate (gypsum), which usually is discarded.

Triple Superphosphate: This is approximately 46-48% P_2O_5. Acidulating phosphate rock with phosphoric acid produces concentrated or triple superphosphate, which is essentially monocalcium phosphate containing very little gypsum. Triple superphosphate is used mostly to furnish P_2O_5 in mixed fertilizers and is water-soluble. Its high analysis compared with single superphosphate offers savings in storage and shipping.

Ammonium Phosphates: Several ammonium phosphates can be prepared, but only the mono and the di compounds are made for fertilizer purposes, alone, or in combination with other salts.

Granulated diammonium phosphate is produced in much greater quantities than monoammonium phosphate and has become the most popular of all phosphate fertilizers due to its high analysis, stability and favorable economics.

1.2 Product Market Specifications

Crude domestic bright sulfur on the U.S. market is 99.5% - 99.9% pure and commercially free from arsenic, selenium and tellurium.

Sulfuric acid is supplied in many concentrations and grades. Exxon Minerals Company, U.S.A. at the Crandon facility plans only to produce 93% grade acid which is the predominant grade utilized in the manufacture of phosphoric acid and in other areas.

Phosphoric acid is produced and sold at different grades of concentration, from 30% P_2O_5 up to 72% P_2O_5. The 54% wet process orthophosphoric acid takes the largest portion of the market and is also the basic component for the diammonium phosphate manufacture.

Diammonium phosphate (DAP) is usually produced under the formula 18-46-0 (NPK).

The suggested specifications for the market study are as follows:

Sulfur	99.5-99.9% pure, free from arsenic, tellurium and selenium
Sulfuric Acid	93% H_2SO_4
Iron Pellets	As per description and chemical analysis
Phosphoric acid	54% P_2O_5
Diammonium phosphate	18-46-0

Potential products to be purchased for manufacturing operations:

Phosphate rock	68-72 BPL (32% P_2O_5)
Ammonia	Anhydrous

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Iron Pellets Calculated Composition

	Iron Pellets	Sponge Iron 92% Reduced
Fe	65.1%	88.75 total Fe
Fe_2O_3	93.0	81.65 Fe met.
Cu	0.02	0.029
Pb	0.01	0.014
Zn	0.01	0.014
S	0.02	0.029
As	0.03	0.044
SiO_2	3.28	4.47
Al_2O_5	0.78	1.06
CaO	1.47	2.00
MgO	0.83	1.13
Mn	0.3	0.41
O_2	-	2.05
Au	0.05 gr/T	
Ag	4.0 gr/T	

These pellets will have an average diameter of 12mm, with a compressive strength of +400 kg pellet.

TABLE V

SMELTER SULFURIC ACID SPECIFICATIONS

93% -66 Baume

H_2SO_4	93 - 94
SO_2	300 - 500 ppm
Iron	30-50 ppm
NO_3	Less than 1 ppm
Cadmium	.01 - .03 ppm
Mercury	1 ppm
Zinc	1 ppm
Lead	1 ppm
Arsenic	Less than 1 ppm
Chlorine	Less than 0.5 ppm
Copper	Less than 1 ppm
Selenium	Less than 1 ppm
Color	Water white to light yellow

TABLE VI

2. MARKETING

Introduction

This part of the pyrite processing study covers the marketing aspects of the Crandon Pyrite concentrates and the products resulting from the treatment of these materials. It also includes the marketing of the sulfuric acid that is generated in a proposed zinc refinery treating Crandon zinc sulfide concentrates.

Commodities Reseach Unit (CRU) has been selected to perform the market study and the analysis of the products from the Crandon pyrite that can be marketed. A copy of CRU's complete report is available in the Appendix for further review. Both products to be marketed, or purchased to make the final products, have been considered. The various products and materials that were examined are as follows:

Products to be Marketed	Products to be Purchased
Pyrite concentrates	Phosphate rock
Liquid SO_2	Ammonia
Sulfuric Acid	
Sulfur	
Iron Pellets	
Phosphoric Acid	
Diammonium Phosphate	
Gypsum	

The opportunities in the U.S./Canadian market based on the source of the products have been investigated and assessed.

Products Eliminated

During the early phase of the CRU Marketing Study it was determined that the market for liquid SO_2 was not large enough (200,000 MTPY) to warrant liquid SO_2 production. The same applies to the byproduct gypsum market. The U.S. market for byproduct gypsum is 600,000 metric tons per year against the Exxon potential production of 2.4 million MTPY. Also the gypsum produced in the manufacture of phosphoric acid contains impurities that are not amenable to gypsum board and other products utilized in the building trades without additional treatment.

Further, it was realized that the market, per sė for phosphoric acid, was a captive market and that the major portion of the market was used in the production of fertilizer.

The market study shows that the market is tight for elemental sulfur and it has been recommended that the process for producing this material be investigated. During the analysis of the commercial processes for making elemental sulfur, it was found to be energy intensive and it is doubtful that it can compete economically with Frasch or other recovery processes. A cursory look will continue into the production costs of this product in Phase II.

Also eliminated from further investigation were the iron products from pyrite such as pigments, iron powder, etc., either due to a limited market or production considerations.

2.1 Markets for Pyrite Concentrates

Pyrite once was the world's major source of sulfur, but its relative importance has declined in this century because of the development of the Frasch process for mining elemental sulfur, and perhaps more importantly because of production of byproduct sulfur and sulfuric acid from nonferrous metal operations, natural gas and petroleum.

Nevertheless, in Europe and Asia, pyrite is still a significant source of sulfur. The USBM estimates that in 1975, of the total world sulfur production of almost 50 million tons, pyrite accounted for 10.2 million tons. The major processors of pyrite are the USSR, Spain, China, Japan and Italy. These countries have plentiful local sources of pyrite and there is no chance that it would be economical to ship pyrite to them from the US.

With a few exceptions, the pyrite roasting industry in North America has disappeared because of competition from less expensive sulfur sources. Moreover, industry experts are convinced that there is little chance of a reversal because of (a) almost no existing roasting facilities, (b) the high cost of pyrite roasting, (c) future adequacy in North America of other byproduct sulfur/sulfuric acid supplies, from coal burning power plants, etc.

North American Producers

Pyrite occurs very commonly in mineral deposits with sulfide mineralization, and many North American mines separate waste pyrite from their ores. In almost all cases they have no use for this material and store it in tailings ponds or use it as mine fill. Table 1 shows the amount of pyrite that has been processed in the US since 1950.

TABLE 1

US PRODUCTION OF Pyrite[1]

Year	1000 tons
1950	946
1955	1,023
1960	1,032
1965	889
1970	859
1975	635
1977	420e

Note

1 pyrite that was processed
e CRU estimate based on reported sulfur content of pyrite.

Source: USBM

In the United States, only one company today processes the pyrite it mines. This is Cities Service at its copper/zinc/pyrite mines at Copperhill, Tennessee. Copperhill is a very old and unusual operation, whose economics have depended as much on the output of byproducts as on copper. Besides roughly 10,000 STPY of 52% zinc concentrates, the major byproducts have been sulfuric acid and iron oxide pellets derived from processing pyrites.

The iron circuit at Copperhill apparently never performed well and was shut down in May 1979. Currently, Copperhill still roasts 3,000 STPD (approximately one million STPY) of pyrite solely for production of sulfuric acid, and virtually all the iron cinder is stored.

Small quantities of byproduct pyrite are sold from two other US mines to small distributors who in turn dry and size the material for sale to several very small markets. The Climax (Colorado) mine of Climax Molybdenum Co. (AMAX) sells about 3,000 STPY in this way, reportedly for $22/ton F.O.B. Climax, wet.

In Arizona, Magma Copper Co. (Newmont) similarly sells about 7,000 STPY. In both cases the amount of pyrite sold is only a small fraction of the amount available at these mines. The main markets for this pyrite are the acidification of soil (especially in California and other parts of the Southwest where soils are basic) and for coloring of bottle glass. Based on CRU interviews, they estimate that the US market for pyrite in soil acidification is under 10,000 STPY, and for bottle glass is under 5,000 STPY. In any event, neither of these markets is available for Exxon's pyrite; soil acidification, because of the shipping distance to areas where it is needed; and beer bottle glass, because the pyrite must be +20 mesh so that it will not blow out the stacks of the glass making furnaces.

In Canada, roasting of pyrite is limited to several long existing facilities. Inco, at Copper Cliff, Ontario, actually roasts a nickel bearing pyrrhotite, with recovery of the nickel as the main motivation for the process. Approximately 800,000 STPY of pyrrhotite containing over 1% Ni is processed to make 5.3 million kg of nickel oxide, 630,000 tons of iron oxide pellets, and sulfuric acid (actually produced by Canadian Industries, Ltd. in an adjacent facility).

Cominco, at Kimberly, B.C., roasts 250-300,000 STPY of pyrite and/or pyrrhotite from local mines, to make sulfuric acid which is used in phosphate fertilizer production. The remaining iron calcine is stockpiled.

The only other significant movement of pyrite in Canada is from Noranda, which ships about 23,000 STPY from the tailings pile of the former Horne Mine (shut down July 1976) at Noranda, Quebec. This material is sent to the White Pine Copper Smelter (Copper Range Co.) in Michigan at a price of $1/ton plus freight (approximately $20/ton). White Pine, which mines a low sulfuide ore, is in the unusual position of having a deficiency of sulfur for its smelting process; thus the purchase of pyrite.

Markets For Exxon's Pyrite

As no other company is likely to build a new pyrite roasting facility to use Exxon's concentrates, the only possible customers are companies within shipping range that already use pyrite in existing facilities. This narrows the list quickly to two prospects: White Pine and Copperhill, both of whom were contacted.

White Pine has an obvious interest in Exxon's pyrite because Crandon is closer than Noranda, Quebec, and so the delivered cost might be less. Unfortunately, White Pine's total requirements represent less than 10% of Exxon's projected output of pyrite concentrates.

The White Pine specifications for impurities in the Noranda pyrite are as follows:

Zn	2%
Pb	3%
As	1%
Ni	250 ppm
Bi	100 ppm
Se	100 ppm

White Pine is concerned about their ability to handle Exxon's extremely fine material and about the dust control problems that could result.

Copperhill represents the only prospect that theoretically could take all of Exxon's output of pyrite concentrates, and we found that they have an interest in discussing the idea. For various reasons, Copperhill might like to have the option of mining at a lower rate while still operating the roasting facility at a high rate. This could be accomplished by bringing in pyrite from outside.

Copperhill did not express any immediate misgivings about the specifications of Exxon's material, but the decision to pursue this idea would certainly have to be based on detailed economic analysis taking into account the shipping costs, handling problems, chemical composition, etc., as well as a policy decision by Cities Service to curtail their own mining.

2.2 Market for Sulfur

Sulfur is one of industry's most important and versatile raw materials. It finds application at some stage in nearly all industrial production, usually as its derivative sulfuric acid. Sulfur mainly occurs in the elemental form, metallic sulfides, sulfate minerals, in conjunction with liquid and gaseous hydrocarbons and most abundantly in coal.

Within the Western World, the major producer is North America, which in 1978 produced 19.2 million metric tons, equivalent to 35% of global output. West Europe was the second major western world producer whose output totalled 7.7 million metric tons in 1978.

The Western world remains the major consumer; in 1978, the region accounted for almost 71% of the consumption, reaching a record level of 36.3 million metric tons of sulfur.

As in the case of production, North America accounts for the major share of consumption. In 1978 North America sulfur consumption reached record levels of 14.7 million metric tons. Similarly, West Europeal consumption recorded new highs of almost 11 million metric tons.

Current Situtation and outlook

During 1978 demand for sulfur continued its upward trend, due principally to the growth in the phosphate fertilizer industry. However, there was no matching growth in supply, and by mid year delivery schedules were falling behind, as the market tightened considerably in the second half of 1978.

In the Western world, output from non elemental sectors rose, due largely to a recovery in the nonferrous metals smelting sector. Given the improved market conditions, pyrite production increased by 2%. Output of elemental sulfur remained unchanged as the increased production by recovered producers was cancelled out by the declining Frasch production in the US and Mexico. The sulfur market entered into a period of growing demand and tightening supply, which eventually manifested itself in higher prices. By the end of 1978 prices were renegotiated by +$10 per ton. This situation has improved little in 1979. Looking ahead, Western world demand will increase as a result of the continuing growth of the fertilizer industry's requirements, particularly phosphoric acid and the more modest growth in industrial end uses. It if evident that the Western world supply/demand balance will be tight until the 1980s unless sulfur resources are developed, which by today's standards are considered uneconomic.

Unfortunately, there has been no historical precedent for a sulfur shortage of the potential dimensions identified. Until recently, there have always been reserves of material available to voluntary producers when market developments have outstripped byproduct sulfur supply. Thus it must be assumed that unless supplies of abatement sulfur or recovered from coal, oil shales, etc., enter the market, the growth in demand will slow down in all sectors as investment in sulfur using capacity slows, awaiting assurances of supply of sulfur at realistic prices. There are no structural changes in the pattern of demand anticipated, merely a deceleration in growth in response to market prices until new sources can be exploited.

The United States Sulfur Industry

The United States sulfur industry is the world's major producer. In 1978, domestic production of 11,168,000 metric tons of sulfur represented 20% of global production. While consumption of 12.6 million metric tons

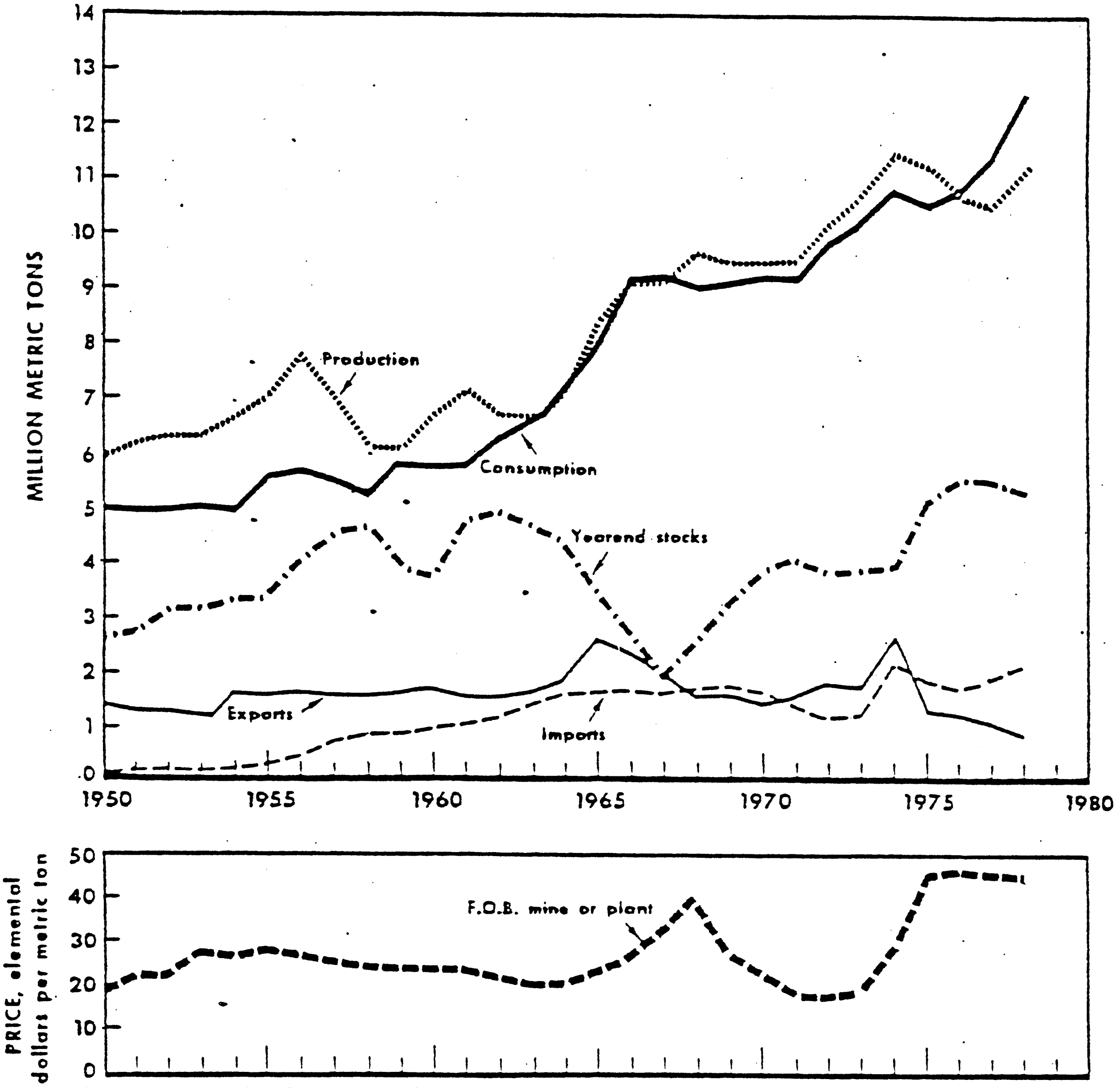


Figure 1

Trends in the Sulfur Industry in the United States

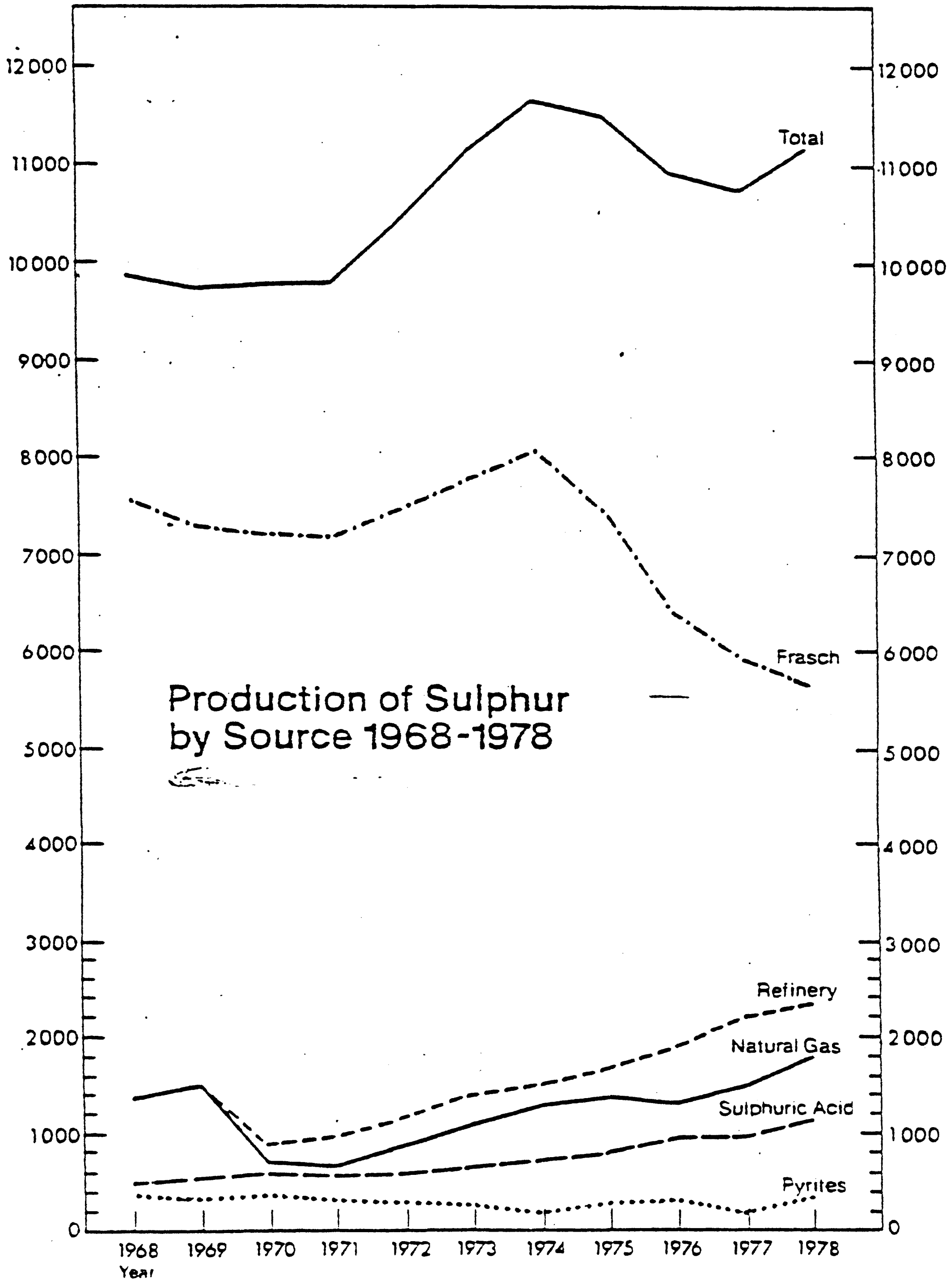

Production of Sulphur
by Source 1968-1978
12000
11000
10000
9000
8000
7000
6000
5000
4000
3000
2000
1000
0
Total
Frasch
Refinery
Natural Gas
Sulphuric Acid
Pyrites
1968
Year
1969
1970
1971
1972
1973
1974
1975
1976
1977
1978

Figure 2

accounted for 23% of world usage. Currently the Frasch sulfur sector accounts for the major output of sulfur, but as can be seen from the following figure, Frasch usage has fallen steadily over the past 5 years, following a modest recovery in the early 1960s from its downward trend. The figure clearly illustrates, how the increased production over the past two years as stemmed entirely from the output of recovered elemental sulfur and byproduct sulfuric acid.

While production of sulfur has fluctuated considerably over the past 10 years, the fluctuations in the consumption of sulfur have been far less pronounced, with the trend moving upward, in spite of a slight fall in 1975. The United States remains a net importer of sulfur. Seven out of the past ten years, imports have exceeded exports, including the last four consecutive years. Mexican Frasch and Canadian recovered sulfur producers have played an increasing role in the US market where their combined exports to the US totaled 1,967,000 metric tons in 1978.

The developments of the United States industry over the past 25 years is summarized in Figure 2.

US Current and Projected Supply

US production of sulfur in all forms totaled 11,168,000 metric tons in 1978, a 4% increase on the previous year.

Table 2 - Production of Sulfur in all Forms
(1000 metric tons)

	1966	1970	1976	1977	1978
TOTAL	9,891	9,710	10,879	10,727	11,168
Frasch	7,579	7,196	6,365	5,915	5,648
Recovered					
(1) Natural gas	1,381	669	1,298	1,426	1,752
(2) Refinery		811	1,890	2,198	2,303
Byproduct H_2SO_4**	437	546	957	960	1,103
Pyrite	368	344	291	169	301
Other forms^2	126	114	78	59	61

Sources:
1. Includes a small quantity from coking operatins
2. Hydrogen sulfide and liquid sulfur dioxide
** Further analysis of the byproduct sulfuric acid is included in Section 2.3.

Production of Frasch sulfur has declined from its peak of over 8 million metric tons in 1974, to its present level of 5,648,000 metric tons. The decline in production over the past four years has resulted from an interaction of the following factors:

(1) The closure of a number of mines with diminishing reserves, particularly on the Gulf Coast. During the past three years five frasch mines have ceased production -Lake Pelto and Grande Ecaille operated by Freeport Minerals Co. and Spindletop, Fannett and Bully Camp operated by Texasgulf. Commissioning of the Comanche Creek mine by Texasgulf has been insufficient to redress the balance.

(2) The increased gas prices, so vital an element in production of Frasch sulfur.

A brief discussion of the cost structure of the industry will clearly illustrate why there is little chance of any expansion of the Frasch industry unless a significant technical break-through is achieved in energy saving. Of the costs of production, the cost of natural gas is crucial, and it is significant that many of the mines are fortunate to have contracts for long term supplies of gas. For example, Freeport's Garden Island Bay dome gas supply is assured until 1989 through an intrastate contract, while Grand Isle supplies are contracted for 10 years with an intrastate gas company. This has insured that gas supplies are available below $2 per mcf. The availability of gas at these prices is crucial to the older mines, where the water requirement has been increasing.

An indication of the future for those companies still in production can be gauged from the following estimates of gas consumption per operation.

Location	Gas Consumption mcf/ton
Louisiana	
Garden Island Bay	6.9
Grand Isle	3.8
Texas	
Comanche Creek	41.5
Long Point	9.1
Moss Bluff	9.0
New Gulf	7.6
Rustler Springs	5.0

During the review period all of the above mines will see their consumption of gas per metric ton of sulfur increase as the mines age.

Recovered Elemental Sulfur

Production of recovered sulfur reached record levels of 4,055,000 metric tons in 1978, a 12% increase on the previous year. As a result of the decline in Frasch production, recovered surplus accounted for 36% of total domestic sulfur production.

Table 3 - Recovered Elemental Production*
(1000 metric tons)

	1970	1975	1976	1977	1978
Total recovered	1,480	3,017	3,188	3,624	4,055
Natural gas	669	1,364	1,298	1,426	1,752
Petroleum refinery	811	1,653	1,890	2,198	2,303
Year end stocks		273	270	269	222

*Mineral Industry Survey

Unlike the Frasch industry, which is characterized by a small number of producers and mines located in the States, the recovered sulfur industry is highly fragmented. In 1978 recovered sulfur was produced by 57 companies, operating 147 plants in 29 states. However, the majority of the operations are small scale and five major companies operating 37 plants accounted for 56% of total recovered sulfur production in 1978.

Table 4 - Recovered Sulfur Production by State
(1000 metric tons)

State	1977	1978
Alabama	284	405
California	507	443
Florida	332	341
Illinois	248	202
Indiana		71
Kansas	5	17
Louisiana	160	185
Michigan/Minnesota	74	79
Mississippi	294	493
New Jersey	130	120
New Mexico	48	64
Ohio	23	23
Oklahoma	10	9
Pennsylvania	83	74
Texas	1023	1107
Wisconsin	1	48
Wyoming	46	48
Others	343	379
Totals*	3624	4062

*may not add due to rounding

Rcovered Elemental Sulfur - Natural Gas

In 1979 possibly more so than ever before, the forecast of recovered sulfur production fron natural gas sources is dependent on political decisions.

Recovered Elemental Sulfur - Other Forms

Recovered sulfur, other than from natural gas processing or petroleum refineries is at the moment minimal. However, while operations in this area may be of only minor significance at now, they are considered by certain sources to be areas of major potential.

These unconventional sources of recovered sulfur can be categorized as follows:

(1) Coal gasification
(2) Oil shales and tar sands
(3) Power plants

(1) Coal gasification - given the impetus provided by the recent energy policy to produce 1-1.5 million barrels per day of synthetic fuel from coal liquification and gasification by 1990 a substantial quantity of sulfur could be recovered. The recovery of the sulfur at the point of production would also enhance the chances of production resulting from the economies in pollution control. At the moment, however, there are no commercial operations in production, but tests are underway on both pilot and semi-industrial scale plants. It is considered unlikely that any commercial production will be seen before 1990 in view of the cost element. Two pilot plants to produce synthetic fuel will cost over $3.5 billion, while the fuel itself is forecast to cost between $27-$47 per barrel.

(2) Oil shales and tar sands - would appear to suffer from the same disadvantages as coal gasification, notably technological and financial. In the U.S., the largest deposits of oil shales are located on the borders of Utah, Colorado and Wyoming. Government proposals are to produce 0.5 million barrels per day of fuel. The U.S. oil shales are generally thought to have a fairly low sulfur content and cannot be regarded as a major source of recovered sulfur. Sulfur recovery from oil shales is not expected before 1990, and is forecast to be in the order of 200,000 STPY.

(3) Power plants, as a result of burning high sulfur coal, SO_2 emissions have been emitted which, until recently, have not been recovered. However, under pressure from the Environmental Protection Agency (EPA), power stations are obliged to comply with clean air regulations. The question of the form in which the SO_2 emissions are recovered remains. A recent publication** by the Tennessee Valley Authority and EPA has studied the relative trends of the processes for cleaning up the SO_2 emissions. The conclusion is that recovery of elemental sulfur (by the Wellman-Lord/Allied process) was in excess of the recovery by conventional sulfuric acid production, even when the increased cost of distributing sulfuric acid was considered. Elemental sulfur is recovered from two utility companies, North Indiana Public Service Co. (NIPSCO) at Mitchell Station which currently recovers 60 STPD sulfur and Public Service Co. of New Mexico which produces 40 STPD sulfur. Annual production from these two units is estimated to be 35,000 ST of sulfur.

* Sulfur, Mineral Policy Series, Dept. of Energy, Minerals & Resources, Canada

** "Potential Abatement Production and Marketing of Byproduct Sulfuric acid in the US" prepared for the US Environmental Protection Agency, Washington DC.

Table 5 - United States: Sulfur Supply Forecast
(1000 metric tons)

	1978	1980	1985	1990	2000
TOTAL	11,168	12,748	13,558	16,500	22,850
Frasch	5,648	6,300	5,700	5,050	3,000
Recovered	4,055	4,678	5,478	8,150	15,400
(1) Natural gas	1,752	1,800	2,000	1,800	1,200
(2) Refinery	2,303	2,853	3,403	4,000	5,500
(3) Power plants	15	15	25	750	2,000
(4) Coal processing	5	5	50	1,400	6,200
(5) Oil shales/tar sands	-	-		200	500
Byproduct H_2SO_4	1,103*	1,320	2,200	3,100	4,200
Pyrite	301	200	100	100	-
Other forms	61	70	80	100	250
Reclaimed sulfuric acid	-	700	850	950	1,600

*excludes 613,000 metric tons of reclaimed H_2SO_4 from petroleum refining and coal production

Source CRU estimates

U.S. Current and Projected Demand

For the third consecutive year, apparent consumption of sulfur in all forms exceeded domestic production. Apparent consumption of sulfur in all forms attained record levels of 12,600,000 metric tons in 1978, and 8% increase on the previous year.

Table 6 - Apparent Consumption of Sulfur
(1000 metric tons)

Apparent Consumption (1)	1968	1970	1976	1977	1978
Total (2)	9,127	9,375	10,941	11,657	13,600
Frash - Domestic	5,026	5,152	4,737	4,942	4,909
Imports	797	548	743	781	993
Recovered elemental -					
Domestic	1,298	1,495	3,123	3,518	4,049
Imports	843	1,014	1,012	1,228	1,185
Byproduct sulfuric acid	437	546	957	960	1,103
Pyrite	510	476	291	169	301
Other forms	126	144	78	59	61

Source: USBM
Note: (1) Apparent Consumption = shipments + imports - exports
(2) Total may not add due to rounding

Table 7 - Shipments of Sulfur in all forms
(1000 metric tons)

Shipments (1)	1974	1975	1976	1977	1978
Total	11,513	10,220	10,476	10,845	11,289
Frasch	8,025	6,175	5,954	6,030	5,736
Recovered elemental	2,588	2,947	3,196	3,627	4,088
Byproduct sulfuric acid	664	779	957	960	1,103
Pyrite	165	241	291	169	301
Other forms	71	76	78	59	61

Note: (1) Shipments = sold or used.

Over 83% of the domestic shipments of sulfur was used for the production of sulfuric acid, the balance of up to 1 million metric tons was used by a wide range of industries. The breakdown of elemental sulfur sold by end use is identified overleaf. (It can be seen from the table that of total elemental sulfur sales, 985,000 metric tons cannot be identified by end use - but it is assumed that the majority of this tonnage is transformed into sulfuric acid.)

In this section of the report, only the consumption of elemental sulfur will be considered. The usage of sulfur in sulfuric acid will be considered in the Sulfuric Acid review.

Development of Sulfur Consumption

In view of the diverse end uses of sulfur, it is proposed to examine the developments in demand on the basis of the following major categories.

Agricultural Chemicals - in 1978, end use in the group totaled 272,000 metric tons, representing 2% of the total sulfur usage. One of the major uses within this group is the direct application of sulfur as a soil conditioner.

Table 8 - Direct Application of Sulfur
(1000 metric tons)

1970	1974	1975	1978	1977	1978
26.4	59.1	47.0	85.9	41.3	110.0

Source: USDA

Historically usage has fluctuated considerably but substantial growth potential exists in the Pacific States region, notably California, which in 1978 applied amost 70,000 metric tons. As sulfur has become the limiting factor in certain areas, a strong growth in usage is predicted in spite of the forecasted higher price levels. By the end of the review period, direct application of sulfur is expected to be in the order of 500,000 STPY.

Pulp and Paper - consumption of sulfur by the pulp and paper industry was 283,000 metric tons in 1978, in all forms, of which 96,000 metric tons was elemental, the balance being sulfuric acid and sulfur dioxide. Historically, usage of elemental sulfur by the pulp and paper industry has been irregular, indeed until 1978, it appeared that the decline in recent years in the consumption of non-acid sulfur had been arrested. However, it is too early to forecast whether the apparent fall in usage in 1978 is a typical, or the return to recession in the pulp and paper makret. It is anticipated that growth in demand for non-acid sulfur will not exceed 2%/yr in the review period.

Sulfuric acid - the transformation into sulfuric acid is the major end use of sulfur. Of the total 12,075,000 metric tons of elemental sulfur consumed in 1978, sulfuric acid accounted for 9.3 million metric tons or 77% elemental sulfur usage. The phosphate fertilizer industry is the main ultimate end user of the sulfuric acid. In terms of sulfur, the fertilizer industry usage of the past four years has developed as follows:

Table 9 - Consumption of Elemental Sulfur by End Use
(1000 metric tons)

	1975	1976	1977	1978
Food	3	4	5	N/A
Pulp and paper	104	112	147	96
Synthetic rubber, cellulose fibres, plastics	131	86	65	N/A
Agricultural chemicals	91	89	257	287
Paints and allied products, industrial organics	131	89	275	214
Petroleum refining/coal products	123	85	111	108
Other industrial inorganic chemicals	235	342	221	167
Rubber and misc. plastics	2	10	N/A	17
Sulfuric acid				
Domestic sulfur	6796	7160	7435	7064
Imported sulfur	888	887	2162	2239
Unidentified	994	670	678	985
Exports	1260	1188	1044	898
TOTAL	10,758	10,722	12,400	12,075

As can be seen that over 77% of sulfur consumed is used for the manufacture of sulfric acid.

A more detailed discussion of the sulfuric acid industry can be found in 2.3 Sulfuric Acid, page 22 of this section.

Other End Uses - totaled 506,000 metric tons in 1978. As in the case of the pulp and paper industry, the growth in usage throughout the reveiw period is not expected to exceed 2.0%/yr.

Future Developments

By 1980, US domestic consumption of sulfur in all forms is expected to increase to 12.6 million metric tons, reaching over 18 million metric tons by 1990.

Table 10 - United States Sulur Demands
(1000 metric tons)

	1980	1985	1990	1995	2000
End Use	13,513	15,443	18,360	21,060	23,780
Fertilizer	8,128	9,652	11,760	13,800	15,800
Industrial	5,385	5,791	6,660	7,260	7,986

The above fertilizer end use forecast is generated on the basis of the phosphate/phosphoric acid forecasts in the later chapters. The forecast of industrial end uses is derived from an assessment of the growth prospects of each of the major sectors.

Pricing Patterns

Any industry, in which a large share of the market is controlled by involuntary producers, whose industrial cycles do not coincide with that of the voluntary producers, is subjected to unstable market conditions. The sulfur industry is a good example of such a pattern, with recovered sulfur prices historically acting as a depressant on the market.

An examination of the historical development of prices reveals a gradual decline of prices from the early days of the Korean war through into 1963, despite the entry of new producers. The mid 1960s witnessed a firming of prices as demand recovered, particuarly in the fertilizer sectors. However, by 1968 the peak prices had been reached and a gradual decline in prices followed under the impact of Canadian and Mexican supplies on the domestic market, and the addition of Polish products on the international market. This fall in prices was finally arrested in 1872 by which time prices had reached an all time low.

Since 1972 there has been a gradual, though intermittent, recovery in sulfur prices. The following price series illustrates the pattern, and clearly identifies, the price differential of the US Frasch, Mexican Frash and Canadian recovered prices.

Table 11 - Mid Year Sulfur Prices (Current US$)

a) Exports	1975	1976	1977	1978
US Frasch (bright) FOB Gulf Ports - per long ton	65	61-71	60-61	60-65
Mexican Frash FOB Coatzacoalcos per metric ton	58	56-65	45-48	45-48
Canadian recovered (bright) FOB Vancouver per long ton	60-65	38-42	35-38	35-41

The following table presents a history of domestic prices. However, because most sulfur is sold on negoitated contract prices, the terms of which are usually confidential, these prices serve only to identify the overall trend. Furthermore there are considerable regional price variations within the US. This arises because of; (a) the freight aspect; (b) the competion from recovered sulfur - both Canadian and domestic US producers.

Table 12 - Current Prices at Selected Locations
$ per long ton (molten sulfur)

Tampa	78-85
US Gulf Coast	68-73
US West Coast	28
Pacific North West	41

Table 13 - Sulfur Domestic and Trade Price History
($ per metric ton)

	Average unit value of Shipments FOB mine/plant			Average unit value of Imports and Exports	
	Frasch	Recovered	Total	Imports	Exports
1956	26.92	N/A	N/A	N/A	N/A
1960	24.47	23.77	23.50	N/A	N/A
1965	23.06	21.33	22.82	18.50	24.89
1970	24.03	21.22	23.51	22.57	23.52
1971	17.78	17.70	17.75	19.88	18.46
1972	17.69	15.90	17.30	14.54	17.83
1973	18.92	15.70	18.13	12.26	19.69
1974	31.01	24.17	29.34	24.16	37.61
1975	49.37	35.57	44.91	36.76	54.20
1976	50.38	37.02	45.72	33.89	50.00
1977	48.88	36.91	44.38	32.43	47.90
1978	48.80	40.07	45.17	34.75	41.91

Source: USBM

Prevailing Commercial Arrangements

Sulfur is normally sold under long term contracts to major industrial consumers, on a delivered price basis at regional terminals. The terminal prices vary considerably with location, and contract prices are well below the list prices quoted in this study.

The recovered sulfur and byproduct sulfuric acid producers have progressively obtained control of the markets in the Western and Central States. Canadian recovered sulfur sales have been confined to the Northern States. Penetration of the more southerly markets has been restricted by freight costs. The Mexican Frasch industry has remained competitive in South Eastern and Florida areas. Expansions of the Mexican marketing area have been limited by the high freight element involved reaching in the inland markets. The Frasch producers, under pressure from recovered, byproduct producers and imported sulfur, have found their market area gradually constricted to the Southern and Eastern States and the inland waterways.

Frasch producers normally ship molten sulfur by water from their mines or transhipment terminals on the Texas and Louisiana Gulf Coast to the marketing terminals. The basing point the Gulf Coast Market is Port Sulfur, Louisiana. Marketing points are strategically located either on the inland waterway system or along the East Coast adjacent to ports served by deepwater vessels. From the marketing terminal, molten sulfur is transported by barge, truck or rail directly to the point of consumption. A map of the relative locations of the sulfur terminals is presented in Figure 2.

Recovered sulfur is sold mainly by its producers, the oil and gas companies, as yet there has been little development of a merchant market for sulfur. This has stemmed from the reluctance of oil and gas producers to prejudice their oil and gas output by a build up of onsite liquid molten sulfur. Hence, the major producers have opted to market their own product. For example, Amoco Oil Co., Cities Services, Exxon Chemical Co., Inc., Gulf Oil Corp., Mobil Oil Corp., Phillips Petroleum Co., Shell Oil Co., Standard Oil Co., and Texaco Inc.

Potential Markets

The major area of potential sales will be the existing sulfuric acid producers operating sulfur burning units. As illustrated in Figure 4, the majority of sulfur burning plants are located in the Eastern half of the United States. Three concentrations are evident:

(1) — Florida
(2) North East
(3) Mid West

The Florida market, in CRU's opinion, will remain the preserve of the Frasch producers and Gulf recovered producers. Exxon's recovered elemental sulfur from Green Bay or Evansville is unlikely to be competitive in view of the freight costs. Thus the two remaining areas are the North East - particularly New Jersey and Virginia, and the Mid West - Illinois and Ohio.

The North East market is currently well served by the Gulf Frasch producers; (1) Texasgulf moving considerable quantities of sulfur through its Carteret, NJ, Newall, PA, Norfolk, VA, and Morehead City, NC molten sulfur terminals; (2) Duval operates terminals in the area at Norfolk, VA and Wilmington, NC; (3) Freeport operates a terminal at Uncle Sam, NC.

Most sulfuric acid producers in the North East (with the exception of North Carolina which is served by Frasch producer operated terminals) are potential purchasers of recovered sulfur. These can be easily identified from the listing of sulfur burning acid producers in Table 14. The only constraint is likely to be the cost of freighting from Green Bay or Evansville to the Carteret and other New Jersey terminals. While the concentration of sulfuric acid producers in the Mid West is less dense than the North East, there is more scope to identify individual buyers.

In the region there are two customer terminals in operation, which are conveniently placed to serve the Evansville location.

(1) East St. Louis, Illinois operated by Monsanto
(2) Wurtland, Kentucky operated by DuPont

The East St. Louis terminal would be ideal for sales of sulfur to Allied Chemicals' plant at East St. Louis, where the annual sulfur requirement is 50,000 metric tons. Products could be moved further up the Mississippi to Marseilles to serve the Illinois acid producers. A Green Bay location would also be favorably sited for potential sales to Illinois.

The Wurtland terminal unfortunately only serves DuPont's acid plant at this location. The annual sulfur requirements of the plant is put at 60,000 metric tons.

The Evansville locations allows access to the Ohio River and the potential sales to DuPont at Cleveland, Ohio with an annual requirements of 56,000 metric tons and Minnesota Mining and Manufacturing at Coply with an annual requirement of 24,000 metric tons.

The list of potential buyers can be expanded to include Mobil at Depue, National Distillers at Dubque, First Mississippi at Madison, DuPont at East Chicago and Stauffer at Hammond. There seems adequate scope for the sales of Exxon's 134,000 metric tons to the above acid producers.

New Uses for Sulfur

In addition to the existing conventional end uses, there has been considerable interest, promoted by the sulfur institute, in new uses for sulfur. The new uses of sulfur can be summaries as follows:

Sulfur asphalt - technically and commercially this appears to be a very viable process, but the development of this area depends upon the price relationship between asphalt (re oil/gas) and sulfur. However, there are two important factors which could be instrumental in the take-off of sulfur asphalt; (1) the decline of asphalt production as crude oil extrusion processes are improved, and (2) the technical advantages of sulfur asphalt may outweigh the immediate cost disadvantages. The main advantage lying in its insulation qualitites. At the present time tests are in hand on a sand based sulfur/asphalt strip in Texas.

Sulfur concrete - sulfur concrete is resistant to acidic attack and as such may find acceptance in smelting activities. At the moment tests are underway at the ARSACO smelter, which have proved very promising.

Sulfur impregnation - for either wood or cement - which enhances both strength and resistance to water and frost. The take-off in consumption of non conventional uses of sulfur will be stimulated by the availability of economically priced sources of sulfur rather than a pull from the demand side. Given the tight supply/demand position expected in the review period and the resultant price developments, it is in the CRU's opinion, unlikely that by 1990 any of the non conventional uses of sulfur will have made a considerable impact on the sulfur market.

Conclusions

The current tight supply/demand position in the sulfur market is expected to continue into the 1980s. Indeed, by 1990, on the basis of projected consumption growth rates the Western world is moving towards a 4 million metric ton deficit. However, in view of the current price levels and expected developments, the bulk of the shortfall will be met by increases from voluntary production, notably Frasch production in the United States and Mexico, increased imports of Polish sulfur and from remelted stock piles of recovered sulfur in Canada.

The development of this scene and the continued upward trend in prices should result in Exxon having little difficulty in disposing of its sulfur output. Prices in the 1990s are expected to reach between $70-80 (1979 $)/MT ex-terminal Tampa. There are however, considerable discounts offered by recovered producers over those of Frasch producers. Discounts are normally between $20-25/MT according to location. It is anticipated that given the tighter market conditions the discounts will be of more modest levels in the 1980s particularly in the East Coast markets.

The market for Exxon sulfur will be the Mid West area, in view of the small quantity involved, it is considered unlikely that Exxon will have to secure more than two purchasers.

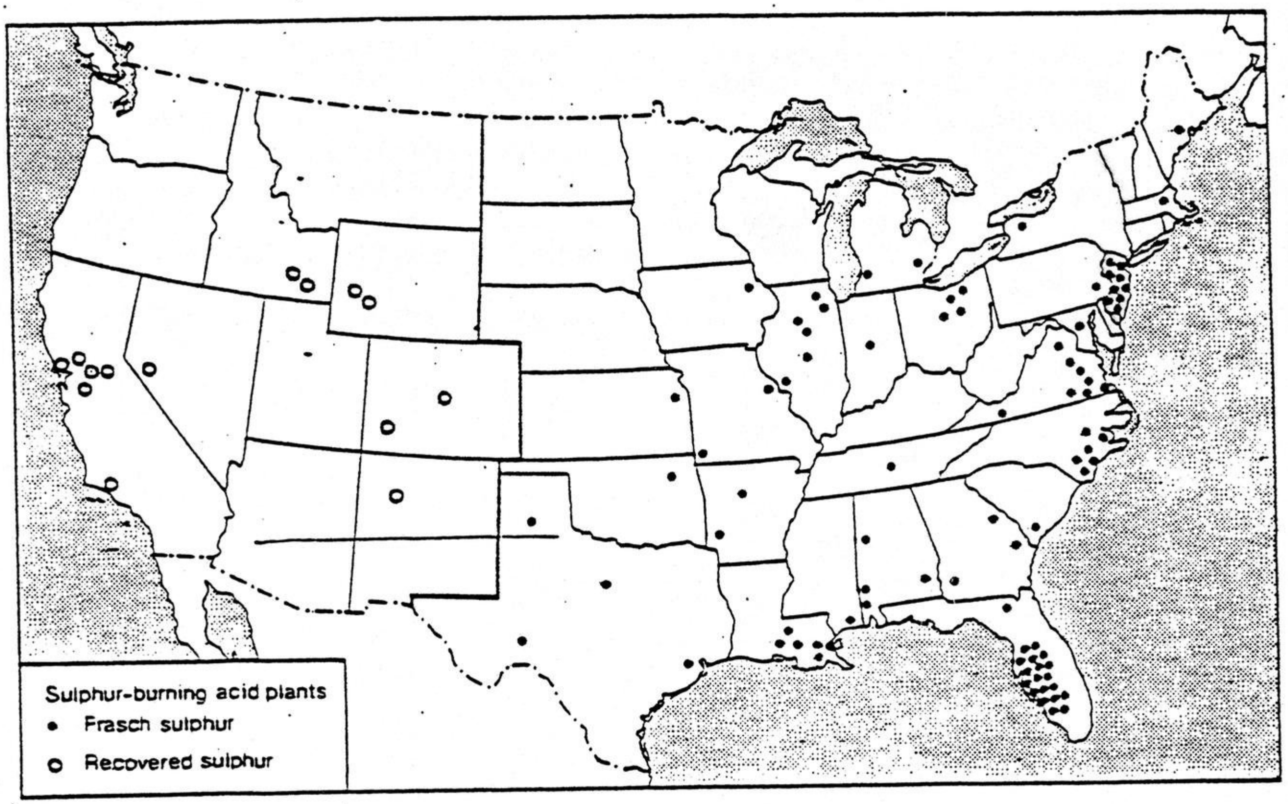
2.3 Market for Sulfuric Acid

Introduction

Sulfuric acid is the largest tonnage industrial chemical in the United States, production totalling 35,653,000 metric tons in 1978. Sulfuric acid is used in most industrial sectors but the phosphate fertilizer industry accounts for the major share - 60%, the balance of consumption is spread between a wide range of industries - petroleum refining, 5%; copper leaching, 5%, titanium oxide, 3%; hydrofluoric acid, 2%; alcohols, 2%; explosives, 2%; aluminum sulfate, 2%; ammonium sulfate, 2%; iron and steel pickling, 2%; cellulosics, 2%; uranium milling, 2%; surface active agents, 1%; others, 12%. In view of the wide range of end uses, sulfuric acid is often considered as an economic indicator. Sulfuric acid is

Geographic distribution of sulphur terminals

Figure 3



Geographic distribution of sulphur-burning acid plants (1978)

Figure 4

particularly responsive to rapid changes in supply and demand largely because of the expense and difficulty of storing the product. Consequently inventories are kept at a minimum. Although buffered to some extent by the wide variety of outlets, in view of their relatively small individual market size, the fortunes of the sulfuric acid industry have been dependent upon phosphate fertilizers.

Sulfuric Acid Capacity

At the beginning of 1979, there were 73 companies producing sulfuric acid at 133 locations, with a total nameplate capacity of over 51,000,000 metric tons of 100% H_2SO_4.

Table 14 - U.S. Sulfuric Acid Capacity and Operating Rates
(1000 MTPY, 100% H_2SO_4)

	Capacity	Operating Rate %
1960	20,475	76
1965	22,755	95
1970	35,380	73
1971	35,712	71
1972	36,529	74
1973	37,338	75
1974	38,570	79
1975	40,882	69
1976	42,072	69
1977	43,327	72
1978	45,560	77

Source: SRI

Of the above capacity, 81% is produced from elemental sulfur feedstocks, 8% from sludge acids, 8% from smelter gases and 3% from other sources - H_2S, pyrite, etc.

Capacity is currently well in excess of production, from its peak operating rate of 95% in the mid 1960's operating rates have since fluctuated between 69-80% of total capacity. Prior to 1970, the typical operating level was generally 75-80%. However, several factors in the 70's have affected these rates: (1) A substantial incremental capacity has been introduced due to the construction of byproduct acid plants particularly at copper smelters. Operating rates at such plants have generally been low as copper producers have invested in excess capacity so as not to inhibit metal production. (2) The main market for sulfuric acid is the phosphate fertilizer sector and consequently the operating rates in the acid sector have paralled those of phosphate plants.

Sulfuric Acid Production

Total sulfuric acid production has grown from 14,746,370 metric tons of 100% H_2SO_4 to 35,912,000 between 1955 and 1978. Three market phases can be identified. (1) the slow but steady growth over the period up to 1973; (2) the pre-fertilizer price hike growth in 1974 and the consequent stagnation in 1975 and 1976; (3) over the past two years, spurred on by the growth in the phosphate fertilizer sector, output has increased by 5.7 million metric tons 100% H_2SO_4.

As can be seen from Table 3, production of sulfuric acid by the contact process now dominates the industry. In 1955, of the 13.9 million metric tons of new acid production, 85% was via the contact process; by 1976 (the last year for which chamber process production was recorded) this had increased to over 99% - with only two chamber process plants remaining. The balance comprises fortified acid.

In terms of production by sulfur source, elemental sulfur accounts for the major share. In 1977, the burning of elemental sulfur by acid plants accounted for 88% of total output of new acid. Of the remaining 12% supplied by other sources, smelter gases accounted for 10% (of which copper represented 7% of the total) with H_2S and pyrite the remaining 2%. There are several other small sources which have not been identified separately - SO_2, $FeSO_4$ and coke oven gases.

Table 15 - H_2SO_4 Production by Sulfur Source
(1000 metric tons of 100% H_2SO_4)

	NEW ACID				
	FROM NEW SULFUR				
	Elemental S	H_2S	Smelter Gas	Pyrite	Total
1955	10,493	308	1,009	1,467	13,277
1960	11,180	599	1,074	1,547	14,400
1965	16,658	844	1,207	1,252	19,961
1970	20,531	611	1,668	1,134	23,944
1971	20,420	544	1,610	1,080	23,654
1972	22,633	499	1,696	807	25,635
1973	23,666	453	1,863	513	26,495
1974	26,034	408	2,033	392	28,867
1975	23,532	363	2,382	572	26,849
1976	23,643	318	2,928	690	27,597
1977	25,983	272	2,936	399	29,590
1978	N/A	N/A	N/A	N/A	N/A

	NEW ACID				
	FROM NEW SULFUR				
	Total	Sludge Acids*	Total	Fortified Acids*	Total Acid
1955	13,277	620	13,897	849	14,746
1960	14,400	1,099	15,499	724	16,223
1965	19,961	1,642	21,603	942	22,545
1970	23,944	1,694	25,638	1,148	26,786
1971	23,654	1,527	25,181	1,159	26,340
1972	25,635	1,561	27,196	1,091	28,287
1973	26,495	1,446	27,941	1,042	28,983
1974	28,867	1,453	30,320	684	31,004
1975	26,849	1,442	28,291	1,066	29,357
1976	27,479	1,451	29,030	1,181	30,211
1977	29,590	1,399	30,989	1,510	32,499
1978	N/A	N/A	34,720	933	35,653

Source: SRI

Note: *1. Sludge acids, i.e., virgin acid produced by decomposition of spent acid from petroleum rifining, sulfanation and petrochemical processes.

2. Recovered acids - brought back to strength by blending with new acid or oleum or concentrated and distilled.

Table 16 - H_2SO_4 Production by Process and by Strength
(1000 metric tons of 100% H_2SO_4)

	BY PROCESS NEW			BY STRENGTH*			
	Chamber	Contact	Total	Fortified	100% H_2SO_4	Oleum(1)	Total
1955	2,106	11,792	13,989	849	11,026	1,615	14,747
1960	1,706	13,794	15,500	724	12,850	1,667	16,224
1965	1,155	20,447	21,602	942	19,407	1,982	22,544
1970	291	25,346	25,637	1,148	23,807	2,686	26,785
1971	191	24,989	25,180	1,159	23,915	2,234	26,339
1972	130	27,198	27,328	1,091	25,799	2,362	28,419
1973	97	27,844	27,941	1,042	26,355	2,532	28,983
1974	119	30,202	30,321	676	28,428	4,314	30,997
1975	88	28,203	28,291	1,066	27,380	1,890	29,357
1976	73	28,952	29,029	1,181	28,282	1,513	30,210
1977	N/A	N/A	30,986	1,510	30,553	1,636	32,496
1978	N/A	N/A	34,720	933	N/A	N/A	35,653

Source: USDC
Note: *Contact only.

(1) Oleum or fuming sulfuric acid contains free SO_3 dissolved in the acid. Can be expressed in terms of percentage H_2SO_4 equivalent.

Sulfuric Acid Consumption

In 1978, consumption of sulfuric acid in the United States totaled 37 million metric tons of 100% H_2SO_4, a 9.5% increase on the previous year.

The fertilizer industry has remained the major end user of sulfuric acid. In 1978, fertilizer production consumed over 24 million metric tons 100% H_2SO_4 or 65% of the total. The development of the fertilizer sector has been one of the main factors promoting the growth of sulfuric acid consumption. Usage by the fertilizer sector has increased by 350% since 1960, when the industry accounted for only 39% of usage.

The major growth factor in the fertilizer sector has been the emergence of the phosphoric acid industry. As detailed in Table 5, consumption of sulfuric acid used in the production of phosphoric acid has increased from 3.3 million metric tons in 1960 to 21.8 million metric tons in 1978. The spectacular increase in the growth of consumption of phosphoric acid, has almost been matched by the decline of consumption in the production of single superphosphates.

Table 17 - Distribution of Sulfuric Acid by End Use

	1960	1965	1970	1978
Total	100.0%	100.0%	100.0%	100.0%
Fertilizers	39.4	46,6	60.8	65.0
Petroleum refining	8.7	8.3	7.0	4.5
Copper	N/A	N/A	2.6	4.9
Alcohols	8.9	7.9	6.2	2.9
Titanium dioxide	8.9	6.6	5.5	2.4
Hydrofluoric acid	2.6	2.6	3.2	2.1
Aluminum sulfate	2.5	2.2	2.1	1.7
Others	29.0	25.8	12.6	16.5

Outside of the fertilizer sector, the second major area of usage is in copper leaching where usage in 1978 reached 1.8 million metric tons. The usage of sulfuric acid in petroleum refining has declined marginally over the years. In effect the petroleum refining industry is largely a recycling industry, with consumption in one form or another being negligible. The consumption of sulfuric acid by the other industries remains stable, although its consumption in the production of alcohols and titanium has declined.

Table 18 - Consumption of Sulfuric Acid by Fertilizers
(1000 metric tons of 100% H_2SO_4)

Year	Phosphoric Acid	Single Super-Phosphate	Ammonium Sulfate	Others	Total
1960	3,306	2,057	1,308	308	6,979
1965	7,225	1,808	1,696	406	11,135
1970	11,581	1,088	1,472	386	14,527
1971	12,514	1,017	1,340	376	15,247
1972	14,410	1,100	1,293	380	17,183
1973	14,767	1,005	1,455	425	17,652
1974	15,433	1,133	1,506	496	18,568
1975	17,267	786	1,467	415	19,935
1976	18,027	622	1,406	407	20,462
1977	20,567	552	1,477	419	23,015
1978	21,854	467	1,420	408	24,149

Source: SRI

Total shipments of sulfuric acid exceed the level of production with respect to deliveries of acid used in the oil refinery alkylation processes, steel pickling, nitric acid concentration, etc., and then reshipped as "spent acid" for use in other sectors. The main source of so called "spent acid" is the oil refinery industry while its main uses are in the regeneration of concentrated sulfuric acid by burning waste acid in a sulfuric acid plant, purification by hydrolysis, concentration by evaporation or fortification by the addition of SO_3.

Pricing Patterns

Sulfuric acid prices are normally quoted list price ex works. Historically actual prices have been contracted at levels considerably below listed prices. Discounts are available for large accounts, contract customers and to match specific competition.

Table 19 - Sulfuric Acid List Price
($ per metric ton)

	East Coast
1968	31.4
1970	31.4
1971	30.6
1972	30.6
1974	37.0
1975	42.3
1976	42.3
1977	42.3
1978	48.3
1979	54.0

Note: In Mid 1979 list prices for other regions are as follows:

Gulf Coast	47.9
Midwest	51.4
West Coast	52.4

Source: Chemical Marketing Reporter

In order to illustrate the discrepancy between list prices and actual prices, it is necessary to compare the prices quoted in Table 6, with the average shipment value recorded by the USDC.

Table 20 - U.S. Sulfuric Acid Shipment Value
($ per metric ton)

	All Shipments	Interplant Transfers (1)	Commercial Shipments
1955	17.44		
1960	N/A		
1965	15.12		
1970	17.29		
1971	17.36		
1972	16.53		
1973	16.64	15.50	16.79
1974	21.20	20.66	21.23
1975	29.37	28.70	29.43
1976	28.07	27.09	29.07
1977	30.00	30.68	29.90
1978			

Source: USDC

Note: (1) Company transfers from primary plant to downstream plant.

As can be seen, throughout the 1970s average shipment values have been well below the prevailing list prices. The sale price for larger transactions has in fact been below the average value of all shipments which has been boosted by the inclusion of all sales, oleum and other premium grades.

The price structure of the sulfuric acid industry is particularly complex as the market is dominated by two groups of producers with vastly differing sales considerations.

(1) Virgin producers, i.e., those operations based upon sulfur burning. Even within this group there are two distinct types of producers; (a) those based upon local recovered sulfur supplies and having less expensive feedstocks; (b) those based upon Frasch sulfur - which itself is a voluntary production product. Virgin producers are voluntary acid manufacturers, for whom acid is their primary sales product.

(2) Fatal acid producers - are involuntary producers - mainly smelters, for whom acid is a byproduct disposal problem.

The situation has been one in which voluntary producers have been caught in a cost/price crisis. Faced with increasing sulfur prices, they have been forced to cut their prices in order to compete with smelter acid producers.

This is amply evidenced in Table 21, in which prices in Arizona reflect the abundance of smelter acid supplies. Historically the problem was less severe for virgin producers as sulfur supplies were relatively inexpensive and fatal acid producers tended to serve the total markets. However, as sulfur prices increased, and under the pressure of a buoyant copper market, Mountain States smelters were forced to look further afield for markets to ensure disposal of their byproduct acid. Because of their low "production cost," fatal acid producers were able to remain competitive over longer distances, and have been prepared to sell their product at prices substantially below those of virgin producers. In actual terms, Arizona smelters have been prepared to sell acid for as little as $6/MT F.O.B. to Nebraska and Kansas. Indeed in extreme cases, where smelters have had insufficient onsite storage, they have been prepared to move acid for as little as $3/MT rather than jeopardize metal production. As a result current smelter acid spot prices are in the order of $6-18/MT 100% tanks, Western works $14-16/MT 100% tanks Gulf and $7-18/MT 100% tanks, New Mexico, while inland Cities Services are selling $22.75/MT F.O.B. Copperhill, Tennessee.

These spot market prices for smelter acid can be compared to list prices of $57-60.80 West Coast; $52.75-55.75 US Gulf; and $58.65 Midwest for Virgin acid.

Future Market for Sulfuric Acid

By the end of 1978, there were some 187 power plants in the United States thought to be out of compliance with the current applicable emissions regulations. The total level of SO_2 emissions from these plants equates to a sulfuric acid production of 15.87 million metric tons of 100% H_2SO_4. The total potential abatement byproduct acid from this source would account for 45% of total current acid production. However, as a number of plants would close down, others would purchase fuel of low sulfur content, and others would opt for limestone scrubbing. EPA/TVA project production of sulfuric acid at between 2,317,540 metric tons and 5,075,680 metric tons.

Having established the level of potential abatement acid production at between 2.3 and 5 million metric tons H_2SO_4, the other major source of supply will be smelter byproduct acid. Capacity of smelter acid is estimated to be in the order 5.4 million metric tons with a further 500,000 metric tons to be commissioned in 1979. The balance of capacity comprises sulfur burning and sludge acid plants.

Table 21 - Sulfuric Acid Unit Shipment Value; Sected States[a]
(Dollars Per Short Ton)

	Arizona	California	Florida	Illinois	Louisiana	New Jersey[b]	Pennsylvania	Texas[c]
1965	21.18	16.62	12.75	19.00	N/A	20.64	17.93	16.17
1970	14.15	18.49	15.92	19.51	14.39	26.12	22.19	16.48
1971	16.57	20.42	15.52	18.95	15.73	25.08	26.84	16.45
1972	16.26	22.72	13.93	19.60	16.44	22.63	20.02	15.34
1973	11.92	18.05	15.34	20.98	17.58	24.05	20.77	14.97
1974	12.71	23.52	21.16	36.26	21.02	33.43	24.89	16.80
1975	12.51	35.80	31.93	45.18	37.46	38.16	32.52	31.27
1976	10.36	34.83	30.91	38.31	41.29	50.25	31.68	29.80
1977	12.49	37.55	29.71	34.49	43.95	47.80	31.21	31.37

Source: USDC

Notes

a. Data are for all shipments, interplant transfers and commercial.
b. Data for 1965-1974 include New York.
c. Data for 1965-1972 include Oklahoma.

With this background and the expected increased movement of Canadian smelter acid into the United States, there seems to be little alternative to a prolonged period of potential oversupply in the US/North American acid market. There is, however, some potential for a slight easing of the situation.

(1) The reduction in sulfur burning capacity in the short term continues as elemental sulfur prices continue to firm. However, the supply of recovered elemental sulfur is expected to become a major sulfur source by the 1980's and may mitigate extensive closures.

(2) The closure of some acid plants in the face of compliance with emission control regulations - as in the case of Allied, which closed its 200,000 metric tons H_2SO_4 Cleveland plant in 1973.

(3) The failure of abatement acid production to reach production levels anticipated by the EPA/TVA.

In view of the oversupply situation which is expected to continue well into the 1980s there will be little hope for producers to exert much upward pressure on prices. This will become more evident as byproduct producers expand their share of the market. Inevitably this will act as a depressant to any price increases which may be proposed by the sulfur virgin acid producers in response to higher sulfur prices.

In an evaluation of the future sulfuric acid prices that would be expected by a potential producer, a number of important factors must be taken into consideration.

(1) Exxon's sulfuric acid will be involuntary and any sales/marketing program must consider that this material poses a byproduct disposal problem, and eventually a potential production bottleneck. As detailed earlier, distress sales by Mountain States' smelters have been made to California markets for as little as $3/MT F.O.B. as the necessity to dispose of the acid due to insufficient onsite storage has over-ridden all other factors. The philosophy that sulfuric acid is merely a byproduct problem, should not however, deter the involuntary producer from attempting to obtain a high net back on the acid. However, it must be evaluated along side the potential bottleneck problems from failure to dipsose of the acid.

(2) Potential disposal problems will undoubtedly arise from fluctuating levels of production as sulfuric acid production is dependent upon the vagaries of metal processing. It is therefore unlikely that any new smelter acid producer could expect any major consumer to pay near list prices for fatal acid, for which neither the composition nor production could be guaranteed.

(3) Competition from other acid producers - the expected weak market conditions will force fatal acid producers to accept lower net backs, because of their unfavorable locations, than virgin acid producers. Exxon's main competition will not come from virgin acid producers but from other fatal acid operations. As stated earlier, Mountain States' producers are prepared to accept net backs of only $6.00/MT as they are forced to seek markets as far afield as Nebraska and Kansas. The expansion of production in the Mountain States areas will undoubtedly force smelter producers to look to the Midwest market. The other major competitor will be the Canadian industry. Canadian fatal acid directed towards the Midwest will increase substantially as CIL expands its range of suppliers and develops its market penetration. Net backs on Canadian acid are estimated to be slightly higher in certain cases than those of the New Mexico and Arizona smelters. In Table 22 estimated net backs for Canadian fatal acid for delivery to the North Central region are presented.

Table 22 - Estimated Net Backs for Canadian Fatal Acid
(1979 $ per metric ton)

	West North Central	East North Central
INCO	10	16
Noranda	5	11
Texasgulf	4	10

Exxon will be faced with a highly competitive market in the North Central States by the mid 1980s. In view of its position as a new supplier of fatal acid, it is CRU's opinion that Exxon cannot expect its potential net back to be related to the prevailing list prices or to the net backs achieved by virgin acid producers.

In the present climate of price cutting in the North Central States area, prices are in the order of $35 per metric ton delivered, in spite of list prices of $58/MT. In the future there will be a slight firming of prices as fatal acid suppliers attempt to improve their net backs by following the price rises posted by virgin producers. CRU estimates that the delivered price in the North Central States by 1990 will remain in the range of $35-40/MT on the basis of 1978 constant $. For whom Exxon can expect a net back in the order of $10-15/MT.

Potential Market for Crandon's Sulfuric Acid

The markets of potential interest to Exxon's production of sulfuric acid can be identified as the North Central region. Although some potential for movement of acid to the Gulf area exists, it depends entirely upon the freight element from Evansville to the major consuming center in central Florida.

Two options are open to Exxon with regard to its sales of acid.

(1) Direct Sales - in the market review, a number of existing producers who may wish to cease production should a competitively priced byproduct be available, were identified.

  (a) In the east of the region - Minnesota Mining and Manufacturing at Coply and DuPont at Cleveland could be receptive to offers of acid supplies.

  (b) In the west of the region - National Distillers at Dubuque, Mobil at Depue, are potential purchasers, while the sulfur burning plants of DuPont at North Bend and W. R. Grace at Joplin are considered vulnerable.

In addition to direct sales to major consumers, the existing merchant markets in the area could absorb up to 100,000 metric tons H_2SO_4 for the wide range of industrial end uses.

(2) Merchant Sales - the retailing of sulfuric acid requires a substantial investment in both storage and distribution facilities if a major proportion of sales are made to smaller consumers. An attractive alternative to handling sales internally, is to negotiate with a major sulfuric acid broker. The most obvious candidate is CIL, which in 1979 expects to move 1.3 million MT of sulfuric acid. By the early 1980's CIL expects to handle up to 1.7 million MTPY of sulfuric acid (excluding the output of Anaconda, with whom it is negotiating). In the longer term, they expect deliveries to reach 3 million MTPY.

The main advantages in dealing with a broker is the assured movement of the product and the saving in distribution costs. In the case of CIL, contracts are normally of ten year duration plus a one year introduction period, during which acid production will be irregular, and a two-three year run down period at the end. The arrangement usually operates as follows:

(1) The acid producer invests in 6 weeks production storage equivalent, while CIL guarantees an equivalent storage, thereby assuring a 3 month total capacity.

(2) The producer, once the plant is operating normally, informs CIL of its expected production for the year and sales are agreed on the basis of ±10%. Any deviation from this is costed on the basis of existing spot prices, i.e., (a) if the producer exceeds the agreed figure, his net back on the surplus tonnage reflects the current market price; (b) if production is below the agreed level, the producer bears the cost of CIL's incursion into the spot market to maintain its sales obligations. The wider the range of supplies CIL deals with, the less severe will be the dislocation from any individual failing to meet his contracted volume.

It is CRU's and Davy McKee's recommendation that Exxon seek assistance in its marketing of sulfuric acid. Direct approaches to major consumers could be made to the existing producers identified above, and the balance of production be offered to CIL or a similar organization.

2.4 Market for Iron Pellets

The forecasts suggest that US consumption of iron pellets will expand relatively rapidly during the forecast period. At present there is substantial excess capacity in the pellet industry in North America. The growth in consumption (plus exports) can be expected to take up much of this slack during the early 1980's. If all consumption were to be met by US production there would be a need for additional capacity after 1985. However, when Canadian capacity is considered, there remains little need for new capacity (beyond that already planned) well into the second half of the 1980's. In addition, it is our view that there will be substantial supplies of pellets from outside North America competing for a share of the US market throughout the 1980's.

The overall view of the market prospects, therefore, is that there will be a continuing downward pressure on pellet prices in the US market for the next few years and probably continuing through most of the 1980's. Potential supply will be adequate to meet the growing demand such that producers will not be able to raise prices to the point at which high-cost new projects will be sustainable.

We therefore believe that the current caution of the major iron ore companies concerning future investment is correct. Major new projects do not appear justified even through the USA is a competitive location for investment due to production costs and business climate.

Some further additions of US pellet capacity can be expected in the second half of the 1980's to ensure that domestic producers do not lose their share of the home market, but it is expected that caution in investment and a generally easy supply of iron pellets will prevail at least into the second half of the 1980's.

The market for iron pellets is very large and, although the general market conditions may be unfavorable, it remains possible that individual and small operations may find conditions advantageous. Thus, while it may be difficult to finance and bring into production large increments of capacity such as a typical 4 million TPY unit, smaller operations may find marketing of their product easier and less depressing on prices. Similarly, particular qualitities of pellets, or the need to recover only part of the capital cost of the total operation, could place an individual operator in a price or cost position untypical of the industry as a whole. Hence, while the overall assessment is that the market and price prospects for iron pellets are generally unfavorable, with prices being depressed below the full costs of new operations, and most likely falling in real terms over the next ten years, further investigation would be required to ascertain whether this position applies to the product of any particular company or process.

The analysis has considered the balance of demand and supply in numerical terms only as far as 1990. Beyond that date it seems likely that consumption of steel in the USA will continue to increase at a slow rate, on an average of perhaps 1-1.5% per annum. There will, therefore, be an attendant demand for iron ore, increasing at approximately this rate to the year 2000. By the late 1980's it will be necessary for further major new production capacity for pellets to be established in the USA or Canada, if the market demand for iron is not to be met from overseas projects. During this period, prices can, therefore, be expected to move upwards in real terms to the point at which such major new investments become profitable. The precise timing or extent of such developments is not predictable at this stage because the market conditions of the late 1980's and 1990's will depend not only upon steel consumption in the USA, but upon the developments in iron ore mining and processing outside the USA during the 1980's. If there are large quantities of surplus pellet production capacity in areas such as Latin America and Africa, then international market prices will be such that US investment in pellet production will be delayed until the depressing impact of this surplus on pellet prices has passed. Alternatively, if many of the large overseas projects do not proceed as planned, the opportunities for investment in the USA may be better for the 1990's.

The overall assessment of the prospects for the iron pellet market, however, is that it will be difficult for a new producer to enter the US market successfully in the foreseeable future and hope to recover the full cost of his capital plus a normal profit, unless there are special features of quality or production cost associated with his operations. The most promising area of investigation, assuming that the pellet product could be technically suitable, might be the production of the superior grade pellets required for direct reduction feed.

Prospects for Exxon's Pellets

Specifications

The byproduct iron oxide from Exxon's pyrite could be processed into 180,000 MTPY of pellets with the following composition:

Fe	65.1%	Pb	0.01%
Fe_2O_3	93.0	Zn	0.01
SiO_2	3.28	S	0.02
Al_2O_3	0.78	As	0.03
CaO	1.47	Cl	0.02
MgO	0.83	P	0.02
Mn	0.03	K	0.01
Cu	0.02	Na	0.01

Discussions with steel companies and other iron ore producers indicate that these would be considered good quality pellets. The iron content is quite high for US pellets and other components seem to fall within the range of normal practice. This is confirmed in Table 10, where the analyses of most of the major types of US pellets produced in 1977.

Table 23 : Analyses of US Iron Ore Pellets, 1977 (percent)

	Fe	P	SiO_2	Mn	Al_2O_3
Exxon	65.1	0.02	3.28	0.03	0.78
Empire-Cleve.-Cliffs	63.0	0.019	6.39	0.07	0.53
Marquette-Cleve.-Cliffs	63.4	0.051	5.00	0.07	0.76
Pioneer-Cleve.-Cliffs	59.6	0.057	7.87	0.34	2.81
Tilden-Cleve.-Cliffs	63.0	0.038	5.92	0.10	0.68
Groveland-Hanna	61.6	0.028	6.87	0.81	0.45
Aurora-Pick. Mather	62.5	0.015	6.00	0.20	0.37
Eveleth Taconite	64.6	0.013	5.32	0.09	0.37
Hibbing-Pick. Mather	64.4	0.002	5.02	0.08	0.15
Minntac-U.S. Steel	63.4	0.014	5.74	0.16	
Minorca-Inland Steel	65.8	0.014	3.62	0.13	0.20
National Steel	63.9	0.008	5.19	0.10	0.16
Reserve Mining	60.4	0.04	8.64	0.37	0.54
Bethlehem-Morgantown, PA	65.1	0.008	3.37	0.10	1.12
Pea Ridge, Miss.-Meramec	67.6	0.075	1.88	0.03	0.30
Pilot Knob, MO-Hanna	64.7	0.011	4.58	0.12	0.81

	CaO	MgO	S	Moist.*
Exxon	1.47	0.83	0.02	
Empire-Cleve.-Cliffs			0.001	2.31
Marquette-Cleve.-Cliffs			0.001	2.38
Pioneer-Cleve.-Cliffs			0.001	2.06
Tilden-Cleve. Cliffs			0.001	2.68
Groveland-Hanna	0.94	0.62	0.002	2.51
Aurora-Pick. Mather	0.44	0.44	0.004	3.25
Eveleth Taconite	0.37	0.41	0.002	2.09
Minntac-U.S. Steel				2.59
Minorca-Inland Steel	0.50	0.45		
National Steel	0.23	0.37	0.003	2.47
Reserve Mining	0.42	0.65		2.95
Bethlehem-Morgantown, PA	0.31	1.90	0.008	-
Pea Ridge, Miss.-Meramel	0.24	0.16		0.15
Pilot Knob, MO-Hanna	0.10	0.09	0.003	2.07

*Note: On a dry basis, the analyses of Fe and other constituents would be proportionally higher, generally bringing Fe into the range of 64-66%.

Source: American Iron Ore Association.

Markets

We should report that in the opinion of industry experts with whom CRU contacted that the size of this pellet operation would be far below an economic scale. The prevailing industry opinion is that 4 million STPY is now the minimum economic size for a new conventional pellet plant. Davy McKee's engineering/economic work in Phase II of this project will quantify this statement.

On the other hand, the small output of the proposed facility makes it hard to imagine any problem in finding a market for the pellets as blast furnace feed. In 1978, the US and Canada produced 122 million metric tons of iron ore and the supply of pellets to the US steel industry amounted to 82 million metric tons. The destination of the majority of these pellets is to blast furnaces around the Great Lakes, to which Exxon's pellets would also have easy access. Under these circumstances, and also considering the good quality of the pellets, Exxon should have no difficulty shipping its 180,000 metric tons into the market at close to the prevailing market price. The customers could be any number of integrated steel companies situated on the Great Lakes or Midwestern river system.

Pellet Prices

The history of posted prices for iron ore pellets at lower Great Lake ports is shown in Table 11. It is understood that the posted price is sometimes just a starting point for negotiations between seller and buyer. Discounting has occurred during periods of especially slack markets or for low quality pellets. Nevertheless, the trend of posted prices probably can be taken as reasonably representative of prices of good quality pellets.

Table 24: Lake Superior Pellet Prices at Rail or Vessel Lower Lake Ports

Year	Date	Price per long ton unit
1962-69		$ .252
1970		.266
1971-72		.280
1973		.291
1974	1-1 to 3-25	.291
	3-25 to 4-26	.29884
	4-26 to 5-2	.31189
	5-2 to 6-24	.3550
	6-24 to 12-30	.40619
	12-30 to 1-1-75	.44559
1975	1-1 to 2-7	.44559
	2-7 to 7-9	.452
	7-9 to 1-1-76	.472
1976	1-1 to 109	.472
	1-9 to 8-16	.5045
	8-16 to 1-1-77	.531
1977	1-1 to 1-7	.531
	1-7 to 1-1-78	.555
1978	1-1 to 3-21	.555
	3-21 to 9-6	.584
	906 to 1-1-79	.609
1979	1-1 to 4-4	.609
	4-4	.655

Source: Cleveland Cliffs Iron Company

The long term outlook for pellet prices is not especially favorable, and we would not expect to see sustained "real" price increases in the foreseeable future. This is because of the probable existence of more than ample North American pellet capacity during much of the 1980's, and beyond that period because of the depressing effects of large new foreign iron ore developments.

The current posted pellet price, $.655/long ton unit, translates to $42/metric ton of Exxon's pellets. We think it would be a fair approximation to use this as the estimate for future prices in constant 1979 dollars.

2.5 Phosphoric Acid & Phosphate Fertilizer

Phosphoric Acid

Phosphoric acid is the most important inorganic acid produced and consumed in the United States in terms of production value, and second to sulfuric acid in volume. The major end-use of phosphoric acids is in the production of phosphate fertilizers, which accounts for over 85% of total consumption. Other uses in order of significance are livestock and poultry feeds, building and water treatment, food and beverages, direct acid treatment of metals, and fire control.

Its importance to the US phosphate industry is illustrated by the fact that it accounts for 60% of total US phosphate rock production and 85% of domestic phosphate rock consumption.

For the purposes of this report it is proposed to examine the developments of 54% P_2O_5 wet process orthophosphoric acid, i.e., fertilizer grade acid as used in the production of diammonium phosphates.

The US Phosphoric Acid Industry

In 1978, phosphoric acid was produced by 24 companies at 32 locations throughout the US. Capacity currently stands at 8,841,000 MTPY of P_2O_5, a 68% increase since 1967.

Production of Phosphoric Acid

Production of wet process phosphoric acid has risen dramatically, to over 8 million MTPY by 1978. The incremental production from the industry has stemmed not only from expansions of capacity but also from a gradual improvement in utilization rates. In 1978, allowing for the unrecorded debottlenecking, capacity utilization rates were in excess of 90% in wet acid plants. (Other sources such as IMCC have suggested that in 1978/79 shipments from the phosphoric acid industry were 100% of capacity.)

Table 25 - Wet Process Phosphoric Acid Production, USA, 1955-1978
(1000 MT of P_2O_5)

1955	703
1960	1201
1965	2627
1970	4211
1971	4551
1972	5240
1973	5370
1974	5612
1975	6250
1976	6560
1977	7100
1978	8050

Source: USDC

The industry enjoyed a high capacity utilization rate in the early 1970s due to a combination of factors, the strengthening of prices and the shortfall in capacity, a consequence of the poor market in the 1960s and the lack of incentive to invest. By 1973 operating rates were in excess of 80%. However, two related factors caused reductions of utilization rates in the following years, a relaxing of price controls prompted an overinvestment in new capacity, and consumption of finished phosphate fell in response to the mid 1970s price hike. Since 1976, demand has recovered, spurred on by the substantial increase in US exports of solid phosphate and consequently utilization rates have improved accordingly, to an estimated 90% in 1978.

Phosphoric Acid Consumption

As stated, the phosphate fertilizer is the major user of phosphoric acid. In 1978 it is estimated that of total domestic use, the fertilizer industry accounted for 93% of wet process phosphoric acid (including up-grading into superphosphoric acid). Outside the fertilizer sector the second major consumer is the animal feed industry, which has an annual consumption of up to 338,000 metric tons of P_2O_5 for the production of dicalcium phosphates. Other uses of significance are in construction and water treatment.

The changing pattern of the phosphate fertilizer industry has had a marked effect on the development of phosphoric acid usage, principally the demise of the single and enriched superphosphate industry, the slow growth of triple superphosphate and the rapid emergence of ammonium phosphates both solid and liquid as the major P_2O_5 medium. The following table identifies the pattern of phosphoric acid consumption by fertilizer product.

Table 26 - Total US Phosphoric Acid Consumption
(1000 MT of P_2O_5)

Year	Triple Superphosphate	Ammonium Phosphate Solid	Ammonium Phosphate Liquid	Direct Acid	Total
1965	1005	1182	200	19	2406
1970	1016	2337	472	37	3862
1971	1038	2693	529	31	4291
1972	1138	2998	581	29	4746
1973	1160	3111	585	35	4891
1974	1182	2810	615	29	4636
1975	1130	3250	467	27	4970
1976	1094	3664	631	23	5412
1977	1228	4301	663	30	6222
1978	1254	5378	736	30	7398

Source: USDC, SRI, TVA and CRU estimates.

The utilization of phosphoric acid falls into three major categories:

(1) Captive onsite use
(2) Merchant sales within the fertilizer industry
(3) Non fertilizer demand

As 93% of the production is used in fertilizers the first two sectors are clearly the main channels.

Of the US phosphate fertilizer producers producing triple superphosphate or diammonium phosphates, according to plant list details, only three plants producing finished concentrated phosphates have a requirement for merchant acid.

(1) American Plant Food at Galena 27,000 MT of P_2O_5
(2) Standard Oil - has a total requirement of 54,000 MT of P_2O_5
(3) Valley Nitrogen at Chandler - 14,000 MT of P_2O_5

It is estimated that only 7 of the 24 producers of phosphoric acid have substantial surplus tonnages (over 300,000 MT of P_2O_5) available per year. Of these, three companies dominate.

Freeport has a contract with Agrico for the sale of 300,000 MTPY of P_2O_5 until 1982. The balance of their production (non-tolled) is sold on the domestic and international merchant acid markets.

CF Industries moves approximately 50% of its Plant City, Florida production, 110,000 MTPY of P_2O_5 as merchant acid.

Texasgulf sells about 16% of its Lee Creek, North Carolina production, 160,000 MTPY as merchant product in the domestic and international market. (100,000 MTPY of P_2O_5 is moved in the domestic market.)

There is a substantial although unquantified tonnage of phosphoric acid moved to the blending/mixing tier of the industry. Estimates of consumption at this level have put utilization at 300-400,000 MTPY of P_2O_5.

Price Developments

In view of its single role as an intermediate in the fertilizer industry, phosphoric acid prices have followed the pattern set by finished phosphate fertilizer products. The decline in prices through the late 1960s and early 1970s followed by a marked increase in 1974, even though not as pronounced as the increases in finished phosphate prices.

The following table of prices, extracted from shipping information produced by the USDC, illustrates the cyclical developments.

Table 27 - Wet Process Phosphoric Acid - Prices per short ton, 1955-1977
($)

	Shipments & Interplant Transfers	Commercial Shipments Only
1955	124	
1960	109	110
1965	99	99
1970	85	83
1971	80	79
1972	79	79
1973	93	97
1974	147	139
1975	154	N/A
1976	165	N/A
1977	163	165

1978 and 1979 witnessed a firming of prices as the international phosphoric acid market tightened. Although one cannot directly compare the current Gulf Coast price of $270/MT with the values listed above, it illustrates the turnaround in the phosphoric acid market over the past 18 months. This trend is expected to continue into 1980, as Gulf prices, in excess of $300/MT, are firmly expected.

Long Term Development of the Phosphoric Acid Indstury

Existing capacity for phosphoric acid, at the beginning of 1979, totalled 8,841,000 MT of P_2O_5, although in many cases plants have been debottlenecked and therefore operate in excess of nameplate capacity. A number of new projects are under consideration for the post 1980 period which will raise capacity to over 11 million MTPY of 1990. For the period 1990-2000 new developments in capacity can only be related to the growth in P_2O_5 demand and an assumed maintenance of exports of finished products.

The following capacities are forecast to be operational by 1990.

(1) Occidental Chemicals: a 350,000 STPY of P_2O_5 wet process phosphoric acid unit will be commissioned by 1980 at Swift Creek, to enable Oxychem to comply with its SPA committment.

(2) Grace has announced its proposal to construct a 363,000 STPY P_2O_5 wet process acid project in the 1980s.

(3) USSAgrichem are considering a joint venture operation to replace their existing Ft. Meade operation.

(4) Gardinier will expand its overall capacity by the addition of a 363,000 STPY P_2O_5 unit.

(5) Texasgulf is reviewing the addition of 310,000 STPY P_2O_5 acid capacity at Lee Creek in the 1980s.

(6) CF Industries is proposing to construct a 363,000 STPY P_2O_5 phosphoric acid unit at their new Hardee County site.

(7) Farmland Industries has a project under consideration for a 363,000 STPY P_2O_5 plant linked to their new mining operation.

(8) In addition to the new capacity, a number of companies are expanding capacity of their existing units. IMCC is debottlenecking its New Wales subsidiary at Mulberry to over 1,000,000 STPY P_2O_5. Agrico and CF Industries are debottlenecking existing capacity.

The above developments should result in the addition of over 1.5 million MTPY P_2O_5 of new capacity, and debottlenecking is seen as adding up to 1 million MTPY P_2O_5 of capacity.

Table 28 - Development of Phosphoric Acid Capacity/Production
(1000 MT of P_2O_5)

	1980	1985	1990	1995	2000
Capacity	9,350	10,600	11,500	12,500/ 13,100	13,800/ 1,520
Production	9,050	9,850	10,700	11,550	13,070

In the period 1990-2000 capacity developments are expected to match demand developments which will be a growth rate of between 2.0-3.0 pa, with a slight easing in the level of utilization. By 1995 a new generation of replacement units will be required as little further bottlenecking of existing units is envisaged after 1990.

The outlook for prices in the remainder of the century is difficult to predict, although one can draw conclusions from a number of developments, that suggests a continued upward trend in prices, inspite of cyclical fluctuations.

(1) Increased manufacturing costs due to environmental constraints on new plants and expansions.

(2) The reduction of available quantities of higher grade phosphate rock and the required process modifications and improvements.

Conclusions

The market for phosphoric acid has improved significantly and is likely to continue to improve into the 1980s. The United States production of 8,050,000 MTPY of P_2O_5, approximately 400,000 MTPY of phosphoric acid were exported in 1978, and exports are forecast to reach 600,000 MTPY by 1980. Given the continued improvement in international spot prices, the United States will maintain its phosphoric acid exports at 750,000 MTPY of P_2O_5 in the late 1980s.

While the export market will remain buoyant, although any price explosion will be contained by underutilized capacity in West Europe, little growth in the domestic merchant market is envisaged because the majority of additional capacity will be used captively by producers. The only growth in the domestic merchant market will be in granulation and fluid blends even though upgraded superphosphroic acid is more likely to be the major product.

Furthermore, of the total US triple superphosphate and ammonium phosphate producers, the majority of companies are self sufficient in phosphoric acid. There is however, substantial tonnage moved between plants in order to maintain downstream production namely, Oxychem who is currently purchasing acid to upgrade to superphosphoric acid as part of its Soviet contract.

There is a market for wet process phosphoric acid for non fertilizer uses, defluorinated phosphates, dicalcium phosphates and sodium phosphates. In 1978 usage in these industry totalled 305,000 MTPY of P_2O_5. The market is fragmented with a number of small producers. The potential for a producer of acid based upon purchase of phosphate rock is poor in the non fertilizer sector.

To summarize, the demand for wet process acid is largely served by captive producers, the only market is the TSP/AP sector, which is largely self sufficient. Outside this sector are a wide range of smaller fragmented users who are currently served by existing phosphoric acid producers. The growth in the fertilizer acid market is not expected to generate a substantial incremental demand by these in the 1990s.

It is therefore recommended that Exxon's involvement in phosphoric acid will be confined to its production as an intermediate for downstream production.

Phosphate Fertilizers

The use of phosphate fertilizers in North America is particularly well established - hence the recent relatively slow growth of consumption compared with developing countries. In 1977/78 North America accounted for about 18% of world demand, consuming just over 5 million metric tons of P_2O_5. Its market share is expected to remain unchanged throughout the 1980's, with an average annual growth rate of about 2% reaching nearly 7.5 million metric tons of P_2O_5 by 1990. Most of this demand will still be for triple superphosphate and diammonium phosphate, particularly as the importance of blending in fertilizer manufacture increases.

Supply comes entirely from domestic producers, and demand will probably be met by increased capacity utilization. It is also likely that diammonium phosphate capacity will expand in the long term, maintaining North America's position as the largest producer. North America is of prime importance as an exporter of concentrated products, and plays a dominant role in determining the nature of the world market itself, treating it as an extension of the home market. Growth in other regions will therefore focus on triple superphosphate and particularly diammonium phosphate, as North America's requirements are unlikely to change.

Latin America

Consumption in Latin America has grown rapidly in recent years, reaching just under 2 million metric tons of P_2O_5 in 1977/78. Brazil is the main market for phosphate fertilizers accounting for about two-thirds of demand, mostly in the form of diammonium phosphate. Growth is expected to remain at a high level throughout the 1980's, and by the early 1990's Latin America will consume about 5 million metric tons of P_2O_5 per annum, about 10% of world demand.

Although this region has significant phosphate rock resources of its own, mostly in Brazil, Mexico and Venezuela, they are not yet fully developed, so most countries are net importers. North America has a strong influence on the nature of demand and readily exports TSP and DAP to Latin America. DAP is emphasized, being granulated and blended with domestically produced nitrogen. In the future, most countries will try to minimize imports, but domestric capacity, even allowing for new plants, will be insufficient to meet growing demand. Possible exceptions will be Mexico and Venezuela which may attain self-sufficiency through local production. Mexico now exports some TSP, but this will probably cease as the existing plant is converted to DAP production for domestic use.

Asia

Demand for phosphate fertilizers has risen steadily in the last few years, reaching 4.4 million metric tons of P_2O_5 in 1977/78, about 15% of the world market. However, Asia should be considered as four regions with distinct patterns of demand. The West (Middle-East) consumes very little phosphate fertilizer, and the expanding industry is chiefly export-oriented. In central Asia, particularly India, there is a rapidly increasing demand for fertilizers largely due to the development of agriculture. In 1977/78, consumption in India was 867,000 metric tons of P_2O_5, 34% greater than the previous year. Consumption in the Far East has grown relatively slowly in recent years as the market is a well developed one. The other main region is China, the largest single consumer in Asia and accounting for just over half the market, mainly in the form of TSP and DAP. Future demand in China, India and other parts of central Asia such as Thailand and the Philippines, will continue to grow rapidly at about 7% per annum, reaching over 10 million metric tons of P_2O_5 by 1990.

Demand is now satisfied largely by local production and Chinese exports. However, future phosphate fertilizer capacity will be insufficient to meet demand particularly in developing Central Asia and imports will rise. A good deal of low analysis phosphate fertilizer is produced domestically, especially in China, but production and use of TSP and, particularly, DAP will tend to increase. Imports of these products will also rise steadily.

Oceania

Consumption of fertilizers in Australia and New Zealand tends to be erratic, fluctuating from year to year, reflecting the agricultural economy. However, the overall trend is one of relatively slow growth as would be expected of a well developed region. In 1977/78 demand for phosphate fertilizers was slightly over 1 million metric tons of P_2O_5, a very small percentage of the world market. Future growth is expected to show a similar pattern through the 1980's reaching, slightly over 1.5 million metric tons of P_2O_5 in the early 1990's.

Traditionally, the market has been dominated by single superphosphate met entirely by local production. However, there is growing interest in DAP as an intermediate for fertilizer production, encouraging relatively cheap imports. However, in tonnage terms these will remain quite a small proportion of total supply. Increased domestic production of these concentrated products is also likely.

Outlook Beyond 1990

By the end of the century phosphate fertilizer consumption is forecast to reach 65.6 million metric tons of P_2O_5. This modest forecast is based upon the assumptions that:

(1) The residual value of phosphate fertilizers will prevent over-optimal applications.

(2) The failure of the developing world to achieve its potential. There is a considerable confusion between consumption forecasts, some of which are based upon needed food production to supply forecast population levels. The forecasts presented in this report reflect actual usage, while forecasts based on need rather than achievement overstate fertilizer growth prospects.

Table 29: Development of Global Phosphate Fertilizer Consumption
(1000 metric tons of P_2O_5)

	1980	1985	1990	1995	2000	Avg. Annual growth rate 1980-2000
Total	33,950	42,450	49,830	57,495	65,615	3.3%
West Europe	6,500	7,300	8,000	8,600	9,000	1.6
East Europe	9,800	13,000	15,500	17,000	18,750	3.3
Africa	1,150	1,600	2,050	2,555	3,215	5.3
North America	6,150	6,800	7,500	8,280	8,920	1.9
Latin America	2,500	3,750	4,750	6,060	7,730	5.8
Asia	6,500	8,600	10,500	13,400	16,300	4.7
Oceania	1,350	1,400	1,530	1,600	1,700	1.2

Source: CRU estimates

Supply/Demand Situation

An examination of the post 1980's supply/demand balance for phosphate fertilizers indicates that if production is to match the growth in demand, additional capacity will have to be commissioned by the mid 1980's. On the basis of all known plants and projects, current capacity forecasts reveal a potential short fall, starting by 1984-1985. It is too soon to draw many conclusions from such developments apart from the main conclusion. If a repeat of the chaos of the early-mid 1970's is to be avoided, up to 10,000,000 metric tons of additional capacity is required. This additional tonnage represents about 37,100 MTPD of P_2O_5 phosphate fertilizer units by 1990 (this excludes any replacement factor for existing units).

In the period post 1990's, the assumption must be that given the available supplies of phosphate rock, there is no raw material constraint on the supply of phosphate fertilizers to the market. The only constraint may be the level of capital investment.

Diammonium Phosphate

Undoubtedly the US domestic market for diammonium phosphate will continue its upward trend for the remainder of the century. Consumption of diammonium phosphate is forecast to increase at an average annual growth rate of about 2% over the next 20 years. This projection is based upon the following considerations.

(1) A continued displacement of single superphosphate, and the absence of any growth in triple superphosphate usage. Indeed in the period 1990-2000, domestic usage of triple superphosphate will decline, as the trend toward higher use of multi-nutrient fertilizers increases.

(2) The expansion of the dry bulk blend industry is one of the primary disappearance channels for diammonium phosphate.

(3) The usage of diammonium phosphate as a direct application fertilizer is expected to increase marginally, particularly at the expense of triple superphosphate.

In terms of the market for Exxon's production of diammonium phosphate, in the physical sense the mid west corn belt market offers potential for any producer, at competitive prices. At this juncture, however, it is of interest to consider how the mid west market is currently served.

Production facilities in the region are limited. There are only three producers with a continued capacity of 770,000 metric tons per year. The balance between local production and consumption is all moved by the Gulf Coast producers.

Gulf production is moved by a combination of barge and rail. As can be seen from the map in sulfur section, the inland waterways system allows Gulf producers the potential to move product to Minnesota, Wisconsin, Iowa, Indiana, Illinois and Ohio. Product is then off-loaded to terminals/railheads for subsequent transport inland. In addition to barge transported product, considerable qualities are moved directly by rail, particularly in the South Eastern region.

The marketing structure/channels of distribution in the mid west corn belt area include all possible modes. However, for the purpose of this analysis four main channels are identified.

1. Cooperatives - there are at present three major primary producer/retailer co-operatives in the USA manufacturing diammonium phosphate:

   a) CF Industries formerly Central Farmers, is owned by 17 regional farm supply cooperatives in the US and 2 in Canada. CF Industries, through its highly sophisticated distribution network, markets fertilizers in 42 states throughout the US. CF Industries has a particularly well developed distribution system in the mid west.

   b) Farmland Industries is owned by 2200 locally owned member associations, and markets fertilizers in 15 mid west states.

   c) Mississippi Chemicals is arranged as a cooperative, with 20,000 members, retailing mainly in the south east.

In addition to retailing their own brand products, the above cooperatives also move other producers' diammonium phosphate.

There are a number of smaller cooperatives which are not primary producers that operate on the distribution/bulk blending level. These include CENEX, Farm Bureaum, Land and Lakes, Midland Farmers, Tennessee Farmers and Western Coops.

It is estimated that 40% of all fertilizers in the area are moved through the cooperative system.

2. Major Fertilizer Producers - outside of the cooperative producers, there are 18 producers with diammonium phosphate facilities. The individual marketing systems of some of the major producers are briefly described below.

   a) Agrico - markets its diammonium phosphate production through a series of major distribution centers.

   b) Allied - the Agricultural Division operates 40 terminals at various locations, while also moving product through independent dealerships.

   c) Beker - retails its diammonium phosphate via regional representatives.

   d) First Mississippi - handles domestic sales through one of its subsidiaries.

   e) W. R. Grace - markets intermediates and finished fertilizers through 100,000 outlets, including its bulk blending operations.

f) IMCC - manages domestic sales through its own State level agencies.

g) Kaiser - sells to distributors and directly through co-owned retail outlets in the south east and mid west.

h) Hooker - maintains mixing and warehousing facilities throughout the mid west and Great Lakes area.

i) Olin - markets through its dry fertilizer distribution center at Joliet.

j) Royster - operates a wide distribution network - 2000 retail outlets. It owns a fleet of private rail cars.

k) Swift - operates at a major farm distribution center level.

l) USS Agri - operates numerous bulk blending operations, in addition to moving product through dealerships and agencies.

3. Distribution Companies - operate retailing chains throughout the mid west. The best example of this is Terra Chemicals/Riverside, which have combined into the major distribution company in the mid west.

4. Bulk Blenders - while the major primary producers operate their own bulk blending facilities, there is a whole range of companies buying diammonium phosphate for use in the production of dry mixtures, dried bulk and bagged. It is estimated by TVA that there are over 7000 bulk blenders in operation in the US. The major blenders in the market area are listed in the appendix (this excludes primary diammonium phosphate producers' blending plants).

The main marketing centers in the corn belt are essentially the internal waterway terminals and major rail heads. For product moving northward from the Gulf, the first major distribution point is St. Louis, where product is transhipped by barge or rail to the Missouri and Kansas markets. Further north along the river system, product is transhipped at various points, Dubuque, Fort Madison and Minneapolis-St. Paul. In Illinois, product is moved as far north as Joliet. Eastwards along the Ohio river, product is moved as far as Cincinnati for distribution to Ohio consumers.

As Exxon's minerals division has no distribution or marketing system, for phosphate fertilziers, it is recommended that in the event of diammonium phosphate fertilizer production being economically feasible at either a Green Bay or Evansville location, the output be offered to the major cooperative groups and to bulk blenders for subsequent retailing. The major problem likely to be encountered will be the economics of moving phosphate rock to Green Bay or Evansville, to be transformed into diammonium phosphate, and then to transport the finished fertilizer back along the internal system to the major distribution centers identified above.

Green Bay

The marketing area for diammonium phosphates produced in Wisconsin is considered to be the following states:

Table 30 - Green Bay - Marketing Area - Consumption by Sate
(1,000 Metric Tons)

		1968	1970	1975	1976	1977	1978
Total		815	681	1224	1752	1960	1808
Wisconsin	(ENC)	123	64	111	150	151	135
Iowa	(WNC)	132	149	317	451	433	478
Illinois	(ENC)	100	178	272	440	565	460
Indiana	(ENC)	175	32	65	96	131	112
Ohio	(ENC)	103	44	84	120	136	127
Minnesota	(WNC)	93	117	266	318	328	308
Nebraska	(WNC)	84	87	84	138	172	135
Michigan	(ENC)	5	10	25	39	44	53

Source: TVA

The local market for diammonium phosphates produced at a Green Bay location is currently in the order of 1.9 MT. Consumption of diammonium phosphates in the region has increased almost three-fold in the 1970s although adverse weather conditions in 1978 limited further developments of usage.

The marketing area encompasses the US corn belt, particularly in the East North Central States where of the 61,136,000 acres harvested in 1978, 24,000,000 were under corn. Average P_2O_5 applications to the region's corn crop have been 78 lb/acre, with applications as high as 83 lb/acre in past years. In the areas sewn to corn in the West North Central region the average application is only 35 lb/acre with levels in Kansas as low as 9 lb/acre.

In terms of the development of the market in the region, limited growth can be expected because of the already high level of P_2O_5 fertilization and the large proportion of cropped area. Nevertheless, some groth is expected -in 1978, the cropped area was some 5 million acres below maximum levels and there is potential for increased application rates in the West North Central States. Incremental demand for the region, as a whole, is estimated to be in the order of 2% per year for the remainder of the decade. However, this is totally dependent upon the continued attractive cost/value ratio of fertilizers, and a strong international demand for US food-stuffs. On the basis of 1.5-2% annual increase, demand for diammonium phosphate is expected to rise to 2.5-2.7 million metric tons by the year 2000.

Evansville

In the event of the plant being located at Evansville, the marketing area will encompass a number of states disclosed above. The additional states designated to be in an Evansville marketing area are Kentucky, where consumption of diammonium phosphate has increased five fold over the past 8 years to 91,000 MT in 1978 and Tennessee, where usage of a mere 6,000 MT in 1970 increased to peak of 75,000 MT in 1977 and stood at 69,000 MT in 1978.

The marketing potential of the Evansville plant is more favorable than of Green Bay in terms of its easy access to the major consuming area via the inland waterway system to the North West Central States, notably Iowa, Illinois, and Minnesota which used 1.5 million MT in 1978. There seems to be limited scope for development of a direct application diammonium phosphate market to the east or south of Evansville, the market being dominated by NPK mixtures. However, as the majority of mixtures are diammonium phosphate based, some possible but as yet unquantified (except by a detailed study) market may exist at a bulk blender/mixer level.

Although there are no existing or proposed diammonium phosphate producers in either Kentucky or Tennessee, the major source of competitive suppliers will be from the large integrated Florida producers and major producers in Florida and Alabama. The Florida diammonium phosphate producers account for the majority of product consumed in the Midwest. The balance of supplies is produced by the Illinois and Iowa producers identified earlier.

Domestic Prices

In spite of significant improvements in the international market prices for diammonium phosphate, the domestic prices remain relatively depressed. This follows a three year period of relatively depressed prices at all levels. The development of diammonium phosphate prices is summarized in the following table and reveals the current price levels at some $30 per ton below those of 1975.

Table 31 - United States Domestic DAP Prices by Region*
(Average prices paid by farmers $ per short ton)

	1970	1973	1975	1976	1977	1978
Illinois	95	115	220	180	186	185
Indiana	96	115	215	180	186	185
Iowa	98	125	220	180	186	185
Kentucky	N/A	N/A	215	175	182	N/A
Minnesota	94	125	210	200	186	185
Nebraska	97	115	225	185	184	184
Ohio	90	115	215	170	186	185
Tennessee	N/A	N/A	226	200	182	N/A
Wisconsin	100	115	220	215	186	185
US Average	95	119	216	177	187	187

*October 15th

Source: USDA

Future Domestic Prices

Although it is virtually impossible to forecast prices over the next 20 years, it is our opinion that the trend in real terms will be upward. This is confirmed by a recent World Bank price forecast, which suggest that diammonium phosphate prices by 1990 are expected to reach $199.7 metric ton (1977$). The increase in price largely reflecting the higher production costs of new plants commissioned to meet incremental demand.

On the basis of $200/metric ton F.O.B. Tampa price by 1990, it is CRU's opinion that the Green Bay and Evansville locations may not be competitive on the basis of delivered prices in the mid west estimated by CRU at between $250-260 per short ton (1977$).

Conclusions

Undoubtedly the US domestic market for diammonium phosphate will continue its upward trend for the remainder of the century. Consumption of diammonium phosphate is forecast to increase at an average annual growth rate of about 2% over the next 20 years. This projection is based on the following considerations:

1) A continued displacement of single superphosphate, and the absence of any growth in triple superphosphate usage. In the period 1990-2000, domestic usage of triple superphosphate will decline, as the trend toward higher use of multi-nutrient fertilizers increases.

2) The expansion of the dry bulk blend industry is one of the primary usage channels for diammonium phosphate.

3) The usage of diammonium phosphate as a direct application fertilizer is expected to increase marginally, particularly at the expense of triple superphosphate.

In terms of the market for Exxon's proposed production of diammonium phosphate, in the physical sense the Midwest corn belt market offers potential for any producer, at competitive prices.

2.6 Availability of Raw Materials

2.6.1 Phosphate Rock

For the duration of the review period and indeed beyond, there will be ample supplies of phosphate rock available to serve the domestic US market, and afford the US a substantial, though decreasing, exportable surplus. As can be seen from the following table, from the present export level of 15 million metric tons, a decline to 8 million metric tons is envisaged by the year 2000.

In terms of available supplies of phosphate rock, the two major areas with surplus will be Florida and North Carolina; the phosphate rock production of both the Western States and Tennessee is unlikely to be able to support much merchant rock over and above their captive requirements. Indeed, for the purposes of this study, the Florida/North Carolina deposits should provide more than adequate resources.

Companies which will have product available as detailed earlier are Amax, which will have up to 3.5 million metric tons per year from 1985 onwards; Agrico, who will have between 1-1.5 million metric tons per year available, depending upon the development of prices; Brewster Phosphates, who will have, via American Cyanamid and Kerr McGee, up to 3.00 million metric tons per year; W. R. Grace will have a potential 3.00 million metric tons per year available; International Minerals and Chemical Corporation which, during the 1980's and 1990's, will have approximately 3.5 million metric tons per year over and above domestic commitments; Mobil and Swift between them have a potential merchant availability of up to 5 million metric tons per year available; and, finally, North Carolina Phosphates mines should produce an estimated 4.0 million metric tons per year to put on the domestic/export market.

Table 32 - Phosphate Rock - Supply/Demand Balance (1000 metric tons)

	1978	1980	1985	1990	1995	2000
Phosphate rock production		53,000	55,500	55,000	58,000	59,200
Demand		38,560	42,460	44,830	47,960	51,860
Phosphoric acid		31,300	34,500	36,270	39,000	42,500
SSP		860	860	860	860	860
TSP		1,900	2,500	2,900	3,100	3,350
Technical*		4,200	4,300	4,500	4,700	4,850
Direct application		300	300	300	300	300
Imports		1,000	1,000	1,000	1,000	1,000
Export availability		15,440	13,540	11,170	11,040	8,340

Source: CRU

2.6.2 Availability of Ammonia

Global Overview

Global ammonia capacity has almost doubled in the past ten years from 49 million metric tons N in 1969/70 to 96 million metric tons N in 1979/80. By the mid 1980's, on the basis of all known plants and projects, world capacity is expected to increase to 120 million metric tons.

Table 33 - Evolution of Ammonia Capacity (1000 metric tons N)

	1966/7	1970/1	1975/6	1980/1	1985/6	1990/1
WORLD	34,504	53,181	71,022	100,499	120,468	134,214
West Europe	9,991	14,118	14,882	17,155	18,933	21,489
East Europe	8,015	13,703	21,962	31,387	37,296	42,000
Africa	347	780	1,228	3,009	4,180	4,540
North America	9,057	13,528	14,082	17,238	19,972	21,670
Latin America	789	1,310	2,501	4,505	8,615	10,854
Asia	5,098	9,019	14,608	24,353	30,954	33,125
Oceania	85	480	452	452	536	541

Source: British Sulphur Corporation and CRU estimates

United States Ammonia Industry

US ammonia capacity currently stands at 15,493,000 metric tons N; indeed, actual operating capacity can be considered as substantially less, as the above total includes 2 million metric tons of capacity which is currently idle and given no improvements from the present market conditions is anticipated to remain idle. In addition to the idle capacity identified above, there is a further 2,117,000 metric tons N of capacity which can be classified as vulnerable and can be expected to cease production by the 1980's.

Table 34 - US Ammonia Capacity (1000 metric tons N)

	1970	1975	1976	1977	1978	1979
NH_3 capacity	12,457	13,721	14,200	16,081	16,434	15,493

Source: TVA

The combination of increased gas costs and the low level of ammonia prices over the past two years has had a marked effect on production. Over the past two years in particular, capacity utilization rates have declined from the mid 1970's levels of almost 90% to a little over 80% in 1978.

Table 35 - US Ammonia Production (1000 metric tons N)

1975	1976	1977	1978
12,230	12,471	12,980	12,669

Source: USDC

By 1981, the present oversupply position is expected to reach its peak, before the market tightens into the late 1980's. This is evidenced by the fact that only two projects have been deterred for the 1980's. As yet it appears that none has reached the detailed engineering stage save the coal-based Grace Ebasco project, which may be abandoned in favor of gasoline production.

It is expected that by 1985, given a tightening of the market, US domestic capacity will be expanded by the addition of up to 1.5 million metric tons N of capacity, either as reactivated units or new capacity.

Table 36 - Development of US Ammonia Capacity (1000 metric tons N)

	1980	1985	1990	2000
Nominal NH_3 capacity	15,873	15,798	17,300	19,000

Source: CRU estimates

The following tabulation identifies domestic US producers who have ammonia surplus to their captive downstream requirements. A proportion of this output will, however, be absorbed as direct application consumption.

Table 37 - US Ammonia Producers - With Merchant Potential

Company	Location	Theoretical Surplus (1000 metric tons N	Comments
Agrico	Verdigio, OK	1150	Expansion of UAN solutions could absorb any surplus NH_3
Allied		150	Quantities available from a range of plants
American Cyanamid	Fortier, LA	300	
Amoco	Texas City, TX	368	No captive downstream
Chevron	Pascagoula, FL	368	No captive downstream
Union Oil (Collier)	Kenai, Alaska Wilmington, CA	527	Logistics of Alaskan operation unfavorable for Wisconsin operation
Cominco	Borger, TX	230	No captive downstream

Table 37 (Cont'd.) - US Ammonia Producers - With Merchant Potential

Company	Location	Theoretical Surplus (1000 metric tons N	Comments
Farmland Industries	Various	600	Major surpluses at Enid and Pierce
First Mississippi	Pascagoula, FL Fort Madison, IA	480	Pascagoula unit to be fully operational by 1980's
IMC	Sterlington, LA	350	Should have substantial merchant potential once first plant reactivated

In addition to the above, two cooperatives have "merchant" product available, but in most cases production is geared to the needs of members. However, an upturn in the market could tempt sales of surplus production to third parties.

As can be seen from the above table, there will be a limited number of US domestic producers who will be capable of supplying 125,000 MTPY of merchant product in the 1980's, particularly as there appears to be an increasing trend toward the upgrading of ammonia into downstream products by erstwhile merchant suppliers. Nevertheless, there will be adequate product available well into the review period. However, it must be emphasized that there is a considerable body of opinion with the view that in the US and indeed on a global basis, the supply/demand balance for nitrogen in the 1980's may be much tighter than is commonly predicted. Should this scenario develop, i.e., the expansion of capacity outside the US is not as substantial as was otherwise thought. The resulting interaction of supply/demand will force prices on the international market upward, thereby allowing a proportion of the otherwise idle capacity to be reactivated.

Regardless of which of these scenarios develops, it is unlikely that the US or, indeed, North America (for the purposes of an examination of the US ammonia supply, the Canadian production has no real alternative to the US market) will be able to avoid the inexorably increasing dependence upon imported ammonia.

The following table briefly examines the North American supply/demand balance for ammonia to 1990. As can be seen, even allowing for a continued flow of Canadian product into the US and an anticipated expansion in capacity, the import requirement for ammonia will approach 2.8 million metric tons N by 1990.

Anhydrous Ammonia

The principal concern for Exxon with regard to the future market position of ammonia concerns the availability and price of merchant ammonia.

The United States ammonia industry is currently in the middle of a recession, with over 2 million metric tons of ammonia capacity idle. The enforced closure of this capacity results from: (a) the increased gas prices - on the basis of a $2.5/mcf price and a requirement of 40.00 mcf, feedstock costs along of $100 were above landed prices the Soviets and Mexicans were able to achieve; (b) the US is the largest merchant market, and in 1979 up to 1.6 million metric tons will be aimed at the US market from USSR, Mexico, Canada and Trinidad.

Looking ahead to 1990, the situation can be expected to change. The current ills of the industry have inevitably reusited in an absence of new projects and the idle plants, unless carefully mothballed, will be unavailable for reactivation at short notice. The net result will be a reduction in the availability of domestic merchant ammonia at competitive prices. However, it is thought that the potential shortfall caused by a shrinkage of domestic production will be more than adequately filled by imported ammonia from Canada, Mexico, Trinidad and the USSR. Imports of offshore ammonia will remain competitive at landed prices, inspite of forecast increase in prices in real terms. This is foreseen as insufficient to tempt new domestic ammonia production at least in the 1980's.

The supply of ammonia, albiet imported via brokers or conducted from the remaining lost cost gas producers, is unlikely to impose any serious constraint on the developments of Exxon's proposed diammonia phosphate production.

Domestic producers with available tonnages, sufficient for Exxon's annual requirements are: Agrico, Allied, American Cyanamid, Amoco, Chevron, Cominco, Farmland Industries, First Mississippi, IMCC and Union Oil. Of the offshore producers, Trinidadian product is handled through Oxychem's subsidiary Interore while Pemex sells Mexican ammonia directly. Canadian product is normally handled by the individual companies; Canadian Fertilizers, Cominco, Cyanamid, Esso and Sherritt Gordon.

3. TRANSPORTATION

Introduction

The transportation consultant, Jones, Bardelmeier and Company Ltd. has prepared a report covering the estimated transportation costs and transportation mode in order to establish the F.O.B. realization of all products from Crandon pyrite.

The mine site where the pyrite concentrate will originate, is Crandon, Wisconsin. The two process centers at Green Bay, Wisconsin and Evansville, Indiana, are the final destination of pyrite concentrates and the origin of shipment for final pyrite products which will be transported to their final destination.

Rather than repeat the total transportation report in this section we have summarized the areas of impact. The complete Jones, Bardelmeier and Company Ltd. report is available in the appendix for complete review.

The commodities and the annual volume in metric tons per year of the selected products and materials are as follows:

	Base Case	Alternate Case A
Pyrite concentrates	267,000 MTPY	1,094,000 MTPY
Iron pellets	180,000	718,000
Sulfur	134,000	----------
Sulfuric acid	400,000	1,694,000
DAP	562,000	1,572,000
Phosphate rock	810,000	2,264,000
Anhydrous ammonia	125,000	346,000

It is concluded that the transport of pyrite concentrates at 15% moisture from the mine site at Crandon, Wisconsin, to a processing center at either the Green Bay area in Wisconsin or the Evansville, Indiana area can be most economically accomplished by railroad. The same is true for shipments to the marketing areas of Copperhill, Tennessee. Therefore, interruption to the shipping schedules due to winter water navigation problems will not be a factor.

The optimum transportation cost for the movement of pyrite concentrates from Crandon, Wisconsin, to White Pine, Michigan, at 15% moisture content is via truck where the road rate is marginally less than rail.

With regard to the Evansville area processing center, the most economic transportation mode for all other commodities is via the Ohio River. In recent years, the Ohio has experienced freeze-ups for periods up to two months during the winter season. Therefore, we recommend that rail rates be substituted as appropriate for a two-month period in each calendar year.

The most economic transport mode to and from a Green Bay area processing center for the other commodities (except anhydrous ammonia) is via Lake Michigan. The Great Lakes navigation season has been progressively lengthened over the past several years. We expect this trend will continue. However, for planning purposes, we recommend that rail rates be substituted as appropriate for a four-month period in each calendar year.

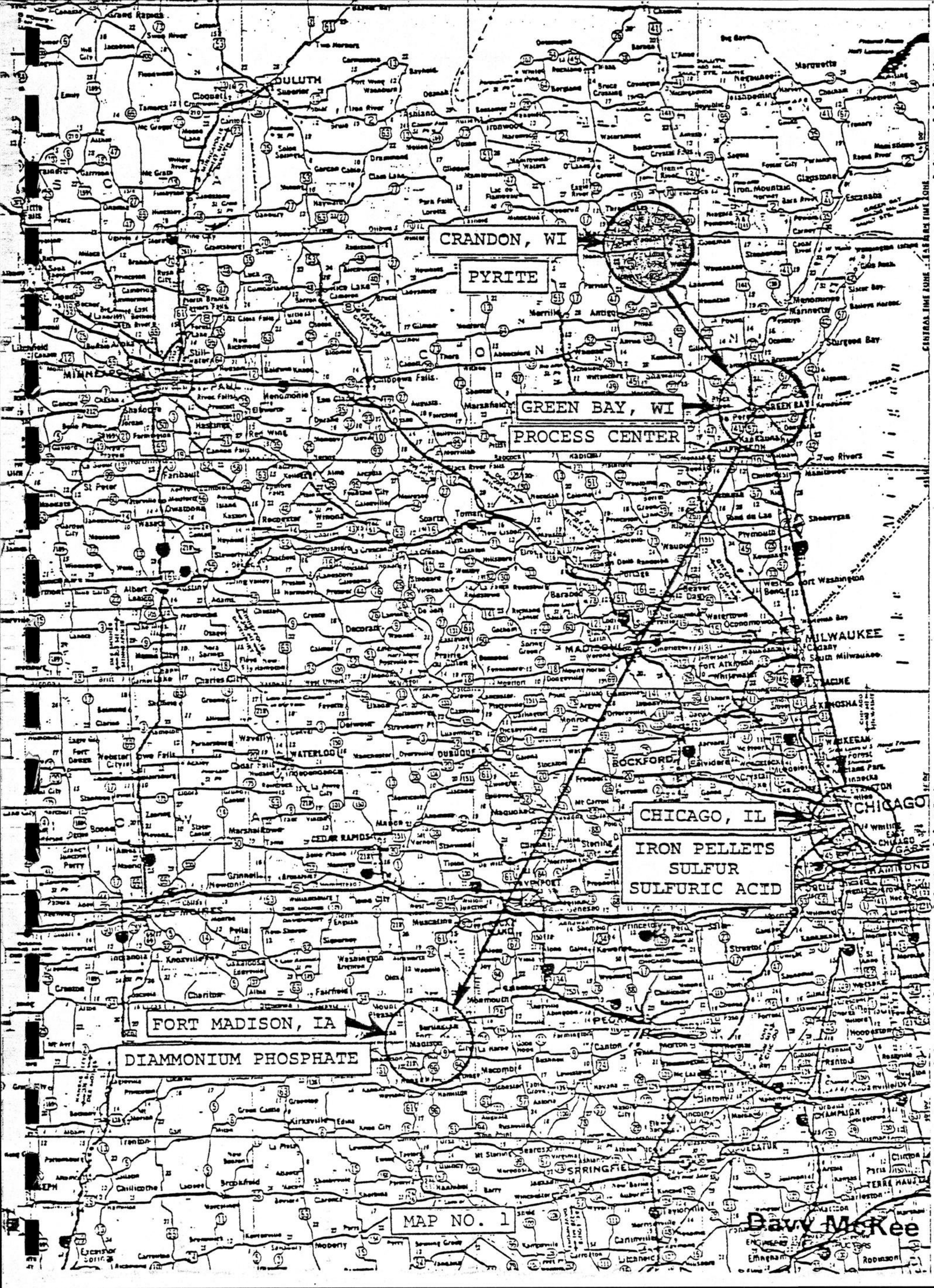
From the area processing centers we have selected the most economical mode and the market areas to determine the destination for the potential products. This is shown below and pictorially on maps 1, 2, 3, and 4.

Process Center	Product	Market	Mode
Evansville, Indiana	Sulfuric Acid	St. Louis	River/Rail
	Iron Pellets	Granite City	River/Rail
	Diammonium Phosphate	Fort Madison	River/Rail
	Sulfur	St. Louis	River/Rail
Green Bay, Wisconsin	Sulfuric Acid	Chicago	Lake
	Iron Pellets	Chicago	Lake
	Diammonium Phosphate	Fort Madison	Lake/River
	Sulfur	Chicago	Lake

Further on in Phase II of the study, we have utilized the above process centers and market destinations to determine the potential revenues.

Summary of Optimum Transportation Rates

The following tabulation summarizes the optimum (lowest cost) transportation rates developed by Jones, Bardelmeier and Company, Ltd., and the Consulting Center USA Inc. for each of seven commodities between mine, processing centers, market areas and raw material sources. Rates are expressed in U.S. dollars per metric ton effective at mid 1979 and escalated to mid-1985 levels. The most economic mode of transport is listed for each commodity and service.



MAP NO. 1

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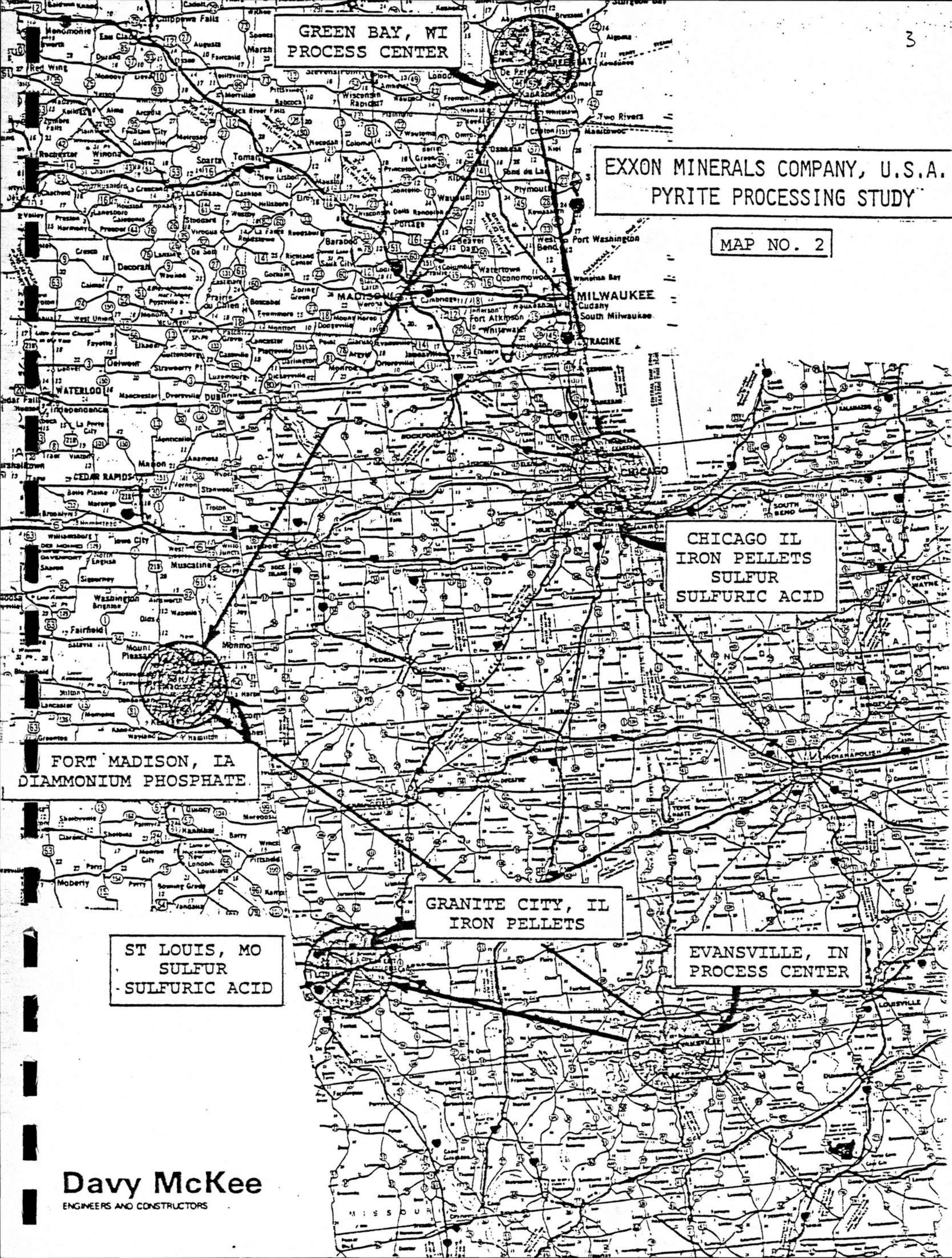
EXXON MINERALS COMPANY, U.S.A.
PYRITE PROCESSING STUDY

MAP NO. 2



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In support of this tabulation, Schedules 1 through 35 describe for each commodity and service all the transportation modes for which rates were developed. Each transportation rate is identified by individual transport mode and estimates of cargo handling rates are separately noted. This information is shown in the appendix.

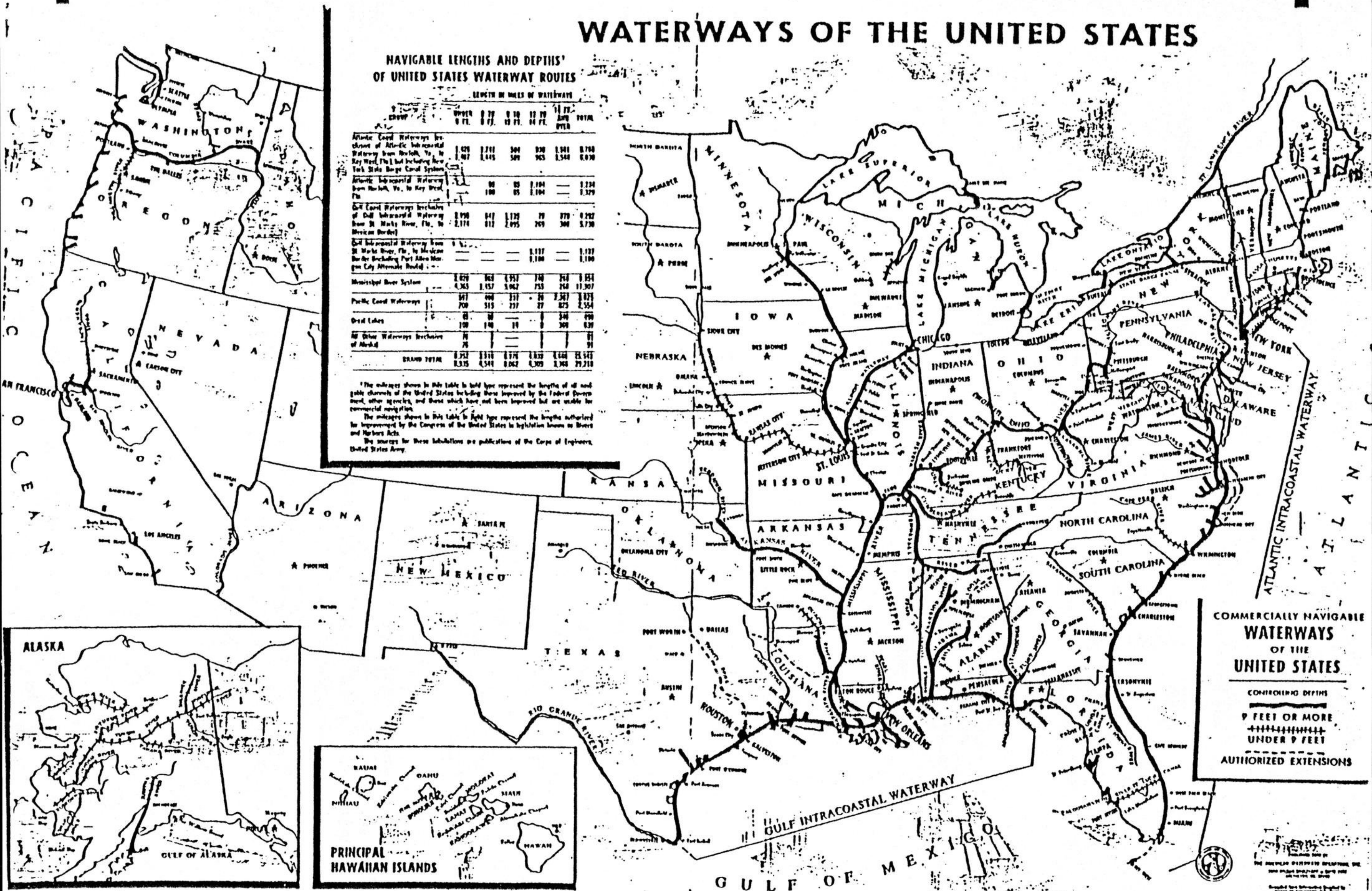
SUMMARY OF ESTIMATED OPTIMUM TRANSPORTATION RATES

Schedule No.	Commodity	Origin	Destination	Rate US $/MT Mid '79	Mid '85	Mode
1	Pyrite	Crandon	Green Bay	11.44	16.80	Rail
2			Evansville	24.43	36.14	Rail
3			Copperhill	31.72	46.58	Rail
4			White Pine	15.50	22.18	Road
5	Iron Pellets	Evansville	Granite City	5.56	8.22	River
6			Chicago	10.73	15.74	River
7			Pittsburgh	11.19	16.42	River
8		Green Bay	Granite City	11.63	17.11	Lake/River
9			Chicago	3.38	4.96	Lake
10			Pittsburgh	15.94	23.53	Lake/Rail
11	Sulfur	Evansville	Chicago	7.43	10.90	River
12			E. St. Louis	3.31	5.15	River
13		Green Bay	Chicago	5.00	7.35	Lake
14	Sulfuric Acid	Evansville	Chicago	11.16	16.38	River
15			E. St. Louis	6.09	8.94	River
16			Burnside	14.59	21.43	River
17		Green Bay	Chicago	6.50	9.69	Lake
18			E. St. Louis	19.86	29.22	Rail
19			Burnside	26.64	39.23	Rail
20	DAP	Evansville	Ft. Madison	5.37	7.88	River
21			Omaha	12.79	18.78	River
22			Minneapolis	9.39	13.80	River
23		Green Bay	Ft. Madison	10.10	14.80	Lake/River
24			Omaha	15.81	24.19	Lake/River
25			Minneapolis	14.29	19.57	Rail
26	Phosphate Rock	Tampa	Evansville	12.16	17.82	Ocean/River
27			Green Bay	15.08	22.10	Ocean/Lake
28		Pocatello	Evansville	42.32	57.96	Rail/River
29			Green Bay	43.29	59.28	Rail
30		Morocco	Evansville	19.04	28.98	Ocean/River
31			Green Bay	16.13	23.67	Ocean/Lake
32	Anhydrous Ammonia	St. Louis	Evansville	14.85	21.05	River
33			Green Bay	26.50	38.94	Rail
34		Terre Haute	Evansville	13.04	19.16	Rail
35			Green Bay	23.65	34.75	Rail


CRANDON, WI
GREEN BAY, WI
CHICAGO, IL
FORT MADISON, IA
GRANITE CITY, IL
ST. LOUIS, MO
EVANSVILLE, IN
COPPERHILL, TN
BURNSIDE, LA
TAMPA, FL
Gulf of Mexico
Map of Inland Waterways
Davy McKee

MAP NO. 3

WATERWAYS OF THE UNITED STATES



NAVIGABLE LENGTHS AND DEPTHS[1] OF UNITED STATES WATERWAY ROUTES

GROUP	LENGTH IN MILES OF WATERWAYS					
	UNDER 6 FT.	6 TO 9 FT.	9 TO 12 FT.	12 TO 14 FT.	14 FT. AND OVER	TOTAL
Atlantic Coast Waterways (exclusive of Atlantic Intracoastal Waterway from Norfolk, Va., to Key West, Fla., but including New York State Barge Canal System)	1,429 1,407	1,211 1,445	304 309	930 963	1,301 1,544	[illegible] [illegible]
Atlantic Intracoastal Waterway from Norfolk, Va., to Key West, Fla.	—	90 100	85 85	1,104 1,104	—	[illegible] [illegible]
Gulf Coast Waterways (exclusive of Gulf Intracoastal Waterway from St. Marks River, Fla., to Mexican Border)	2,950 2,174	847 812	1,129 2,095	79 269	370 300	[illegible] [illegible]
Gulf Intracoastal Waterway from St. Marks River, Fla., to Mexican Border (including Port Allen-Morgan City Alternate Route)	—	—	—	1,137 1,100	—	1,137 1,100
Mississippi River System	[illegible] 4,363	963 1,157	[illegible] 5,062	740 753	[illegible] 260	[illegible] 11,307
Pacific Coast Waterways	517 700	400 515	[illegible] 237	[illegible] 27	2,367 825	[illegible] 2,554
Great Lakes	[illegible] 100	[illegible] 140	— 19	[illegible]	[illegible] 300	[illegible] [illegible]
All Other Waterways (exclusive of Alaska)	[illegible] 76	[illegible]	—	[illegible]	[illegible]	[illegible] 91
GRAND TOTAL	[illegible] [illegible]	[illegible] [illegible]	[illegible] [illegible]	[illegible] [illegible]	[illegible] [illegible]	[illegible] [illegible]

[1] The mileages shown in this table in bold type represent the lengths of all navigable channels of the United States including those improved by the Federal Government, other agencies, and those which have not been improved but are usable for commercial navigation.

The mileages shown in this table in light type represent the lengths authorized for improvement by the Congress of the United States in legislation known as Rivers and Harbors Acts.

The sources for these tabulations are publications of the Corps of Engineers, United States Army.

MAP NO. 4

Davy McKee
ENGINEERS AND CONSTRUCTORS

(5)

Transportation

Assumptions & Limitations

The 1979 dollar rate estimates were developed from a combination of sources: published commodity cost and rate data by modes, published commodity point-to-point rates, class and annual volume trainload rates where applicable, conversations with selected barge carriers for rates on similar movements; and discussions with rail equipment suppliers and inland waterway experts regarding equipment costs, availability, transport seasonality problems, and loading, unloading and transit costs and technical problems. In our opinion, the rates and transportation costs quoted in this study should be viewed as reasonable and responsible estimates of the costs of moving the commodities under study but they should not be considered absolute. Subsequent rate negotiations with carriers, based on the magnitude of the total volumes available for shipment, could yield rate levels 10-15% lower than we estimated.

We then converted the 1979 dollar transportation rate estimates into 1985 dollars using an intermodel rate forecasting model developed by the Consulting Center which assumes a continuation of recent trends regarding rate increases relative to inflationary cost increases and which is tied to Chase Econometric's July 1979 Long Term Macro Economic Forecast. As with any forecast, every effort has been made to incorporate the most probable relationships among significant factors but unforeseen major changes in the economy or in the manner by which transportation modes are regulated could substantially alter the estimates.

The rate estimates described herein are conservative in that they do not reflect the very real potential Exxon has to negotiate lower rates by offering participating carriers an opportunity to carry high value minerals extracted from the proposed mine as well as the low value refuse products. Due to the confidential and tentative nature of Exxon's plans, no information regarding destinations nor annual volumes for the mine's primary products were available. No attempt was made, therefore, to determine the extent to which Exxon could use the primary products as a "carrot" to obtain lower rates on the movements under study.

Another somewhat subtle limitation to this study is how the pyrite concentrates will behave under transportation. While we believe our ultimate assumptions have led us to a rational recommendation, we are predicating our insights on assumptions we believe are reasonable rather than on an explicit understanding of technical problems related to the physical or chemical characteristics of Crandon fine pyrite concentrates.

The Consulting Center's rate estimates and opinions regarding the most probable route and most likely mode involved in transporting the study commodities between points were made upon consideration of the following factors:

1) Shipments handled in multiple car or volume train load rates (i.e., volume economics).
2) Shipment annual volumes, movement frequency and distance.
3) Minimization of seasonality effects or other fluctuations in service (interrupted service on the Great Lakes and Northern tier inland waterways during winter months, for example).
4) Achievement of maximum rate discounts.
5) Model capacity constraints.
6) Equipment considerations.

Selection of routes was made based upon system configurations and the assumptions that:

1) Each carrier would maximize potential length of haul
2) Transfer and terminal costs should be minimized
3) Service seasonality factors must be considered
4) Technical considerations are taken into account

Methodology

The Consulting Center's methodology for determining the optimal mode (or combination of modes) and price of moving the study commodities from origin stockpile to destination involved weighing rate and overall capital cost and service data for each mode. The sources for these data were numerous and were obtained from several different directions. These data sources will be described in more detail in the following section but in general they come from the following approaches:

One was to ascertain the means and rates by which the same or similar commodities are currently being transported between the same or similar origin/destinations. Another was to examine modal long term perspective cost data pertaining to the movement of bulk commodities to try to get an idea of what a carrier's rate "floor" would be. A third was to examine existing sources (such as tariff schedules on file at the ICC for rail and joint rail/water rates) and to talk to experts in the various modes to obtain better overall cost and rate information.

We then processed this information through the following steps and considered the factors described above to determine the "optimal" mode and route.

First, using transportation maps and distance tables, we determined the potential list of routes, modes and mileage involved in transporting each designated commodity between its origin and destination. Based on our intuitive feel for rates and service by mode and on the commodity statistics for the East Central territorial division of the U.S. (see Appendix F),(1) we hypothesized as to which mode or combination of modes was likely to be employed.

Second, we developed transport rates per ton mile at 1979 dollar levels for each mode. We next applied these data to the annual volumes by commodity for truckload, multiple rail car, trainload and bargeload movements for each mode to the appropriate modal mileage distances for each movement.

Third, we determined each mode's transfer and terminal points and charges for each movement in 1979 dollar levels and converted to rate per ton-mile.

Fourth, we computed the transport turnaround times and required equipment and facility costs for each mode for each movement, in 1979 dollar levels and converted to cost per ton-mile.

Fifth, using the Consulting Center's intermodal rate forecasting model and Chase Econometric's July 1979 Long Term Economic Forecast we projected capital and rate increases by mode to 1985 dollar levels.

Sixth, we determined, on the basis of our economic analysis the optimal mode or modal combination for each commodity movement.

Last, we evaluated the effect external problems (such as service seasonality), logistical attributes, equipment limitations or other special factors affected the determination of the optimum mode.

Rail

1. Carrier short line station mileage table established the rate basis miles between origin and destination points.
2. Annual carload waybill samples and carrier cost profiles of territorial movements by commodity groups and class of traffic. Carrier cost information extracted from annual financial reports applied to carload movements from the waybill data provided us with an idea of rail rate "floors" by commodity; rate data with cross checks for tariff data described next.

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(1) In the Appendix the predominant factors contributing to the commodity movements by motor carrier are small volume shipments moving less than 150 miles.

3. Existing point-to-point, multiple car load and annual volume trainload rate quotations by commodity were obtained, if one existed, from tariff schedules on file with the ICC. We first tried to locate an established point-to-point tariff rate for each commodity between the same points involved in the movement being analyzed. Since the proposed Exxon movements are all new ones, however, these often did not exist. In these cases, therefore, we tried to locate a tariff between similar points in the same rate territory and if this was unavailable, to ascertain the commodity class rate over the distance involved for each movement. Most quotes obtained in this search were indeed class rates.(1) As such they are conservative since Exxon would undoubtedly be able to negotiate rates lower than class rates once its plans are more concrete. This search also included efforts to locate existing rate quotes for each commodity for single or multiple cars and for unit trains.

4. Since we were unable to obtain single, multiple and unit train commodity rates for all the movements under study in some cases we had to establish a discount from class rates. To do so we used our existing comparative studies of single, multiple and unit train rates for selected commodities. This analysis also included rate discounts attributable to annual volume allowances.

5. The Consulting Center's disaggregate Rail Financial Forecasting model, tied to Chase Econometric's most recent Long Term Economic Forecast, and based upon algorithms reflecting historic trends in commodity general rate increases, was used to express 1979 transport rates and capital costs in 1985 dollars.

6. Estimated the commodity rate effects attributable to rail deregulation using the disaggregate Rail Financial Forecasting model.

<u>Inland Waterway</u>

1. Base rates were obtained from a survey analysis by Corps of Engineers and the Department of Transportation of barge rates quoted for commodity movements by individual segments of each major river. These were brought up to 1979 dollar levels using appropriate (historical) factors for annual rate increases due to inflation. Appropriate distances for each origin destination movements were computed from Corps of Engineers' waterway mileage tables.

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(1) All rates were updated to reflect all relevant Ex Parte rate increases, etc.

2. The base rates were evaluated against results obtained from a spot survey and discussions with selected barge operators servicing each commodity on the rivers involved in the movements. These operators quoted rates on similar movements from different origins and destinations. The Consulting Center also discussed service, equipment availability, service limitations and seasonal movement patterns with waterway experts and the selected barge operators.

3. The Consulting Center's intermodal rate forecasting model (integrated with Rail model), tied to the Chase Forecast, produced estimated barge rates in 1985 dollars.

Private Truck

1. The results of a Department of Transportation Private Truck study, developed on a commodity basis done in the early 1970's, was combined with current analyses conducted by the Consulting Center under contracts, to identify base costs for chemical and dry bulk movements. These operating and capital recovery costs were adjusted for prevailing productivity and inflation trends consistent with other studies, particularly a very recent study done by the Consulting Center for a major motor carrier rate bureau.

2. Adjustments of private truck commodity movement costs, using rate scales based on mileage hauled employed in prior truck/rail elasticity studies, were also made.

3. The Consulting Center's intermodal rate forecasting model (integrated with Rail model), tied to the Chase Forecast, produced estimated private truck rates in 1985 dollars.

4. Surveyed bulk transport operators for equipment availability and limitations.

Ocean & Great Lakes

The only commodity in this study to be transported between ports on salt water is phosphate rock from Florida (port of Tampa) and Morocco (port of Safi). We have developed ocean transportation rates for phosphate rock between the following ports:

- Tampa and Contrecoeur, Canada in foreign flag Panamax size bulker (approximately 60,000 DWT) for discharge, storage and reloading to Seaway size vessels for transport to Green Bay, Wisconsin.
- Tampa and Green Bay, Wisconsin in U.S. flag Seaway maximum size bulker (approximately 35,000 DWT draft restricted to 26,000 M.T. cargo).

- Tampa and New Orleans, Louisiana in U.S. Flag bulker (approximately 35,000 DWT) for discharge, storage and reloading to river barges or rail cars for transport to Evansville, Indiana or Green Bay, Wisconsin.
- Safi and Contrecoeur, Canada in foreign flag Panamax size bulker for Green Bay.
- Safi and Green Bay, Wisconsin in foreign flag Seaway maximum size bulker.
- Safi and New Orleans, Louisiana in foreign flag Panamax size bulker for Evansville.

We have developed mid 1979 capital and operating costs for the Panamax and Seawaymax size bulkers. Vessel operating costs consisting of crew wages, insurance premiums, repairs and maintenance, and stores, subsistence and general and administrative expenses have been escalated at 10% p.a. to mid 1985. Voyage distances, steaming times, fuel consumption and price, port expenses and seaway tolls have been calculated or estimated and combined with the vessel capital and operating costs to determine a representative ocean transportation rate for each service at mid 1979 and mid 1985 cost levels.

Results of these calculations on a ballast return basis are as follows:

	Mid '79	Mid '85
Tampa - Contrecoeur - Panamax	$ 6.95/MT	$10.17/MT
Tampa - Green Bay (US Flag) - Seaway	25.19	36.96
Tampa - New Orleans (US Flag) - 35,000 DWT	3.64	5.31
Safi - Contrecoeur - Panamax	8.00	11.74
Safi - Green Bay - Seaway	20.00	29.46
Safi - New Orleans - Panamax	10.52	15.47

We have also calculated for comparison purposes the mid 1979 one year time charter market rates for each of the services described above. Present short term time charter rates yield ocean transportation rates some 10% less for the Panamax bulkers than those listed above and about 20% less for the Seaway size bulkers.

By combining the movement of phosphate rock with the movement of other commodities in a complementary direction it is possible to lower the phosphate rock transportation rates. This is possible as long as complementary rates are more than high enough to offset incremental voyage times required for the backhaul commodity. For example, the present iron ore rate from the Gulf of St. Lawrence to the U.S. Gulf of $1.625/GT is insufficient to cover the incremental cost of this movement as backhaul to phosphate rock from Tampa to Contrecoeur in our Panamax bulker at $12,112/day. The $1.625/GT is sufficient to cover incremental costs at the present one year time charter rate of $10,400/day.

In addition to iron ore moving from the Gulf of St. Lawrence to the U.S. Gulf, other commodities and routes complementary to the phosphate rock movements are:

- In the case of Morocco phosphate rock

  Iron ore from Gulf of St. Lawrence to Europe
  Wheat from Great Lakes/Gulf of St. Lawrence to Europe
  Coal from U.S. east coast or Gulf to Europe

- In the case of Florida phosphate rock

  Coal from U.S. Gulf to Tampa

Note that a U.S. flag vessel would be required by law between the U.S. ports of Tampa and Green Bay. Such a vessel could not competitively carry Canadian iron ore to the U.S. Gulf. The iron ore rates are set to foreign flag rate levels, not to U.S. cost levels.

It is our experience that the ocean transportation element of total raw material procurement cost should be based on ballast return voyages unless complementary commodities are completely under the control of the same rate making entity. Therefore, for purposes of this study, ocean transportation costs are developed on a ballast return basis.

Other Factors

Equipment

The type of equipment required to move each commodity via the mode and route indicated is also shown in Appendix D. There are two commodities whose movement will demand the use of highly specialized equipment: anhydrous ammonia and sulfuric acid. They will all require specially lined, anticorrosive tank equipment. Anhydrous ammonia requires refrigeration, and also has relatively high handling costs and expensive storage facilities.

Given a 1985 start-up date and the likelihood that substantial changes in rail regulation should be enacted by that time, it is our opinion that the rail industry will be permitted to offer long term contract rates by that date. If so, unlike today, shippers will potentially not have to purchase or lease tank cars or other specialized equipment because railroads should be able to obtain enough equipment on the strength of long term rate contracts. Of the 1,652,774 total freight cars in service at the end of 1978, 22% are owned or leased by car companies and shippers. These private firms account for 99% of the tank car fleet and 33% of the covered hopper fleet. The specialized equipment and single loaded direction movement charcteristic of these cars has forced the railroads to progressively shift this heavy capital cost to shippers. Moreover, the ability of the shippers to transfer the equipment costs to the rail carrier would insure favorable service arrangements.

Our optimum case assumes, therefore, that Exxon will not have to purchase or lease rail cars and the corresponding financing charges are embodied within the rail rate. If rail deregulation does not occur, however, current trends suggest Exxon would have to acquire rail tank car equipment. The type, estimated amounts, and costs included in our analysis are shown in Appendix E.

If water is the preferred mode for the route from Green Bay, Wisconsin to inland destinations via Chicago, Illinois, a fleet of load line barges must be built which will qualify to operate in open waters of Lake Michigan as well as inland waterways. If, however, the movement is from Green Bay to Chicago as a destination, then all dry cargo would be carried by regular Laker type vessels at the typical Laker rate structure which is prescribed by the basic Escanaba to Chicago ore rate. Load line barges generally cost at least double their counterparts on the inland waterway system and are subject to more rigid maintenance, environmental and safety inspections.

Truck Transportation

The Consulting Center concluded that in general, except for the pyrite movement to White Pine, Michigan, truck transportation (specifically private contract carriage) was not a realistic alternative for carrying the bulk and chemical commodities in the annual volumes estimated by Exxon. Although the trucking industry has carried some of these commodities in the past, the movements generally repesent high valued commodities in small shipment amounts, infrequent shipments, or were carried short distances. Moreover, since volumes defined for this study were large enough to qualify for multiple car or trainload rail rates or bulk water rates, and the transport equipment was sophisticated and heavy duty, the corresponding trucking rates were found to be non-competitive.

Service Seasonality

For seasonal reasons, the Great Lakes, Upper Mississippi River and Missouri River are closed approximately 4 months of the year. In addition, even the Ohio River has experienced two months of inactivity due to freezing the past few years. Therefore, the commodities under study can only be shipped via water over these routes the remainder of the year. This limitation means either that commodities would have to be stored in volumes great enough to avoid interrupting operation of the mine or the processing plant or that the mine and/or processing plant (depending upon where it is located) would have to be either shut down, or cut back (if alternate rail mode then utilized) two to four months of the year.

Intermodal Cargo Handling Rates

The movement of pyrite from Crandon to Evansville and Copperhill involving a water mode of transportation (Lake Michigan or inland waterway) will also involve the discharge, storage and reloading of the pyrite at Green Bay, Chicago and/or Chattanooga. We have estimated a rate of $2.48 per MT for each transfer via storage between transportation modes.

The movement of iron pellets from Green Bay to Granite City and Pittsburgh via water requires a transfer via stockpile at Chicago (for Granite City) and at a lower Lake Erie port (for Pittsburgh). The 1979 posted rate for the discharge to storage and reloading iron pellets at all Great Lake ports (except Conneaut) is $3.24 per MT.

Estimates of 1979 terminalling charges for sulfuric acid at Chicago for movements involving water transportation between Green Bay and East St. Louis and Burnside range from #3.00 to $5.60 per MT. We have used an average of $4.30 per MT in our transportation rate estimates.

DAP moving from Green Bay to Ft. Madison and Omaha via the water mode requires a transfer at Chicago for which we have estimated a current thru-put rate of $2.75 per MT based on phosphate rock transfer rates quoted for New Orleans.

For the discharge and reloading via storage of phosphate rock, the current rate at New Orleans is $2.75 per MT. We have used this rate for a Chicago transfer facility as well. The rate of $2.65 per MT at Contrecoeur has been provided by that facility's management.

Estimated current terminalling charges for anhydrous ammonia at Chicago for movements involving water transportation between East St. Louis and Green Bay range from $4.30 to $11.00 per MT. We have used an average of $7.65 per MT in our transportation rate analysis.

CAPACITY CONSTRAINTS

In general neither the rail or inland waterway networks required for these movements have system capacity limitations so severe as to favor one mode over the other based on the future total forecasted volume.

Rail

Within the rail network the possibility of capacity constraints depends upon which rail carrier the projected traffic is routed over. For the healthier carriers we know of no present capacity problems and a Department of Transportation study indicates the most likely future capacity problems lie in the far west due to coal movements. If a carrier is financially marginal its track system is either already under slow orders or will likely become so in the near future. As noted in the section of this report discussing the financial conditions of railroads, the ICG, "Milwaukee" or "Rock Island" rail carriers are definitely financially marginal and if their respective networks are avoided (at least during the near term) shippers should not be confronted with substantial failures by operators or problems inherent with the network.

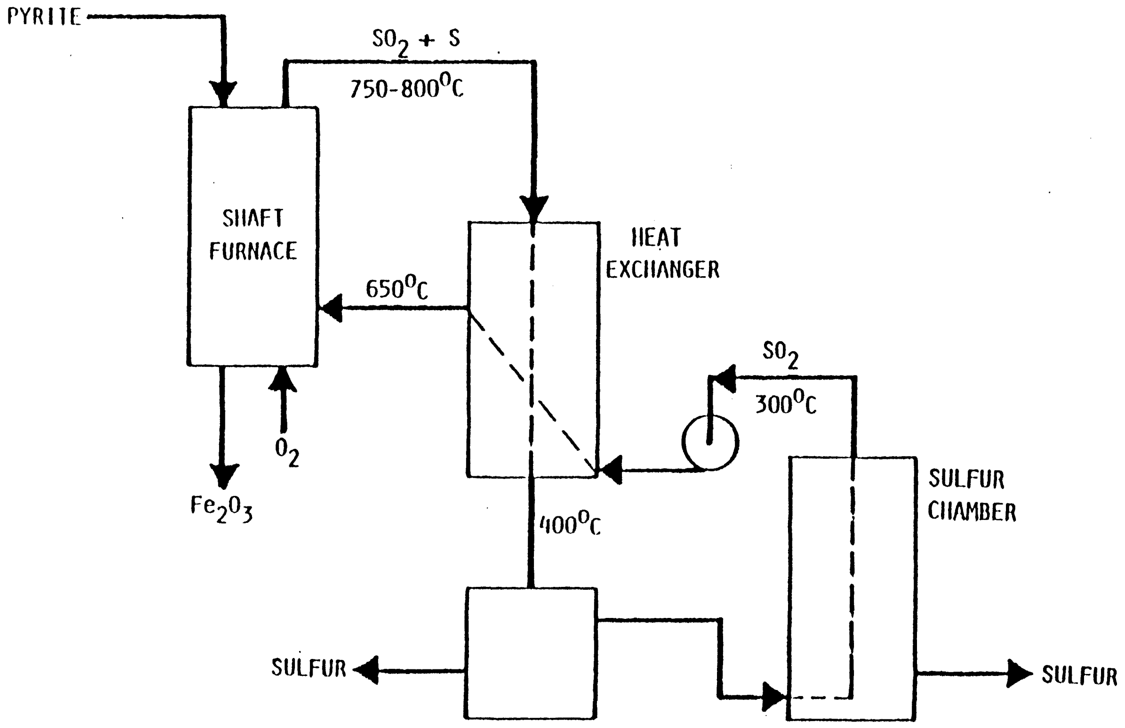
Inland Waterway

Several sections of the inland waterway network report capacity constraints which would affect the prospective operation being considered. Of these the Alton Lock 26, on the Upper Mississippi River, is the worst. It reports an average 4 to 5 hours delay with peak delays as long as a week. And, although the construction of its replacement finally appears to be underway with solicitation of construction bids, it will be 10 years before it is complete.

The Lower Mississippi and Ohio River reportedly do not have significant points of congestion along the lower portion of the River where the prospective traffic for this study will predominate.

The Illinois River is reported to not have any immediate problems. Some transit dealys are experienced when some bridges are closed during rush hours.

The Industrial Lock at New Orleans has average delays of one hour, but this lock reportedly can be bypassed and the cost to replace it, if delays worsen, would not be particularly contentious to any of the Corps of Engineers budget aspirations.



1. $2FeS_2 \rightarrow 2\,FeS + S_2$

2a. $FeS + SO_2 \rightarrow Fe_3O_4 + S_2$

2b. $FeS + O_2 \rightarrow Fe_2O_3 + SO_2$

2c. $Fe_3O_4 + O_2 \rightarrow Fe_2O_3$

---

2. $FeS + O_2 \rightarrow Fe_2O_3 + S_2$

PROCESS BLOCK FLOW DIAGRAM
HALVORSEN PROCESS

FIGURE 10

Davy McKee

EXXON MINERALS COMPANY, U.S.A.

PYRITE PROCESSING STUDY

pyrite is countercurrently treated with a hot stream (650°C) of SO_2 gas and oxygen. The heat of reaction 5 raises the temperature in the furnace to 900-950°C. Heat is also produced by the $S + O_2 = SO_2$ reaction and helps to replace the consumed SO_2. Simultaneiously, the endothermic reaction 1 also takes place. In the heat exchanger the SO_2 + S gas mixture enters at 750-800°C and is cooled to 400°C. Most of the sulfur is condensed and collected in a tank before the gas flows into a chamber where additional cooling and settling removes the balance of the free condensed sulfur. The SO_2/S-free gas is now recycled to the shaft furnace via the heat exchanger where its temperature is raised from 300°C to 650°C. Because of the low equilibrium content of sulfur in the gas mixture, it is evident that large quantities of SO_2 have to be recycled.

The reaction in the Halvorsen process should take place at the highest possible temperature up to 950°C in order to yield the highest sulfur content in the gas. The large quantities of gas will contain correspondingly large quantities of heat. Autogenous operation presupposes that this quantity of heat is used for preheating the incoming gas. Therefore, large dimensions characterize the process equipment, especially the heat exchangers.

Duisburger Kupferhutte (D.K.) in Germany built a pilot plant (3) for a modified version of the Halvorsen process early in the 1950's. The sulfur production at the pilot plant was 1 ton per day.

The D.K. version did not attempt to operate autogenously. The heat content of the exit gas was used to produce steam. Heating of the incoming gas was performed in a gas preheater by burning about 200 kg (440 lb) of coal per ton of sulfur produced.

The process requires industrial oxygen. Even so the nitrogen content gradually builds up, requiring a bleed that also removes some SO_2 from the system, requiring an effluent treatment system.

D.K. operated with pyrite lumps or pellets in a shaft furnace. It was found that a long retention in the furnace (about 15 hours) is required to complete the reaction. Finally, the test work was discontinued.

4.4 SO_2 FROM PYRITE

For many years, pyrite has been roasted to make SO_2 for sulfuric acid production.

[16] $6FeS_2 + 16O_2 = 2Fe_3O_4 + 12SO_2$

[17] $6FeS_2 + 33/2\ O_2 = 3Fe_2O_3 + 12SO_2$

The roasting of pyrite with air is the only process route for production of SO_2 used in commercial scale. In some cases enriched air or commercial oxygen may present some advantages in roasting, but for the Crandon pyrite, the use of air will produce a 16% SO_2 gas. This concentration is above the requirements for the production of sulfuric acid.

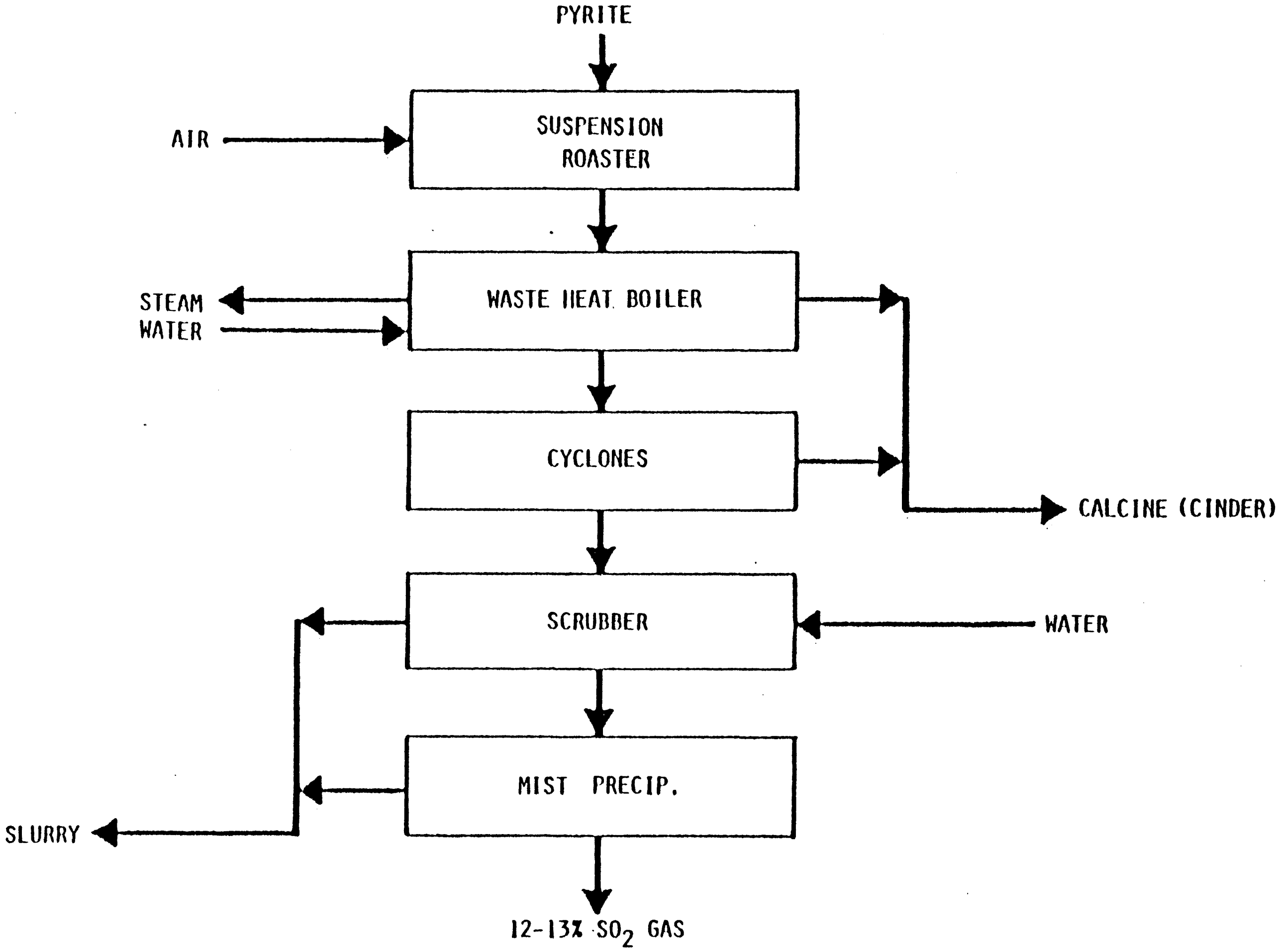
Pyrite roasting has been performed in rotary kilns, multiple hearth furnaces and more recently, in fluidized or turbulent bed reactors (TBR). Also, in the case of a very fine feed, cyclonic or flash roasters have been used. Flash roasters are low energy devices.

The TBR handles particle sizes from 6mm down. The turbulence demands a greater power consumption, but it provides the retention time required by larger particles for a more complete reaction. The bed mass also helps to control the temperature of the furnace.

The process consists of admitting the finely divided sulfides to a refractory lined reactor either as a water slurry or a free loose partially dried material. The resulting ore bed is supported on a perforated constriction plate through which air is introduced under pressure of about 25 kilopascals (3 to 4 psi). This causes the whole bed to be fluidized and act as a boiling mass. The initial heat is supplied by an auxiliary fuel burner (gas or oil), to attain roasting temperature after which autogenous roasting will continue so long as the sulfur content of the feed is above 12%.

From the reactor the offgas usually passes through a waste heat boiler (Figure 11) followed by a system of cyclones and precipitators to collect the gas-borne fine calcine particles. Bed overflow from the roaster is cooled and mixed with the fine fraction from the boiler and dust collecting system. When extremely fine materials are processed, some preliminary agglomeration may be required to overcome feeding problems or excessive dust in the exit gases.

In an operation using this type of roaster, where the feed material is approximately 95% minus 200 mesh and 37% minus 20 microns, approximately 80-85% of the material entering the roaster is gas-borne. (13) In another operation, analyzing 90% minus 150 mesh and 18% minus 20 microns, the amount of calcine in the dust-laden gas is as high as 95%. (14)



PROCESS BLOCK FLOW DIAGRAM
PYRITE ROASTING

FIGURE 11

Davy McKee

EXXON MINERALS COMPANY, U.S.A.

PYRITE PROCESSING STUDY

The principle of the flash roaster or cyclone furnace is that of a furnace fired with coal dust. Both the pyrite and part of the combustion air are blown in at the top toward the furnace center line, and secondary air is blown in at the bottom. Using an injection nozzle for the secondary air inlet and a tangential gas outlet, the gases inside the furnace are given a rotary or cyclonic movement. The gases exit the furnace, through a waste heat boiler and a dust collecting system as in the other type roasters.

Once the bulk of the cinder had been recovered from the gases, the gases are scrubbed and demisted prior to their use for SO_2 recovery or conversion.

4.5 CINDER RECLAMATION (IRON PRODUCTS)

In current commercial practice, after sulfur removal, the residue known as pyrite cinder consists of iron oxides with all the other elements originally present in the pyrite, except the bulk of the sulfur and part of the arsenic if present in the feed.

Depending on factors such as location and composition, the cinder may have some value as an iron ore, or as a source of nonferrous metals, or both, or may constitute a waste disposal problem. The process scheme for the cinder treatment will consequently have to fit the cinder characteristics and composition and the requried specifications for its final use.

Ore dressing methods such as magnetic beneficiation is performed at Fellonica, Italy, (15) after a magnetic roasting of pyrite cinder in order to reduce the slagging components of the cinder. This procedure provides an iron concentrate, but does not remove the nonferrous elements, if present.

Direct mild acid leach has been tried by a European producer (16) to remove and recover copper as a profitable major impurity from the cinder. In Finland, Outokumpu, and in U.S.A. Bethlehem Steel at Sparrows Point, (17) Maryland, commercially recover cobalt from cinders by a sulfatization-leaching procedure. The removal of zinc and lead from iron dust in the iron and steel industry is currently practiced under reducing conditions that produce acceptable clean metallic iron and volatilizes the zinc and lead that are recovered as dust from the flue gases. (18)

For many years and in different countries coarse pyrite cinders have been treated for the recovery of minor components such as copper, zinc, lead, cobalt, silver and gold by using the Henderson process. The iron residue, also called purple ore, is amenable as direct feed to the iron sintering operations. The Henderson process will be described in more detail.

Crandon pyrite contains all the above mentioned minor components, except cobalt, and its particle size is extremely fine. The only known route that would remove all such minor components selectively from the iron matrix is by chlorine chemistry.

The free energy data (21) for the reactions

[18] $MeO(s) + Cl_2(g) = MeCl_2 + 1/2\ O_2(g)$

[19] $MeS(s) + Cl_2(g) = MeCl_2 + S(g)$

where Me stands for some of the more common nonferrous metals in pyrite cinders such as Zn, Cu, Pb, Ag, Au, Hg, suggest that most metals easily convert to chlorides. All sulfides readily form chlorides even at low chlorine pressures.

Most impurities in pyrite cinder exist in the form of oxides. The oxides of Ag, Hg, Cd and Pb easily form their respective chlorides, followed by those of Cu, Zn and Bi. The oxides of Si, Ti, Fe and Al are not expected to convert to chlorides under the presence of oxygen. Accordingly, iron will remain in the form of oxide, while almost all the nonferrous heavy metals will convert to chlorides.

In the presence of sulfur and oxygen it is recognized that Cl_2 is evolved according with the reactions:

[20] $2NaCl + SO_2 + O_2 = Na_2\ SO_4 + Cl_2$

[21] $CaCl_2 + SO_2 + O_2 = CaSO_4 + Cl_2$

In oxygen or air these reactions are expected to procede to the right-hand side, especially at low temperatures (400 to 600°C - 750 to 1000°F).

At higher temperatures with oxygen present and with a relatively weak oxide, the following reaction occurs:

[22] $ZnO + CaCl_2 = ZnCl_2 + CaO$

Metal chlorides have the following general properties:

a) high solubility in water
b) high volality at relatively low temperatures

Accordingly, the technology of chlorine chemistry must be grouped into

1) chlorination - lixiviation route
2) chlorination - volatilization route

The chlorination-lixiviation route chlorinates at low temperature by the use of $NaCl_2$ as reagent. The volatilization may be performed either by Cl_2 or $CaCl_2$ at higher temperatures.

4.5.1 Chlorination-Lixiviation (Leaching)

Henderson Process (19)

Known also as the Ramen and the Duisburger-Kupferhutte (DK) process (Figure 12), the Henderson Process consists of reroasting the cinder mixed with sodium chloride in a multiple-hearth furnace at about 550°C, followed by leaching the roasted cinder by percolation with the acid solution obtained by scrubbing the gases leaving the roaster (HCl, SO_2, SO_3). Since the leaching is performed by percolation, a coarse size material is required.

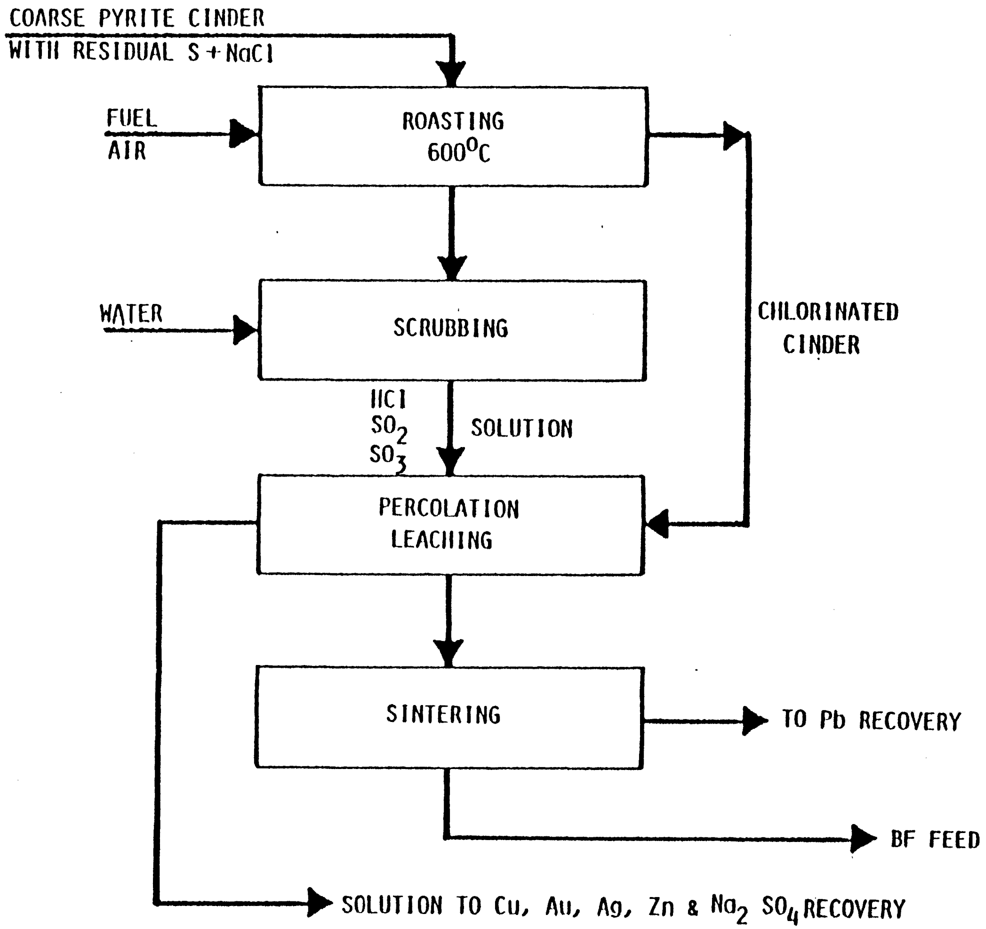
The leaching removes most of the copper, silver and gold, and the zinc not bound to the cinder as a ferrite, and the sodium sulfate formed during roasting with the sulfur remaining in the feed.

Copper is recovered from the solution by cementation on iron. Precious metals are collected with the copper. The solution is concentrated by evaporation to crystallize the sodium sulfate. After most of the iron has been removed from solution by aeration and limestone pH control, with the simultaneous removal of sulfate ions as calcium sulfate, zinc can be recovered by treating the liquor with lime and separated as an impure zinc hydroxide. Today, at least one plant is recovering the zinc directly from the liquor by liquid ion exchange technology, followed by electrowinning (Espindesa Process). (20)

When appreciable quantities of lead are present, they can be recovered by either of two methods. In the first, lead is recovered by volatilization during high temperature agglomeration of the pyrite cinder. The second method involves leaching. After the first leach to remove copper and other nonferrous materials, the cinder is leached with a hot (70 to 80°C) brine solution, whereby the lead is dissolved. The solution is cemented with iron in a similar manner to that employed in copper precipitation.

The present trend toward more finely sized concentrates due to increasing use of froth flotation, is also conducive to lower content of nonferrous metals in the residual pyrite. That combination produces a feed not amenable, for technical and economic reasons, for the above process.

The Henderson (DK) process is oriented toward the recovery of the nonferrous metals rather than the purification of the iron residue. Since the metals extraction is performed by percolation leaching, the cinder must be of coarse size.



PROCESS BLOCK FLOW DIAGRAM

HENDERSON (DK) PROCESS

FIGURE 12

Davy McKee

EXXON MINERALS COMPANY, U.S.A.

PYRITE PROCESSING STUDY

Several of the Henderson (DK) process disadvantages are listed blow:

- The liquid effluent contains sodium and calcium chlorides. They are not amenable to economic recovery, and their disposal constitutes an environmental problem.
- Reagents (NaCl) are not recovered, and large amounts of sodium chloride are required.
- Zinc recovery is not complete enough, if present in substantial amounts, to produce a clean iron residue, and lead recovery requires a separate leach stage.

It is the general consensus in the industry that leaching operations for cinder cleaning shall be considered only if the metals recovered can economically justify the operation.

The process is a well established one and is or has been used in many countries around the world.

4.5.2 Chlorination-Volatilization (21)

The cinder treatment processes to be discussed here are all based on selective chlorination in an oxidizing atmosphere, using gaseous chlorine or suitable chlorides as chlorinating agents.

Metal chlorides have comparatively low boiling points and a correspondingly high vapor pressure at moderate temperatues. This means that they can be fairly easily evaporated at temperatures of about 800°C.

Sodium chloride in some side reactions forms sodium sulfates, silicates and ferrites that are undesirable from the point of view of the iron and steel producer. The calcium salts may help in the slagging process, but there is a danger of inadequate removal of sulfur with the subsequent formation of $CaSO_4$.

The most important disadvantage for $CaCl_2$ is its sensitivity to water vapor. This means that preferably fuel, free from hydrogen, should be used.

[23] $CaCl_2 + H_2O = 2HCl + CaO$

4.5.2.1 Chlorination with Calcium Chloride

4.5.2.1.1 Vuoksenniska Process (22, 23, 32)

There has always been some interest in combining the chlorination with pelletization. Ordinary sintering is impossible with Crandon's finely sized material.

This combination of cleaning and pelletizing has been used for the first time on a large scale by Vuoksenniska in Finland in 1952. It was in use for only two years. The installation had a capacity of 90 tons per day or about 30,000 tons per year.

A simplified flow diagram is shown in Figure 13. Pyrite cinder was pelletized with $CaCl_2$ and sintered in a shaft furnace. During the sintering stage the volatile nonferrous chlorides were also driven off. The thermal economy of the process was rather poor with heat consumption stated as 4 million kilo joules per MT of pellets.

Elements like Cu, Zn, and Pb are driven off to an adequate extent, but the residual sulfur content of the pellets was excessive. It varied generally between 0.1 and 0.3% in the pellet, but should have been 0.05% or lower. The high sulfur caused the formation of a stable $CaSO_4$ which could not be split at temperatures below the softening point of the pellets.

The process used an electrostatic precipitator for the collection of the nonferrous chlorides in a powdered form. Severe corrosion problems were encountered.

Perhaps the most important reason for discontinuing this process was the difficulty of recovering the cobalt content of their particular grade of pyrite cinder. The cobalt is now being recovered by the Kokkola sulfatization process.

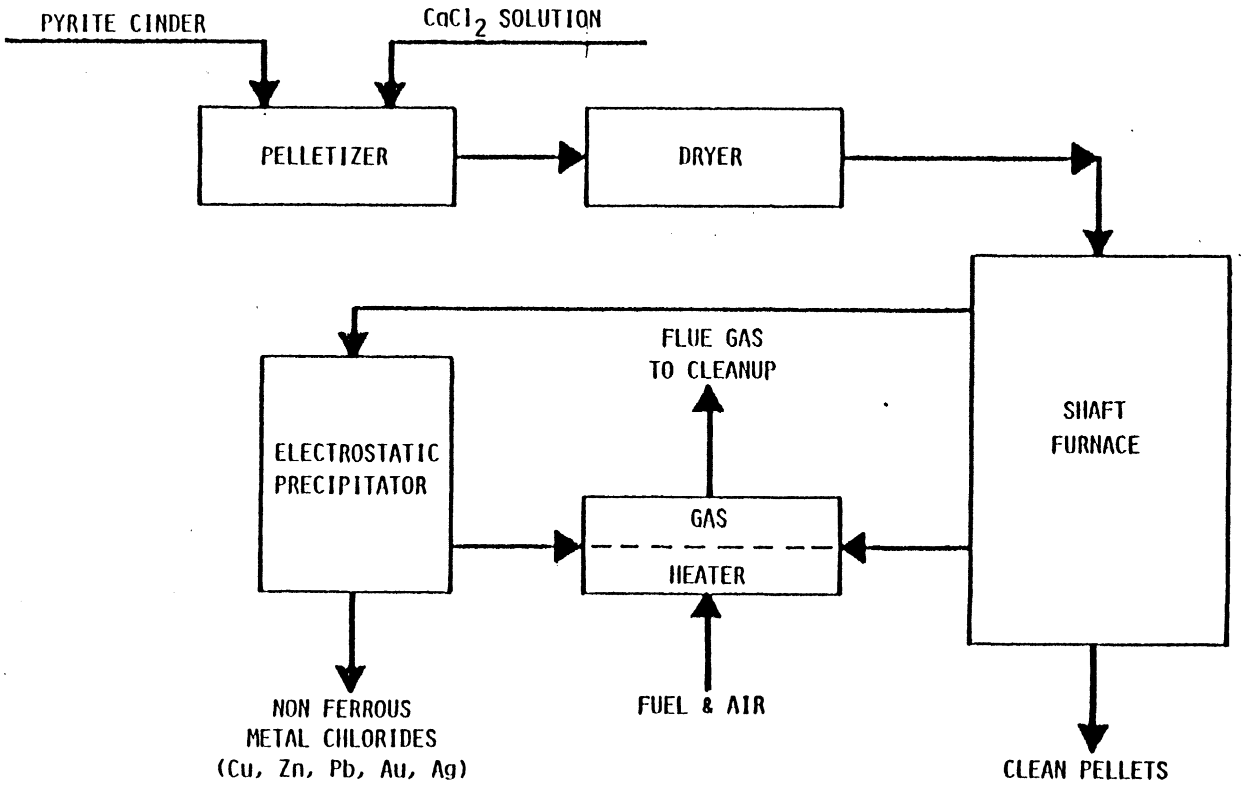
4.5.2.1.2 Kowa Seiko Process (22 to 28, 32)

In the Kowa Seiko technique, the problems associated with the Vuoksenniska process have been overcome.

In 1958, the study of the chlorination volatilization process based on information obtained from Vuoksenniska was started by Amagasaki-Dowa in Japan, and a pilot plant having a shaft furnace with a 50 tons of pellets per day capacity was built at Amagasaki in 1960.

In February 1961 the Kowa Seiko Co. was established to commercialize the improved process, and its Tobata plant was built for an integrated operation from pyrite to cinder pellet as raw material for iron making.

The Tobata plant was started with shaft furnaces and a wet treatment for the gas effluents. The operation with shaft furnaces was continued for about two years. The removal of copper, zinc, etc., was very satisfactory, as pellets containing less than 0.01%Cu were obtained.



PROCESS BLOCK FLOW DIAGRAM
VUOKSENNISKA PROCESS
FIGURE 13

Davy McKee

EXXON MINERALS COMPANY, U.S.A.

PYRITE PROCESSING STUDY

The principal problems were that pellets having sufficient crushing strength for use as blast furnace feed could not be made, and removal of sulfur from the pellets was difficult.

It was found that these troubles could be covercome by holding the temperature of the furnace at 1200 to 1250°C for a certain time. However, partial melting of pellets took place at this high temperature due to slagging problems (resulting from addition of $CaCl_2$). A smooth operation was difficult.

To overcome these difficulties, the use of a rotary kiln was studied jointly with Yawata Iron & Steel Co. In 1965 the shaft furnaces were abandoned and replaced by rotary kilns. Since then successful operations have been attained.

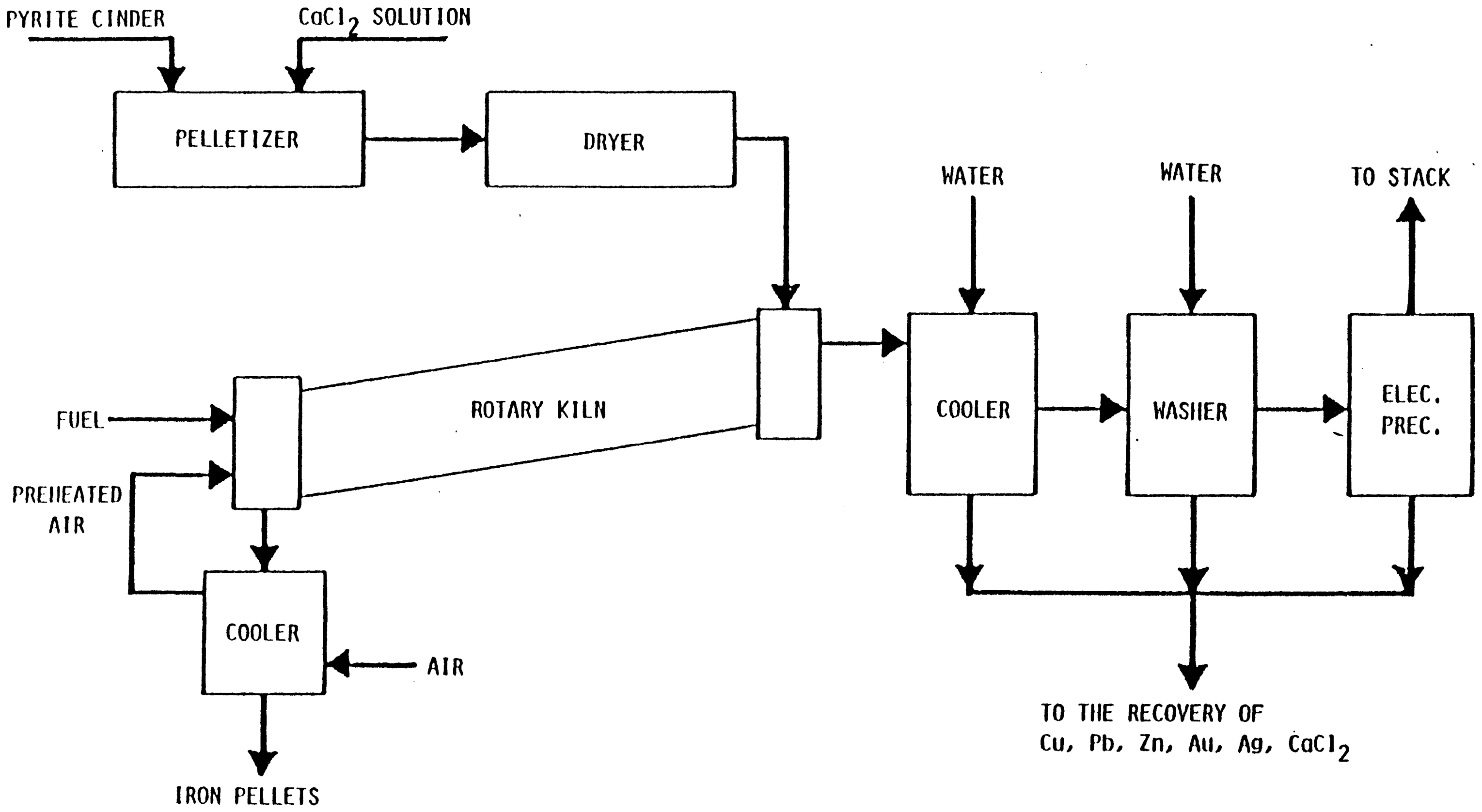
Presently the Kowa-Seiko process has three commercial plants in operation in Japan: one at Tobata (22,000 tons of pellets per month) and one at Amagasaki (28,000 tons of pellets per month). A third plant at Tomakomai Chemical in Hokkaido was scheduled to start operations in late 1974. To our knowledge the only commercial plant built out of Japan is Cities Service Plant at Copperhill, Tennessee. This plant was shut down early in 1979. Figure 14 represents in block diagram the current concept of the process.

Hot cinders after roaster discharge are cooled to 60°C with a spray of calcium chloride solution, and at the same time, the moisture is controlled between 11 and 12%.

Due to the cinder porosity and uneven surface, it is not easy to obtain the wetting uniformity suitable for pelletizing. Further, the particle size is fine, and its size distribution is inadequate for the manufacture of satisfactory green pellets. For this reason, the cinders are conditioned for balling through a combination of blending, kneading and grinding.

The $CaCl_2$ requirements are claimed to be about 1.3 times the theoretical stoichiometric for Cu, Zn, and Pb, when low H_2 content fuels are used such as 70% CO steel converter gas. For other fuels the $CaCl_2$ required is higher, being 1.5 the ratio estimated for a heavy oil fuel operation. In order to achieve a convenient CaO/SiO_2 ratio in the final pellet, the balance of calcium above the $CaCl_2$ content is added as calcium hydrate or lime slurry.

Final moisture control of the cinder after conditioning is made in a pug mixer and green pellets of 10-15mm diameter are made by the way of a balling disc.



PROCESS BLOCK FLOW DIAGRAM

KOWA SEIKO PROCESS

FIGURE 14

Davy McKee

EXXON MINERALS COMPANY, U.S.A.

PYRITE PROCESSING STUDY

The green pellets have a cold crushing strength of about 4 kilograms per pellet which is not adequate for charging into a rotary kiln. The pellets are dried at a temperature not higher than 250°C in a conveyor dryer to a moisture content below 1%. This produces a dry pellet with crushing strength increased to about 30 kilograms.

After removing the portion below 7mm, dried pellets are charged into a rotary kiln. A total retention time of 160 minutes includes 40 minutes at the volatilization temperature of 800-1000°C where lead, zinc and copper are removed as chloride vapors. During the last 10 minutes at 1200-1250°C the calcium sulfate formed in the process decomposes, providing a very effective desulfurization, and at the same time sintering is completed to obtain strong pellets of about 400 to 500 kilograms/pellet.

The treated pellets are cooled to 100°C by air, and the heat recovered is returned to the kiln as combustion air.

It is stated that more than 95% copper, 60 to 80% lead, 90% zinc, about 90% gold, and 95% silver are recovered.

The exhaust gases from the rotary kiln at a temperature of over 400°C are dedusted in a dust chamber and washed in a cooling/washing tower directly by circulation of a water solution that dissolves and extracts hydrochloric acid, chlorides, sulfuric acid, sulfates, etc.

The clean gas is passed through a mist precipitator to remove residual acid fumes and lead salt mist, and then discharged into the atmosphere.

At Tobata plant the gases after the mist precipitators have the following contaminants:

Cl_2 = 0.15 grams/Nm^3 (0.08 grains/scf)
SO_2 = 1.1 grams/Nm^3 (385 ppm)
Cu = 0.025 grams/Nm^3 (0.014 grains/scf)
Pb = 0.025 grams/Nm^3 (0.014 grains/scf)
Zn = 0.03 grams/Nm^3 (0.016 grains/scf)
Fe = 0.03 grams/Nm^3 (0.016 grains/scf)
H_2O = saturated at 45°C (110°F)

The washing solution is vacuum cooled and recycled. A bleed is removed to recover valuable metals. Also values are recovered from the drain of the mist cottrell. After metals recovery, a final solution of $CaCl_2$ is left from which most of the required $CaCl_2$ is recycled into the process.

The Kowa Seiko process is alo well established and in commercial use. The first commercial plant, at Tobata, Japan, started operations in 1961 and after some modifications, the basic process has been in continuous operation for the last 18 years. The second Japanese plant at Amagasaki has been working at full capacity for the last 14 years.

Some of the advantages of the process may be summarized as follows:

1) The gaseous flow from the process kiln containing the nonferrous metals is cleaned to such an extent that the nonferrous and precious metal recoveries are high and the gases to atmosphere can meet the most strict regulations. The residual oxides of sulfur are recovered as gypsum.

2) It is free of liquid effluents.

3) Purification and pelletizing are carried out simultaneously.

4) The iron pellets produced have excellent chemical and physical properties.

5) Any undesirable fine material resulting from the process can be recycled into the agglomeration circuit.

6) Reagents (calcium chloride) are amenable to recycle.

Disadvantages are:

7) High energy requirements in both fuel and electric energy.

8) High capital cost.

9) High operating labor cost.

10) Extensive preventive maintenance.

11) Highly skilled operators are required.

The energy requirements are the most controversial feature of this process. Drying and pelletizing are performed as separate functions and due to the nature of the process, no heat recovery is possible. The fuel requirements are stated as:

. Drying - 0.91×10^6 kJ (0.87×10^6 Btu)/MT

. Pelletizing - 1.86×10^6 kJ (1.76×10^6 Btu)/MT for a total of 2.77 x 10^6 kJ (2.63 x 10^6 Btu) per metric ton of pellets. When this is compared with predicted fuel requirements of 464,000 kJ (440,000 Btu)/MT for pelletizing magnetitie, and 1,045,000 kJ (990,000 Btu)/MT for pelletizing hematitie, in current iron ore operations, the outlook is not too favorable.

4.5.2.2 Chlorination with Chlorine Gas

4.5.2.2.1 Lurgi-Duisburger Kupferhutte (LDK) Process (22, 29, 30, 32)

In order to overcome the difficulties and higher operating cost faced by the DK chlorination roasting-percolation leaching when dealing with fine pyrite concentrates, chlorination volatilization with chlorine gas was jointly investigated by Lurgi and Duisburger Kupferhutte.

Following investigations in the laboratory and in bench scale operations up to 3 ton/day, carried out by Lurgi and DK, a 100 ton/day pilot plant was built (1965) and operated (from 1966) at Duisburg to test the LDK process.

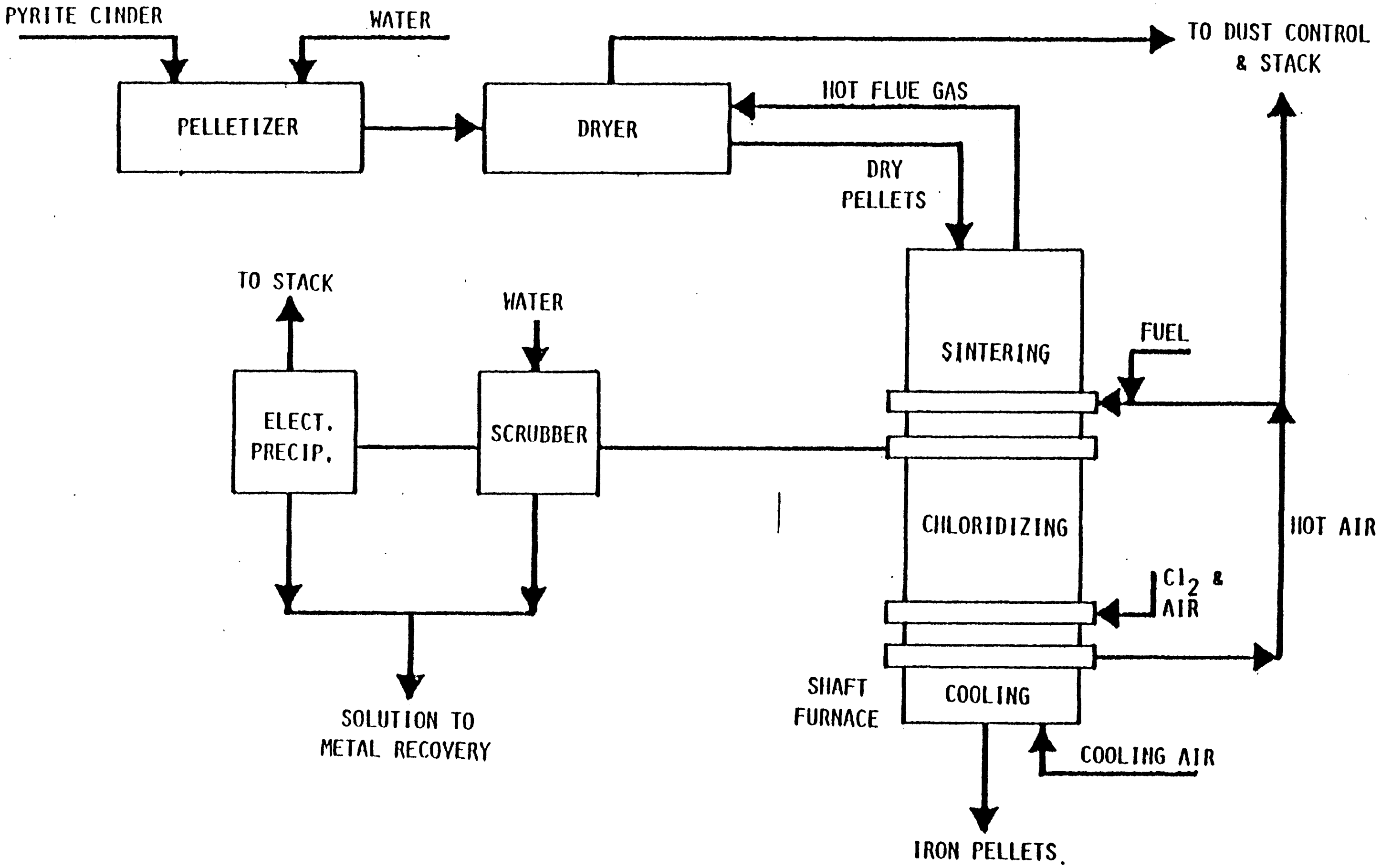
Figure 15 shows a simplified block diagram for the LDK process in its most recent version.

The cooled cinders, with no more than two percent moisture, are ground in ball mills to the fineness required for pelletization. The ground material, mixed with additives such as bentonite and lime, is prewetted in a screw conveyor to about 8% moisture and conveyed to the pelletizing disc, where additional water required for the formation of pellets is added.

The green pellets are transferred from the pelletizing disc onto a roller conveyor, which also serves to separate the undersize. Subsequently, the green pellets are dried with hot gas on a belt dryer.

The dry pellets delivered from the belt dryer have sufficient strength to withstand charging into the chlorination shaft furnace. To separate fines abraded from the pellets during drying, the dry pellets pass over a parallel wire type screen to the shaft furnace.

The shaft consists of three identifiable zones. From top to bottom the zones are: induration, chlorination and cooling. The dried pellets are countercurrently heated in the induration zone with heating gases to induration temperatures. The waste gases from the induration zone are drawn off at the furnace top, dedusted, and conveyed to the stack.



PROCESS BLOCK FLOW DIAGRAM
LURGI-DUISBURGER KUPFERHUTTE PROCESS

FIGURE 15

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In the chlorination zone the indurated hot pellets are countercurrently treated with a cold chlorine-air mixture where the nonferrous and precious metals are volatilized as chlorides. These chlorides are discharged hot out of the shaft just below the induration zone and pass through a venturi scrubber for rapid gas cooling and for washing out a high percentage of chlorides; subsequently, a wet electroprecipitator eliminates mists still contained in the gas. Separation of the incoming heated gases from the exiting gases with the chlorides is done by automatic regulation of the differential pressures between the respective zones.

Subsequently, the pellets pass through the cooling zone, where they are countercurrently cooled with air. The heated cooling air is discharged below the chlorination zone separately from the chlorination gases, as described above. Thus, with this method all three gas streams are kept separate.

The dissolved chlorides leaving the scrubber and electroprecipitator, after being reclaimed from the chlorination exit gases, contain a low percentage of abraded dust and free hydrochloric acid from excess chlorine. This solution is treated by conventional techniques for the recovery of the nonferrous metals.

The LDK 100 ton/day pellet chlorination plant had been built not to treat any special type of cinder but to gain experience and to compile data on a commercial scale with the various qualities of cinder for further larger designs. Table X gives average operating data and Table Y contains data on the pellets produced.

Table X

Pellet Drying Conditions

Blaine number	2800-4500 cm^2/g
Bentonite addition	max 1%
Addition of water in prehumidifier	about 8%
Moisture of green pellets	12-18%
Pellet size	10-18mm
Hardness of green pellets	1-2.5 kg/pellet
Hot gas temperature for pellet drying	350-550°C
Moisture of dry pellets	0.1%
Hardness of dry pellets	10-15 kg/pellet

Shaft Furnace Operational Data

Throughput of cinder	80-100 ton/day
Hot gas temperature	1100-1250°C
H_2O content of combustion gases	5-10% H_2O
Chlorine consumption (times stoichiometric)	1.3-2.0
Chlorine concentration in chlorine air mixture	5-17 vol%
Temperature of heated cooling air	400-500°C
Temperature of discharged pellets	100-200°C

Exit Gas Data

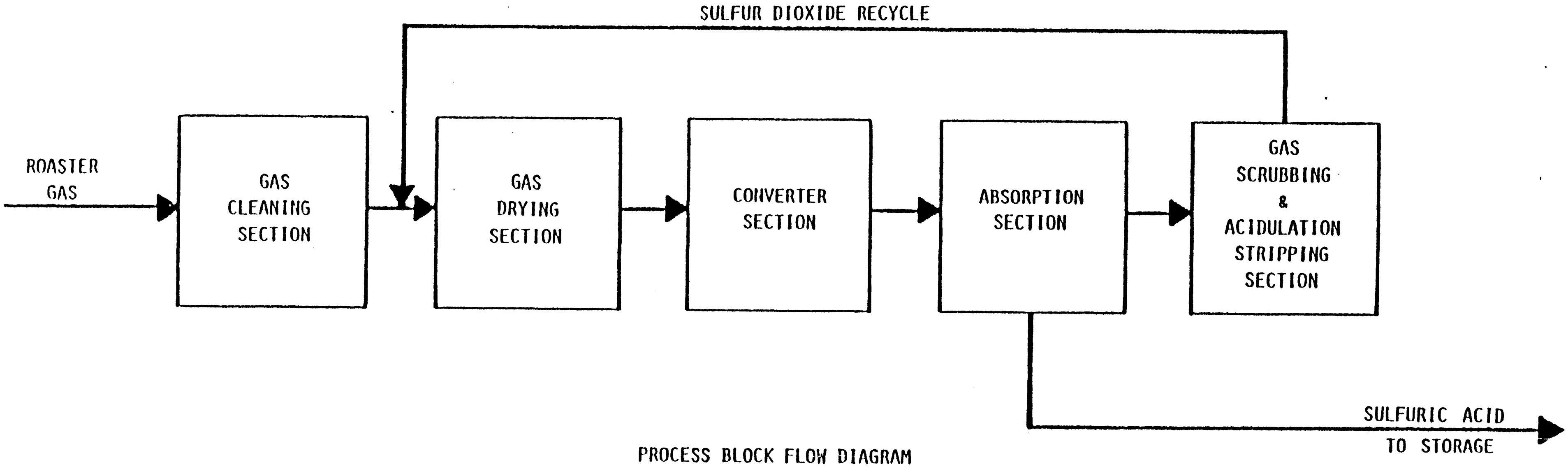
Temperature of exit gas at furnace top	200-400°C
Dust losses in exit gas at furnace top	1%
Temperature of outgoing chlorination gases	800-1000°C

Table Y

Data on Pellets Produced

Abrasion according to tumbler test	4-8%
Crushing strength	150-300 kg/pellet
Abrasion rates according to Linder	10-13%
Porosity	32-36%
Pellet resistance during reduction (expressed in mm water gauge at 80% reduction)*	6-10
Copper	0.02% (max 0.05%)
Zinc	0.05% (max 0.25%)
Lead	0.05%
Sulfur	0.02%
Gold and silver volatilization	90%

*Carol Lake pellets, 4.0: Wabush pellets, 8.9.



PROCESS BLOCK FLOW DIAGRAM
PYRITE ROASTING GAS TO SULFURIC ACID
(DAVY MCKEE SINGLE ABSORPTION AMMONIA SCRUBBING)

FIGURE 21

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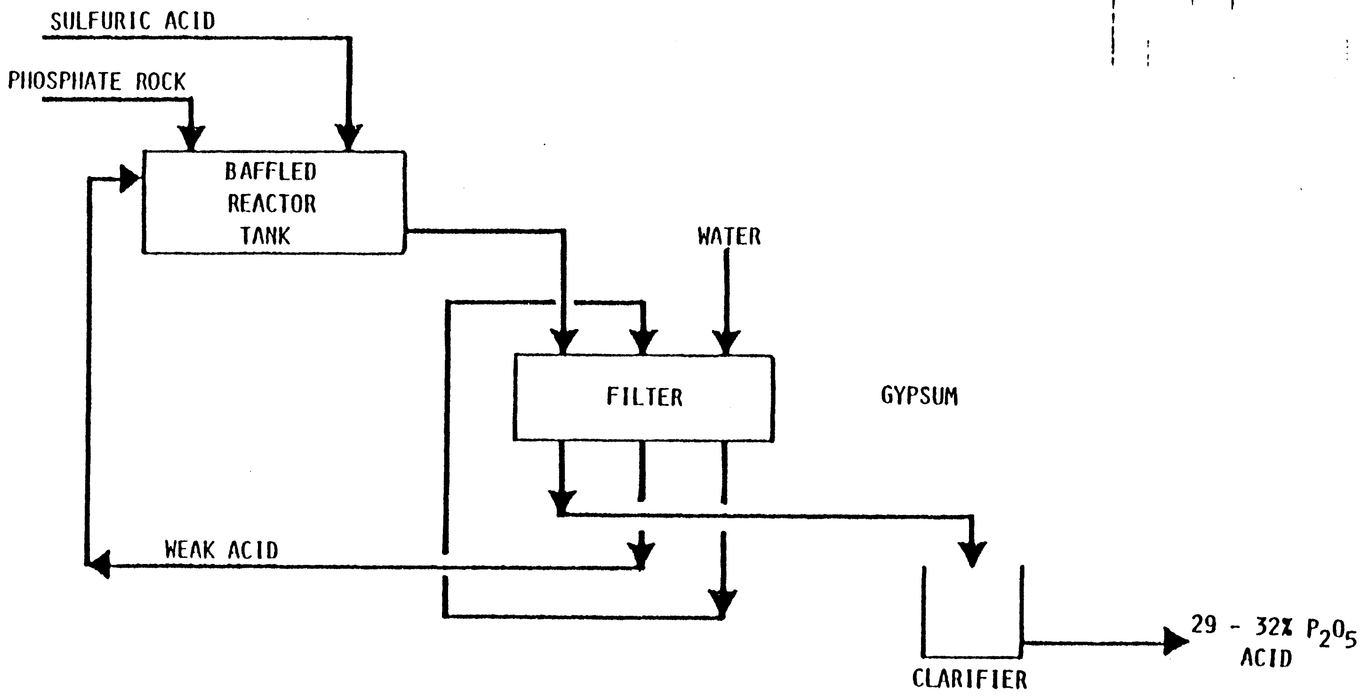

PROCESS BLOCK FLOW DIAGRAM
PHOSPHORIC ACID
DIHYDRATE PROCESS

FIGURE 22

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controlled to ensure completeness of reaction and growth of gypsum crystals to the size necessary for effecting good separation of acid and gypsum in the filtration step. After leaving the last stage reactor tank, the slurry is split into two streams in a ratio of about 15 to 1. The larger stream is recirculated to the premixing tank to be intermixed with the fresh sulfuric acid; the smaller is pumped to a filter for separation and washing of the gypsum crystals. Filter operation usually involves three wash stages. The product acid, containing 28-32% P_2O_5, is separated from the gypsum in the first stage, and the phosphoric acid remaining is washed from the gypsum residue during the second and third stages. Contaminated pond water is used as the wash on the third stage; the filtrate from this is circulated over the gypsum in the second stage, where the acid concentration reaches about 20% P_2O_5, and is then pumped back to the premixing tank. The washed gypsum cake discharged from the third stage is usually reslurried with contaminated water and pumped to a disposal area.

Although the new plants constructed since 1960 employ the same basic principles as those used in the old process, improved engineering design and materials of construction have decreased capital and operating costs per unit of capacity and have improved overall operating efficiency. In these plants (Figure 18) single-tank, multiple-compartment reactors replace the multiple-tank train. Precise design of the tank interior is important to assure complete reaction of the rock and sulfuric acid and prevent the bypassing of unreacted rock. A series of agitators and baffles forces circulation of the slurry through prearranged paths to give the same effect as the slurry recirculation and cascade arrangement in the train system.

Filtration of the gypsum-acid slurry is a major operation. About 5 tons of gypsum filter cake (dry basis) are collected per ton of P_2O_5 produced. This amount is equivalent to about 2.6 tons of gypsum per ton of pyrite.

4.10.2 The Hemihydrate-Dihydrate Process

This process involves precipitation of calcium sulfate in the hemihydrate form followed by recrystallization to dihydrate. The method produces large, well-formed dihydrate crystals, and it is claimed that phosphate substituted in the calcium sulfate lattice is released and dissolved during the recrystallization.

The process worked well both on a small scale and in the pilot plant. A full-scale plant was built in England about 1929 but did not operate well, mainly because of difficulty in controlling the size of the crystal aggregates.

More recently development work on the hemihydrate-dihydrate process has been done in Japan. The inital work was done by Murakaimi and Tanaka and the Nissan Company. Nippon Kokan Kabushiki Kaisha and Mitsubishi Chemical Industries also operate and build hemihydrate-dihydrate plants.

In a typical Japanese process phosphate rock is mixed with sulfuric acid and with recycled first-wash acid in a premixer, and the mixture flows into the digester, where it is held at 90 to 100°C until dissolution is complete (the time varies with the type of rock). The slurry then flows through a series of recrystallizing tanks, where it is held at 50 to 60°C until recrystallization to dihydrate is complete. It is desirable to maintain a free H_2SO_4 content of 3 to 5% to accelerate dihydrate formation. Slurry is recycled within the recrystallization system but is not returned to the digester. Filtration is rapid and gives acid of about 30% P_2O_5 contents. Very good recovery of phosphate is claimed, with loss of only 2% of the initial P_2O_5 in the filter cake. It is claimed that a cleaner gypsum is produced by this method.

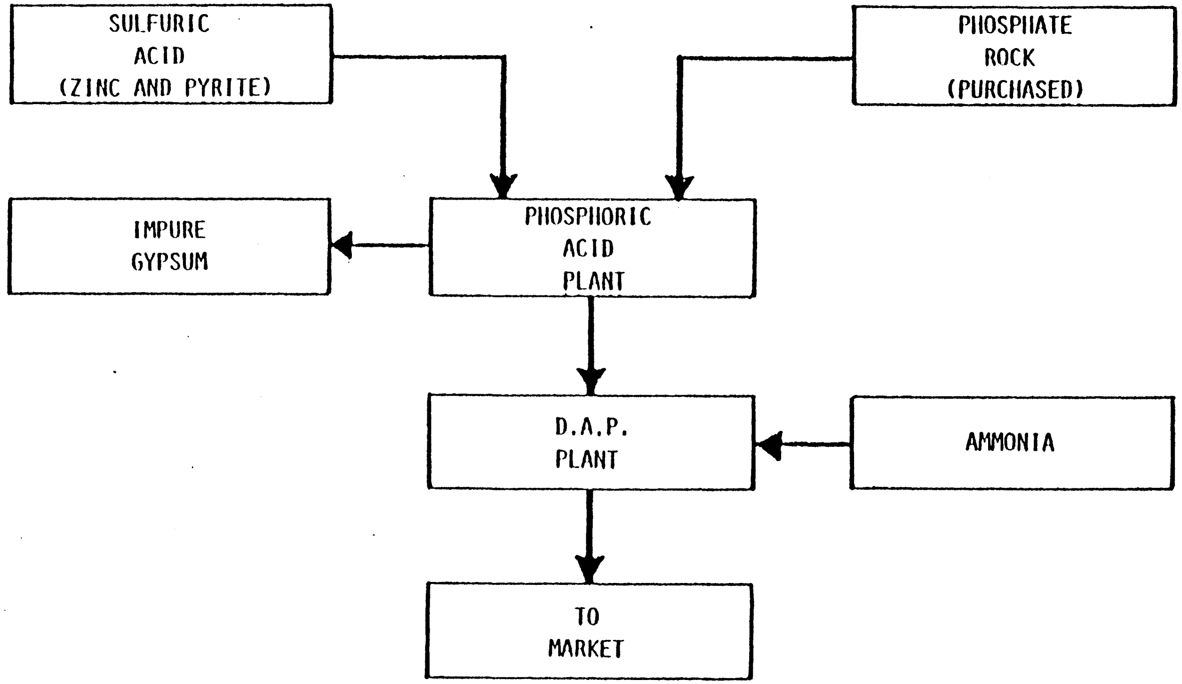
In a variation of the hemihydrate-dihydrate process, the slurry is filtered before recrystallization to dihydrate takes place. The dihydrate slurry is then filtered and the filtrate recycled to the rock digestion system. As compared to filtration after recrystallization, an extra filtration is required, but it is relatively simple since no washing is attempted. The main advantage is that a higher concentration is obtained - 40 to 42% P_2O_5 versus 30 to 32%.

4.11 DIAMMONIUM PHOSPHATE (DAP) (Figure 23)

Diammonium phosphate is currently produced in a granular form. The standard process for the production of the fertilizer grade involves the direct reaction of phosphoric acid with liquid or vapor ammonia.

In a reactor tank, phosphoric acid with a 28-30% P_2O_5 concentration is partially neutralized with ammonia. The resulting slurry is pumped into the granulator where it is distributed over a large cascading recycle stream of dry solids. The slurry wets the fine particles in a drum where they are coated and rolled to produce the required granule size. Vapor or liquid ammonia is introduced continuously under the rolling bed in the granulator to complete ammoniation to the product mole ratio required.

The wet granules overflow directly into a dryer, where they are dried by direct contact with a co-current hot air stream.



BLOCK FLOW DIAGRAM
FERTILIZER PLANT
FIGURE 23

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4.2 PROCESS SELECTION

Selection

The state-of-the-art on pyrite processing has been explored and the unit processes identified and defined. The scope of work requires consideration of only commercial processes, but it has been expanded to provide a more thorough panorama on the subject.

The two major marketable commodities produced from the sulfur portion of pyrite, elemental sulfur and sulfuric acid, have both well defined and proven technologies. The iron portion has also well established processing routes for its commercial preparation.

The actual behavior of the Crandon's fine pyrite concentrate under storage and handling is not known. Supposition is that no unsurmountable problems are expected. For the purpose of this study it is assumed that a partially dried pyrite (about 12-16% moisture) and partially agglomerated by tumbling will have a safe and acceptable behavior.

The commercial route for the production of sulfuric acid from pyrite comprises two stages: sulfur dioxide generation and its conversion into sulfuric acid. It is proposed to roast the pyrite in a fluidized bed reactor with partially dry feed, as indicated above. Some sintering and large dust carryover are expected, but both are within current commercial practice.

The sulfuric acid plant is to be a double catalysis unit. For a preliminary evaluation of the overall pyrite treatment concept, alternate considerations would be only academic.

As indicated in the CRU market study, a captive processing of sulfuric acid into ammonium fertilizers, via phosphoric acid, is suggested for continuity into an overall process concept.

Most of the wet phosphoric acid produced in the world is made by the dihydrate process. Complete designs are offered under other names, but differ in detail rather than in principle. Davy McKee's in-house experience (Prayon process) includes 33 plants built throughout the world in the last 17 years.

For cinder reclamation (iron products), the marketing study indicates that only iron pellets as blast furnace feedstock deserves serious consideration. In this area there is only one well established commercial process applicable to fine pyrite with the Crandon composition: the Kowa Seiko process.

In order to perform an economical evaluation for the overall processing system, it is proposed to follow process block flow diagram, Figure 19.

The selected processing units that are to be estimated, both as to capital and operating costs, will be as follows:

- Pyrite handling and preparation
- Roasting in turbulent bed reactors
- Sulfuric acid manufacture, double catalysis
- Phosphoric acid manufacture, Prayon method
- DAP manufacture
- Production of clean iron pellets by the Kowa Seiko process
- Recovery of nonferrous metals sludges

As a possible alternate, the breakdown of pyrite into elemental sulfur and iron residue is technically possible. There is only one facility (Kokkola, Finland) producing sulfur from pyrite, and only for one half of the sulfur content. Nevertheless, in order to produce a preliminary evaluation for this potential processing route, the overall process block diagram as shown in Figure 20 has been prepared. The same assumptions for pyrite handling behavior is taken.

After a cursory analysis on items such as gas handling, energy consumption and information available on equipment selection, the electric smelting route has been selected, without implying an endorsement. At this point any selected route will not affect the order-of-magnitude results.

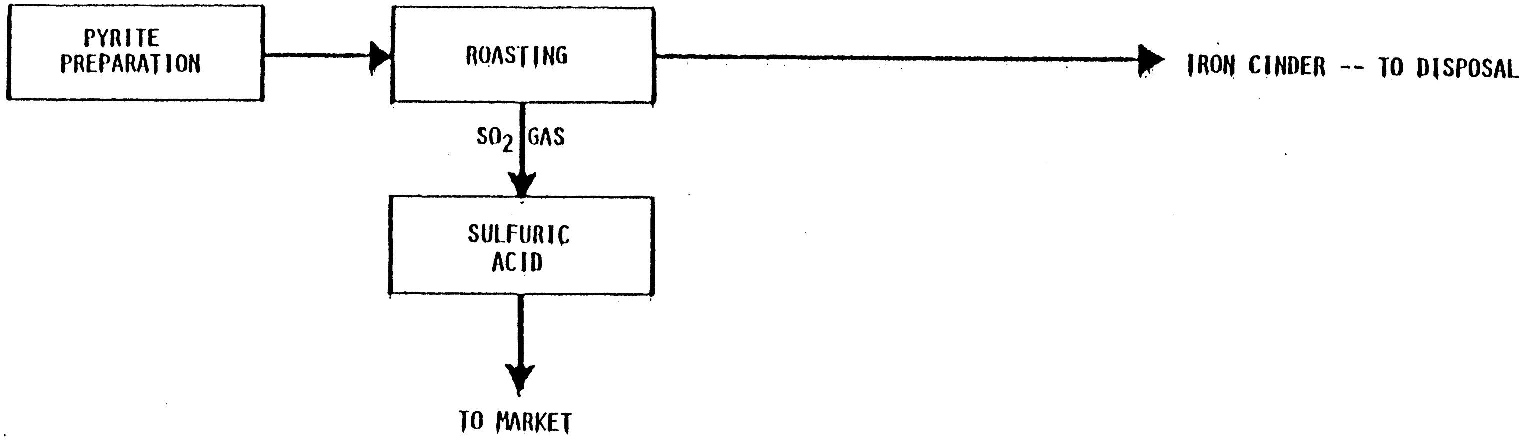
For roasting, the same type of fluidized bed reactors as in the former overall system is chosen.

The Allied (partial reduction - Claus) process is applied to the SO_2 conversion into elemental sulfur. It is assumed that the residual cinder is amenable to treatment for iron and nonferrous recoveries as in the former case.

The alternate processing units to be estimated for both, capital and operating costs, as per Figure 4 will comprise:

- Pyrite handling and preparation
- Pyrite smelting - electric furnace
- Matte granulation
- Matte roasting - turbulent bed reactor
- Partial reduction - natural gas
- Claus unit
- Sulfur cleaning

The iron cinder treatment with a Kowa Seiko type facility is assumed to be identical to the one shown in block flow diagram, Figures 1, 2 and 3.



PROCESS BLOCK FLOW DIAGRAM

SULFURIC ACID ONLY. IRON CINDER TO DISPOSAL

FIGURE 1

ALR 1/15/80

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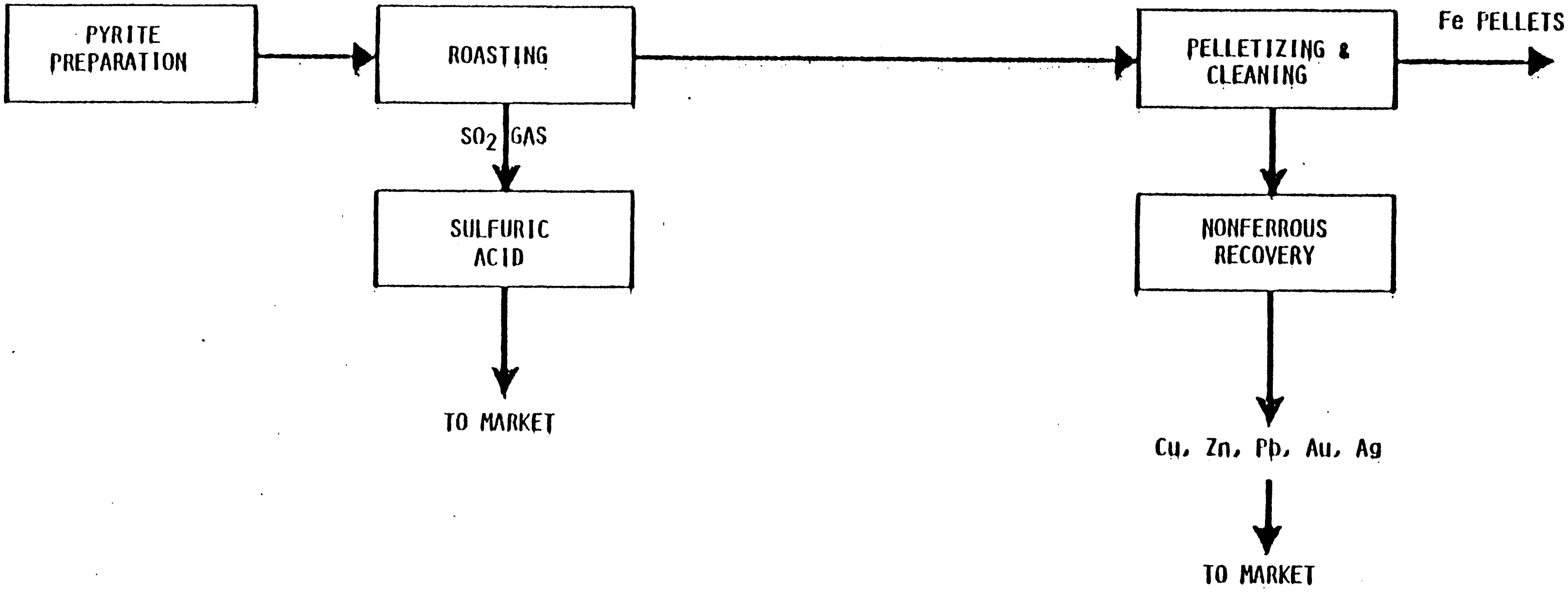

PROCESS BLOCK FLOW DIAGRAM

SULFURIC ACID, IRON PELLETS
AND NONFERROUS METAL RECOVERY

FIGURE 2

ALR 1/15/80

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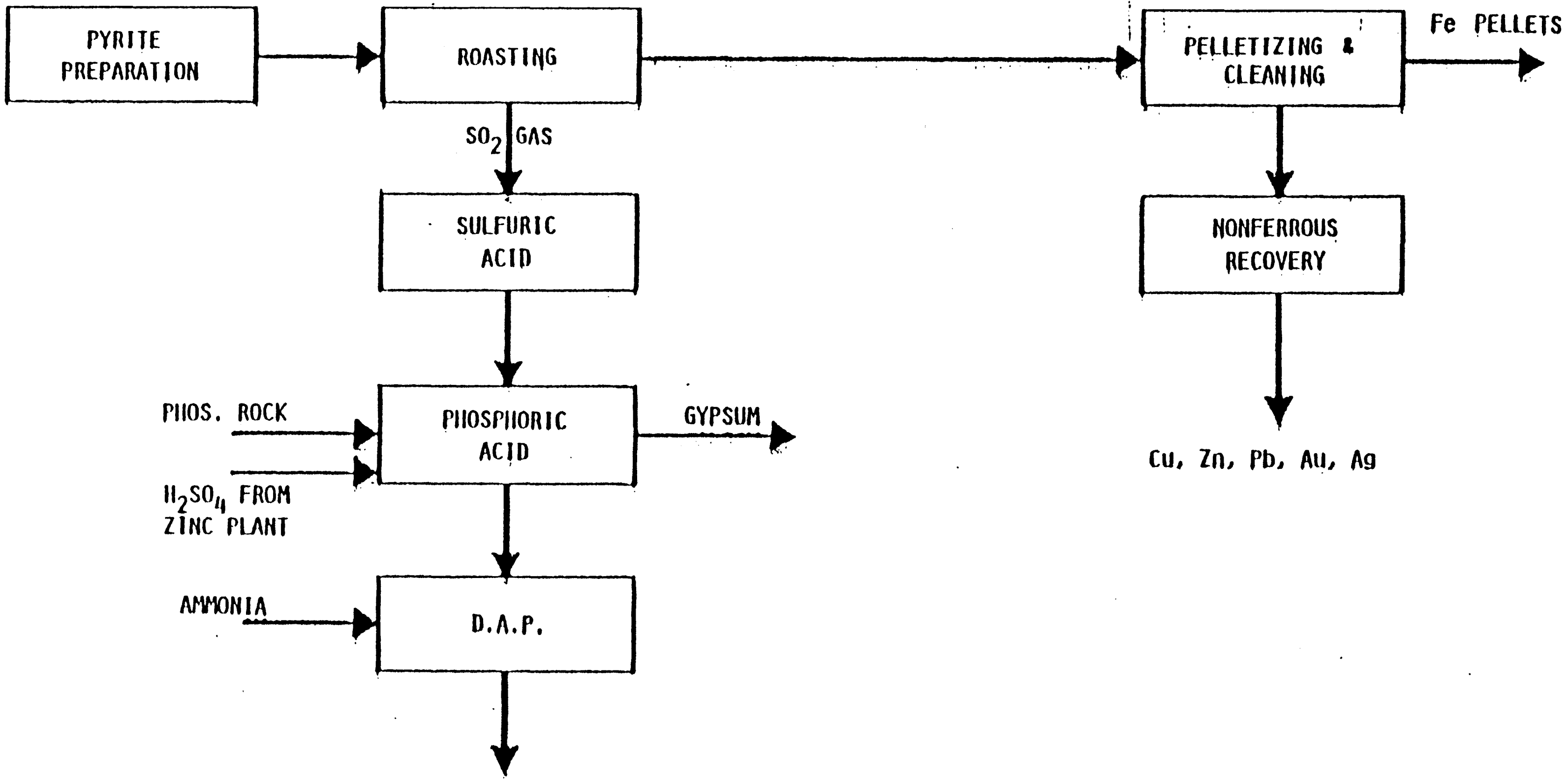

PROCESS BLOCK FLOW DIAGRAM
PELLET ROUTE
SULFURIC ACID, PHOSPHORIC ACID, D.A.P. AND IRON PELLETS
FIGURE # 3

ALR 1/15/80

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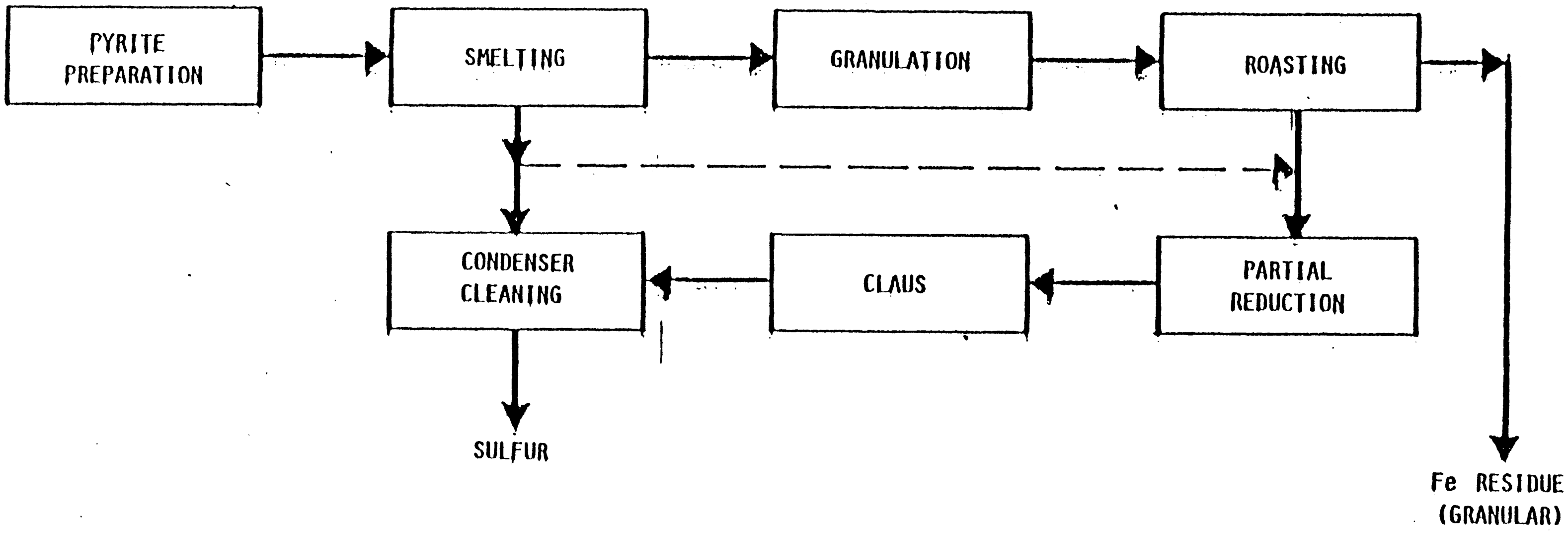

PROCESS BLOCK FLOW DIAGRAM
SULFUR RECOVERY & IRON RESIDUE

FIGURE # 4

ALR 1/15/80

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November 1979

EXXON MINERALS CO. USA
PYRITE PROCESSING STUDY

PHASE I

MARKETING, TRANSPORTATION, PROCESS TECHNOLOGY

5. SUMMARY & CONCLUSIONS

The sections of Phase I of the pyrite processing study review in detail the marketing, transportation, the process technology and the selection of that technology. The assessments made will be utilized in Phase II report to determine the capital and operating costs and the revenues. The findings can be summarized as follows to indicate the option or options which are considered to have the best potential.

5.1 MARKETING

- None of the byproduct possibilities examined appear to offer a great potential of an economic return during the period through the 1990s as a commercial project.

- The possibility of selling Crandon pyrite concentrates to Cities Services Company should be pursued as a first priority as this would permit the removal of the pyrite with nominal, no-return, capital investment.

- The possibilities of the manufacture of sulfuric acid and iron pellets should be the second priority. Fatal sulfuric acid, i.e., non-volunteered acid must be sold as produced so as to not obstruct the operations of the mine and zinc concentrator. Historically, fatal acid demands a lower negotiated price, in this case $4.00-$16.00/MT F.O.B., which will probably be below the production costs. The disposal of this sulfuric acid should be done through one or two contract buyers or to a broker such as Canadian Industries Ltd. (CIL).

- The prospects for the sale of elemental sulfur are favorable in view of the relatively small tonnage to be produced. Two options are open, first, direct sales to existing acid producers; second, negotiate with local chemical companies to dispose of the tonnage. In either case, the disposal of 134,000 MTPY of sulfur in a tight market should not pose problems.

- The market potential of phosphoric acid and diammonium phosphate at either Green Bay or Evansville is not sufficiently good to warrant investment in production facilities and the complexities of the logistics involved in the purchase and shipping of raw materials and the disposal of byproduct gypsum.

- The preferred site location as far as transportation and markets are concerned would be Green Bay, Wisconsin.

5.2 TRANSPORTATION

- The most economical mode of transportation from the mine site at Crandon to either process center at Green Bay, Wisconsin, or Evansville, Indiana, is by railroad.
- The same applies for the shipment of the Crandon pyrite to Cities Service Co. in Tennessee.
- The most economic mode of transportation for all products from and to Evansville, Indiana, is via the Ohio River.
- The most economic mode of transportation for all products from and to Green Bay, Wisconsin, is via the Great Lakes except ammonia.
- The transportation costs from the mine site at Crandon to the process centers immediately impacts the viability of further processing the Crandon pyrite.
- The transportation costs for Crandon pyrite to Copperhill, Tennessee (Cities Service Co.) at $31.72/MT dry may preclude the purchase and use of this material by that consumer.
- The Great Lakes navigation season which reduced by four months during the winter season and the Ohio River navigation season which reduced by two months during the winter further increases the transportation costs. During those periods, railroad transportation must be utilized.
- All transportation modes are available at both Green Bay and Evansville.

5.3 PROCESS TECHNOLOGY

- As indicated in the process evaluation, the state-of-the-art processing units have been summarized and selected as follows: (Figures 1, 2 and 3)
    - Pyrite handling and preparation
    - Roasting in turbulent bed reactors
    - Sulfuric acid manufacture, double catalysis
    - Phosphoric acid manufacture, Prayon method
    - DAP manufacture
    - Production of clean iron pellets by the Kowa Seiko process
    - Recovery of nonferrous metals sludges

- An alternate processing route to produce elemental sulfur by the electric furnace and a Claus unit is as follows: (Figure 4)
  - Pyrite handling and preparation
  - Pyrite smelting - electric furnace
  - Matte granulation
  - Matte roasting - turbulent bed reactor
  - Partial reduction - natural gas
  - Claus unit
  - Sulfur cleaning
  - Production of clean iron pellets by Kowa Seiko process
  - Recovery of nonferrous metal sludges

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PHASE I

7. GLOSSARY OF TERMS

APC	Air Pollution Control
B.P.L.	Bone Phosphate of Lime
CAAA	Clean Air Act Amendments
Calcine	Metal oxide after sulfur removal by roasting
C.I.L.	Canadian Industries Ltd.
Cinder	Pyrite product after sulfur removal by roasting
C.R.I.	Consolidated Research, Inc.
C. R. U.	Commodities Research Unit, Ltd.
DAP	Diammonium Phosphate
DK	Duisburger Kupferhutte
D.W.T.	Dry Weight Tons
EPA	Environmental Protection Agency
Fatal Acid	Involuntary Producers, Mainly Smelters
Fl-C	Fluo-Chlor
F.O.B.	Free on Board
Frasch Sulfur	Sulfur produced from natural deposits mined by melting underground and pumped to the surface
H_2SO_4	Sulfuric Acid
H/DK	Halverson/Duisburger Kupferhutte
Intermodel	From one method of transportation to another
J.B.C.	Jones, Bardelmeier & Co. Ltd.

Kg	Kilograms
Kg/y	Kilograms per year
Kj(Kilojoule)	1.0 Btu
LDK	Lurgi-Duisburger Kupferhutte
L.T.U	Long Ton Unit
Matte	A crude mixture of metal sulfides formed in the smelting of sulfide ores
mcf	million cubic feet
Micron	1/1000 of a millimeter = .00004"
MM	Million
mm	millimeter
MT	Metric Tons (2200#)
MTPA	Metric Tons Per Annum (2200#)
MTPY	Metric Tons Per Year (2200#)
N	Nitrogen
Net Back	Commodity Price less Transportation
NPDES	National Pollutant Discharge Elimination System
P_2O_5	Phosphoric Acid
Phos Acid	Phosphoric Acid
Phos Rock	Phosphoric Rock
PSD	Prevention of Significant Deterioration
PSF	Pounds Per Square Foot
Slimes	A very fine material in slurry form

Smelter Acid	Sulfuric acid made from smelter gases
SO_2	Sulfur Dioxide
ST	Short Tons (2000#)
STPA	Short Tons Per Annum (2000#)
STPY	Short Tons Per Year (2000#)
TVA	Tennessee Valley Authority
U.S.B.M.	United States Bureau of Mines
U.S.D.A.	United States Department of Agriculture
U.S.D.C.	United States Department of Commerce
Virgin Acid	Sulfuric acid made from elemental sulfur