AGENCY FOR INTERNATIONAL DEVELOPMENT
WASHINGTON, D. C. 20523

BIBLIOGRAPHIC INPUT SHEET

FOR AID USE ONLY

1. SUBJECT CLASSIFICATION

A. PRIMARY: Agriculture

B. SECONDARY: Fertilizers

2. TITLE AND SUBTITLE

Expansion of the fertilizer industry in the Philippines

3. AUTHOR(S)

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4. DOCUMENT DATE	5. NUMBER OF PAGES	6. ARC NUMBER
1974	49 p.	ARC RP668.62.H638

7. REFERENCE ORGANIZATION NAME AND ADDRESS

National Fertilizer Development Center, Tennessee Valley Authority
Muscle Shoals, Alabama 35660

8. SUPPLEMENTARY NOTES *(Sponsoring Organization, Publishers, Availability)*

9. ABSTRACT

With worldwide demand of phosphate and nitrogen fertilizers exceeding supply, alternatives to meeting the needs of the Philippines must be found. This report recommends that at least one phosphoric acid plant be built to convert copper smelter, a by-product sulfuric acid to the fertilizer industry. Additional sulfuric acid, obtained by diverting present production from ammonium sulfate, is necessary. The high cost of imported phosphate rock requires that intensive exploration for phosphate deposits be undertaken in the country.

To decrease the nitrogen fertilizer deficit, it is suggested that an ammonia-urea complex be constructed, the importation of liquefied natural gas (ING) be investigated, storage modes and capacities be determined, and for economic reasons, the direct application of ammonia to the soil be continued.

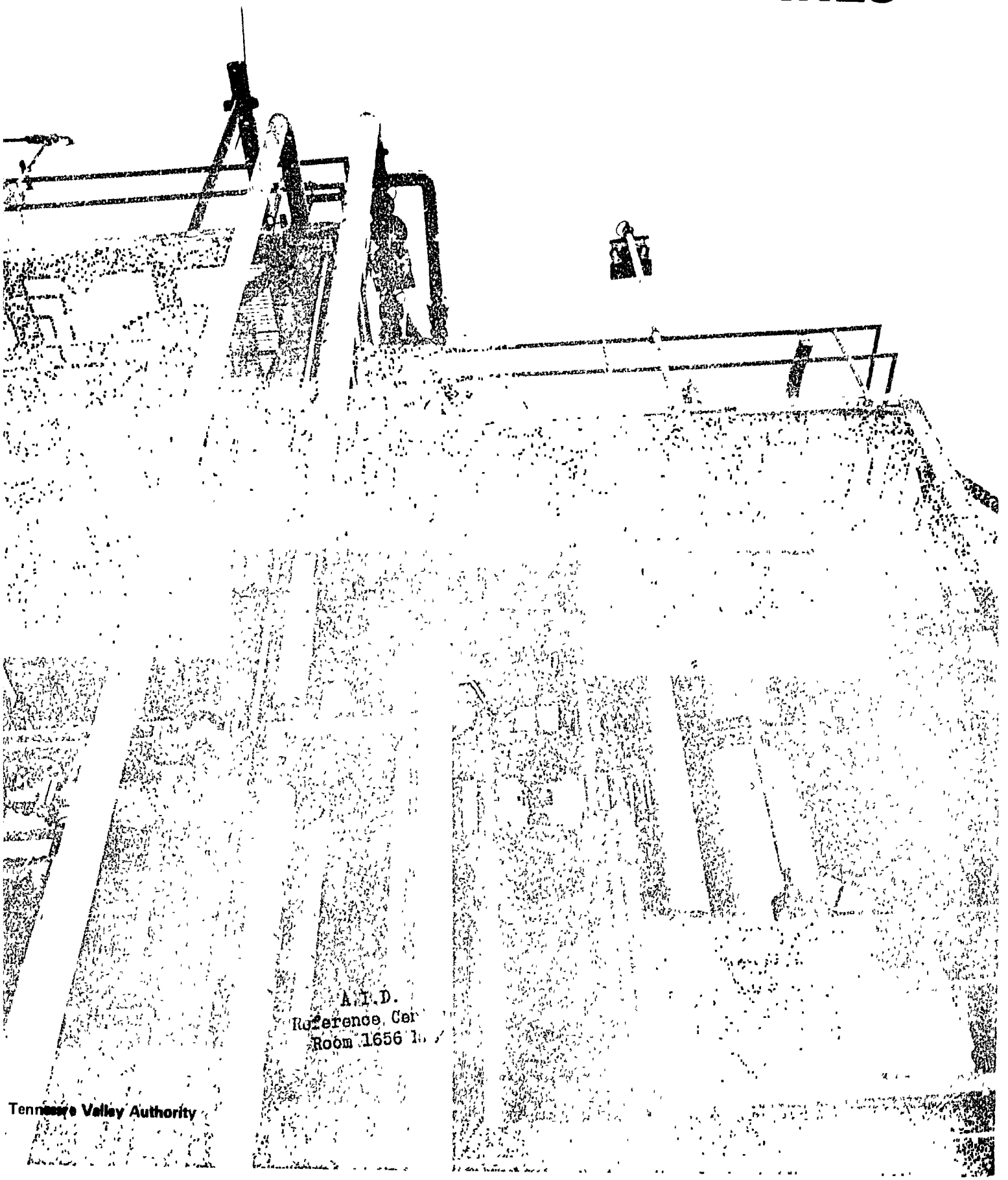
The appendices discuss the feasibility of producing sulfur-coated urea in Southeast Asia, the supply and utilization of phosphate rock in Southeast Asia, and the supply of ING and crude oil available for importation to the Philippines.

10. CONTROL NUMBER	11. PRICE OF DOCUMENT
PN-AAB-476	
12. DESCRIPTORS	13. PROJECT NUMBER
	14. CONTRACT NUMBER: PASA ASIA(QA)-19-74
	15. TYPE OF DOCUMENT

AID 590-1 (4-74)

RP
668.62
H638

Expansion of the Fertilizer Industry in the PHILIPPINES



A.I.D.
Reference Cen
Room 1656 N

Tennessee Valley Authority

FOREWORD

This report was prepared during a 3-week visit to the Philippines, January 10 to February 2, 1974. The authors are employed by the Tennessee Valley Authority (TVA) and were assigned to this work at the request of the U.S. Agency for International Development (USAID) to assist the Philippine Government and the Fertilizer Industry Authority (FIA) to improve capabilities to plan for and provide fertilizer requirements in support of agricultural production goals.

The authors worked with and were assisted by FIA and the Agricultural Development Office of the USAID Mission in Manila. They were assisted by interviews with industry representatives of Lepanto Consolidated Mining Company, Planters Products, Maria Cristina Fertilizer Corporation, and Atlas Fertilizer Company Liberal use was made of data supplied by G. M. Blouin, E. A. Harre, and other employees of TVA, Muscle Shoals, Alabama, and Paul J Stangel, Fertilizer Analyst, TVA, presently on temporary assignment with USAID in Jakarta.

The report is in two parts, dealing with phosphate and nitrogen fertilizers, respectively. In general, F. P. Achorn was responsible for the nitrogen report and T. P. Hignett for the phosphate report. However, the authors worked as a team and each contributed to the other's work.

PASA ASIA(QA)19-74

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SUMMARY

PHOSPHATE FERTILIZERS

Worldwide supply and demand estimates for phosphate fertilizer indicate that the supply-demand ratio will be at a minimum in 1974 and will improve in 1975 to 1977. The adequacy of supplies in 1978 and beyond will depend on future developments.

The estimated demand in four Southeast Asian countries, including the Philippines, will exceed estimated production by 190,000 tons[1] of P_2O_5 in 1974 and the deficit will increase to about 300,000 tons in 1980 unless additional plants beyond those now definitely planned are provided. In the Philippines, the deficit will increase from 33,000 tons in 1974 to 65,000 tons or more in 1980 unless new facilities are provided.

Plans for copper smelter projects, while not firm, would provide 400,000 to 800,000 tons of byproduct sulfuric acid, perhaps by 1977. Additional sulfuric acid for phosphoric acid production might be obtained by diverting present sulfuric acid production from ammonium sulfate if necessary. The prospective supply is sufficient to support at least one large phosphate fertilizer plant (120,000 tons or more of P_2O_5/year) and perhaps two plants with a total output of 270,000 tons of P_2O_5/year

It is recommended that at least one phosphoric acid plant be built as soon as plans for copper smelter projects become sufficiently definite. Final products suggested for initial production are TSP, DAP, and 10-25-25. Total P_2O_5 in these products would amount to 120,000 tons or more/year. Export of TSP or phosphoric acid to nearby countries is suggested. The economics of production is discussed in some detail.

The high cost of phosphate rock delivered to the Philippines is a serious obstacle to economical production of phosphatic fertilizers. The cost may decrease as freight cost becomes more stable and additional supplies of phosphate rock are developed. It is recommended that intensive exploration for phosphate deposits be undertaken in the Philippines and that possible sources of supply in other countries be investigated, particularly those countries that are closer to the Philippines than the U.S.

It is recommended that emphasis be placed on higher analysis products in future planning. Ammonium sulfate should be phased out in favor of urea; 16-20-0 could be replaced by 28-28-0. These steps would decrease the cost of nitrogen fertilizer to the farmer and release more sulfuric acid for phosphate fertilizer production.

[1] All tonnages in this report are stated as metric tons.

NITROGEN FERTILIZERS

A shortage of nitrogen fertilizers has developed in international trade which, in turn, has caused a shortage of these fertilizers in Southeast Asia and the Philippines. World supply and demand data show the world nitrogen deficit could be as high as 6.2 million tons and as low as 1 million tons in 1977. In Southeast Asia it could be as much as a half million tons in 1977. The Philippines deficit is predicted to increase from 140,000 tons this year to about 195,000 tons in 1977. The deficit likely will continue to increase unless additional quantities of nitrogen are imported or produced.

Some suggestions for remedying this problem are as follows:

1. It is recommended that the construction of one ammonia-urea complex be started as soon as possible The supply-demand situation should be evaluated again in 1976; if a world and Philippines deficit continues, construction of another ammonia-urea complex should be started in 1977 Both complexes should have large ammonia plants (1,000 to 1,500 tons/day).

2. Possibly the first ammonia-urea complex could be a joint venture between the Philippines and a natural gas-producing country (Indonesia, Malaysia, Brunei, etc.). This plant should have a capacity of 1,500 tons/day of ammonia; it would be located at the site of the natural gas supply and half of its production should be primarily as urea designated for shipment to the Philippines

3. If these plans do not develop satisfactorily, an ammonia-urea complex should be constructed in the Philippines. The complex should have a capacity of 1,000 tons/day it probably would have to use fuel oil as a feedstock.

4. The possible importation of liquefied natural gas (LNG) for use by several industries should be investigated thoroughly. If the investment cost of the large storage facilities, required because of large ships used to ship LNG, could be shared by several industries (electrical, fertilizer, petro-chemical, etc), ammonia probably could be produced more economically from LNG than from heavy fuel oil or naphtha. The price of natural gas does not seem to be increasing as fast as crudes or heavy fuel oil. Therefore, LNG may be economically feasible for use by several industries in the Philippines.

5. When solid urea facilities are installed it is recommended that granular urea be produced using a pan granulator and the procedures presently being used by TVA. These granules are of larger size (suitable for bulk blending) and have greater crushing strength than prills.

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They probably will have superior storage characteristics to conventional prills.

6. It is recommended that the anhydrous ammonia atmospheric storage tank and terminal being considered by FIA be located at a new phosphoric acid or new ammonia plant location. In this report it was assumed to have a capacity of 14,000 tons. Consideration should be given to installing several smaller tanks in different consuming areas rather than the installing of one large tank at the ammonia plant.

7. If a decision is made to produce ammonia and urea in the Philippines with naphtha or fuel oil as the feedstock, a large plant (1,000 tons/day of ammonia) would be more economical than the small plants being considered (two 180 tons/day and one 800 tons/day units). Even at today's high prices, urea can be imported for about $250/ton. To produce it for this price in a 300 tons/day unit (associated with a 180-ton ammonia plant), naphtha would have to be available at almost no cost (with a 20% ROI). Furthermore, the price of urea could well be less than $250/ton by the time such a plant is built.

8. Some studies should be made concerning bulk and bagged storage of urea, which will be imported or manufactured in the Philippines. Experiences in the U.S. show that dehumidified storage is ideal for storing large piles of urea.

9. Efforts to promote direct application of ammonia should be continued since this is probably the most economical form of nitrogen to the farmer.

APPENDICES

Appendix A discusses the possibility of producing sulfur-coated urea (SCU) in Southeast Asia. SCU is a new controlled-release nitrogen fertilizer that has shown promise for supplying nitrogen more efficiently to rice, sugarcane, pineapple, and some other crops

Appendix B deals with the supply and utilization of phosphate rock in Southeast Asia, including the character and availability of phosphate rock from various sources, the possibilities of direct application of ground rock, and granulation of ground rock with urea or other fertilizer materials

Appendix C deals with the supply of LNG for importation to the Philippines for ammonia production.

Appendix D is an evaluation of crude oil and natural gas supply. This information is presented to show the various potential supplies of crude oil to the Philippines

PLANS FOR EXPANSION OF THE PHOSPHATE INDUSTRY IN THE PHILIPPINES

SUPPLY AND DEMAND FORECASTS

TVA has estimated world consumption of fertilizer P_2O_5 by fertilizer years (July 1-June 30) through 1978 (2). Supply is estimated on the basis of present and announced planned capacity. Since the average production seldom equals the plant capacity, two levels of capacity utilization were used. The "high" level assumes 95% capacity utilization in developed countries and 70% in developing countries. The "low" level assumes 85% and 60%, respectively, which is actually higher than was achieved in most recent years.

Historically, actual production of fertilizers has exceeded consumption by about 4%. The difference is explained by losses in handling, unreported consumption, and miscellaneous other causes. Therefore, the consumption was multiplied by 1.04 to provide a direct comparison of supply with demand. These estimates are shown in table 1. The estimates indicate that the supply-demand ratio will be at a minimum in 1974 and will improve in 1975 and 1976.

It is difficult to explain the present shortage of phosphate fertilizer on the basis of the estimates in table 1. If the supply level is midway between the high and low level, there should be an adequate supply even in 1974. One explanation is that the emphasis on increased grain production has caused an abrupt increase in demand, particularly in the U.S Farmers, expecting a shortage and increased prices, bought fertilizers early and, in some areas, applied them in the fall rather than in the spring. This may have created a temporary shortage. Incomplete data for some states in the U.S. show a 25% increase in the sale of fertilizers for the first few months of the 1974 fertilizer year, as compared with a similar period of 1973. Much of this increase may be caused by farmers switching from spring to fall application. This situation has caused a tight supply in the U.S. and, since the U.S. is the principal phosphate exporter, it has had an effect on the world market and may have induced importing countries to purchase supplies early for stockpiling. If this is the case the shortage may be alleviated in a few months. If not, increased supplies should cure the shortage in a year or two unless the demand substantially exceeds estimates.

Table 1. Estimated world supply and demand of phosphate fertilizer (2)

Year	Supply High[a]	Supply Low[b]	Consumption	Consumption x 1.04	Excess or deficit High	Excess or deficit Low
	(millions of metric tons of P_2O_5)					
1972	24.7	23.2	21.1	21.9	+2.8	+1.3
1973	25 9	24.4	22.4	23.3	+2.6	+1.1
1974	27.5	25.9	23.6	24.5	+3.0	+1.4
1975	29.6	27.8	24.8	25.8	+3.8	+2.0
1976	31.6	29.6	26.1	27.1	+4.5	+2.5
1977	33.7	31.0	27.3	28.4	+4.3	+2.6
1978	34.2	31.6	28.6	29.7	+4.5	+1.9
1979			29.9	31.1		
1980			31.2	32.4		

[a]Based on operation at 95% of capacity in developed nations and 70% in developing areas.
[b]Based on operation at 85% of capacity in developed nations and 60% in developing areas

The fertilizer supply levels of table 1 are not adjusted to take into account the usage of P_2O_5 for nonfertilizer products. Instead it was assumed that nonfertilizer P_2O_5 markets were supplied by electric-furnace phosphorus, and fertilizer P_2O_5 was supplied by wet-process acid, nitric phosphates, superphosphates, and basic slag Since data were not available to pinpoint trends, it was assumed that use of wet-process acid for nonfertilizer products would be offset by fertilizer usage of furnace acid. However, this likely is not the case, fertilizer use of furnace acid has declined, while nonfertilizer use of wet-process acid has increased. The net usage of wet-process phosphoric acid for nonfertilizer products could be as much as 5% to 10% of the fertilizer P_2O_5 supply on a worldwide basis. If so, the supply values of table 1 should be reduced, which would help explain the current shortage.

The principal nonfertilizer uses of phosphates are for detergents and animal feed supplements. The latter use has grown rapidly, and some fertilizer products have found use as animal feed supplement Low-fluorine phosphate products made from wet-process superphosphoric acid have been extensively used for animal feed supplements recently.

Developing Asia as a whole has relied on imports to supply a substantial part of the demand for phosphate fertilizers and this situation is expected to continue. Additional planned facilities should approximately double the 1972 production by 1978. However, the increased production is expected to fall short of supplying the 1978 demand by some 700,000 to 850,000 tons of P_2O_5.

Stangel has estimated the deficit of supply in four Southeast Asian countries as shown in table 2 (5). These estimates indicate an excess of demand over supply of 190,000 tons of P_2O_5 in 1974 increasing to about 300,000 tons in 1980. In the Philippines the excess demand (deficit supply) will increase from 33,000 tons in 1974 to 65,000

Table 2. Trade balance (deficit) of phosphate fertilizer for Asian countries, 1974-1980 (5)

Country	1974	1975	1976	1977	1978	1979	1980
			(1,000 mt P_2O_5)				
Indonesia[a]	79.9	105.4	112.2	53.0[b]	63.7	93.6	120.2
Malaysia[a]	19.3	20.6	22.0	23.4	24.7	26.1	27.4
Thailand[c]	57.7	62.4	67.1	71.8	76.5	81.3	85.9
Philippines[d]	33.2	38.4	43.7	49	54.3	59.6	64.8
Total deficit	**190.1**	**226.2**	**244.8**	**197.2**	**219.2**	**260.6**	**298.3**

[a]Includes 6,000-10,000 mt of phosphate rock used each year by both Indonesia and Malaysia. Concentrated phosphates is not likely to replace phosphate rock in these markets

[b]Indonesia plans to start up a 92,000 mt (P_2O_5)/year TSP plant in 1976.

[c]Does not take into account new granulation facilities now being planned with the Japanese

[d]Includes only existing facilities

tons in 1980 if no new plants are built. These estimates are based on a consumption level of about 105,000 tons, which is lower than that estimated by FIA or Ewell (3), and assumes that production from present plants will be 40,500 tons/year, the level in 1972 and 1973.

It is evident that there is a need for additional phosphate fertilizer production in the Philippines, and that there would be a market for additional phosphates in nearby countries.

RESOURCES AND FACILITIES

Atlas Fertilizer Company has a small phosphoric acid plant rated at 35 tons/day and a single superphosphate facility with a rotary den rated at 15 tons/hour. A granulation unit produces grades such as 12-12-12, 14-14-14, and 16-20-0. Planters Products' facilities include a phosphoric acid plant that operates at about 60 tons of P_2O_5/day and a two-train granulation unit, each rated at 250 tons of product/day. (Single superphosphate facilities at Planters are not in use.) Principal products are 16-20-0 and 14-14-14. Both plants produce sulfuric acid from pyrites and use some of the acid to make ammonium sulfate (ammosul). Some of the ammosul is sold straight and some is used in the granulation plant For various reasons, the phosphate facilities have been operated at less than full capacity. At Planters, lack of ammonia is the principal limiting factor. (The phosphoric acid is fed directly to the granulators together with ammonia to make the desired grades.)

Two copper smelting projects planned in the Philippines will produce byproduct sulfuric acid. Copper ore concentrates currently are shipped to Japan and the U.S. for smelting, but increasing percentages will be smelted in the Philippines in the future. One of these smelters (Atlas) will be located on the island of Cebu near the present Atlas fertilizer plant. Three alternative capacities are under consideration which would produce 225,000, 450,000, or 540,000 tons of sulfuric acid. A decision is expected soon as to which size smelter to build.

Just before leaving the Philippines we were informed that Atlas plans to treat the copper ore by a process that recovers about half of the sulfur content as elemental sulfur and the remainder as sulfuric acid. The planned production will be 230,000 tons of sulfuric acid and 80,000 tons of sulfur/year. Atlas proposes to utilize the sulfuric acid to produce phosphoric acid and phosphate fertilizer, the sulfur would be available for use either to expand the capacity of the proposed plant or to supply another phosphate plant

The planned Lepanto smelter on the west coast of Luzon near Poro Point would produce from 167,000 to 250,000 tons of sulfuric acid. Plans are not firm yet but a decision is expected by mid-1974 with completion of the plant in 1977. An alternative process under consideration is being developed in a pilot plant. It produces elemental sulfur as a byproduct.

At various points, substantial amounts of pyrites are produced as copper ore is concentrated Apparently, much of this material is being used for sulfuric acid production, except for material in relatively inaccessible places Some of the pyrites have high arsenic content which would cause difficulty in sulfuric acid production Complete information as to the amount of usable and accessible pyrites available was not obtained.

Both smelter locations appeared to be suitable for phosphate fertilizer plants insofar as deep-water ports for importing phosphate rock are concerned.

Numerous deposits of phosphate rock have been found in the Philippines, but all are small ranging from a few hundred tons to 40,000 tons Some of these deposits are being mined. However, there is not enough rock in known reserves to supply an appreciable percentage of the Philippines' future needs For the purposes of this report it was assumed that all phosphate rock for proposed plants would be imported It is suggested that intensive exploration be carried out in an effort to locate larger deposits of phosphate rock if there is any reasonable hope of doing so.

ALTERNATIVES OF IMPORTATION VERSUS PRODUCTION

The alternatives open to the Philippines for supplying its phosphate needs are (1) to import phosphate fertilizer materials to meet its increasing needs, (2) to increase production sufficiently to supply needs, or (3) to increase production by more than enough to supply domestic needs with the intention of exporting the surplus to nearby countries.

The general trend in countries having neither sulfur nor phosphate rock is to produce phosphate fertilizer to supply only their own needs—if the needs are sufficient to support an economical scale of operation. Several countries that have either sulfur or phosphate rock are planning to produce phosphate fertilizer materials both for their own needs and for export. For example, Mexico and Iran are exporting phosphoric acid for use as a fertilizer intermediate, using indigenous sulfur resources and imported phosphate rock. Morocco, Algeria, and Israel are exporting phosphate intermediates based on indigenous phosphate rock. The U.S. has both phosphate rock and sulfur and is the largest exporter of phosphates.

Several exporting countries are producing or planning to produce phosphoric acid which may be used in the importing country to make ammonium phosphate or granular NPK fertilizers Another material well-suited for use in granulation plants is nongranular monoammonium phosphate (MAP). Finished fertilizers such as granular triple superphosphate (TSP) or diammonium phosphate (DAP) may be used for direct application or in blended fertilizers or in NPK granulation.

Charlton, Crerar, and Akroyd recently concluded that TSP and MAP are economical materials for export (1). They predicted a growing world market in these materials. Unfortunately, there is no assurance of an adequate supply of any of these materials

Since the estimated demand for phosphate fertilizers should be sufficient to support an economical scale of operation by 1980, and since the Philippines expects to have a supply of byproduct sulfuric acid from copper smelting, it is appropriate to consider plans for production of phosphoric acid for use in fertilizer manufacture.

In general, a minimum economical scale of operation may be about 300 tons of P_2O_5/day or 100,000 tons/year This amount is about equivalent to the estimated fertilizer needs of the Philippines in 1977 or 1978. If full production were obtained by that time, present smaller plants could be shut down or the excess could be exported to nearby countries. There is also a need for detergent phosphates which might be supplied from the proposed plant.

The economics of production of phosphoric acid and phosphate fertilizer in the Philippines as compared with importation are discussed in detail in another section of this report. Economic comparisons are difficult because of the unstable prices of phosphate rock, phosphate fertilizer materials, freight, and the unknown cost of byproduct sulfuric acid. However, if the phosphate rock is imported from the U.S. the cost of phosphoric acid produced in the Philippines will be somewhat higher than the cost of phosphoric acid produced in the U.S. from the same rock at the same price shipped to the Philippines when a 20% ROI is assumed in both cases.

The reason for this differential is mainly freight costs. Freight on 3.37 tons of rock (required for 1 ton of P_2O_5 in acid), at the assumed rate of $30/ton, contributes $101 to the cost of 1 ton of P_2O_5 produced in the Philippines, whereas freight on 1.85 tons of phosphoric acid (54% P_2O_5) at the assumed rate of $40/ton amounts to $74. Thus, there is a $25 differential favoring importation of acid due to freight costs. Another $20 to $25 differential results from the larger scale of operation in the U.S. These factors are partially offset by the cost of clarifying the Florida acid for shipment, by port storage facilities required at the shipping and receiving ports, and by the possibility of low-cost, byproduct sulfuric acid in the Philippines. Even so, the economics of production in the Philippines would be marginal if it can be assumed that phosphoric acid or equivalent phosphate intermediates will be available from the U.S. at the estimated price, an assumption that appears doubtful

A survey of announced plans for exporting phosphoric acid indicates that if all plans are completed, there may be as much as 1.4 million tons of P_2O_5 available for export by 1977 (most of it by 1975) from the following countries:

Mexico	Tunisia	Morocco
USA	Israel	Algeria
France	Iran	Spain

However, most of the production has already been contracted, except in the case of projects that are still indefinite; contract prices delivered in Europe with escalation for the price of phosphate rock have been reported to exceed $300/ton of P_2O_5.

There is no assurance that an adequate supply of phosphoric acid will be available from the U.S. or any other source, and the estimated cost of producing phosphoric acid in the Philippines appears attractive in comparison with present world prices. It is, therefore, recommended that a phosphate fertilizer facility be planned to utilize the byproduct sulfuric acid from either the Atlas or the Lepanto smelters or both. Reinforcing this recommendation is the consideration that alternative use of the sulfuric acid to make ammonium sulfate is unattractive, it produces a low-grade nitrogen product with a high delivered cost per unit of nitrogen. In effect, ammonium sulfate production merely disposes of the sulfuric acid at the expense of the farmer except in cases where sulfur is limiting to plant growth.

Production of phosphoric acid in the Philippines would be more attractive if a more economical source of phosphate rock than Florida could be found. It is recommended that this possibility be investigated, as discussed in a later section of this report (appendix B).

The estimated cost of producing phosphoric acid in the Philippines from imported phosphate rock and imported elemental sulfur is substantially higher than when byproduct sulfuric acid is used, assuming any reasonable price for

the byproduct acid. The investment cost for a sulfuric acid plant to supply a 300-tons/day phosphoric acid plant would be about $10 million including auxiliary facilities. The estimated cost of sulfuric acid from imported sulfur is about $35/ton (including 20% ROI), assuming sulfur at $60/ton (including freight cost of $30).

TECHNOLOGY OF PHOSPHORIC ACID PRODUCTION

Several proven processes for manufacture of phosphoric acid are available. No attempt will be made to enumerate all of them or to describe any of them in detail. However, a brief summary of advantages and disadvantages of a few of the leading processes may be in order.

Most modern plants use some modification of a "standard" dihydrate process, sometimes called the Prayon process, although various modifications of the original Prayon process have been developed by engineering firms. A recent improvement is wet grinding of the phosphate rock in a ball mill; the ground rock is fed to the process as a slurry. Wet grinding has the following advantages wet rock can be used without drying, the electric power consumption is said to be 30%-40% less than with dry grinding, and dust losses and air pollution due to dust are eliminated.

Strong sulfuric acid (98%) can be used in the modified Prayon process without dilution, this is also true of several other processes. The process is said to be readily adaptable to a large variety of phosphate rocks including low grade rocks (64-68 BPL), and high carbonate rocks which cause foaming. Process control is said to be relatively simple The phosphoric acid is produced at a concentration of 28% to 31% P_2O_5. Dihydrate plants of this type are offered by Davy Power Gas, Dorr-Oliver, and other contractors

The "isothermal process" offered by Gulf Design Company is a dihydrate process that has the advantage that grinding of the rock is not required although crushing may be required if the rock contains large lumps. One large plant in Florida is operating on unground flotation concentrates using this process. Elimination of grinding lowers both investment and operating cost. The process employs a single reaction vessel with a single agitator, which simplifies the equipment. The vessel is operated under vacuum (reduced pressure) to control the temperature by evaporation, and the circulation pattern is such that temperature control within 0.3°C is attained. It is claimed that scaling problems are eliminated. A possible disadvantage is that there has been less experience with a wide variety of phosphate rocks. Also operation with coarse rock may require unusually close control of the free H_2SO_4 content of the liquid phase.

The Kellogg-Lopker process employs a novel two-tank reaction system. Advantages claimed are similar to those of the isothermal process: use of coarse rock, simplification of the reaction system, and optimization of gypsum crystallization. As only one commercial-scale plant is known to be operating (a 240-ton/day plant in England), experience with a variety of rocks probably is limited.

The Fisons two-stage hemihydrate process has the advantage that it produces phosphoric acid at a concentration of 50% P_2O_5 or higher, thus eliminating the need for further concentration for most purposes. It also utilizes coarse rock and produces a sludge-free acid, eliminating any need for clarification. The calcium sulfate is initially formed as hemihydrate, $CaSO_4 \cdot \frac{1}{2}H_2O$, and after filtration it is recrystallized to gypsum, $CaSO_4 \cdot 2H_2O$. This procedure increases the P_2O_5 recovery and produces an unusually pure gypsum which may be used for plaster, wallboard, or cement additive. Eliminating the concentration step may be an important advantage when byproduct sulfuric acid is used, as steam for concentration would not be available from the burning of sulfur Also the high recovery would be particularly important when delivered price of phosphate rock is high. One commercial plant is in operation in the Netherlands (60,000 tons of P_2O_5/year) and another is under construction in Yugoslavia Limited experience with a variety of phosphate rocks is a disadvantage. Hemihydrate processes operate at a higher temperature than dihydrate, which may increase corrosion rates The filtration section of a two-stage hemihydrate process is more expensive than in a single-stage dihydrate process, but the overall cost of the plant is claimed to be less than a dihydrate plant employing acid concentration

Several other processes employ double crystallization (hemihydrate-dihydrate) to improve recovery and produce purer gypsum. One of these is the Nissan process (Japan) in which the recrystallization is carried out without an intermediate filtration. This process produces phosphoric acid of the usual concentration (about 30% P_2O_5). Other processes using double crystallization include the Dorr-Oliver HYS process (used in Finland) and the Singmaster-Breyer process which is under development in France.

ECONOMICS OF PHOSPHORIC ACID PRODUCTION IN THE PHILIPPINES

For the purposes of the present evaluation it will be assumed that the standard dihydrate process will be used in the Philippines, because of the wide experience with this process. However, the newer processes should be considered and a decision reached based on prospective costs and the experience and reliability of the contractor.

It will be assumed that Florida rock of 33.0% P_2O_5 content (72 BPL) will be used, although the plant should be capable of using any commercial rock, and an active search for a less expensive source is recommended.

The assumed overall recovery of P_2O_5 in phosphoric acid is 90% of that in the rock purchased. Most engineering contractors will claim and guarantee higher recovery. However, experience indicates that the average recovery seldom exceeds 90%. Actual filter cake losses usually range from 4% to 1.5% depending on the process, during periods of well-controlled operation. However, additional losses occur due to losses of phosphate rock in grinding and handling, upsets in plant operation, leakage, spillage, sludge, mist carryover, and miscellaneous causes. Provision should be made to collect leakage from pumps, water from washing pipes and equipment, and other points for return to the process.

It is assumed that a plant will be located adjacent to a copper smelter. The assumed price of the sulfuric acid is $15/ton (100% H_2SO_4 basis). No price has been established. Generally, smelter plants sell byproduct acid at whatever price is necessary to insure disposal. A smelter plant in eastern Tennessee sells acid at about $10/ton plus freight with shipment over about 300-mile radius. Smelters in Arizona are being forced to recover acid to prevent atmospheric pollution; the value of the acid is zero or even negative as there is no market within economic shipping distance Other smelters in western U.S. have induced phosphate fertilizer manufacturers to build plants nearby to utilize byproduct acid, presumably at an attractive price Some Canadian smelters have built their own fertilizer plants.

Phosphate rock cost was assumed to be $20/ton plus $30 freight from Florida. This assumption may seem optimistic at present, but it seems likely that costs may decline when shortages of rock and fuel are alleviated.

Investment Costs

The investment cost for a typical battery-limits phosphoric acid plant located in the U.S. or Europe with a capacity of 300 tons of P_2O_5/day is shown in table 3.

Obviously the investment cost may vary considerably depending on local conditions and other factors that are discussed below. Also, total cost would be considerably higher than the battery limits cost.

ROCK UNLOADING

The cost of unloading the rock to storage is not included in table 3. Rock imported to the Philippines will arrive by ship; the cost of unloading and transport to storage will depend on port facilities and relative location of port and acid plant.

Table 3. Typical capital investment for phosphoric acid production in U.S.A. or European locations
300 mt/day (P_2O_5) = about 100,000 mt/year as 54% P_2O_5 phosphoric acid.

Battery limits cost[a]

Section	Cost US $1,000
Rock storage	330
Rock grinding	1,200
Reaction and filtration	3,500
Acid concentration	1,100
Clarification	530
Gypsum disposal and scrubber pond	740
Total	**7,400**
Phosphoric acid storage[b]	1,300
Sulfuric acid production[c]	5,200

[a]Auxiliary and supporting facilities may range from 50% to 75% of battery limits costs
[b]Storage facilities for 30,000 tons of acid for ocean shipment
[c]Facilities for producing 850 tons H_2SO_4/day from elemental sulfur including sulfur storage

ROCK STORAGE

If the rock is received dry and dry grinding is used, it would be desirable to store the rock in a building or shed to protect it from rainfall. The investment in table 3 provides for protected storage for 20,000 tons of rock. This may or may not be sufficient depending on the size and reliability of shipments. Some types of rock can be stored in the open, which would reduce storage costs. If dry grinding is used, the rock would have to be dried. Drying facilities are not included in the present estimate.

ROCK GRINDING

The principal choices are dry grinding, wet grinding, and no grinding. Wet grinding, which is planned in some U.S. plants, is said to be less expensive than dry grinding. Grinding costs also vary with size and hardness of rock. For instance, Morocco rock is softer and easier to grind than Florida rock. Rock from Queensland, Australia, probably will be fine enough to use without grinding. Some processes will accept rock without grinding although crushing of any material coarser than about 1 mm is necessary. Obviously, elimination of grinding would be desirable, but successful use of unground rock is said to require more precise control of conditions in the reaction step.

REACTION AND FILTRATION

The cost of the reaction and filtration step varies with the process, kind of rock, and desired recovery efficiency. The present estimate is based on data for Morocco rock which is said to require more filtration area than Florida rock. Most systems can be operated at increased capacity at the expense of lower recovery. If the rock contains appreciable percentages of chloride, it would be desirable to use metal more corrosion-resistant than stainless steel (316 or 317) which would increase the investment cost. Alternatively it may be desirable to install facilities to wash the rock to remove chlorides which are usually present as soluble salts.

CONCENTRATION

The phosphoric acid is usually produced at a concentration of 30% P_2O_5 and concentrated in vacuum steam evaporators to 54% P_2O_5. Steam for this purpose is supplied from the sulfuric acid plant, utilizing the heat from burning the sulfur or pyrites. When byproduct steam is not available, evaporation by submerged combustion is a possibility, but this method has fallen into disfavor because of pollution problems and P_2O_5 losses.

Some processes can produce acid of 50% P_2O_5 concentration directly without an evaporation step. This concentration may be sufficient for ammonium phosphate production or shipping. Elimination of the concentration step is an economic advantage but may be at least partially offset by increased cost in the reaction-filtration step.

CLARIFICATION

Most acids deposit sludge on standing due to post-precipitation; clarification is required if the acid is to be shipped. The amount of sludge and hence the need for clarification depends to some extent on the amount and character of the phosphate rock. Many plants clarify part of the acid for shipment or for DAP production and utilize the sludge-laden residual acid for TSP production.

STORAGE

The amount of acid storage required depends on whether the acid is to be shipped and, if so, in what size ships. If the acid is not shipped, only a few days surge storage may be needed to permit continued operation of downstream plants during the delays in acid production. When the final product is TSP, DAP, or other finished fertilizer, storage requirements are shifted to these products.

GYPSUM DISPOSAL

Gypsum may be disposed of in ponds or by dissolution in sea water. Most plants located near the sea utilize the latter method. Care must be used to prevent accumulation in harbors or estuaries In some cases the gypsum slurry may be pumped far enough out to sea to a point where wave action will dissolve it Another method is to transport the gypsum to deep water by barge. A third method is to pump sea water to the plant to dissolve the gypsum and discharge the solution into the sea. About 100 tons of sea water is required to dissolve one ton of gypsum.

If there is a market for gypsum for cement additive, wallboard, or plaster, special treatment is usually required to render it suitable for these purposes Small amounts of gypsum may be incorporated in fertilizer as a filler, granulation aid, or to supply sulfur needs of crops. Gypsum may be used to make ammonium sulfate by reaction with ammonia and carbon dioxide This is done in India, Austria, and some other countries Calcium carbonate is a byproduct of this reaction.

Figure 1 and table 4 show the estimated total investment cost for phosphoric acid plants of capacities ranging from 100 to 900 tons of P_2O_5/day for a location in the Philippines. These estimates are based on information received from several U S. contractors in December 1973. The U.S. investment cost was multiplied by a factor of 1.25 because of the assumed higher cost of construction in the Philippines. Perhaps this assumption is conservative Construction costs have risen sharply in the U.S. because of stringent pollution control regulations. If less stringent standards are acceptable in the Philippines some reduction in cost is possible. Also construction costs in the Philippines may be less than in some developing countries.

Table 4. Investment cost for phosphoric acid production facilities as related to scale of operation for a Philippine location

Capacity tons P_2O_5/day	100	200	300	600	900
	US $ million				
U.S. battery limits cost	5.0	6.3	7.4	10.4	13.1
Battery limits x 1.25[a]	6.2	7.8	9.3	12.9	16.4
Auxiliary and support facilities[b]	3.5	4.4	5.2	7.3	9.2
Total investment	**9.7**	**12.2**	**14.5**	**20.2**	**25.6**

[a] To cover assumed higher construction costs in developing country.
[b] 56.25% of battery limits cost.

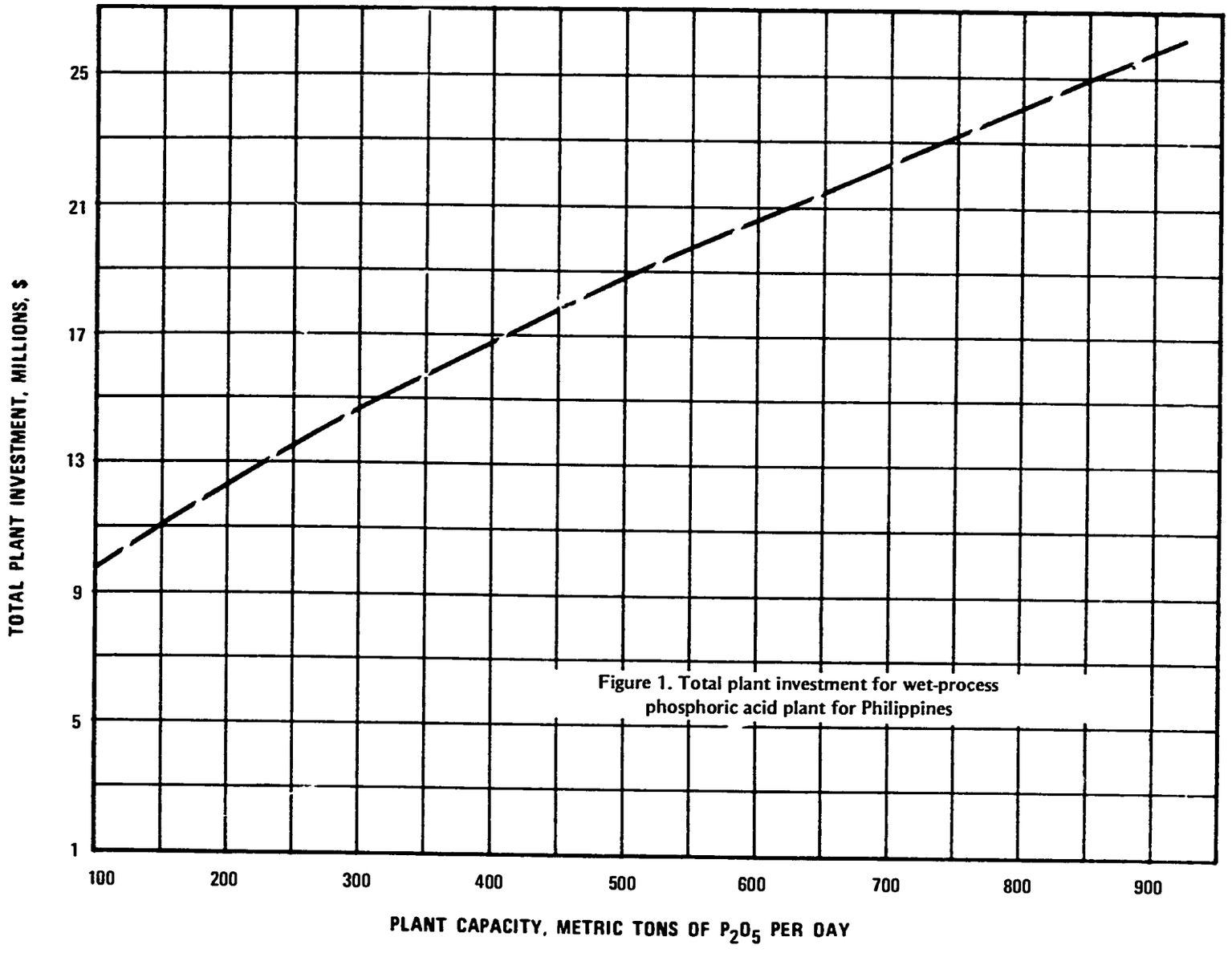

Figure 1. Total plant investment for wet-process phosphoric acid plant for Philippines

Table 5. Estimated cost of production of phosphoric acid in the Philippines

Capacity tons P_2O_5/day	100	200	300	600	900
M tons P_2O_5/year	33	66	99	198	297
Plant investment, $ million	9.7	12.2	14.5	20.2	25.6
Working capital, $ million	1.4	2.4	3.5	6.3	9.1
Total investment, $ million	11.1	14.6	18.0	26.5	34.7
	Production cost, $/ton of P_2O_5 in phosphoric acid				
Phosphate rock,[a] 3.37 tons x $50	168.50				
Sulfuric acid,[b] 2.92 tons x $15	43.80				
Subtotal	212.30				
Water[c]	0.20	0.20	0.20	0.20	0.20
Steam, 4,600 lb x $1/1,000 lb	4.60	4.60	4.60	4.60	4.60
Electricity, 200 kWh x $0.015	3.00	3.00	3.00	3.00	3.00
Operating supplies[d]	1.50	1.50	1.50	1.50	1.50
Operating labor[e]	5.46	2.73	1.83	0.92	0.61
Maintenance (5% of P.I.)	14.70	9.25	7.32	5.10	4.30
Taxes and insurance (2% of P.I.)	5.88	3.70	2.93	2.04	1.72
Analyses (20% of labor)	1.09	0.54	0.36	0.18	0.12
Depreciation 15 years (6.67% of P.I.)	19.60	12.33	9.76	6.80	5.73
Interest (8% of 1/2 of P.I.)	11.76	7.40	5.86	4.08	3.44
Supervision and overhead (100% of labor)	5.46	2.73	1.83	0.92	0.61
Subtotal	73.25	47.98	39.19	29.34	25.93
Total	**285.25**	**260.28**	**251.49**	**241.64**	**238.13**
Interest on working capital, 8%	3.39	2.91	2.82	2.55	2.45
Total production cost	288.64	263.19	254.31	244.19	240.58
10% ROI	33.64	22.12	18.18	13.38	11.68
20% ROI	67.28	44.24	36.36	26.76	23.36
Total including 20% ROI	355.92	307.43	290.67	270.95	263.94

[a]Based on 33.0% P_2O_5 in rock and 90% overall recovery
[b]Based on 49.5% CaO in rock (1.5 x % P_2O_5 in rock)
[c]Includes cooling and scrubber water (recirculated) and fresh water.
[d]Includes antifoam chemicals, limestone for neutralizing scrubber liquor, and miscellaneous supplies
[e]36,300 man-hours/year = $181,500/year

PRODUCTION COST OF PHOSPHORIC ACID

The estimated cost of production of phosphoric acid in the Philippines for plants of various capacities in the range of 100 to 900 tons of P_2O_5/day is shown in table 5 and figure 2. As mentioned previously, the assumed delivered cost of phosphate rock is $50/ton and the assumed price of byproduct sulfuric acid is $15/ton.

It was assumed that the plant would be located adjacent to the smelter so that transportation of the acid would not be necessary. The tentative plans for the smelters indicate that there may be enough byproduct acid to supply a plant of approximately 300 tons of P_2O_5/day capacity at either the Atlas or Lepanto projects. The supply at Atlas may be enough for nearly 600 tons/day. At the Atlas location there is now substantial production of sulfuric acid from pyrites which is being used in a small phosphoric acid plant, a superphosphate plant, and an ammonium sulfate plant. Presumably this acid could be used to supplement the byproduct acid if necessary by closing the small phosphoric acid plant and phasing out ammonium sulfate production in favor of urea. No economical source of supplemental acid is in view at Lepanto. The byproduct acid from Lepanto could be transported to another site (such as Planters Products Co.) where additional acid and certain fertilizer facilities are available. This and other possibilities should be considered.

The three alternative scales of smelter operation at Atlas would produce enough byproduct sulfuric acid to make 72,000, 154,000, and 185,000 tons of P_2O_5/year, respectively, corresponding to 218, 467, and 560 tons of P_2O_5/day if operated at full capacity. Since operation at full capacity may not be attainable it is suggested that the plants be built with excess capacity; assuming 80% capacity operation, the

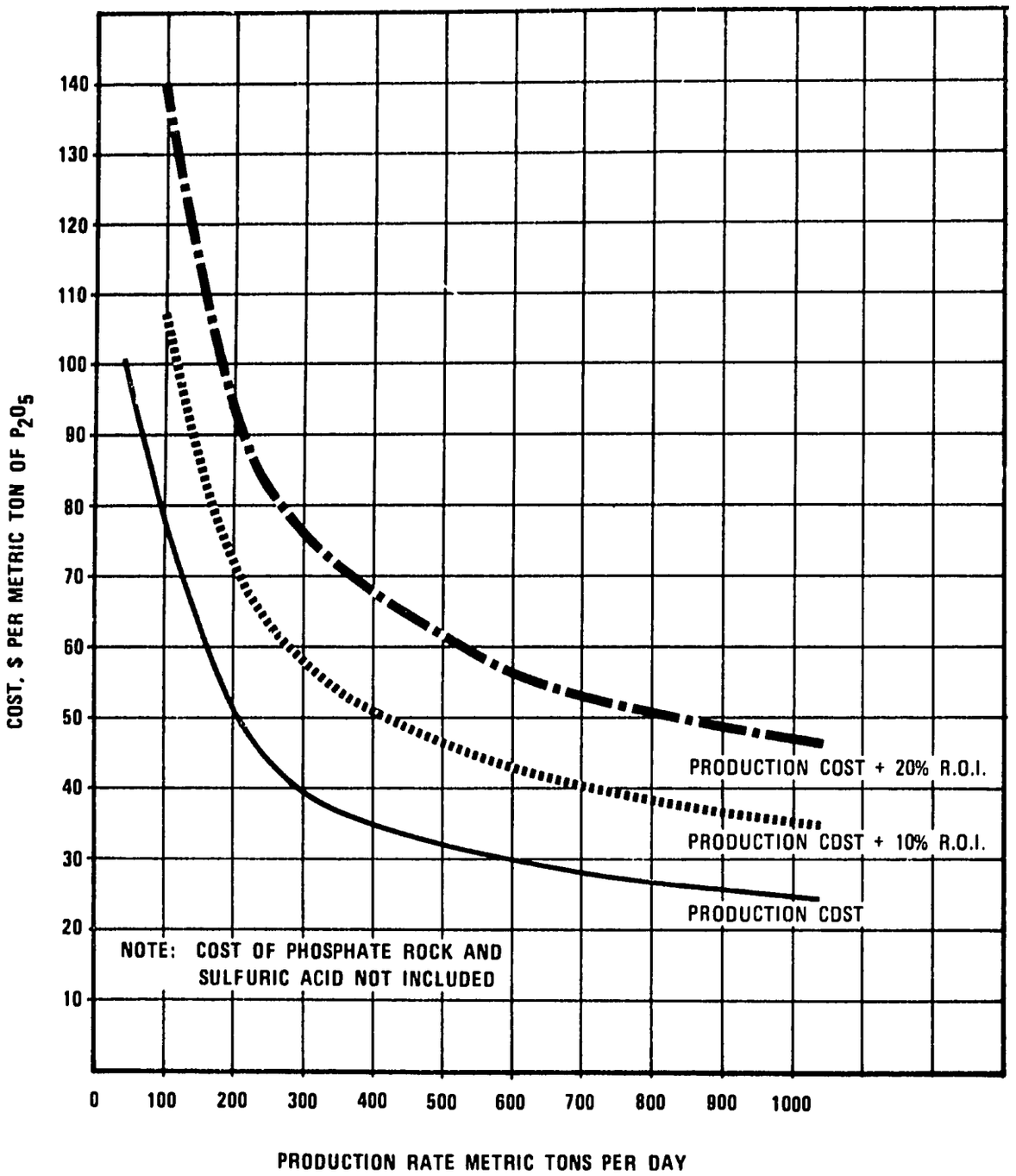

Figure 2. Operating costs and return on investment for phosphoric acid plants as affected by scale of operation

plants should be sized 272, 600, or 700 tons of P_2O_5/day. In the case of the smaller plant, it is suggested the capacity be increased to 300 tons/day with the intention of using supplemental sulfuric acid from present facilities (from pyrites).

The range of byproduct acid output at the proposed Lepanto smelter would correspond to 57,000 to 86,000 tons of P_2O_5/year, equivalent to 173 to 262 tons/day. If there is a possibility of future expansion of smelter operations or supplemental sulfuric acid from pyrites, the scale should be increased accordingly. If sulfur will be produced as a byproduct, it might be shipped to another location, such as Planters Products or Chemphil, where additional sulfuric acid may be available.

Figure 2 shows that the cost per ton of P_2O_5 decreases sharply with increased scale of operation in the range of 100 to 300 tons/day and more gradually in the range of 300 to 900 tons/day. For purposes of the present report it is assumed that proposed plants will have a capacity of about 300 tons/day for the following reasons: (1) this capacity would approximately supply the needs of the Philippines up to 1980, (2) the amount of byproduct sulfuric acid available at any one location may not be sufficient for a larger plant; and (3) a smaller plant would be at an economic disadvantage. When the quantity of byproduct acid has been definitely decided more definite plans can be made.

Figure 3 shows the costs of production (including 20% ROI) at a production rate of 300 tons of P_2O_5/day as affected by the cost of phosphate rock and sulfuric acid. The dominant effect of the cost of rock is evident. A later section of the report suggests some alternate sources of rock that might be cheaper

Operation of the plant at less than full capacity would increase the cost of the product. Rough calculations indicate that the cost would be affected by the percentage capacity utilization as follows:

% capacity utilization	Tons of P_2O_5/year	Cost + 20% ROI $/mt P_2O_5
100	99,000	291
80	79,200	308
60	59,400	337

Full capacity annual production is considered to be 330 times the rated daily capacity. As mentioned previously, it is quite possible to operate phosphoric acid plants at substantially above rated capacity, but usually at the expense of lower recovery.

A rough calculation was made of the cost of producing phosphoric acid from imported sulfur and phosphate rock. The assumed cost of sulfur was $60/ton delivered in the Philippines. The estimated cost of sulfuric acid produced from sulfur was $35.15/ton of H_2SO_4. The estimated cost of phosphoric acid for 200 and 300 tons of P_2O_5/day capacity follow:

Plant capacity tons P_2O_5/day	Cost + 20% ROI $/mt P_2O_5
200	357
300	340

To assess the comparative economics of production of phosphoric acid in Florida and shipment of the acid to the Philippines, a rough calculation was made based on phosphate rock at $20/ton and sulfur at a delivered cost of $39/ton including freight, unloading, and storage. The assumed scale of operation was 600 tons P_2O_5/day with shipment of 100,000 tons/year to the Philippines. The results of the calculation follow:

	$/ton P_2O_5
Cost + 20% ROI at Florida plant	180.24
Florida port storage cost[a]	3.86
Loading for shipment	1.00
Sales cost	1.50
Freight to Philippines $40 x 1 85 tons	74.00
Sludge losses (1%)	2.60
Unloading	1 00
Port storage and handling in Philippines[a]	7.76
	271.96

[a]Includes 20% ROI on facilities cost and working capital for 30,000 tons of 54% P_2O_5 acid storage

The estimated cost of imported phosphoric acid is about $272/ton of P_2O_5, about $18 less than the cost of acid produced in the Philippines However, there is no assurance that acid from Florida will be available in the desired quantity or at the estimated price Current world prices for imported phosphoric acid are substantially higher than the calculated value, perhaps because much of it is based on higher priced rock, and because most of the producing points use imported rock or imported sulfur.

PRODUCTION COST OF PHOSPHATE FERTILIZERS IN THE PHILIPPINES

Phosphoric acid produced in the proposed plant could be shipped as such to other points in the Philippines or to other countries or converted to finished products or intermediates. For the pu pose of the present report it will be assumed that a multipurpose granulation plant will be provided that will be capable of producing granular triple superphosphate, 0-46-0 (TSP); granular diammonium phosphate, 18-46-0 (DAP), granular monoammonium

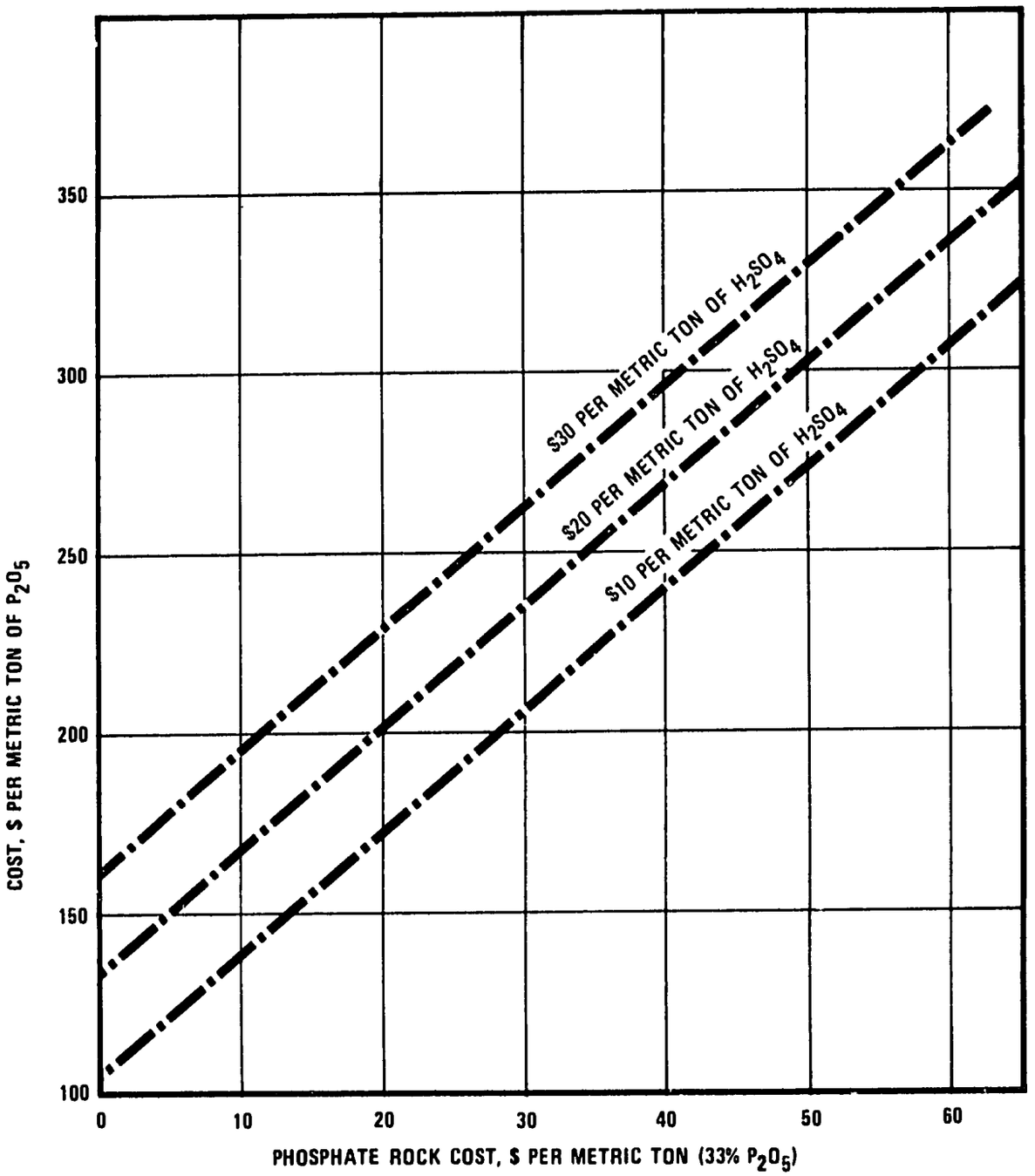

Figure 3. Effect of phosphate rock and sulfuric acid costs on cost of phosphoric acid (300 mt/day of P_2O_5 ROI)

phosphate, 11-55-0 (MAP); or, by addition of potash, NPK grades such as 10-25-25. It may be desirable to produce in a separate facility nongranular MAP for shipment to other granulation plants. DAP or 10-25-25 can be bulk blended with urea to produce other grades such as 28-28-0 or 19-19-19. The blending could be done in small mixing plants in market areas. TSP is not suitable for blending with urea unless it is ammoniated, which can be done in the proposed granulation facility. It should be noted that TSP production results in increased fertilizer P_2O_5 production; 1 ton of P_2O_5 from phosphoric acid produces about 1.43 tons of fertilizer P_2O_5 in TSP. Finely ground rock is required for TSP production; thus, if fine grinding is used for acid production, additional capacity will be needed to supply ground rock for TSP production. If the acid production section utilizes coarse rock or wet-grinding of rock, a separate dry grinding unit would be required to prepare rock for TSP production.

For purposes of cost estimation it is assumed that half of the phosphoric acid is used to make TSP, one-quarter to make 18-46-0, and one-quarter to make 10-25-25. This is not a recommendation; the actual product mix could be determined by domestic and export demand. According to the assumed mix, the annual tonnage at full capacity would be.

Product	P_2O_5 from phos. acid	P_2O_5 from phos. rock	Total fert. P_2O_5	Wt of product
TSP	49,000	21,000	70,000	152,000
DAP	25,000	–	25,000	54,000
10-25-25	25,000	--	25,000	100,000
Total	**99,000**	**–**	**120,000**	**306,000**

The required capacity of the granulation facility would be about 1,000 tons/day. The cost of raw materials for 1 ton of TSP is estimated as follows:

P_2O_5 from phos. acid	0.322 tons x $291	$ 93.70
P_2O_5 from phos. rock	0.138 tons	
At 93% conversion	0.448 tons of rock x $50	22.40
2% loss		2.32
Total		$118.42

The capital investment cost is roughly estimated as follows:

Ammonia storage (6,000 tons)	$1.2 million
Granulation plant	4.8
Bulk & bagged storage (30,000 tons)	0.8
Bagging and other auxiliary facilities	1.3
Total	$8.1 million

The operating cost is estimated to be about $6/ton of product and a 20% ROI would amount to $5.20/ton of product.

The total cost of bulk TSP in storage would be $118.42 + $11.20 = $129.62. For bagged product there would be an additional cost of about $12.00, bringing the total to $141.62

The raw material cost of DAP would be:

0.22 tons of NH_3 x $165	$ 36.30
0.46 tons of acid P_2O_5 x $291	133.86
2% loss	3.40
Total	$173.56

Thus the cost of 18-46-0 would be $184.76 in bulk or $196.76 in bags.

The raw material cost for 10-25-25 would be.

Ammonia	0.121 tons x $165	$ 19.97
Acid P_2O_5	0.250 tons x $291	72.50
KCl (60% K_2O)	0.4167 tons x $66	27.50
2% loss		2.40
Total		$122.37

The total cost of 10-25-25 in storage would be $133.57/ton in bulk or $145.57 in bags.

Rather than to convert all of the phosphoric acid into granular products, it may be desirable to ship some of the acid to other plants or for export However the cost of port storage at dispatching and receiving ports is likely to be high in relation to the relatively small throughput, and the special ships needed for transport of acid may not be readily available Another alternative would be to ship nongranular MAP in bulk. Several processes are available for making powdered MAP; the processes are relatively simple and the equipment is inexpensive

Powdered MAP is a good material for use in granulation plants. It may be used together with urea or ammonium sulfate, sulfuric acid and ammonia, and potash salt to make a variety of NP and NPK. During the granulation the MAP may be converted at least partially to diammonium phosphate by ammonia addition The use of MAP in granulation plants usually decreases the recycle ratio and thereby increases the output

MAP may be stored in bulk and shipped in bulk in ordinary ships or barges in contrast with phosphoric acid which requires special storage and shipping facilities.

Various other products may be considered for manufacture in the proposed plant The multipurpose granulation plant could be adapted to production of ammonium polyphosphate (APP) and urea ammonium polyphosphate (UAP). These materials are now being made by TVA. UAP grades include 25-35-0, 28-28-0, and 36-18-0. APP and UAP are also useful for making liquid fertilizer.

PROSPECTIVE SOURCES OF PHOSPHATE ROCK

The high cost of phosphate rock delivered in the Philippines is a serious obstacle to economical production of phosphate fertilizer. Therefore, there is a need to locate a lower cost source. The nearest commercial deposits are in Nauru and Christmas Islands, Australia, and North Vietnam. The output of Nauru and Christmas Islands is limited, and it is understood that other nations have contracted for it. The Queensland deposit in Australia is under development and production is expected to be available for export. Tests have shown that it is suitable for phosphoric acid production. This seems to be a promising possibility. There are large deposits of phosphate rock in Peru which are not being mined. Perhaps the present high prices will stimulate development, which has been under consideration for several years. It has been rumored that one problem with the Peruvian deposit is the presence of chlorides (salt) which causes severe corrosion in phosphoric acid plants. The chlorides can be removed by washing with fresh water, but no fresh water is available near the Peruvian deposits Perhaps the phosphate could be washed for chloride removal in the Philippines We understand that there is a similar problem with Jordanian phosphate, which is being mined and marketed. It is offered at a lower price than some competing phosphates, but several users have experienced severe corrosion when using it. Phosphate rock from Israel has been reported to contain excessive chloride in some cases Jordan and Israel export rock from Red Sea ports and are, therefore, in better position to supply the Philippines than North African countries. Some phosphate rock may be available from South Africa This rock (apatite) is being used in South Africa, and some excess may be available for export Large deposits of high-grade phosphate rock have been found in Angola, but plans for exploiting them are indefinite. It is expected that the present high price of phosphate rock will encourage increased mining development in many countries with the result that an oversupply may develop in 2 or 3 years and the price may decrease. However, it is not likely that the price will return to former level

RECOMMENDED PROGRAM

It is recommended that at least one phosphoric acid plant of at least 100,000 tons P_2O_5/year capacity be built in the Philippines to utilize byproduct sulfuric acid from planned copper smelting operations. If the supply of acid is sufficient, it is recommended that a larger plant or two plants be built Planning should go forward as rapidly as possible depending on firm decisions regarding the copper smelting. The Atlas location has the advantage that fertilizer facilities are available and supplemental sulfuric acid from pyrites could be made available if the amount of byproduct acid is insufficient. Sulfuric acid now used for ammonium sulfate production could better be used for phosphoric acid, and ammonium sulfate should be replaced by urea which is less expensive per unit of nitrogen. Likewise NPK grades containing ammonium sulfate might be replaced by urea-containing grades except where sulfur in fertilizers is agronomically desirable.

Recommended products are TSP, DAP, and DAP-based grades, such as 10-25-25. These materials can be used for direct application or blended with granular urea TSP might be a useful product for export to Indonesia or other nearby countries Production of powdered MAP for shipment to other granulation plants or for export should be considered if there appears to be a need for it.

The location of the first large phosphate plant would be determined by the development of plans for the smelter projects. Since neither of the plans is definite, either as to timing or amount of byproduct acid (or sulfur), no decision is possible at present. When smelter plans become firm, it will be necessary to move ahead rapidly so that phosphoric acid facilities will be completed by the time that byproduct sulfuric acid is available. In the meantime preliminary planning can proceed, including a search for an economical source of phosphate rock

If both smelter projects become realities, it may be worthwhile considering two large phosphate plants. The resulting production would be considerably in excess of domestic needs for the present decade, but there should be a ready market for the products in nearby countries. The location of a plant to utilize byproduct acid or sulfur from the Lepanto project might depend on whether the product is acid or sulfur, on the cost of transporting the byproduct to alternate locations, the quantity of the byproduct, and the facilities available at the smelter site and at alternate locations.

SHORT RANGE CONSIDERATIONS

Until the proposed new plant is built, there will be a need for temporary measures to alleviate the shortage. More complete utilization of existing facilities would help, since according to Ewell, they are operated at only 67% of capacity. At Planters, shortage of ammonia was identified as a limiting factor, and steps are being taken to improve this situation. Shortage and high price of phosphate rock is another difficulty. It is recommended that use of lower grade rock than the 77 to 75 BPL presently specified be considered.

A program is under way to accelerate the mining of indigenous phosphate rock and guano which occurs in many small deposits. The guano may be used for direct

application, and the rock may be used either for direct application or for superphosphate or for phosphoric acid production. Factors affecting the suitability of phosphate rock for direct application or for processing have been discussed with FIA and the Bureau of Mines.

There may be some calcined aluminum phosphate ore, "Citraphos," available from Christmas Island. This material is said to be suitable for direct application on some crops. Unlike raw phosphate rock, its effectiveness does not depend on acidity of the soil.

It may be desirable to purchase powdered MAP for use in granulation plants This material may be available from Conserv in the U.S. or perhaps from plants in Australia, Japan, or Spain. Possibly finished phosphate or NPK fertilizers could be purchased from Japan or Australia. The cost may be high but it may be justified by the food needs

THE PROBLEM OF SUPPLYING NITROGEN FERTILIZERS

A shortage of nitrogen fertilizers has developed in international trade, which has, in turn, caused shortages of these fertilizers in the Philippines and in the Southeast Asia region. Some of the reasons for this shortage are:

1. Very little capacity has been added recently in North America, Western Europe, and Japan, the normal sources of nitrogen entering world trade Domestic demand has increased in these areas, leaving less product available for export.

2. Shortages of feedstock–interruption in natural gas supply and shortages of naphtha and other petroleum-derived feedstocks–have prevented operation of some plants at a high percentage of capacity.

3. Increased use of urea and other nitrogen compounds for animal feed supplement has decreased the fertilizer supply.

4. Planned expansion in developing countries has not come on-stream as rapidly as planned and those plants that are in opeartion on the average operate at a low percentage of capacity due to a variety of reasons, including feedstocks shortages.

Assessment of the world supply-demand situation for the period 1974-1978 indicates that shortages will continue and may become more severe unless some of the above difficulties can be corrected. Little expansion of production has been announced for Western Europe, Japan, and the United States, but several new plants were announced recently for Canada. Substantial additions are planned in Eastern Europe, USSR, and Mainland China, which may provide some nitrogen for export. Lesser amounts are being considered in Indonesia, India, and South Korea. However, domestic demand in these regions is also expected to increase rapidly. Continued shortages of feedstocks in many countries will limit production, especially for plants that must import hydrocarbons.

Table 6 shows the estimated world supply-demand relationship for fertilizer nitrogen from 1972 through 1978. In estimating future supplies, announced new facilities are included only when plans are sufficiently advanced to indicate a completion date. For this reason, supply estimates beyond 1977 are well below probable levels, therefore, no attempt was made to estimate the deficit beyond 1977. There are numerous planned or proposed new projects that are not sufficiently firm to provide a completion date. Some of these plans may be abandoned, but many are likely to be completed before 1980

Table 6. World nitrogen (N) supply and demand (2)

Year	Supply High[a]	Supply Low[b]	Consumption	Consumption x 1.04[c]	Excess or deficit High[a]	Excess or deficit Low[b]
			million mt			
1972	35.7	32.0	33.7	35.0	0.7	-3.0
1973	38 3	34.4	36.5	38.0	0.3	-3.6
1974	40.9	36.6	39.2	40.6	0.3	-4.0
1975	43.8	39.2	42.0	43.7	0 1	-4.5
1976	46.3	41.5	44.8	46.6	-0.3	-5.1
1977	48.8	43.5	47.8	49.7	-1.0	-6.2
1978	50.0	44.5	50.7	52.7		
1979			53.8	56.0		
1980			56.9	59.2		

[a]Based on 95% capacity in developed countries, 70% in developing countries

[b]Based on 85% capacity in developed countries, 60% in developing countries

[c]Normal relation between supply and consumption

SUPPLY AND DEMAND IN SOUTHEAST ASIA

A summary of projected trade balance for nitrogen fertilizers for the Asian market is shown in table 7.

The data in table 7 also assumes that the only additional production considered in this summary will be from plants already under construction or that have been officially announced for construction. It also assumes that existing plants will continue to operate at their present production efficiencies and that the new plants will operate at 100% of their capacity for 330 days/year. Actually these are optimistic assumptions; judging by previous performance,

Table 7. Projected trade balance nitrogen (N) fertilizer for Asian market (6)

	1974	1975	1976	1977	1978	1979	1980
				million mt			
Nitrogen deficit for 20 Asian countries[a]	-1.51	-1.34	-1.63	-1.57	-2.54	-2.89	-4.57
Supplied by Persian Gulf nations[b]	+0.93	+0.91	+0.99	+0.96	+0.92	+0.90	+0.88
Supplied by Alaska[c]	+0.13	+0.13	+0.13	+0.13	+0.13	+0.13	+0.13
Net trade balance for Asian market	-0.45	-0.30	-0.51	-0.48	-1.49	-1.86	-3.56

[a]Japan, South Korea, Peoples Republic of China, Laos, North Korea, North Vietnam, Cambodia, South Vietnam, Philippines, Indonesia, Bangladesh, Burma, Pakistan, Taiwan, Malaysia, Thailand, India, Sri Lanka, Australia, and New Zealand.
[b]Saudi Arabia, Qatar, Iran, and Kuwait.
[c]Assumes all Alaska urea production will be directed to Asian market. Does not include 1,500 tons/day unit that could be built and on-stream in 1977.

the new plants will probably operate only 85% of the time in developed nations and 60% in developing nations. Therefore, the deficits could be higher than those shown in table 7.

On the other hand, several proposed new plants are still in the "maybe" category. Some of these could be built and in operation by 1978, or perhaps sooner in some cases, which could eliminate projected deficits and even create a surplus supply by that time.

To help bring supply and demand into balance, the region must use its resources to the maximum extent consistent with careful economic planning. Therefore, those countries which have materials available to produce nitrogen fertilizer should produce to supply their own needs and also to supply the needs of other nations of the region which do not have the resources of the production of nitrogen fertilizer

Table 8. Philippine consumption, production, and trade balance for nitrogen[a] (6)

Year	Consumption	Production	Trade balance
		mt	
1970	104,400	53,500	-47,900
1971	132,200	47,700	-84,500
1972	93,000	52,000	-41,000
1973	170,000	52,000	-118,000
1974	200,000	60,000	-140,000
1975	211,000	60,000	-151,000
1976	232,000	60,000	-172,000
1977	255,000	60,000	-195,000
1978	294,000	60,000	-234,000
1979	338,000	60,000	-278,000
1980	372,000	250,000[a]	-122,000

[a]Assume one 1,000 tons/day plant will be constructed and the existing plants will be closed

SUPPLY AND DEMAND IN THE PHILIPPINES

A summary of the projected trade balance for nitrogen fertilizer in the Philippines is shown in table 8. The data show an increasing deficit of nitrogen fertilizers over the next several years until production is increased substantially.

ALTERNATIVES TO MEET DEFICIT

The main question to be resolved by the Philippine Government is how future nitrogen needs can be met most effectively. Several options are available to help deal with the situation. The following general alternatives should be evaluated:

1. Increase production from existing facilities; this course of action can provide some relief but would not be sufficient within itself.
2. Buy needed nitrogen fertilizers on world market; this is a logical short-term solution, but may not be desired for the longer term because of excessive drain on foreign exchange and difficulties in obtaining product when supplies are tight
3. Build additional production facilities. This may be the only way to assure needed future supplies. But even here there are alternatives to be weighed, particularly as to where to produce and the process to be used. A major factor is the lack of an indigenous feedstock for producing ammonia, the basic building block for nitrogen fertilizers.
   a. Ammonia and final nitrogen fertilizer products could be produced in a joint venture in a neighboring country where an adequate supply of natural gas is available.
   b. Feedstock could be imported, in which case both ammonia and final products would be made in the Philippines. The most likely feedstock is fuel oil, although liquefied natural gas (LNG) would be a

good possibility if sufficient additional industrial demand were developed to justify the cost of basic facilities for receiving and handling the LNG.

The following material outlines some of the basic considerations to be evaluated in arriving at a decision.

Improvement of Existing Plants

The Philippines has two ammonia plants. The Maria Cristina plant is old and quite small. This plant, on the island of Mindanao, has a rated capacity of about 37,000 tons/year of nitrogen (4). The other plant—at Limay, Bataan—was built by Esso and is now operated by Planters Products Company. It is somewhat larger, with a capacity of about 84,000 tons/year of nitrogen, but still small in comparison with modern plants in developed parts of the world.

There are good possibilities for increasing ammonia production at both of these plants. Regardless of decisions to build additional production units, in or out of the Philippines, serious effort should be made to maximize ammonia output from existing facilities

The Maria Cristina plant reportedly has been operating at about 80% of capacity based on a 300-day year. However, it also is reported that the synthesis section is old and that its capacity is less than that of the reforming, absorption, and purification sections Although the synthesis section is one of the most expensive sections of the plant, a study should be made to determine how its capacity can be increased to match the capacity of the other sections. Such a change might increase plant capacity by as much as 30%, which could supply an additional 8,000 tons of nitrogen.

Production data indicate that the Planters' facility is producing at less than half of its rated capacity of 84,000 tons. Planters reports that lack of feedstock and maintenance downtime each account for 45% of the downtime, power outages account for the remaining 10%.

Lack of feedstock is the biggest problem, shutdowns because of feedstock shortages greatly increase maintenance problems. There appears to be some problem in scheduling feedstock delivery from the refinery to the ammonia plant This suggests a need for a receiver tank or other equipment to insure that feedstock is available at all times. This one change might increase nitrogen production by 15,000 to 20,000 tons/year. If other efficiencies could also be achieved to bring production to 85% of rated capacity, this would provide 27,000 more tons of nitrogen than is now being produced.

A modernization program for the Planters' facility also should include a topping unit similar to the unit being considered for the new proposed 180 mt/day ammonia plants. If this were done, the plant could import fuel oil and distill off the top light fractions and naphtha for its own use in the manufacture of ammonia. The heavy fractions would be delivered to nearby refineries for further processing.

If naphtha were used in this plant, the following changes in equipment might have to be made:

1. The desulfurizing unit may have to be increased in size because of the increased sulfur content in the naphtha
2. The carbon dioxide (CO_2) absorption unit possibly would need to be enlarged because of the increased quantity of CO_2 (1.58 tons of CO_2/ton of ammonia) which would result from the use of naphtha as a feedstock instead of refinery gas.

In addition, consideration should be given to increasing the capacity of the urea plant since some of the ammonia is used in the manufacture of ammonium phosphate and ammonium phosphate sulfate grades. Also, if naphtha were used, there would be more CO_2 generated during the production of ammonia, which would be available for manufacture of urea Consideration also should be given to importing ammonia to use with this CO_2 to make urea.

Some of the changes that would be required to increase the capacity of the urea unit are

1. Increase the capacity of the urea concentrator and the cooling blower at the prilling towers
2. Increase the size and number of spray nozzles in the prilling tower

Other changes might also be required

Possibilities for improving the profit margin of the Planters' plant should also be investigated One way to do this without increasing the price of urea would be for the Philippine Government to sell feedstock to Planters at a lower price

New Production in Nearby Country

The most economical way to make ammonia is with natural gas at or near the wellhead. For the Philippines, the nearest supplies of natural gas are in Indonesia, Brunei, and Malaysia This suggests the possibility of the Philippines joining with one of these countries to build a large ammonia plant at a natural gas field.

Natural gas in Brunei, for example, has been reported to be about $0.35/1,000 ft^3 This would give an ex-gate (sales) price of ammonia of about $82/ton (1,000 tons/day plant, 100% capacity, 20% ROI, steam reforming), as shown later under "Production Economics." Using this ammonia to make urea in a plant operated at 70% of capacity, the ex-gate price of urea would be about $106/ton. Freight and handling costs of urea from Brunei or Indonesia are estimated to be about $16/ton. This would give a delivered cost of urea of $122/ton, which is considerably less than the cost of urea produced in the Philippines in much smaller plants.

Other calculations indicated that urea produced in a 1,500 tons/day plant in Indonesia could be delivered to the Philippines for about $102/ton.

Import Feedstock for Domestic Production

Another alternative would be to install a large ammonia plant in the Philippines based on imported feedstock. The most likely feedstock would be fuel oil, which would be utilized in the partial oxidation process (described later). However, the possibility of using LNG should not be overlooked; its feasibility will depend largely on developing additional uses to generate a larger requirement.

For purposes of analysis, fuel oil for the partial oxidation process is assumed to cost $12/barrel (bbl), which would give an ex-gate ammonia price of $132/ton with operation at 100% capacity Operation at 70% of capacity would increase the ammonia price to $230/ton, which would give an ex-gate price of urea of about $179/ton.

FIA has under consideration the construction of three ammonia plants, two would have capacities of 180 tons/day and the other 800 tons/day. The feedstock would be naphtha or refinery gas. The smaller plants would have associated with them urea plants with a capacity of 300 tons/day.

The installed investment cost of each ammonia-urea complex (small ammonia plant and associated urea plant) is estimated to be $31,800,000 Urea can presently be imported for $250/ton, to produce urea for this price in a 300 tons/day plant would require that the naphtha cost no more than $7 19/ton (3-year depreciation and 20% ROI). This is completely unrealistic, the cost of naphtha is projected at about $170/ton Even with no ROI the price of naphtha could not exceed $113 50/ton and still meet the import price of urea. Thus, the small ammonia-urea complexes would be expensive "stop-gap" measures.

If a joint venture for large ammonia and urea plants cannot be worked out, the next best alternative that will assure future supplies would be a large ammonia-urea complex in the Philippines based on imported fuel oil. However, it is recommended that such an ammonia plant have a capacity of 1,000 tons/day (rather than 800) and that the complex include a 1,000 tons/day urea plant.

The 400 tons/day of ammonia not used to make urea could be shipped to other fertilizer manufacturing plants. Possible outlets include any new phosphate complex or complexes and the Planters' facility for increased production of NPK mixtures. Some might also go to the Maria Cristina or other plants for prduction of ammonium sulfate for sale close to the plant. In general, however, attempts should be made to substitute urea for ammonium sulfate because of the latter's higher freight and handling cost per unit of plant food.

The following tabulation summarizes expected ex-gate prices in the Philippines for urea under the general assumptions stated previously:

Plant size and location	$/mt of urea
300 tons/day; Philippines	356.17
1,000 tons/day; Philippines	179.00
1,000 tons/day; Indonesia (incl. freight)	122.00
1,500 tons/day; Indonesia (incl. freight)	102.00

Thus, on the basis of economics, the best alternative is for the Philippines and a gas-producing country to invest jointly in a large ammonia-urea complex (1,500 tons/day ammonia) in the gas-producing country. A designated portion of the output of ammonia and/or urea would go to the Philippines. The urea might be shipped in bulk and bagged in the Philippines. In this case, dehumidified bulk storage probably would be required.

If plans for such a venture are completed soon the plant could be in production by 1977 or 1978.

DETAILS OF AMMONIA PRODUCTION

Feedstocks

Nitrogen in most fertilizers comes from ammonia. Ammonia is made by combining atmospheric nitrogen with hydrogen obtained from some hydrocarbon feedstock. Natural gas is the most widely used feedstock; others include naphtha, heavy fuel oils, crude oil, and coal.

Natural gas–Eighty-four of 85 U.S. ammonia plants use natural gas as a feedstock, as do a majority of plants in other parts of the world. The reason is simple–economics. Although natural gas costs more per Btu than some feedstocks, it requires less complicated process equipment for its use, which results in lower production cost. To minimize the cost of transporting the gas, the ammonia plant should be located near the gas wellhead. Plants located in major fertilizer use areas typically are located alongside a major gas pipeline.

Some LNG is shipped in international trade; however, it requires large, expensive, specially-equipped ships and the costs of liquefaction, storage, and regasification are high because of the very low vaporization temperature of natural gas. Even so, LNG may be the most economical feedstock for producing nitrogen fertilizers in the Philippines, if the decision is made to go this route.

The Shell Company in Brunei produces LNG for shipment to Japan. The price, f.o.b. Brunei, in September 1972 reportedly was $0.49/1,000 ft^3, equal to naphtha at $22.74/ton ($2.49/bbl). Naphtha is expected to cost around $170/ton, which is equal to natural gas at $3.66/1,000 ft^3. Price of LNG undoubtedly has increased

also, but its cost tends to increase slower than that of other feedstocks because LNG cannot be readily shipped to many locations and its uses are more limited.

Thus, LNG may well be an attractive alternative to the Philippines for ammonia production. A major problem, however, is the relatively small quantities of LNG that would be required for an ammonia plant. The feasibility of using LNG, assuming a source can be found, hinges on whether enough total use can be developed to warrant the rather high investments involved. Possibly, the cost of shipping and storing the LNG could be shared with other Philippine industries, such as electric power generation.

In addition to Brunei, LNG is produced and marketed internationally by Algiers, Libya, and Iran. LNG production facilities are under construction or planned in several other countries, including Malaysia, Indonesia, and Australia. A detailed listing of LNG sources is given in appendix C. A summary of some of the estimated costs of liquefaction, transportation, and regasification of LNG is shown below.

Cost item	1,000 ft^3
Gas to liquefaction	0.35[b]
Liquefaction	0.33
Transportation @0.08/1,000 miles[c]	0.12
Regasification	0.10
Total	0.90

[a]"Supplementing United States Gas Supplies with Imported LNG," *J Petroleum Techn*, May 1972
[b]Supplied by IVA/AID representative in Indonesia
[c]From points in Brunei and Indonesia

These evaluations indicate the LNG could be imported for as low as $0.90/1,000 ft^3 However, in examples given later in this report it was assumed the 1977 price may be as high as $1/1,000 ft^3

Naphtha has also been widely used as a feedstock. It usually has an initial boiling point of 41°C and its final boiling point is 131°C. It contains unsaturated and aromatic hydrocarbons. It can be used in the same type of ammonia plant (steam reforming) as natural gas if sulfur removal equipment is installed. Most naphtha is obtained as a naturally occuring fraction during distillation of crude oil. Much of the naphtha is cracked to produce gasoline. This was no problem a few years ago; when there was a plentiful supply of gasoline, there was an excess of naphtha which could be used as a feedstock for ammonia plants. However, gasoline is now in short supply and priced higher, which will cause the price of naphtha to increase. Presently the price of naphtha is about $130/ton in the Philippines, and it is expected to increase further in price. It will be difficult to find new supplies of naphtha

Heavy oils, which are heavier than naphtha and occur as residual fuel oil of the type usually used in ships or steam power inputs, and *raw crude oil* are probably the most readily available ammonia plant feedstock to the Philippines. Even these are in short supply and their price has risen dramatically during the past year. Quotes as high as $17/bbl have been made, however, personnel of the Philippine Department of Agriculture and Natural Resources report they can probably purchase crude oil for about $10 to $12/bbl.

These feedstocks have to be treated differently than natural gas or naphtha in ammonia plants Ammonia plants which use them usually cost about 30% more than those which use natural gas. A partial oxidation of the feedstock is required along with liquid nitrogen for washing and combination with the synthesis gas Therefore, in addition to the usual synthesis conversion, CO shift conversion, and CO_2 removal equipment, the plant must have a liquid air plant to supply liquid O_2 to a partial oxidation unit. Also, additional equipment is required to process the extra carbon and sulfur introduced by the heavy oil feedstocks

Many ammonia plants use *refinery gases* as a feedstock. Streams of methane and other low-molecular-weight hydrocarbons amenable to steam reforming are produced by some refineries, others have byproduct hydrogen from catalytic reforming The situation is so varied that little generalization can be made In some instances steam reforming of hydrocarbons is indicated, in others, hydrogen streams can be purified and used directly

One drawback to the use of refinery gas is that a very large refinery or petrochemical operation is usually required to produce enough feedstock for an economically sized ammonia plant Another is that many refineries make hydrogen to use themselves for hydrotreating and hydrocracking. This may be one reason why the Planters' plant does not operate as much as it should.

Only a few ammonia plant installations have been built to use *coal* as a feedstock and some of them replaced coal with natural gas or oil Also, it seems very unlikely that coal gasification will be economical for a single ammonia plant.

Processes

Steam reforming is the process most frequently used and it requires natural gas or naphtha as a feedstock. Steam reforming of natural gas is usually carried out in two stages, using primary and secondary reformers containing a nickel catalyst The catalyst in the primary reformer is contained in tubes heated externally The secondary reformer contains a single bed of catalyst. Feed to the primary reformer consists of a mixture of steam and natural gas. A controlled amount of air is added to the process gas stream as it enters the secondary reformer to provide sufficient oxygen to reform residual methane and to supply the required volume of nitrogen to maintain a 3.1 ratio of hydrogen to nitrogen in the ammonia synthesis make-up gas. Reactions between steam and natural gas (primarily methane) to produce hydrogen are the following:

$$CH_4 + H_2O = CO + 3H_2$$
$$CH_4 + 2H_2O = CO_2 + 4H_2$$

The usual composition of gas leaving the secondary reformer is (volume percentage dry basis): CO_2, 10.4%; CO, 10.0%; H_2, 57.2%; N_2, 22.1%; and CH_4, 0.3%.

Steam is produced by heat recovered from flue gas leaving the primary reformer furnace and process gas leaving the secondary reformer

Sulfur compounds must be removed from the natural gas to prevent poisoning of the reformer catalyst. Usually, the gas is passed through beds of iron oxide to remove hydrogen sulfide and then through activated carbon for removal of organic compounds of sulfur.

The main differences between processes for using naphtha and natural gas are special techniques and equipment are required for removing sulfur compounds from naphtha, equipment is required for vaporizing naphtha, a special catalyst, which is more resistant to poisoning by sulfur is used for reforming naphtha; and larger capacity purification system is required for the removal of carbon dioxide.

Gas leaving the preparation unit is mixed with steam and passed through a converter containing a catalyst, where carbon monoxide is converted to carbon dioxide generating hydrogen by the water-gas shift reaction

$$CO + H_2O = CO_2 + H_2$$

For economic reasons, it is important that the conversion of carbon monoxide to carbon dioxide be as high as possible so as to get a maximum yield of hydrogen. Variables which affect conversion are. concentrations of carbon dioxide, carbon monoxide, and steam in the gas entering the shift converter, catalyst temperature, pressure, and activity, and gas space velocity.

Modern shift converters operate at pressures of about 14 kg/cm^2 or higher, whereas plants built prior to 1950 converted carbon monoxide at near atmospheric pressure. Plants operating at elevated pressure require less catalyst for a given level of carbon monoxide conversion.

After the process gas has passed through the CO-CO_2 shift conversion equipment the CO_2 must be removed so the catalyst in the synthesis section will not be poisoned. One effective solvent for removing carbon dioxide from synthesis gas is a 15%-20% solution of monoethanolamine The solution is circulated continuously through absorber and stripping towers. Usually the monoethanolamine scrubber is designed to reduce the carbon dioxide content to about 200-300 ppm; in plants where liquid nitrogen is used for the final purification step, the system is designed to reduce the CO_2 content to about 50 ppm.

Purity of CO_2 released from the monoethanolamine in the stripping tower is usually about 90%, which is satisfactory for the production of urea.

Process gas leaving the carbon dioxide scrubbing system contains small amounts of carbon oxides, which must be reduced to less than 10 ppm before gas is suitable for ammonia synthesis. This is usually accomplished by methanation. The methanation process involves heating the gas stream to about 300°C and passing the hot gas through a nickel-base catalyst. Under these conditions, the carbon oxides react with hydrogen to form methane and water:

$$CO + 3H_2 = CH_4 + H_2O$$
$$CO_2 + 4H_2 = CH_4 + 2H_2O$$

The water is removed from the gas after it leaves the methanator; methane is not removed because it does not harm the ammonia synthesis catalyst. The equipment cost for methanation is comparatively low, and there is no operating cost except for the initial charge of catalyst

The purified gas must be compressed (2,000 to 5,000 psig) before it is passed into a stream of ammonia which is continuously being circulated through a synthesis converter where the nitrogen (N) and hydrogen (H) combine to form NH_3

The smaller plants, up to 600 tons/day, usually have to use the more expensive reciprocating compressors (usually six stages) and the larger plants usually use the less expensive centrifugal compressors. Also, operating data show there is much less maintenance for the centrifugal compressors than for the reciprocating compressors However, operating data also show that at production rates of less than 600 tons/day the centrifugal compressors become much less efficient than the reciprocating compressors.

The *partial oxidation process* probably is the one the Philippines would use for ammonia production because fuel oil feedstocks will probably have to be used for the manufacture of ammonia In this process, synthesis, compression, methanation, and CO_2 removal sections are the same as for stream reforming. However, the synthesis gas preparation section is quite different and more expensive than for steam-reforming plants.

PRODUCTION ECONOMICS

Economics of Producing Ammonia

The total estimated plant investment cost for ammonia plants in the Philippines is shown in table 9.

Investment figures along with similar investments for plants equipped to use naphtha or coal are shown in figure 4. These investment costs, the cost of various feedstocks, and processes were used to calculate the total estimated production costs which are shown in figure 5. No ROI was

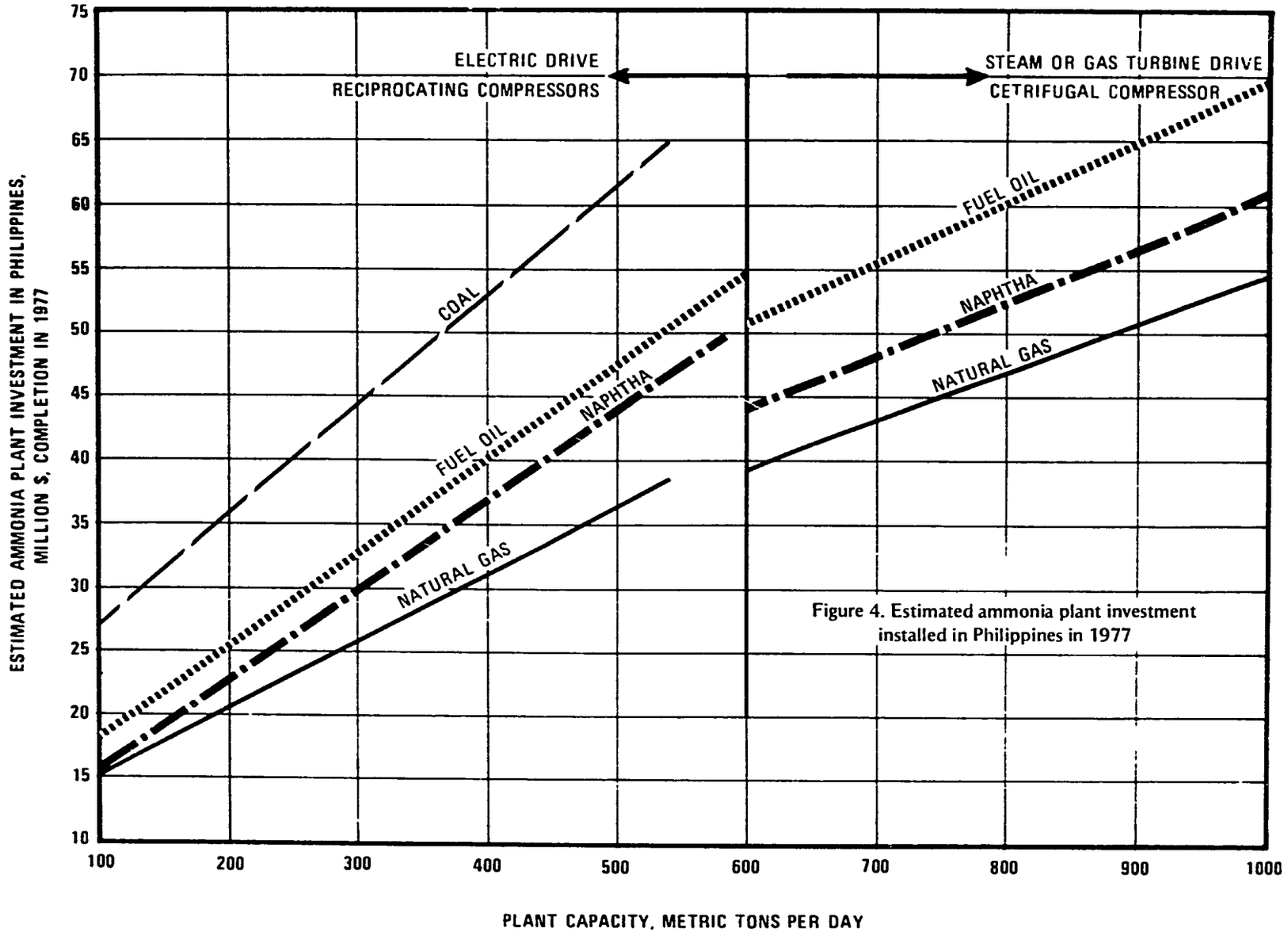

Figure 4. Estimated ammonia plant investment installed in Philippines in 1977

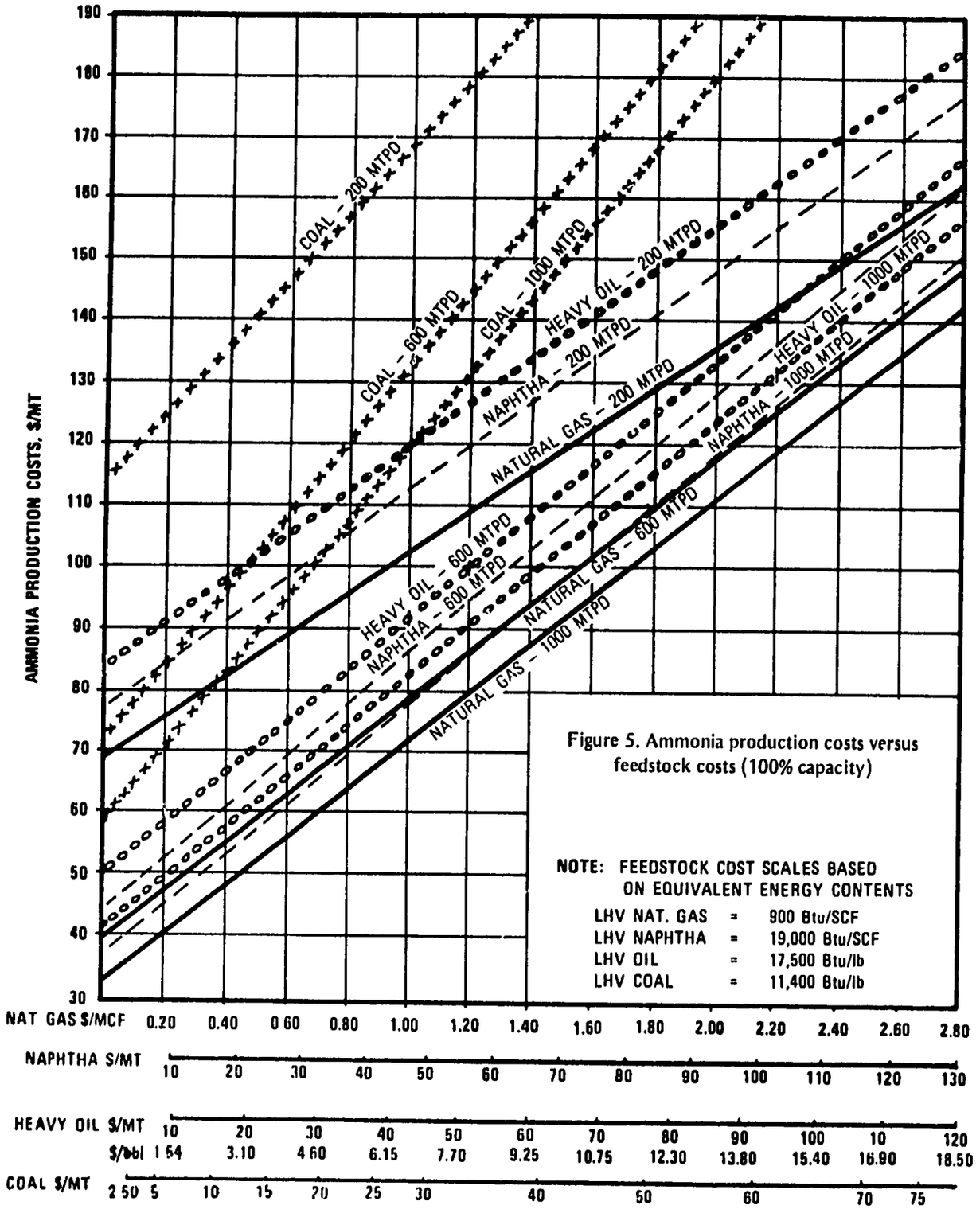

Figure 5. Ammonia production costs versus feedstock costs (100% capacity)

Table 9. Capital investment[a] for ammonia plant in the Philippines

Plant size mt/day	Fuel oil, partial oxidation	Natural gas, steam reforming
	$ million	
200	25.6	20.7
400	40.0	30.0
600	51.0	39.5
1,000	69.3	54.5

[a]Investments are for 1977 and include cost for transporting and constructing plant, construction of auxiliary, and support facilities. Also included is the cost for 15,000 mt of ammonia storage

considered in calculating these production costs. Figure 6 shows similar comparisons with a 20% ROI.

A typical example of a cost calculation for a 1,000 tons/day ammonia plant using steam reforming and partial oxidation is shown in table 10.

The cost of natural gas delivered to the Philippines may be lower than the $1/1,000 ft^3 assumed in these sample calculations. Price at the wellhead in Indonesia is reported to be about $0.35/1,000 ft^3, and when the cost of liquefaction, transportation, and regasification are added the delivered cost is about $1/1,000 ft^3 The $12.36/bbl for fuel oil assumed in the calculation is now the delivered price in several countries. There is considerable instability in the world prices of crude and fuel oil and because of this instability it is difficult to make economic comparisons for the future which involve the use of these materials as feedstocks for ammonia plants. It is not known what the price of crude will be in the 1977-80 period.

The following tabulation shows the equivalent costs of fuel oil, natural gas, and LNG.

Fuel oil/bbl =	Nat. gas/1,000 ft^3	LNG/1,000 ft^3
$ 4.00	$1.05	$1.10
8.00	1.80	1.85
10.00	2.00	2.05
12.00	2.35	2.40

Since LNG presently sells for less than $0.49/1,000 ft^3 in Brunei, it is highly probable that it can be shipped and stored in the Philippines for much less than $2.05 which is the equivalent present import price of fuel oil ($10/bbl).

Most plants in developed countries have an operating time (turndown) of between 85% and 90% because of lack of feedstock, power outages, and annual maintenance, etc. In developing countries this turndown is lower (from 70% down to as low as 40%), depending on the circumstances Figures 7, 8, and 9 show the effect of turndown on the ammonia production cost and the ammonia-ex-gate sales price (20% ROI). Figure 7 is for natural gas feedstocks and steam reforming, figure 8 is for heavy oil feedstock and partial oxidation process, and figure 9 is for naphtha and a modified steam reforming process (extra sulfur removal equipment); with these curves it should be possible to calculate the production costs of ammonia and urea under any conditions (except ammonia plants less than 200 mt/day).

Economics of Producing Urea

The total plant investment for various size urea plants is shown in table 11. The amount of ammonia required to produce the amount of urea is also shown.

These plant capacities versus investment cost are further shown in figure 10. These costs include foreign construction, investment in auxiliaries, and support facilities.

Using these investment figures, the total production cost with and without ROI was calculated for several ammonia

Table 10. Typical cost calculation for 1,000 tons/day ammonia plant

Item	Steam reforming	Partial oxidation
Annual production	330,000	330,000
Total plant investment (P.I.), $	54,500,000	69,300,000
Working capital, $	7,520,000[a]	12,860,000[a]
Materials and utilities	$/ton of ammonia	
Natural gas 38,500 ft^3 at $1 00/1,000 ft^3	38 50	
Fuel oil, 0.965 ton at $80/ton (12.36/bbl)		77.10
Boiler feed water at $0.60/M gal	0.30	0.24[b]
Cooling water 55 M gal at $0.02/M gal	1.10	1.76[c]
Electricity 33 kWh, at $0.015/kWh	0.50	0.75[d]
Labor, 0.12 man-hr at $5/hr	0.60	0.80[e]
Maintenance (5% of P.I.)	8.25	10.50
Taxes and ins. (2% of P.I.)	3.30	4.20
Depreciation (15 years)	11.05	14.05
Analysis (20% of labor)	0.12	0.16
Interest (8% of ½ P.I.)	6.60	8.40
Overhead (100% of labor)	0.60	0.80
Subtotal[f]	70.92	118.76
Interest on working capital	0.91	1.56
Total production cost	**71.83**	**120.32**
20% ROI	37.60	42.00
Ex-gate price	109.43	162.32

[a]Working capital 60 days of material cost plus 90 days production cost.
[b]0.4 M gal at $0.60/M gal
[c]88 M gal at $0 20/M gal
[d]50 kWh at $0.015.
[e]0.16 man-hr at $5/hr.
[f]No credit for S removed from gas.

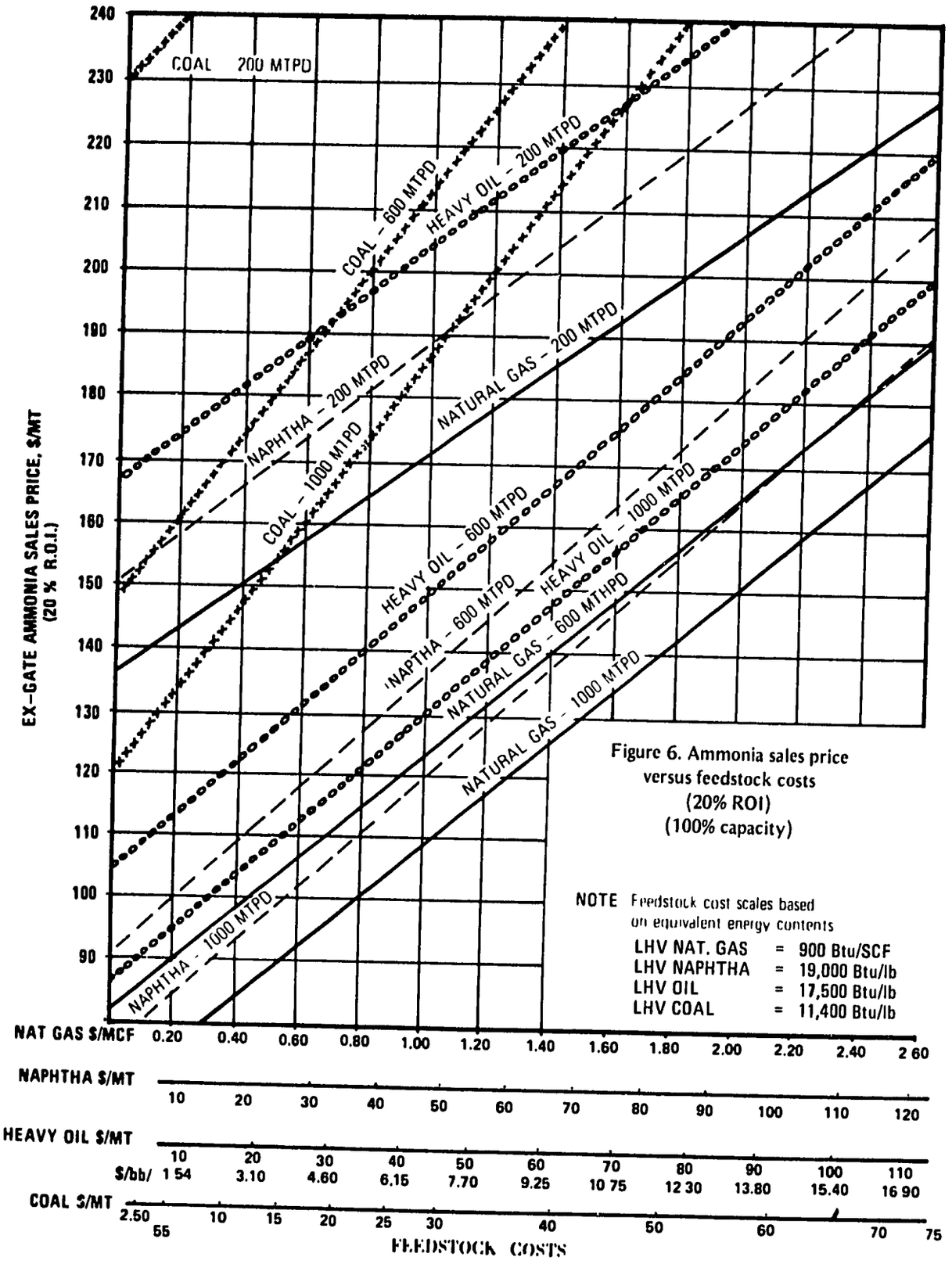

Figure 6. Ammonia sales price versus feedstock costs (20% ROI) (100% capacity)

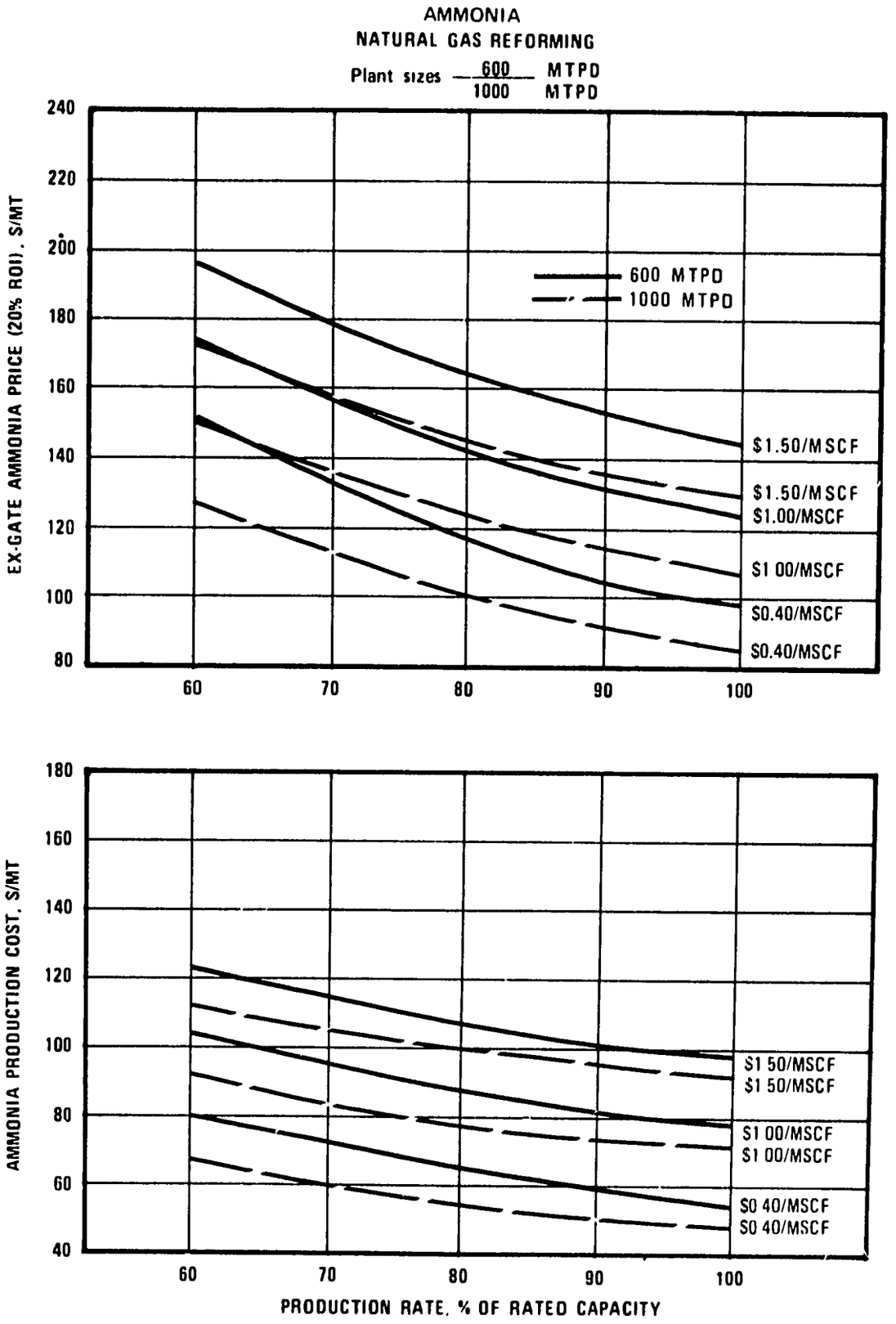

Figure 7. Effect of plant turndown

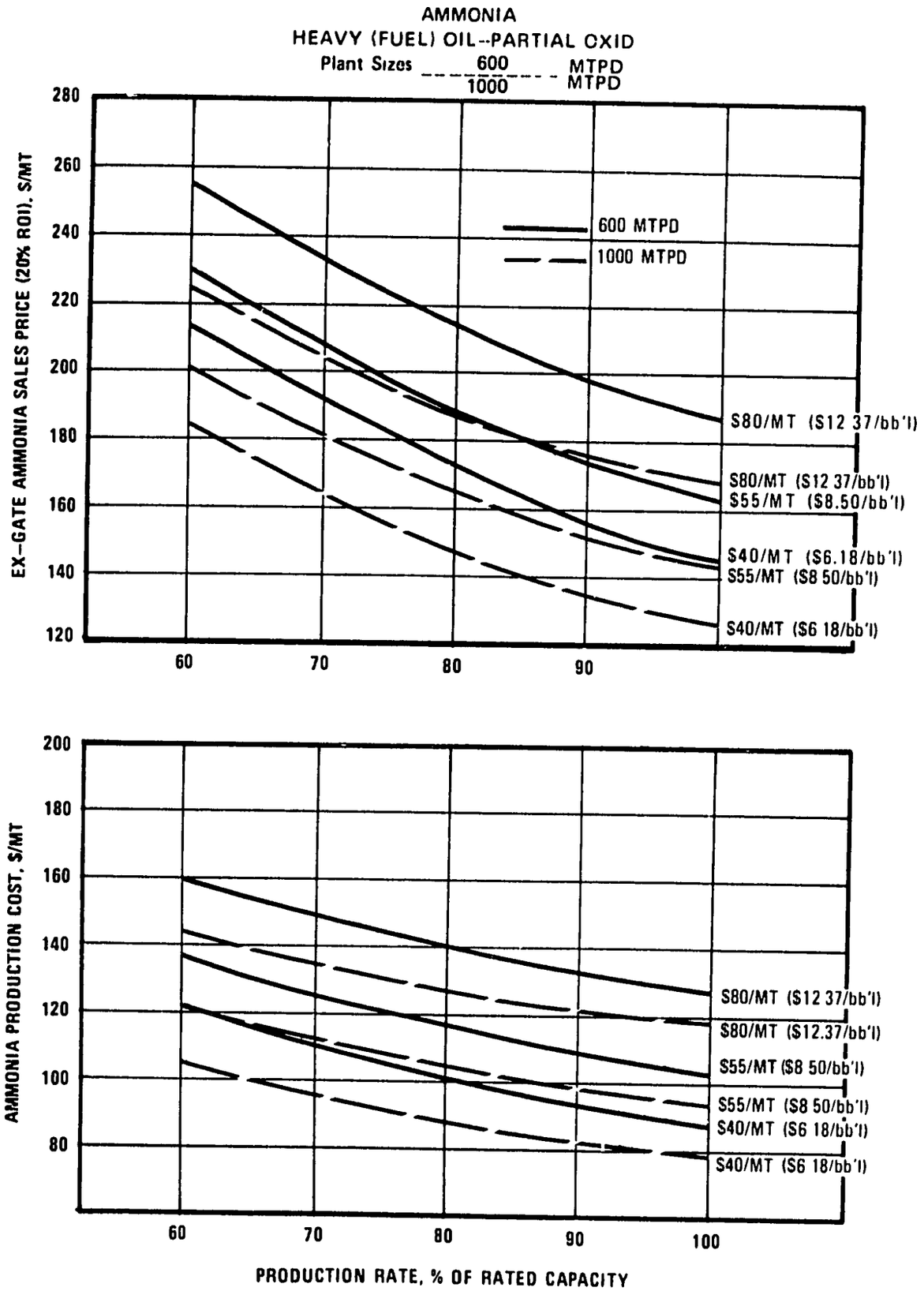

Figure 8. Effect of plant turndown

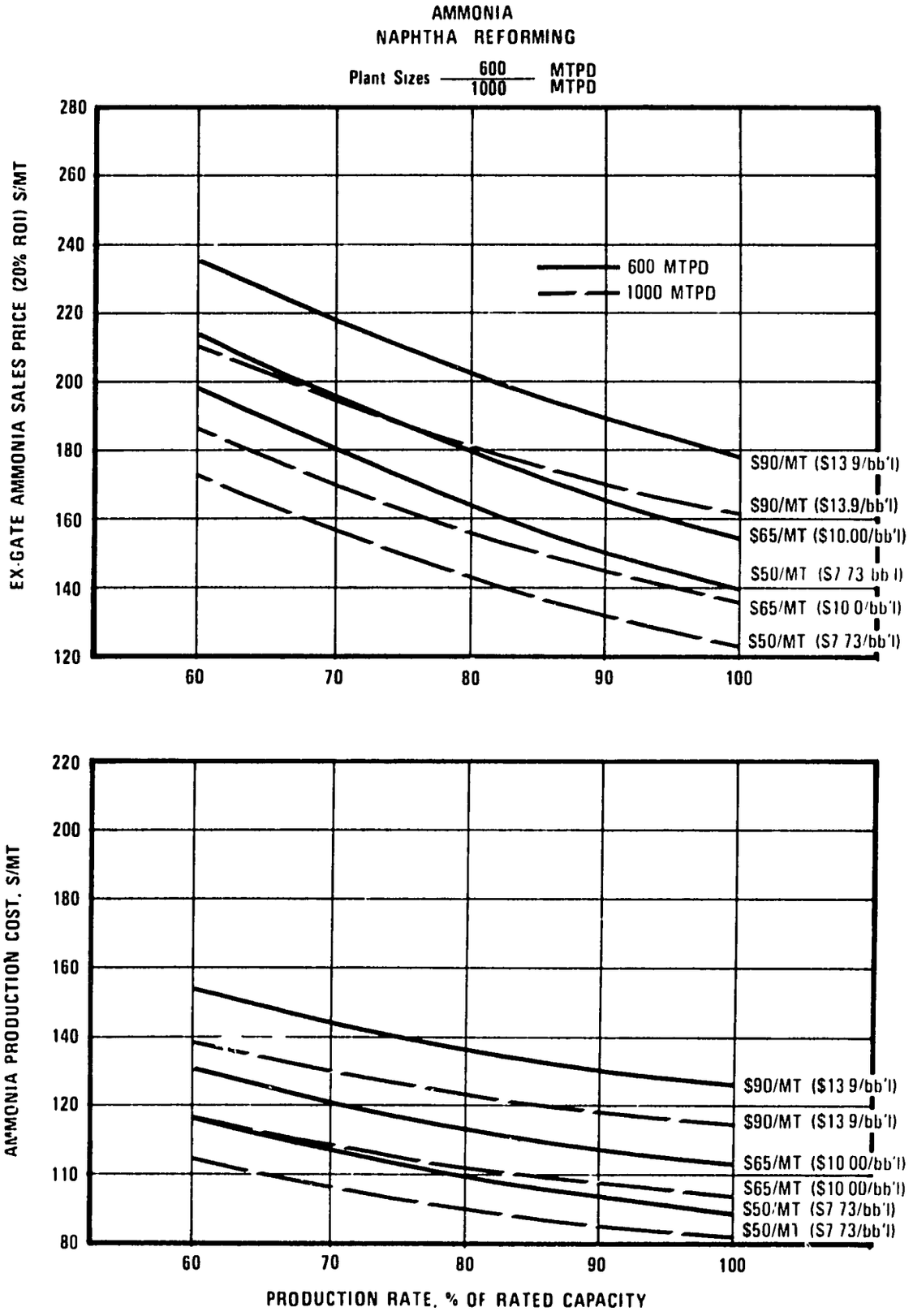

Figure 9. Effect of plant turndown

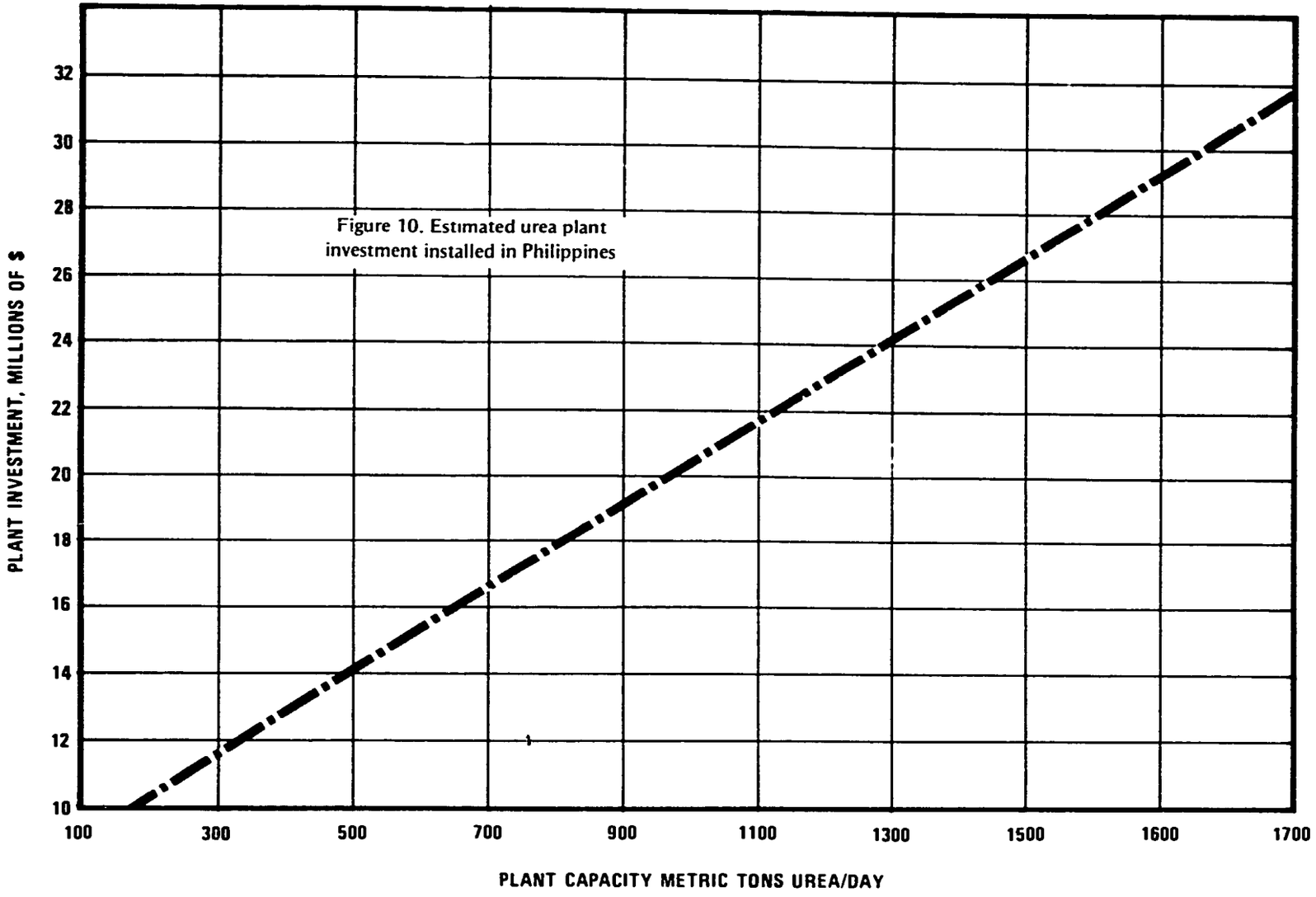

Figure 10. Estimated urea plant investment installed in Philippines

Table 11. Requirements for urea plants installed in Philippines

Plant capacity mt/day	Ammonia required mt/day	Investment $ million
333	200	12.24
1,000	600	21.9
1,667	1,000	30.7

costs. This is the basis for curves of figure 11 and figure 12. In this instance, ex-gate price means sales price that includes 20% ROI.

OTHER CONSIDERATIONS

Atmospheric Ammonia Storage

If an ammonia-urea complex and/or ammonium phosphate plant are to be built, then the ammonia atmospheric storage tank mentioned in the FIA plan should be located at one of these complexes.

It should be possible to receive ammonia from Indonesia and gas-producing countries that are located close to the Philippines. Therefore, if trade arrangements could be developed with these countries, the turnaround time for ammonia supply ships would be relatively short.

It is suggested that the tank have a capacity of 14,000 tons or less. Most of the ammonia transport vessels have capacities of about 6,500 tons or less, and this tank would have sufficient capacity for turnaround times of the average tankers. The terminal would cost about $2,000,000. The effect of annual throughput on terminal charges is shown in figure 13. The charges include allowance for 15 years depreciation and 10% ROI. This data shows the terminal charges will be high for low throughput. To receive a terminal charge of less than $10/ton, at least 41,000 tons/year of ammonia must be passed through the terminal. This cost would be as high as $29/ton for a 14,000 tons/year throughput.

Using the production economic curves, it was determined the ex-gate price of ammonia from the terminal in the Philippines would be about $168. The summary of these costs are shown in table 12.

This cost compares favorably with the equivalent cost of N as urea delivered from Indonesia ($204 versus $276). Therefore, direct application of ammonia which has already commenced in the Philippines probably should continue to increase. Some consideration should be given to the installation of several smaller atmospheric ammonia storage tanks at various other locations instead of installing one large tank.

The ammonia from the storage tank can be shipped in barges which have several pressure-type storage tanks in them. These tanks usually have capacities of about 100 tons and are tested safe for 300 psig operating pressure. The barges may have as many as 20 of these tanks and would be used to deliver ammonia to either atmospheric storage tanks or smaller pressure type tanks. A list of fabricators of the pressure tanks is shown in table 13.

These same types of tanks except smaller in size (15-20 ton capacity) are used on trucks to transport ammonia to the dealer or farmer storage tank.

Ammonia is usually applied by injecting it 6-8 inches beneath the soil surface to prevent nitrogen loss. This is usually done by an applicator equipped with an orifice-type meter (some use piston type metering pumps), a pressure-type tank (200-1,000 gallons) and several injection knives. A list of suppliers for ammonia tanks are shown in table 13.

Nonpressure Ammonia-Urea Solution

Some developing countries have had difficulty finding pressure tanks and equipment available to ship anhydrous ammonia. In Brazil one company receives an ammonia-urea low pressure solution from the Netherlands for use in its NPK complex.

The solution contains 33% N (19.5% free NH_3 and 37.5% urea). It is a clear solution and does not exert a

Table 12. Ex-gate price of ammonia produced in Indonesia shipped to the Philippines and passed through terminals

Item	Cost/mt
Ammonia production (Indonesia)	122
Terminal charge in Indonesia[b]	6
Freight to Philippines	30
Terminal charge to Philippines[c]	10
Total	**168**
Equivalent cost $ per ton of N	204

Table 13. Fabricators of ammonia storage and application equipment

Pressure storage tanks	Application equipment
Mississippi Tank Co Box 1115 Hattisburg, Miss	John Blue Corp. Huntsville, Alabama
Anco Manufacturing and Supply Co. 21 Union Street Tulsa, Oklahoma	Willmar Manufacturing Co. Willmar, Minnesota
Trinity Industries, Inc. 4003 Irving Blvd. Dallas, Texas	Dempster Industries Beatric, Nebraska
Chicago Bridge and Iron Co. 901 W 22nd Street Oak Brook, Illinois	A.M.F Beaird-Inc. Box 1115 Shreveport, Louisiana
	Mississippi Tank Co. Box 1115 Hattisburg, Miss.

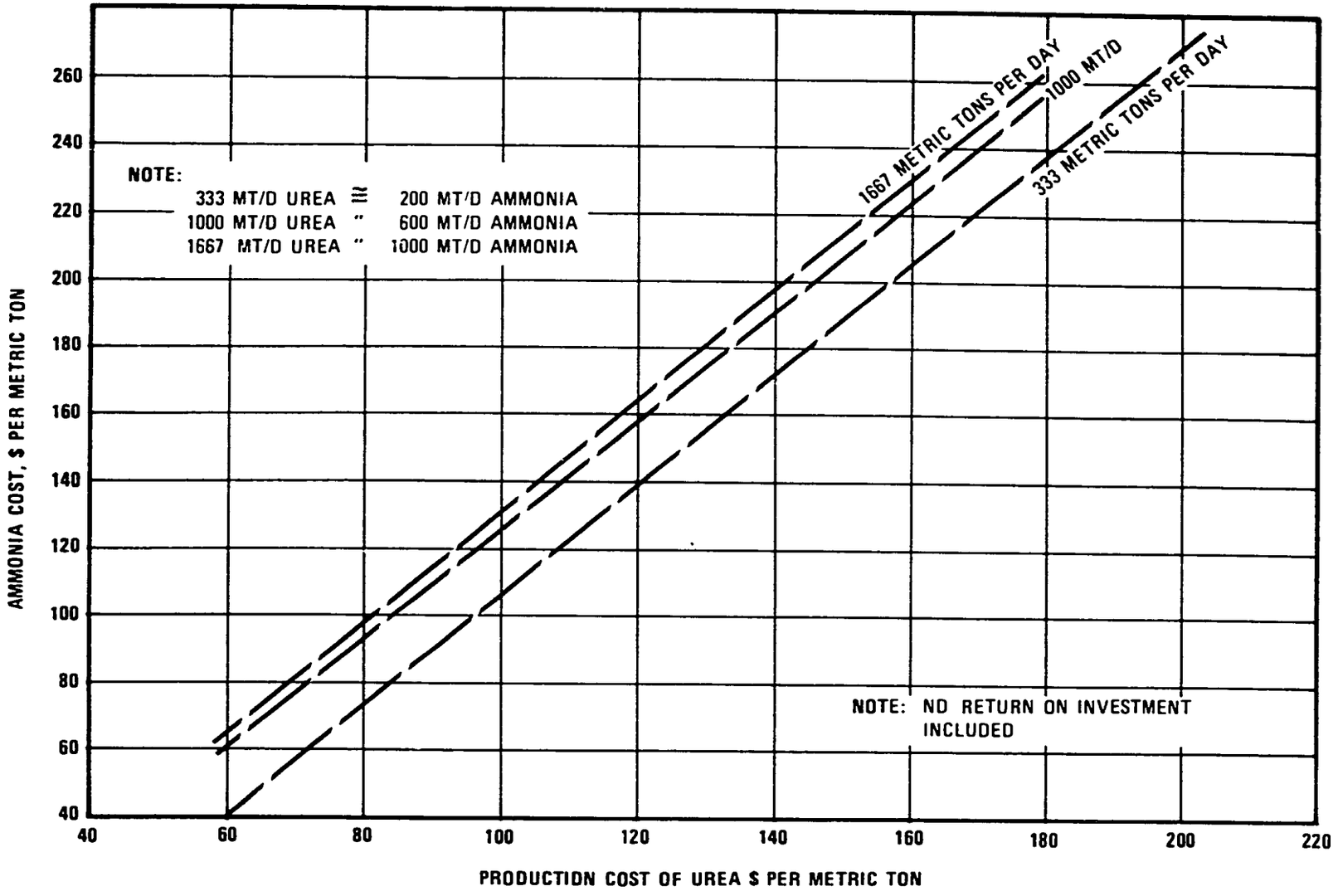

Figure 11. Effect of ammonia cost on urea production cost

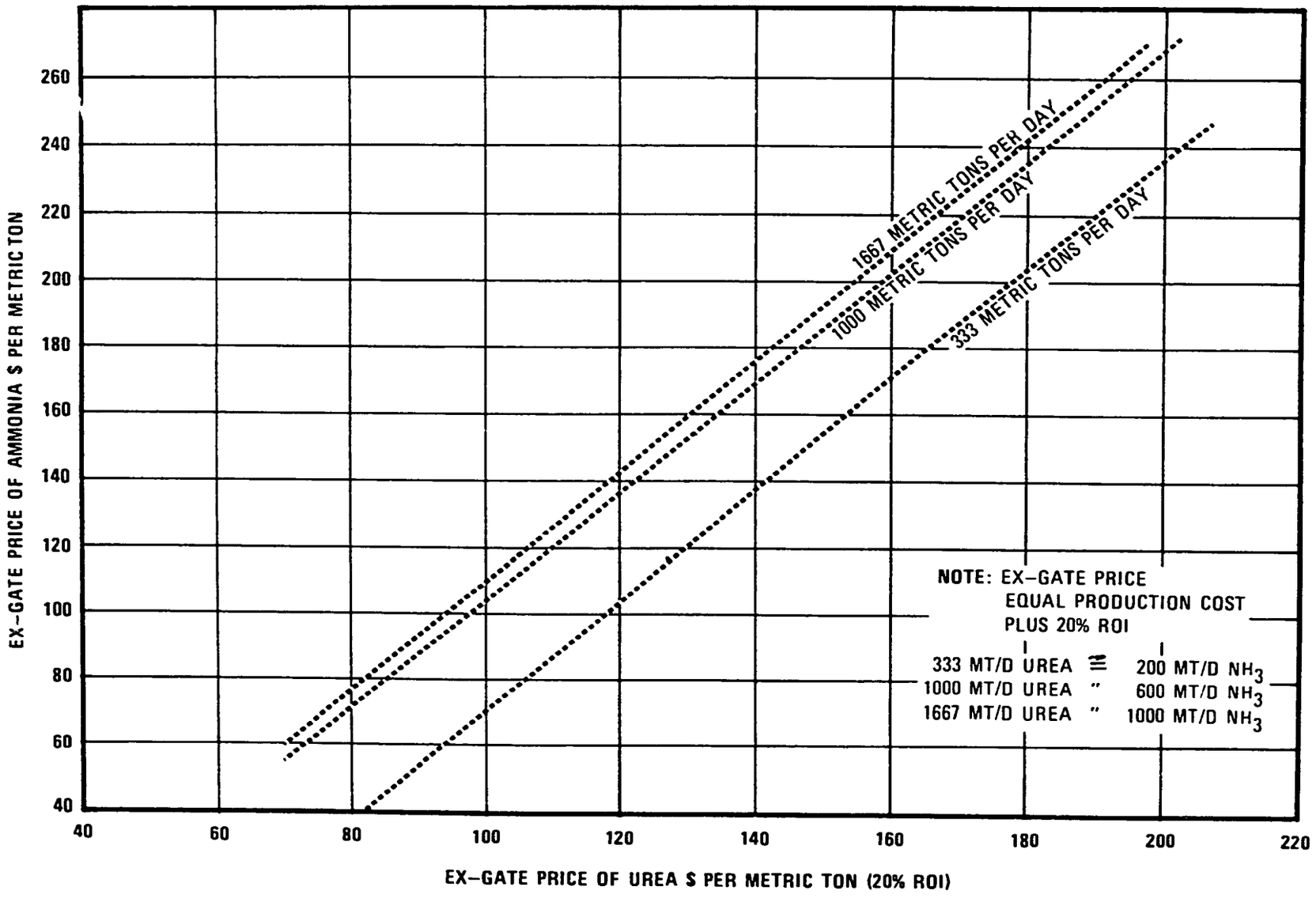

Figure 12. Effect of ammonia cost on ex-gate price of urea

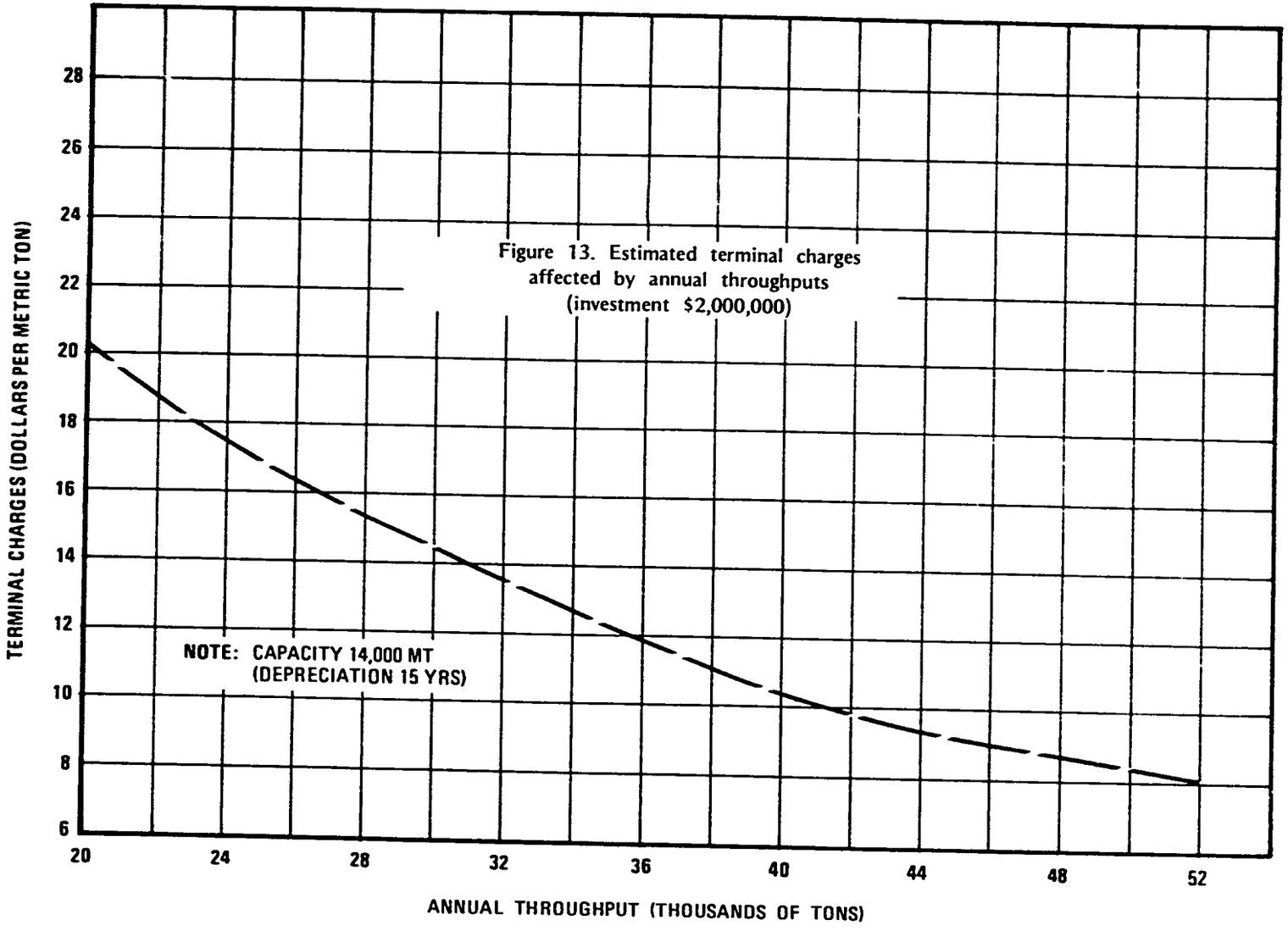

Figure 13. Estimated terminal charges affected by annual throughputs (investment $2,000,000)

gauge pressure until the liquid temperature is about 38°C. Its gauge pressure at 40°C is 35 kg/cm². The solution is shipped from the Netherlands to Brazil in the fuel oil tankers with no special equipment added. The tanks are sealed so that although little or no pressure exists in the tank, no ammonia can escape from them. The solution is pumped from the tankers with a centrifugal pump and through a conventional rubber hose. It is stored in an old fuel-oil storage tank (500,000 gallons). The top of the tank is sufficiently tight to prevent rain from entering; however, it is not sealed. Therefore, a 6- to 12-inch layer of bunker oil is kept on the surface of the liquid to prevent ammonia losses. The Brazilian company prefers to ship the nonpressure solution rather than prilled urea. It is used in an ammoniation-granulation plant with superphosphate and potash to make NPK mixtures.

It would be especially advantageous to Planters to receive this solution because the company has had considerable difficulty increasing its urea production because of lack of ammonia. This solution would be distilled to remove the ammonia and then the urea solution would be concentrated. Both the ammonia and concentrated urea solution would then be combined in the ammoniator-granulator to produce various urea ammonium phosphate grades.

Other companies may have some interest in receiving solution and distilling off the ammonia to make granular NPK mixtures and then concentrating the remaining urea solution to make granular urea in a pan granulator.

Granular Urea

Based on TVA's most recent experiences it is recommended that those complexes which plan to produce a solid urea product do so in a pan granulator. Granules of urea from the pan granulator are of excellent shape and have more crushing strength than prilled urea. Their size is somewhat larger than the prills, therefore, they have less surface area for the collection of moisture from the atmosphere. For this reason, granular urea probably will have superior storage characteristics to the smaller urea prills. Also, it probably will be easier to control the dust and fumes from the pan granulators than from conventional prilling towers. The cost of granulating urea is expected to be about the same as for prilling.

The size of the granule can be varied in the pan granulator process. An excellent granule for coating with sulfur or other coating agents can be produced should it become advisable to produce controlled release products, such as sulfur-coated urea, for use in the Philippines. Granular urea of excellent quality also can be produced in a spray drum granulator.

FIA is investigating the possibility of shipping aqua ammonia (20% N) from the atmospheric ammonia storage terminal to other locations in the Philippines. A cost comparison between producing, shipping, and handling aqua ammonia as compared to shipping anhydrous ammonia is shown in table 14.

Table 14. Cost comparison between production, handling, and shipping of aqua ammonia[a] as compared to anhydrous ammonia[b]

	Aqua ammonia 20% N	Anhydrous ammonia
Conversion cost	1.00	–
Freight	6.00	12.00
Storage cost	4.00	8.00
Total material cost	11.00	20.00
Total nutrient cost	55.00	24.00
Including distilling cost for aqua		
Steam .76/mt x 1.00	0.76	--
Labor, depr tax, ins	0 50	
	1.26	0.00
Total aqua	12.26	-
Total nutrient	61.30	24 00

[a]Aqua ammonia 20% N
[b]Anhydrous ammonia 82 3% N

These calculations show the costs of producing, handling, shipping, and distilling aqua ammonia is 2.5 times more per ton of nitrogen as the cost of shipping and handling anhydrous ammonia

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APPENDIX A

THE POSSIBILITY OF PRODUCING SULFUR-COATED UREA IN SOUTHEAST ASIA

Sulfur-coated urea (SCU) is a controlled-release nitrogen fertilizer under development by TVA. It is made in a pilot plant designed for 1 ton/hour output, but higher operating rates have been attained. The pilot-plant products have been widely tested and have been found to be more effective than straight urea in many cases, due to better utilization of nitrogen by crops. For instance, in several tests with rice grown under intermittent or poorly-controlled flooding, SCU gave substantially higher yields. Superior results also were obtained with sugarcane, pineapple, and some other crops. SCU also has excellent physical properties, even in humid climates.

In view of the present worldwide shortage of nitrogen fertilizers and their high price, it has been suggested that some existing urea production facilities might be converted to SCU production, especially in rice-growing areas. Thus, the improved efficiency of the product could partially compensate for the inadequate supply. Supplying more nitrogen to increase crop production can be done either by applying more nitrogen fertilizer or by increasing the efficiency of utilization by the crops of the same amount of applied nitrogen.

Specifically, it has been suggested that certain urea plants in Indonesia or the Philippines be converted to SCU production. The purpose of the present report is to present certain alternative ways of carrying out this conversion and to discuss some of the uncertainties involved.

The SCU production process, as originally developed by TVA, involves coating *granular* urea of a particle diameter of about 2.0 to 3.3 mm with sulfur applied as a spray in molten form, followed by a coating of wax of specific characteristics, followed by a coating of a powdery conditioning agent. The required weight of coating typically is 18% to 20%, with 1% of the total product weight being a clay preconditioner. The Indonesian and Philippine plants produce prilled urea which has a smaller particle size. TVA's results in coating prills with sulfur only have not been very encouraging. About 27% coating is required. The increased weight of coating would increase the cost, require larger equipment, and lower the grade of the product. As an alternative, additional equipment could be provided in Indonesia or Philippines to produce granular urea for coating. These alternatives need to be analyzed.

The wax used as sealant in most of the TVA work was a petroleum-derived product known as Shellmax 800. TVA has been informed that this and similar products are now in extremely short supply and practically unavailable. TVA is investigating the alternative of a sulfur-only coating. Results indicate that the desired release rate can be attained with a small increase in total coating weight, namely, 20% to 23% for granular urea.

Limited agronomic tests have confirmed that the sulfur-coating is as effective as the sulfur-wax-conditioner coating, although a problem of granules floating on flooded fields has been reported. Also, when urea coated with sulfur only was broadcast by a fan-type distributor, the effectiveness of the coating was largely destroyed. Presumably the impact of the fan blades cracked the coating. Under the same test conditions, the effectiveness of the combination-coated product was not significantly impaired. Probably the application equipment used in developing countries would not cause deterioration of sulfur-only coating but the effect of handling through bagging, storage, and transportation steps has not been fully investigated.

In the meantime, a search is in progress for a sealant that would be more plentiful than the Shellmax 800 wax and equally effective. Encouraging results have been obtained with several coating materials Most promising thus far is a mixture of low-density polyethylene and bright-stock oil

For the purpose of the present estimates, it was assumed that a unit to coat prilled urea would be located adjacent to a urea plant in Indonesia or the Philippines. The capacity of the plant would be 250 tons/day of product. Equipment would be provided to coat prills with sulfur, wax, and conditioner. It was assumed that wax, or a substitute sealant would be available for $300/ton If it is later found that a sulfur-only coating is satisfactory, the equipment for applying the other coatings could be by-passed. It should be noted that there is some risk that a satisfactory product could not be made if a supply of wax or a suitable substitute could not be found and if sulfur-only coating proved ineffective for handling and application conditions in the market area. As an alternative, equipment for sulfur-only coating could be installed, and additional equipment for applying wax and conditioner could be added later if needed.

The plant investment cost has been estimated by G. M. Blouin, TVA, at $3,100,000 for a 250 tons/day SCU plant for a Far East location using 1974-1977 construction costs. Sulfur and conditioner were assumed to cost $60/ton delivered and wax $300/ton. The operating costs are estimated as follows:

Raw materials	Tons/ton of product	Cost $/ton	Cost $/ton of coated product
Urea	0.70	150	105.00
Sulfur	0.26	60	15.60
Wax	0.02	300	6.00
Conditioner	0.02	60	1.20
2% loss			2.56
Subtotal			130.36
Operating cost			10.30
Total production cost			**140.66**

The nitrogen content of the product would be 32% so the production cost of the coated product would be about $440/ton of nitrogen as compared with $326 for uncoated urea.

A similar calculation for a sulfur-only coating (30% S) shows a cost of $135.76/ton of coated product or $424.00/ton of nitrogen.

A rough calculation was made of the cost of granulating urea and coating the granules. It was assumed that the operation would be carried out adjacent to an existing plant. The granulation step would utilize concentrated urea solution such as that used for prilling. Cost of the granulation facilities was assumed to be $2 million, and cost of the total facility (granulation and coating) would be $5 million. The production cost estimate follows:

Raw materials	Tons/ton of product	Cost $/ton	Cost $/ton of coated product
Urea	0.83	150	124.50
Sulfur	0.13	60	7.80
Wax	0.02	300	6.00
Conditioner	0.02	60	1.20
2% loss			2.79
Subtotal			141.90
Operating cost			15.00
Total production cost			**157.29**

If facilities were provided for granulation instead of prilling in a new urea plant, the production cost of the coated product would be further reduced by about $5/ton. Also, the cost would be lower if carried out on a larger scale. The investment and operating cost of a urea granulation unit is expected to be no greater than for a prilling unit. Granular urea is now being produced in full-scale equipment by TVA and by a Canadian company, and two large urea plants under construction in the U.S. will produce granular urea rather than prills.

Also, if the coating facilities were designed for a sulfur-only coating, their investment and operating cost would be much lower. Furthermore, certain technological improvements have been developed in a recent pilot plant operation which could simplify the equipment and its operation. The effects of these improvements have not been fully evaluated in terms of investment and operating costs. It seems likely that eliminating the wax and sealant coating steps plus the adoption of recent process improvements would reduce the investment and operating cost by one-fourth or more. Based on these assumptions, the cost of SCU with a sulfur-only coating and with the cost of urea granulation charged to urea, production is estimated as follows for a 250 tons/day plant:

Investment–$1,500,000

Raw materials	Tons/ton of product	Cost $/ton	Cost $/ton of coated product
Urea	0.80	150	120.00
Sulfur	0.20	60	12.00
2% loss			2.64
Subtotal			134.64
Operating cost			5.15
Total production cost			**139.79**

According to the above estimate, the cost of the coated product containing 37% nitrogen would be $139.79/ton, or $378.00/ton of nitrogen. This is only 16% higher than the cost of uncoated urea. In several tests the nitrogen utilized by crops from coated urea has been about 33% more than from uncoated urea, so a 16% increase in cost could readily be justified.

SCU has much better physical properties than straight urea. It is highly resistant to moisture absorption in humid atmosphere and to caking. This property should be quite useful in tropical areas.

It is recommended that granulation rather than prilling facilities should be used in all new urea plants. Granular urea is much better adapted to sulfur coating than prills, and is also better for most other uses.

Consideration should also be given to converting a small existing plant (200 tons/day or less of urea) in the Philippines or Indonesia to production of granular urea and SCU. The SCU from this unit should be used in a product introduction and study program in Southeast Asia. The plant should be able to make SCU and uncoated granular urea alternately since not all crops are benefited by controlled-release nitrogen fertilizers. Information from TVA should be adequate for design of the plant. As the project is still under development by TVA, close contact should be maintained with TVA to insure that the latest results are available for design and operation of the proposed plant.

APPENDIX B

NOTES ON PHOSPHATE SUPPLY AND UTILIZATION FOR SOUTHEAST ASIA

Because of the high price and scarcity of phosphate rock and phosphate fertilizer in Southeast Asia, questions have arisen regarding alternative sources of phosphate rock and simplified means for utilizing it, such as direct application.

Following are recent data on phosphate rock exports.

Phosphate rock exports, thousands of mt

Source	Jan.-June 1972	Jan.-June 1973
Morocco	6,514	7,910
Florida	6,263	6,037
USSR	3,123[a]	–
Sp. Sahara	21	145
Tunisia	1,203	1,136
Algeria	154	77
Togo	925	1,081
Taiba (Senegal)	650	713
Jordan	423	593
Israel	352	276
Ocean Island	277	376
Nauru Island	673	1,210
Christmas Island	322	618

[a]1/2 of full year

In considering possible supplies for Southeast Asia, those sources that are relatively near might receive first consideration. The output of Ocean and Christmas Islands goes entirely to Australia and New Zealand, as does over 90% of the Nauru rock, the remainder of Nauru rock goes to Japan The deposits on Ocean Island are approaching exhaustion The deposits on Nauru and Christmas Island are not extensive but may last 10-20 years. Nauru might be the best temporary source, as the output is not controlled as tightly by Australia and New Zealand. Nauru rock is high grade and well suited for use in production of phosphate fertilizer (but not for direct application).

There is substantial production of phosphate rock from the Lao Kay deposit in North Vietnam. This deposit is located near the Chinese border and most of the output goes to China. It is distant from ports, so export possibilities are doubtful.

The Queensland deposits in Australia are under development and a 100 tons/day pilot plant is in operation. The plan is to fine-grind the ore, beneficiate it, and then pump it as a slurry to a deep-water port in the Gulf of Carpenteria for shipment to other Australian ports or export. Commercial production of concentrates is expected by mid-1977. The concentrates will contain 33%-34% P_2O_5. Tests by Fisons have been made which show that the ore is suitable for phosphoric acid production. Tests at TVA indicate the rock would not be useful for direct application.

Jordan and Israel export phosphate rock from the Gulf of Aqaba, an arm of the Red Sea. The sea freight distance is much shorter than for North African sources, as long as the Suez Canal is closed. Both ores contain carbonate impurities that increase sulfuric acid consumption and contribute to foaming in phosphoric acid production However, they are usable. Both ores are likely to contain excessive chloride which causes severe corrosion in phosphoric acid production equipment The chloride can be removed by washing with fresh water but fresh water is scarce at the mine site Probably provision should be made for washing these rocks before use in phosphoric acid production However, it was reported that Israel rock was used in a phosphoric acid plant in Scotland without excessive corrosion by addition of copper sulfate as a corrosion inhibitor When producing single superphosphate, the chloride content of the rock is less important.

The maximum level of chloride that can be permitted without encountering serious corrosion is in doubt According to some investigators, no serious problem should occur when the rock contains less than 0.10% Cl Other studies have shown serious corrosion with as little as 0.02% Cl Several reports have indicated that corrosion is not a serious problem with rocks containing less than 0.10% Cl provided oxidizing conditions are maintained Oxidants successfully used to prevent corrosion include $CuSO_4$, HNO_3, and air sparging. Type 317 stainless steel seems to be more resistant to chloride corrosion than 316. Other (more expensive) alloys are still more resistant Further study is needed on methods to prevent excessive corrosion by low levels of chloride in phosphate rock.

It is said that steps are being taken to insure low chloride content of the Israeli and Jordanian rock but the effectiveness of the steps is not known. If rock is purchased from these (or any other) sources for use in phosphoric acid plants, a low level of chloride should be specified and enforced, or else the rock should be washed before using.

Phosphate rock from the Spanish Sahara is being produced in increasing amounts and as much as 3 million tons/year may be available soon Most of the present output is going to Spain. Shipload quantities have been used successfully in phosphoric acid production in the USA. The beneficiation process involves washing with sea water followed by washing with fresh (distilled) water to remove chlorides The chloride removal is not reliably satisfactory according to some reports.

The Phosphate Development Corporation, Ltd. of South Africa, is planning to export phosphate rock as soon as loading facilities at a deep-water port are completed, probably in 1976. The South African phosphate concentrates are high-grade (37% P_2O_5) igneous apatite. Like Kola apatite, the ore is quite satisfactory for fertilizer production. Some changes in operating procedure (but not in equipment) are required to use this rock efficiently in fertilizer production. The company plans to offer technical assistance to purchasers of the rock. The low impurity content of this material should make it especially well suited to manufacture of phosphoric acid for use in production of industrial phosphates such as sodium tripolyphosphates.

The Sechura Desert in Peru contains a deposit of phosphate rock that is believed to be one of the world's largest. A recent report states that the deposit will be exploited, producing 2 million tons of phosphate rock concentrates per year as well as finished phosphate fertilizer.

Large phosphate deposits have also been found in Angola, but plans for developing them are indefinite.

DIRECT APPLICATION OF PHOSPHATE ROCK

In view of the shortage of phosphate rock, it may be questionable whether it should be used for direct application, which is rarely as effective as processing it into more soluble fertilizers. However, there are cases in which direct application may be justified because of the lack of processing facilities, or unsuitability of the rock for processing.

Rock for direct application should be carefully selected; only the most reactive rocks are effective. Examples of the most reactive rocks are those from Gafsa (Tunisia), Sechura (Peru), and North Carolina. Some phosphate from Israel, Morocco, Florida, and Algeria may be sufficiently reactive to be considered for direct application but they are usually somewhat inferior to the more reactive group. Most other commerical rocks are not reactive enough. Reactivity may vary considerably among samples from the same country or the same deposit.

Several tests are available for evaluating the reactivity of rocks and hence their suitability for direct application. One of these is the solubility in neutral ammonium citrate according to the AOAC procedure. Twenty percent or more of the P_2O_5 in the more reactive rocks is soluble in this reagent. The test is valid only when comparing rocks of about the same P_2O_5 content, say 30%-35%. If the rock is diluted with an inert material, a higher percentage solubility is obtained in the analytical procedure which gives an erroneous impression of reactivity. Other procedures are in use, such as solubility in citric or formic acid. Each of these methods can be useful in comparing the relative reactivity of phosphate rocks.

The effectiveness of phosphate rocks also depends on the soil and crops. Raw rock usually is more effective on acid soils. Fine grinding of the rock and uniform mixing with the soil is necessary for the best results.

The application of finely ground rock is inconvenient because of its dustiness. Mechanical application equipment is often ill suited for applying finely ground rock. Therefore, numerous attempts have been made to improve the handling properties by granulation with other fertilizer materials. Usually granulation impairs the effectiveness of the rock. Even though the granule breaks down in the soil by dissolution of the soluble component, the rock remains in a spot at the granule site so that it is not mixed with the soil. However, various granular materials are still being tested and some of them may be useful. One of these is granular urea-phosphate rock, which has been prepared in a pilot plant by TVA and is being tested in several countries.

One convenient method for preparing urea-phosphate rock would be to add the ground rock to the concentrated urea solution just before prilling. Small-scale tests at TVA indicate that prilling of such mixtures is feasible when the ratio of phosphate rock to urea is not more than about 2.3. The exact upper limit has not been established. The 2:3 ratio would produce grades in the range of 30-10-0 to 26-13-0 depending on the P_2O_5 content of the rock.

The prilling of urea-phosphate rock would be similar to prilling of ammonium nitrate-ground limestone mixtures which is done commercially in several plants. The feasibility and cost of converting an existing urea prilling facility to urea-phosphate rock prilling could best be determined by manufacturers of the prilling facilities. Obviously, additional equipment would be required to meter ground phosphate rock and preheat it and mix it with the concentrated urea solution. Also, the spray system might have to be modified. Most commercial facilities that prill mixtures of ammonium nitrate with limestone or other insoluble materials use a rotating conical basket spray system.

TVA has prepared granular urea-phosphate rock materials by use of a pan granulator. A flow diagram of the process is attached (figure B-1). A rough estimate of the cost of pan granulation facilities to produce 365 tons/day of granular 26-13-0 from 200 tons of urea and 165 tons of ground rock phosphate is $1.8 to $2.0 million for Southeast Asia location. Operating cost would be about $7/ton without or $10 with ROI.

Phosphate rock can be granulated with other fertilizer materials such as ammonium sulfate in existing granulation plants using steam, water, or sulfuric acid, or some combination of these as granulation aids. In fact, phosphate rock alone may be granulated with steam and acid. The amount of acid required is about 25% of that required to

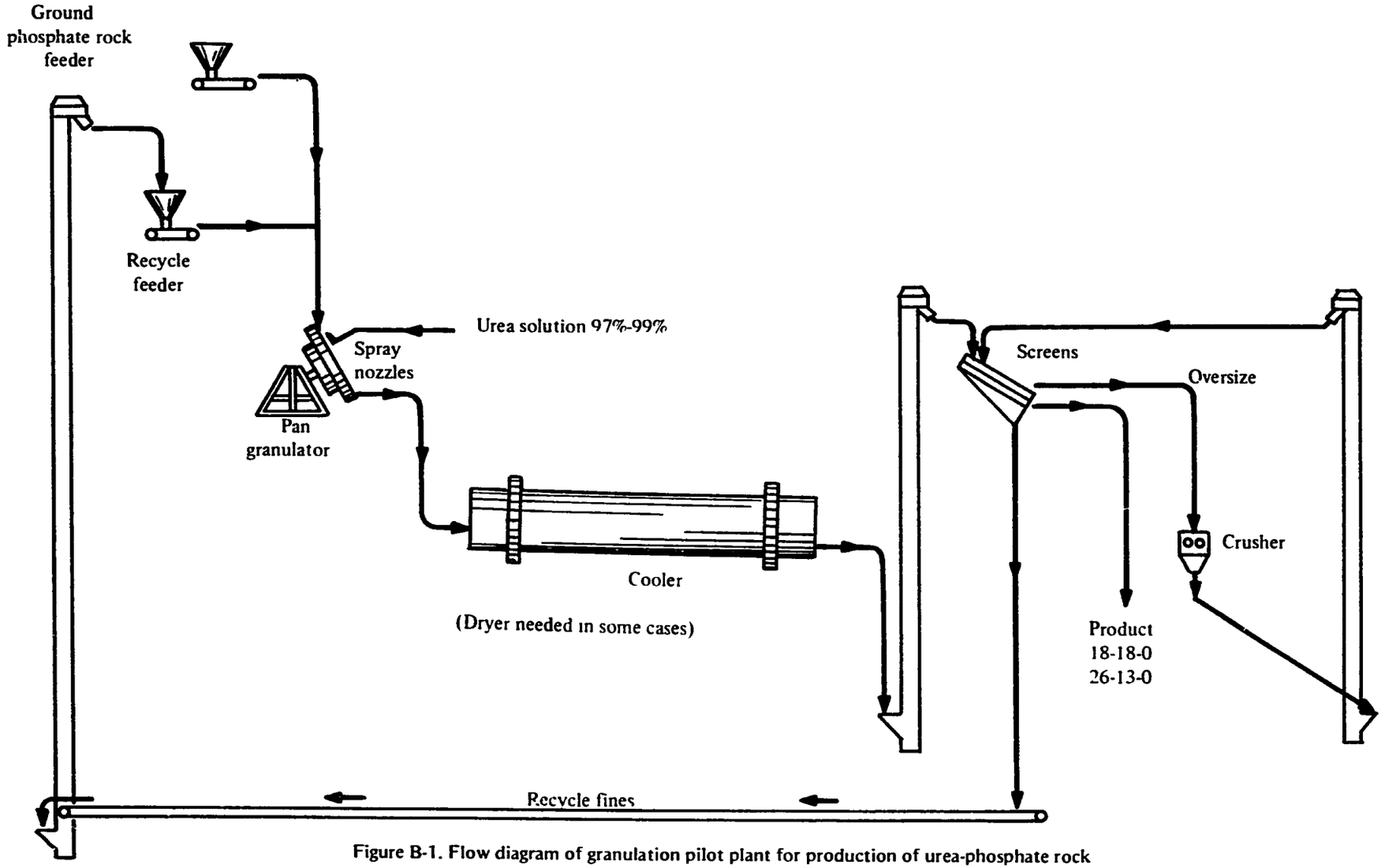

Figure B-1. Flow diagram of granulation pilot plant for production of urea-phosphate rock

make superphosphate. Use of sulfuric acid has the advantage that a portion of the P_2O_5 in the rock is rendered water-soluble and hence immediately available.

Certain aluminum phosphate ores are rendered citrate soluble by calcining at 400°-600°C. Commercially available sources of these ores are Christmas Island and Senegal. The Senegal aluminum phosphate ore is shipped to France where it is calcined and sold under the trade name "Phosphal." At Christmas Island the aluminum phosphate ore overlays the calcium phosphate ore and is removed and stockpiled to permit mining of the calcium phosphate ore. Some of the aluminum phosphate ore is calcined in a small facility on Christmas Island and sold under the trade name "Citraphos."

Calcined aluminum phosphate ores have been shown to be agronomically effective when applied in a finely ground condition. Unlike ground rock phosphate their effectiveness does not depend on acidity of the soil; they are also effective on neutral and calcareous soils. Tests with calcined aluminum phosphate that has been granulated before application have been disappointing. However, tests with granular urea-aluminum phosphate materials have not been completed.

RECOMMENDATIONS

In view of the scarcity and high price of phosphate rock, it should be converted into soluble phosphate fertilizers which are much more effective than the raw rock. As an exception, phosphate ores that are unsuitable for use in conventional fertilizers might well be used for direct application. These include the aluminum phosphate ores of Christmas Island and Senegal as well as small local deposits. Aluminum phosphate ores must be calcined at a carefully controlled temperature to make them effective. Phosphate rock of the calcium phosphate (apatitic) type varies widely in effectiveness. only the most reactive rock should be considered for direct application. Raw ground phosphate rock is effective only on acid soils whereas calcined aluminum phosphate is also effective on neutral and alkaline soils. Both types are more effective when applied in finely ground state. Granulation with other fertilizer materials is not recommended until there is clear evidence of agronomic effectiveness.

APPENDIX C

EVALUATION OF LIQUEFIED NATURAL GAS (LNG) FOR IMPORTATION TO THE PHILIPPINES FOR AMMONIA PRODUCTION

A vast worldwide trade in LNG is foreseen for the near-term (1975-1980). In 1972 at least 11 LNG tankers were in service; capacities range from 550 million to 1.56 billion ft^3 (as vapor) (*Oil Gas J.*, Sept. 11, 1972). Seven more are in operation by now and at least 16 more are in advanced stages of contracting or construction. Table C-1 outlines the scope of worldwide LNG operations as of 1972.

In addition to the operations listed in table C-1, the following are in various stages of planning.

Source	Companies	Destination	Volume million ft^3/day	Literature
Iran	Phillips & Japan	Japan	725 (1976)	OGJ 3-5-73
Iran	NIGC-Transco	U.S. East	750 (1976)	OGJ 10-8-73
Algeria	Sonatrach-Consolidated	U.S. East	150 (1976)	OGJ 10-8-73
Algeria	Sonatrach-Panhandle	U.S. Gulf	450 (1979)	OGJ 9-17-73
S.E. Asia	(See * table C-1)			
Indonesia	Pertamina-Pac. Ltng.	U.S. West	500 (1978)	OGJ 9-17-73
Indonesia	Pertamina (Indonesia)	Japan	-	OGJ 11-26-73
N. Sumatra	(Indo) Pertamina-Mobil	Japan	-	OGJ 3-26-73
Malaysia	Conoco, Esso, Shell	–	-	OGJ 6-11-73
Australia	(See □ table C-1)			

These data strongly indicate that LNG cannot be ignored as a possible feedstock for Philippine ammonia production. This is particularly true because of the recent (1971-present) big finds of oil and gas in Indonesia, Malaysia, Brunei, and Australia, all of which are in close productivity to the Philippines.

Obviously, the principal factors in an evaluation of importing LNG to the Philippines are availability and economics. Even though there is one producing LNG plant (Brunei) and four probable LNG plants in Southeast Asia, virtually all of the outputs have been contracted to the U.S. or, mostly, to Japan. However, it seems possible that the relatively small amount of LNG that probably would be required for NH_3 production in the Philippines (1,000 tons/day NH_3; 38,333,000 ft^3/day, therefore, 1,170,000,000 ft^3/month) could be "dropped off" by a standard LNG tanker on its way to Japan; the 1,170,000,000 ft^3 would be about one-third the capacity of the tanker.

The economics of LNG-based ammonia are difficult to assess, primarily because the c.i.f. prices of LNG are so speculative. Second, the storage facilities for a 30-day supply for a 1,000 tons/day NH_3 plant are also speculative, but very costly.

Table C-1 indicates that the c.i.f. price Brunei to Japan might be $0.49/1,000 ft^3; this would probably be the same for the Philippines except that freight rates have increased at least twofold since September 1972; and it is highly unlikely that any new contracts would be this low. F.o.b. Algeria price for LNG is $0.42/1,000 ft^3 (OGJ July 9, 1973), others will fall in line for new contracts. If, in 1972, short-haul freight on LNG was about one-half of the c.i.f. price (OGJ Sept. 11, 1972), the freight now should be more like $0.50/1,000 standard ft^3, making the present estimated c.i.f. $0.92/1,000 standard ft^3. In addition port storage, and vaporization costs would add about $0.05/1,000 ft^3, giving a total of $0.97/1,000 ft^3. The storage (30-day supply 8 million gallons) and vaporization facilities would also add about $10 million to the ammonia capital plant costs. Therefore, it should be possible to import LNG in the Philippines for about $1/1,000 ft^3. The costs estimated presented earlier in this report show that the ex-gate sales price of ammonia from a 1,000 tons/day plant would be $109.43/ton and from the curves it was determined the ex-gate sales price of urea would be about $99.00/ton. This is probably the most economical procedure for producing nitrogen fertilizers in the Philippines.

Table C-1. Liquefied natural gas projects—worldwide

Source/company	Destination	Start-up	Tankers involved	Price (c.i.f.) 1,000 ft^3
	In operation			
Algeria (Arzew) CAMEL Operator	England (Camvey)	1964	Methane Princess	76.5¢
	France (Le Havre)	1965	Methane Progress, Jules Verne	62.0¢
Algeria (Arzew) Sonatrach-Gazocean	Boston, Mass.	1968	Aristotle	$1.78
	Everett, Mass.	1972	Descartes	$1.20
Alaska (Nikiski) Phillips-Marathon	Japan (Negishi)	1969	Polar Alaska, Arctic Tokyo	52.0¢
Libya (Brega) Esso	Spain (Barcelona)	1971	Laieta	43.6¢
	Italy (La Spezial)	1971	Esso Brega, Portovenere, Liguria	39.0¢
Libya (Brega) Esso	East Coast U.S.	1972	Various	$1.23
	Building, contracted, or in advanced stage			
Algeria (Skikda) Sonatrach	France (Fos)	1972	Hassi R'Mel, Tellier	39.0¢
Algeria (Skikda) Sonatrach	New York (Distrigas)	1973	Descartes	$1.37
Algeria (Arzew) Sonatrach	E. Coast U.S. (El Paso)	1976	Three buildings, six more to be ordered	64.0¢-68.0¢ rising to $1.37
Algeria (Skikda) Sonatrach	Spain (Barcelona)	1974		45.0¢
Algeria (Skikda) Sonatrach	E. Coast U.S. (Eascogas)	1975	Five to build	90.0¢
Algeria (Dellys) Sonatrach	Germany	1977		41.0¢
	France (Fos)			
	Belgium (Zeebrugge)			
* Brunei (Lumut) Shell	Japan (Tokyo)	1972	Gouldia, Gadila, Gari, Gaztrana	48.6¢
	Coldas	1975	Gena, Genota, & Gadania	90.0¢
Iran (Kharg Is.) NIGC	Japan (Itoh)	1976	Five to build	80.0¢
Trinidad, Amoco	Gulf Coast U.S.	1976	Three to build	?
		1977		
		1978		
	Proposed			
Abu Dhabi (Das Is.) BP/CFP	Japan (Mitsui)	1976	Three ordered	80.0¢-$1.00
Alaska (Cook Inlet) various	W. Coast U.S. (Pac. Light)	?	Three to build	90.0¢
□ Australia (Palm Valley) Magellan Petro	Los Angeles (Pac. Light)	1977	Seven to build	$1.00
□ Australia (NW Shell) Burmah Group	Japan	1976	Four to build	?
Ecuador, Ada Group	W. Cost, E. Coast U.S.	?	?	90.0¢
Iran (Qeshm Is.) NIGC	Japan (Guji)	1977	Five to build	?
Nigeria, Shell/BP	East Coast U.S.	?	Eight to build	?
North Sea, Phillips Group	Germany, France, U.S.	?	?	?
Sarawak, Shell	Japan	1977	?	?
USSR (Baltic) Texas Eastern, *et al*	East Coast U.S.	?	Twelve to build	$1.00
USSR (Pacific) El Paso	W. Coast U.S., Japan	?	Twenty to build	$1.00
Venezuela, CVP	East Coast U.S.	?	Seven to build	?
* Indonesia, Pertamina	Japan (Bridgestone-Far E.)	?	?	?
	Possible			
Qatar, QPC	Japan (Bridgestone)	1980	?	?
Pakistan (Sui) Burmah Group	Japan	?	?	?
□ Australia (NW Shell) Burmah Group	West Coast U.S.	?	?	?
Nigeria, Gulf Oil	East Coast U.S.	?	?	?
Nigeria, Guadalupe-Gov't.	East Coast U.S.	?	?	?

Source: *Oil & Gas Journal*, September 11, 1972.

APPENDIX D

EVALUATION OF CRUDE OIL AND NATURAL GAS SUPPLY

The current crisis and the supply of crude oil and natural gas make it very difficult to render any advice as to sources and prices of these materials. The present attitude of the Organization of Petroleum Exporting Companies (OPEC) has greatly aggravated the worldwide shortage of both crude oil and natural gas. However, it is not fully responsible for it, since this shortage has been increasingly apparent to the experts for a number of years The failure to provide incentives for worldwide exploration for additional petroleum and gas revenues is probably one of the major causes for these shortages However, exploration is now being carried out at a rapid pace and numerous crude oil and gas discoveries in Southeast Asia are being reported. Indonesia, Malaysia, and Northern Australia have recently reported discoveries of both crude oil and natural gas. Many of these new discoveries are already in commercial production and many more should be in production within the next few years. By 1980 both oil and natural gas should be available in sizeable quantities.

Prices of these hydrocarbons have been very unstable and are steadily increasing The market price for crude oil is now about $8 to $12/bbl f o b Indonesia and the f.o.b. price for natural gas is about 35 cents/1,000 ft^3 Most of the Southeast Asian new discoveries have tied up with Japanese firms and in a few instances U S companies. Therefore, it may be difficult to purchase either petroleum or natural gas from these sources

Table D-1 shows known crude oil and natural gas reserves This information should be helpful to the Philippine Government in establishing a source of a crude oil or liquefied natural gas for use as feedstocks in their ammonia plants

Table D-1. Known worldwide crude oil and natural gas reserves

Country	Reserves 1-1-74 Oil (1,000 bbl)	Reserves 1-1-74 Gas (billion ft³)	Wells producing oil 7-1-73
Asia-Pacific			
Afghanistan	89,840[a]	4,900	13
Australia	2,300,000	37,700	394
Bangladesh	–	8,000	–
Brunei–Malaysia	1,600,000	20,000	126
Burma	67,800	200	700
China Rep. (Taiwan)	14,000	400	50
India	779,000	2,000	1,500
Indonesia	10,500,000	15,000	2,567
Japan	19,000	700	1,084
New Zealand	224,000[a]	15,000	4
Pakistan	31,200	10,120	16
Philippines	–	180	–
Thailand	10,200	–	25
Total–Asia-Pacific	**15,635,040**	**114,200**	**6,479**
Europe			
Austria	157,000	589	1,250
Denmark	248,500	1,800	4
France	80,000	6,500	284
Germany, West	544,000	12,308	2,782
Italy–Sicily	212,000	5,300	125
Netherlands	251,000	92,000	319
Norway	4,000,000	23,000	4
Spain	60,000	500	26
United Kingdom	10,000,000	50,000	63
Yugoslavia	438,000[b]	1,800	1,012
Total–Europe	**15,990,500**	**193,797**	**5,869**
Middle East			
Abu Dhabi	21,500,000	12,500	142
Bahrain	360,000	4,000	215
Dubai	2,500,000	1,000	39
Iran	60,000,000	270,000	350
Iraq	31,500,000	22,000	133
Israel	2,500	25	29
Kuwait	64,000,000	32,500	692
Neutral Zone	17,500,000	8,000	362
Oman	5,250,000	2,000	97
Qatar	6,500,000	8,000	92
Saudi Arabia	132,000,000	50,900	627
Sharjah	1,500,000	1,500	–[c]
Syria	7,100,000	700	123
Turkey	450,000	200	286
Total–Middle East	**350,162,500**	**413,325**	**3,187**
Africa			
Algeria	7,640,000[d]	105,945	574
Angola–Cabinda	1,500,000	1,500	169
Congo Brazzaville	4,888,000	1,000	19
Egypt	5,125,000	4,200	261
Gabon	1,500,000	6,500	122
Libya	25,500,000	27,000	895
Morocco	750	25	22
Nigeria	20,000,000	40,000	898
Tunisia	950,000	1,500	56
Zaire[e]	200,000	50	–
Total–Africa	**67,303,750**	**187,720**	**3,016**
Western Hemisphere			
Argentina	2,500,000	8,000	4,096
Barbados[f]	250	–	–
Bolivia	260,000	10,000	253
Brazil	799,000	921	1,265
Chile	124,000	3,400	466
Colombia	1,432,000	2,500	2,023
Ecuador	5,675,000	5,000	829
Mexico	3,600,000	11,000	4,345
Peru	1,050,000	3,500	2,499
Trinidad & Tobago	2,200,000	5,000	2,932
Venezuela	14,000,000	42,000	12,461
United States[g]	34,700,249	247,310	503,505
Canada	9,424,170	50,299[h]	22,996
Total–Western Hem.	**75,764,669**	**388,930**	**557,670**
Total Non-Communist	524,856,459	1,297,972	576,221
Communist World	103,000,000[i]	735,400[j]	–
Total World	**627,856,459**	**2,033,372**	**576,221**

[a]Condensate
[b]Government estimate adjusted
[c]Not yet producing
[d]Revised
[e]To go on production at 25,000 bbl/day in 1975
[f]Oil or gas discovered but not developed
[g]Includes Alaska 10 billion.
[h]Does not include Arctic gas
[i]Including Russia with 80 billion, Red China 20 billion, and others 3 billion
[j]Including Russia 706 trillion, Red China 20 trillion, Hungary 3 trillion, and others 6 4 trillion