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NITROGENOUS FERTILIZERS BASED ON NATURAL GAS

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Nitrogenous fertilizers based on natural gas

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NITROGENOUS FERTILIZERS BASED ON NATURAL GAS

Introduction

In countries where natural gas is at present being flared, efforts have been focused at utilizing this wasted and unreplenished natural resource. Products derived from natural gas are numberous although they have been concentrated mainly in the field of nitrogenous fertilizers and raw materials for plastics. The products discussed in this paper are ammonia, ammonium nitrate, ammonium sulphate and urea.

Data on investment and other inputs as well as illustrative cost structure are presented and analyzed for these industries. These data are basically derived from the United States' experience and are obtained from engineering consultants. Some data incorporated in this part of the study were also based on surveys made by experts and consultants for establishing such industries in developing countries. Using these data as a background, an attempt is made to point out differentials that may be encountered when applying these data in developing countries.

The data used here are based on a given technology for each of these products. Alternative technologies, however, have been mentioned briefly in Section 1 of this study. It should be noted that consideration of one technology imposes a limitation on the scope of analysis when related to developing countries, in which case raw material and other input requirements as well as local market conditions may dictate the use of alternative technologies.

Section 1 of the study is devoted to a brief description of products, their uses and production processes. Section 2 presents statistical data covering recent trends on production, consumption and trade of these products. Section 3 is devoted to an analysis of fixed investment, labour and other inputs. In Section 4, an illustrative cost structure depicting the United States' experience is presented and analyzed.

Section 1

Product Description and Processes

Ammonia (NH_3). Synthetic ammonia is a basic chemical which is consumed mainly in the production of nitrogen fertilizers in addition to several other industrial uses. It is utilized in the production of such products as ammonium nitrate, ammonium sulphate and urea. In recent years the direct application of anhydrous ammonia to the soil is also coming into increasing use in the United States as will be shown later in this study. The main reason for this rapid growth is that ammonia is the cheapest source of nitrogen for agriculture, once the methods of utilizing it directly were worked out. The fact that its direct application requires rather advanced farming techniques and additional investment on the part of the farmers would limit its use in the developing countries. Moreover, a solution of ammonia in water may also be produced and is often mixed with other nitrogenous solutions. These solutions may be injected directly into the soil. However, the need for specialized equipment, although not as expensive and technically advanced as for anhydrous ammonia, would still impose some limitations on its use in under-developed countries. On the other hand, in these countries adding ammonia in the aqueous form to irrigation water may prove to be highly successful provided that proper care is used in its application.

As regards other industrial uses, large quantities of anhydrous ammonia are utilized for operating refrigeration machinery both in storage and in transportation, especially in the United States and in Europe. It is also very useful in the engineering industries for nitriding. Its chemical uses include the manufacture of soda ash by the ammonia soda process, the production of hydrogen cyanide, acrylonitrile and other products.

Carbon dioxide is produced as a by-product in manufacturing synthetic ammonia, and when highly purified from traces of oil, can be used for the production of solid carbondioxide or "dry ice". This has considerable application in the refrigeration industry, notably for ice cream manufacture, as well as in atomic energy plants and in the engineering industries.

Ammonia can be synthetized by different routes, but all of them imply the use of a large amount of hydrogen for fixing the nitrogen extracted from the atmosphere. The choice of processes for recovering hydrogen depends essentially on availability of raw material. Most of the recently built ammonia plants, however, have natural gas as raw material. Producing ammonia from natural gas involves one or two processes, the steam-methane reforming process or the partial oxidation process; the former process is preferred because, inter alia, it does not have as many operating problems as the partial oxidation process, and for small and medium size plants it requires less amount of capital investment.

Ammonium Nitrate (NH_4NO_3). One of the most important nitrogen fertilizers is ammonium nitrate. It has a high nitrogen content (33.5 per cent)[1/] and is a quick-acting fertilizer for crops. Its use as a fertilizer was limited because of its tendency to explode and it had the tendency to coalesce in large blocks ("tombstones") instead of remaining in a granulated form more suitable to feed crops. This inconvenience was overcome by granulating ammonium nitrate and coating the granules with clay or diatomacious earth. Ammonium nitrate is also the starting point of several explosives. Another use of ammonium nitrate is in the manufacture of nitrous oxide, which is also used as an anesthetic.

The process to produce ammonium nitrate consists of two stages, the first involves the oxidation of ammonia to nitric oxide (NO), further oxidation of nitric oxide to nitric dioxide (NO_2) which is absorbed in water to form nitric acid. In the second stage, the nitric acid reacts with the required quantity of ammonia to produce ammonium nitrate.

Urea ($NH_2CO\ NH_2$). It is a product of versatile use. Its major use, however, is as a fertilizer where its advantage lies in high nitrogen content, 46 per cent. It also has large application as raw material for thermoplastic resins; urea-formaldehyde compounds are used in glue and plywood manufacture.

There are many urea processes in operation. These include the I.G. Farben process, DuPont, Imperial Chemical Industries, Montecatini, Dutch State Mines, Pechiney - Grace, Chemico and Inventa-Vulcan. Ammonia and carbon dioxide are combined under pressure to form ammonium carbamate.

1/ Pure ammonium nitrate has a content of 35.0% of nitrogen.

This is dehydrated to form urea and water. Unreacted ammonia and carbon dioxide are released, which are recycled or converted into by-products such as ammonium nitrate or ammonium sulphate.

Ammonium Sulphate ($(NH_4)_2SO_4$). It is a widely used fertilizer and has been in use for many years. Ammonium sulphate presents some advantages in respect to other nitrogenous fertilizers, it is easy to handle and ship and does not set in bulk, as ammonium nitrate. In preparing the conventional mixed fertilizers, ammonium sulphate is required in order to give these fertilizers the proper physical conditions.

Until twenty years ago, ammonium sulphate was manufactured in the United States almost entirely as a by-product of the coke-plants of the steel industry. When the demand for nitrogenous fertilizer began to increase during the war at a steadily accelerating rate, new plants were built in which synthetic ammonia was combined with concentrated sulphuric acid to produce ammonium sulphate.

As it is well known, natural gas may contain sulphur. This may be used as an alternative source to mined sulphur for use in production of ammonium sulphate. Certain countries have natural gas rich in hydrogen sulphide (the so-called "sour" gas), such as occurs in Arkansas, West Texas and Wyoming in the United States. Methods have been developed for removing hydrogen sulphide to purify the natural gas, and hydrogen sulphide thus obtained is utilized to make sulphur or sulphuric acid.

Where sulphuric acid is not available but there are convenient deposits of anhydrite or gypsum (calcium sulphate), ammonium sulphate can be made using either of these minerals as a source of sulphur; this alternative process is not used in the United States, but is employed on a large scale in Western Europe.

Section 2

Production, Consumption and Trade

The use of nitrogenous fertilizers has been increasing steadily along with other synthetic fertilizers. Table 1-below indicates world consumption of fertilizers for selected years in the last two decades. The consumption of nitrogenous fertilizers since 1947/48 has been increasing at an average of roughly 500,000 tons per year.

Table 1. World Fertilizer Consumption

(In thousand metric tons) a/

Year	Nitrogenous (N)	Phosphate (P_2O_5)	Potash (K_2O)	Total
1937/38	2,485	3,678	2,960	9,123
1947/48	3,109	5,017	3,104	11,230
1950/51	4,191	6,208	4,514	14,913
1955/56	6,630	7,840	6,830	21,300
1959/60	9,220	9,530	8,380	27,130

Source: Food and Agriculture Organization of the United Nations, Monthly Bulletin of Agricultural and Economic Statistics, "Long-Term Trends of World Fertilizer Consumption", (Rome, February 1962), p.l.

a/ In equivalents of plant nutrients (active components)

The rate of growth for the group of nitrogenous fertilizers, during the post war period, has been faster than that of the other two groups, namely 8.4 per cent per annum as compared to 7.6 per cent and 4.9 per cent respectively for the potash and phosphate fertilizers. This resulted in an increase in the share of nitrogen at the expense of phosphate. Whereas in 1947/48 nitrogen's share was 28 per cent of total chemical fertilizers, and that of phosphate 45 per cent, by 1960 the consumption of the three major groups of fertilizers was shared roughly equally by the three types of fertilizers.

The various types of nitrogenous fertilizers are shown in Table 2 below. Ammonium sulphate and ammonium nitrate share between them over half of the world total. Ammonium sulphate, however, has been losing its predominant position and its share is being gradually equalized to that of ammonium nitrate. Other fertilizers that have decreased their share in total consumption include ammonium sulphate nitrate, sodium nitrate, calcium nitrate and calcium cyanamide.

Table 2. World Production of Nitrogenous Fertilizers by Products, 1954/55 - 1959/60
(Percentages of total output, unless otherwise specified)

Item	1954/55	1955/56	1956/57	1957/58	1958/59	1959/60
Ammonium Sulphate	31.2	31.6	30.0	28.7	28.5	26.0
Ammonium Nitrate	25.2	24.8	23.9	24.6	23.6	24.8
Urea	2.3	2.8	4.7	5.1	6.2	6.4
Combined Fertilizers	5.1	6.0	7.9	8.3	8.7	9.5
Ammonium Sulphate Nitrate, Sodium Nitrate, Calcium Nitrate, & Calcium Cyanamide	16.6	14.2	14.8	14.3	12.1	11.1
Other	19.6	20.7	18.8	19.1	21.0	22.3
Total	100.0	100.0	100.0	100.0	100.0	100.0
Total in Thousand Metric Tons of (N.)	5,600	5,932	6,469	7,030	7,689	8,007

Source: Food and Agriculture Organization of the United Nations, An Annual Review of World Production, Consumption and Trade of Fertilizers, 1959, 1960.

Urea, the newcomer to the field, and combined fertilizers, have been increasing their share of the market. The share of "other" fertilizers that include mainly anhydrous ammonia, aqua ammonia, ammonium nitrate-water solution, and a combination of ammonia, ammonium nitrate and urea dissolved in water, has also been increasing. Their use has been, however, confined mainly to the United States.

The important consumers of nitrogenous fertilizers are the advanced countries. Europe and North America (mainly the United States) shared roughly 73 per cent of the total world consumption in the two years 1959-1960. In the same period, Asia followed with 14 per cent half of which was consumed by Japan alone and the remaining by other countries of the region. The Soviet Union accounted for 8 per cent of the balance and the rest of the world 5 per cent.

The unbalanced pattern of world consumption may also be indicated by the average consumption of nitrogen per hectare of arable land. Europe's estimated consumption in 1958/59 was by far the highest amounting to 24 kilogrammes per hectare, followed by North and Central America 10.5 kilogrammes, Asia 4.1 kilogrammes, and USSR 3.1 kilogrammes; for the rest of the world, consumption ranged between 1.2 and 1.9 kilogrammes.

International trade in nitrogenous fertilizers comprised an important part of world output; export averaged 28 per cent of the total production in the two years 1959-1960. Europe is predominant as the exporting region accounting for 65 per cent of total export in the same period, followed by North America 15 per cent, South America (Chile) 6 per cent and Asia (Japan) 13 per cent with the USSR handling the remaining 1 per cent. Europe imported in the same priod 38 per cent of the total followed by North America 23 per cent, Asia 25 per cent, Africa 9 per cent, with South America, Oceania and the USSR sharing the remaining 5 per cent of the market. Table 3 summarizes production, consumption and surpluses or deficits for two selected years by major regions.

Table 3. Production, Consumption and Surplus or Deficit, 1955/56 and 1959/60

(in thousand metric tons (N))

Region	Production	Consumption	Surplus (+) or Deficit (-)
1955/56			
Africa	38	203	-165
America, North and Central	2,246	1,959	- 45
America, South	227	112	+ 109
Asia	813	1,075	- 311
Europe	3,359	2,780	+ 440
Oceania	19	26	- 7
USSR	500 a/	479	+ 24
World Total	7,202	6,634	
1959/60			
Africa	59	230	- 169
America, North and Central	2,860	2,845	- 150
America, South	206	168	+ 12
Asia	1,100	1,269	- 223
Europe	4,830	3,968	+ 897
Oceania	25	33	- 8
USSR b/	740	709	+ 31
World Total	9,820	9,222	

Source: Same as Table 2.

a/ Estimate

b/ Referring to July through December 1959

An order of magnitude of possible future requirement for nitrogenous fertilizers in the developing regions has been estimated at 30 million tons by 1980.[2/] This compares with a low volume of 4 million tons reported for these regions in 1960. By 1980 the world total was estimated at 70 million tons, assuming a moderate increase in the consumption of fertilizers for the rest of the world. Estimates for the developing regions were derived primarily as follows:

(i) Targets of food requirements were set at 174 to 219 per cent of a base year[3/]. A moderate rate of growth in fertilizer consumption was assumed for countries that have already attained a high use of fertilizers such as Japan and China (Taiwan).

(ii) Average relationship between the value index of crop production and input of fertilizer used per arable hectare in 41 countries in the years 1956-1958 was established. This average relationship was used as a basis for calculating the quantity of fertilizers needed to attain the set targets.

It should be emphasized that the figures given above are not projections of effective demand for fertilizers. They are estimates of requirements that may be needed to attain defined nutritional goals under

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2/ F.W. Parker, "Fertilizers and Economic Development", paper delivered at the Fertilizer Workshop, American Society of Soil Science, Purdue University, February 1962. Estimates for developing countries include 5.0 million tons for China (Mainland).

3/ Set Targets for 1980 (1960 = 100)

Africa	174
Asia and Far East	219
Latin America	194
Near East	190

given assumptions. These goals assume, inter alia, a sustained rate of growth in agricultural output, ranging between a rate of about 3 per cent for Africa, and of 5 per cent for Asia and the Far East. To emphasize the magnitude of such a task, one may refer to the fact that a sustained 5 per cent growth in agricultural output has not been attained in the past by any of the world regions; and only a few countries have succeeded in attaining such high goals for a period extending over ten years. It may be mentioned at this point that these production goals in agriculture compare favourably with those incorporated in the development plans of various developing countries.4/

4/ Parker, op. cit.

Section 3

Fixed investment and other inputs

Fixed investments: these include cost of processing equipment; auxiliary facilities that include utilities, such as a power and steam supply, and cooling water facilities, etc., equipment for laboratories and workshops; buildings and structures; erection cost for equipment, building and structures; as well as miscellaneous costs that include design and engineering fees and allowance for contingencies.

The major components of fixed investment for the fertilizer plants under consideration are: process equipment sharing between 25 and 35 per cent of total investment, erection of process equipment between 10 and 15 per cent, utilities and auxiliaries between 10 and 20 per cent. Because most equipment is installed outdoors, buildings for these plants include mainly facilities for offices, control room, laboratory and workshop, and they share a small part of total investment, roughly between 5 and 10 per cent. The rest of fixed investment goes to design and engineering fees and investment overhead.

Table 4 indicates the fixed investment of new plants in the United States for the several products discussed in this paper. These costs represent plant investments[5/] and they refer to the supply and erection of process equipment required to manufacture the products in given size plants. They refer to small- to medium-size plants. The following are the additional costs that have to be faced:

5/ In the United States this investment is referred to as "battery limits". The investment figures given in the text are "turn key" and presented on a United States Gulf Coast basis.

(i) Purchase of land on which to erect the plant and its amenities.
(ii) Installation of foundations, drains, roads and fences.
(iii) Transportation of equipment from the place of purchase.
(iv) Installation of services such as power and steam supply.
(v) Provision of cooling water facilities, including circulation towers, if necessary.
(vi) Construction and equipment of laboratories and workshops.
(vii) Administration offices and medical services.
(viii) Canteens and lavatories
(ix) Storage and packing facilities.

As a general guide, it can be taken that plant investment should be about doubled to arrive at the total fixed investment of the factory[6/]. If the site is in an isolated area, provision of housing and other amenities is required for the staff and workers.

Investment in the plants under consideration obviously involves economies of scale; that is total investment increases less than proportionately to plant capacity. The investment figures derived from the capacity coefficient given in this paper indicate that quadrupling the capacity of an ammonia plant would require tripling total investment.

There are several reasons for this well known behaviour of fixed investment. Doubling the capacity of unit equipment such as converters, heat exchangers and preheaters would require less than double the steel, and labour requirements for producing larger units also increase less than proportionately, with a consequent decrease in unit cost of producing larger units of equipment. A substantial increase in plant capacity would

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6/ In the engineering and trade circles of the United States this is referred to as "grass roots investment".

also require a smaller expansion in some of the auxiliary facilities such as workshops and laboratories, and erection cost behaves in a simil r way.

Table 4 gives the capacity exponent for several products. It should be emphasized that these exponents are at best a first approximation and are in no way a substitute for a detailed investigation of any particular size plant under consideration. They are applicable only within a certain range of plant capacities.

Table 4. Plant investment in the United States
Total and per ton of annual capacity

Product	Annual capacity (in thousand tons)	Plant investment		Capacity coefficient b/ (in percentage)
		Total (in million dollars)	Per ton of annual capacity (in dollars)	
Ammonia	66	4.1	62	0.88
Ammonium Nitrate	50	2.5	50	0.71
Urea	40	2.6	65	0.67
Sulphuric Acid	66	1.2	18	0.65
Ammonium Sulphate	50	2.4	48	0.65

Source: "Utilization of Natural Gas in Petrochemical and Other Industries"; paper prepared by the Division of Industrial Development and the Department of Economic and Social Affairs, United Nations and presented at the Second Symposium on the Development of Petroleum Resources of Asia and the Far East, Teheran 1-15 September 1962.

a/ The Ammonia plant is based on the steam-gas pressure reforming process, and it is assumed that gas engine driven compressors would be used. The major equipment required includes steam raising capacity, primary reformer, secondary refermer, CO shift reactor, CO_2 stripper, CO absorber, CO stripper, compressors, circulators, heat exchangers, NH_3 convertor and ammonia storage facilities.

The Ammonium Nitrate unit includes a nitric-acid unit of high-pressure type. Ammonium nitrate is produced as prills. Major equipment included in the nitric acid plant are air compressors, ammonia convertors, waste heat boilers, absorption and bleaching columns, pumps and storage tanks. For the ammonium nitrate plant, a neutralizer, evaporator, prilling tower, drier, cooler and bagging equipment are required.

a/ (continued)

The Urea unit is of the "total recycle" type, and includes facilities for prilling. Major equipment includes a reactor, first and second stage condensers, prilling tower, crystallizer, CO_2 compressor, condensator, dryer, NH_3 pre-heater, first and second stage distillers, urea solution concentrator, filler press, centrifuge, separators, pumps and drums.

The Ammonium Sulphate plant consists of two parts. In the first, sulphur is converted into sulphuric acid, which requires a sulphur burner, gas cooler, heat exchanger, sulphur dioxide converter, sulphur trioxide absorption system, acid storage tanks. The second plant requires vacuum crystallizer, centrifuge, drying and bagging equipment.

b/ This is an engineering coefficient. It is the same as elasticity of investment which implies a constant rate of growth for total investment in response to changes in capacity. The following formula defines the relationship with (a) as the constant elasticity, (C) as capacity and (I) total investment:

$$\frac{C_x}{C_y} = \left(\frac{I_x}{I_y}\right)^a$$

This functional relationship when plotted on a logarithmic chart shows itself as a straight line.

Several points may be explored at this stage. It is well known that the increase in plant capacity that yields returns to scale cannot be expected indefinitely. There is a maximum capacity beyond which no return to scale is possible and a further increase in production can be achieved only by adding new units of production. The maxima plant capacity involved vary from industry to industry and change of course with the technology. The economically acceptable plant sizes impose a limit on the other extreme, since because of a steep rise in unit cost of equipment with decreasing capacity, there is a minimum below which it is not economically feasible to operate. Several capacities are illustrated for most products under consideration elsewhere in the paper, and they include both small and large scale operations based on United States experience. These, however, are not necessarily identical with the minimum or maximum scales in the United States. It will be kept in mind that these maxima and minima, particularly the latter, would vary from country to country, depending on the technological feasibilities as well as the economic and market conditions in each country and plant location.

To illustrate this, in the United States, unless under exceptional conditions, it would be extremely unlikely if a new ammonia plant were to be installed with a capacity of less than 180 tons per day, and this would apply to most Western European countries as well. Under different economic parameters such as exist in developing countries, a minimum capacity as low as 30 tons per day may prove to be economical.

Capital saving may be derived from the integration of several fertilizer plants on the same site. Such saving is attained as a result of the utilization of several common auxiliary facilities as well as of reduced installation cost. Fertilizer complexes may include facilities for production of ammonia, ammonium nitrate, ammonium sulphate, and urea. The factory would produce ammonia, part of which would be converted into ammonium nitrate, part into urea and part into ammonium sulphate, thus giving a complete range of nitrogenous fertilizers.

Two hypothetical examples of a large and a small complex of nitrogenous fertilizers grouped in one factory may be as follows:

Product[a/]	I Daily Capacity	II Daily Capacity
Ammonia	140 S. tons	520 S. tons
Ammonium Nitrate	150 " "	500 " "
Urea	60 " "	300 " "
Ammonium Sulphate	150 " "	500 " "

a/ Ammonia required per ton of output: 0.460 tons for Ammonium Nitrate, 0.575 tons for Urea, and 0.258 tons for Ammonium Sulphate.

A United States consultant firm, that supplied the above information on these complexes estimated fixed investment at between 20 and 30 per cent less than when individual plants of the stated capacities are built on different sites.

So far, investment has been analyzed for an advanced country, namely the United States. A differential in investment will arise in under-developed countries because of added ocean freight and insurance on imported equipment and materials, import profits and difference in cost of erection. As regards the latter, it is likely that the lower wage rates in under-developed countries may be offset at least in part by the low factor performance. Furthermore, high cost of specialized engineers and technicians, as well as skilled labour, generally have to be imported for that purpose; the cost of services of these specialists is higher than in their own countries.

An indication of the order of magnitude of the differential in fixed investment may be taken from a survey prepared by a German consultant for the utilization of natural gas of an under-developed country in the Middle East. The survey was based on the experience of the Federal Republic of Germany with adjustment to the conditions of the Middle Eastern country. Assuming the purchase prices of equipment are the same in both cases, the cost of ocean freight and insurance (between 13 and 15 per cent of equipment cost) was added to the cost of equipment in the Federal Republic to arrive at the equivalent cost in the Middle Eastern country. Whereas local wages were lower than in the Federal Republic, they were more than offset by the additional labour required because of lower labour performance. Cost of German personnel required for erection of these plants was more than twice that in the Federal Republic. Furthermore, it was estimated that building and construction unit cost for practically all components of construction was between 130 and 300 per cent higher in this under-developed country; the only exception was the cost of asphalted roads which was estimated at half the German cost.

The cost of investment for the Federal Republic of Germany was recomputed by adjusting for the ocean freight and insurance on equipment, labour and construction costs. The resulting figures showed that the cost of investment for the Federal Republic was between 10 and 15 per cent lower than that suggested for the under-developed country. The investment cost differential would be still higher than that suggested by these figures but for the fact that in computing the investment cost for the Federal Republic some items were left unadjusted; such as the cost of additional buildings required for equipment on account of the difference in climatic conditions in both countries.

Fixed investment discussed so far refers to direct investment in the plant proper; in developing countries additional investment may have to be incurred in economic and social infrastructure, such as housing and other social amenities for the labour force, transportation, power generating and water supply facilities. This type of investment would vary from one country or location to another and in some cases, it may be rather substantial. Such investments, however, have been treated independently of direct investment elsewhere in this study, since it affects production cost through factors of production other than direct investment, i.e. cost of labour, power, transportation, water, etc.

Operating capital may also be mentioned at this stage. In developed countries this may amount to about between 25 and 30 per cent of fixed capital. High operating capital is needed because of the seasonal characteristic of demand for fertilizers. It is expected that this type of capital would be much higher in developing countries because of higher inventories and costs of such items as spare parts, raw materials, etc. The magnitude of the differential between developed and under-developed countries is not possible to ascertain and research into this aspect is needed.

Other inputs: Owing to the large degree of mechanization included in the design of such plants, the labour required for the actual operation of the plant itself is small. Table 5 indicates operating labour required for the various products under consideration. To arrive at total labour requirement one should add maintenance labour as well as labour needed in operating and maintaining the auxiliary activities. Total labour requirement is at least twice that of operating labour.

Another important feature of labour input is the economies of scale obtained with the increase in scale of operation. The number of operators varies only slightly with the capacity of the installation. Furthermore, supporting labour in the auxiliary activities, such as maintenance labour, increases less than proportionately to capacity.

Table 5. Operating labour requirement in nitrogenous fertilizer plants, United States

Plant	Annual capacity (in tons)	Number of workers per 3 shift a day	Man-hour per ton[a] capacity
Ammonia	66,000	12	0.36
Ammonium nitrate	82,500	12	0.29
Urea	40,000	9	0.45
Ammonium sulphate	50,000	12	0.48

Source: Same as Table 4.

a/ Assuming 2,000 working hours per man per year.

It will also be noted that the possibilities of labour-capital substitution in these industries are not very great. The "core" operations in these plants require a highly specialized and automated equipment specifically designed for the chemical reactions needed. It is not possible to modify the equipment specifications, without impairing the technical process or the quality of product, so as to accommodate for more intensive utilization of labour at the expense of equipment. In the auxiliary activities, however (such as internal transport, maintenance) limited labour capital substitution may be possible. On the other hand, integration of several plants into a complex which leads to sharing of labour in the common auxiliary activities would reduce labour requirement.

So far as labour requirements in developing countries are concerned, it is unlikely that direct operating labour in the plant proper would differ significantly from what prevails in developed countries. Such plants are highly mechanized and the few men required should be as qualified as their counterparts in the industrialized countries, which is a question of training. Contractors supplying such plants are experienced in arranging training classes for operating and maintenance men; some of them would be trained on the job in similar plants to become familiar with the operations. Labour requirements in auxiliary activities, on the other hand, may be higher in developing countries because of generally lower levels of performance and of the possibility of some capital-labour substitution.

Other inputs include natural gas, utilities, water, catalysts, chemicals, and sulphur. In Table 6 below inputs required for these industries are given in physical units per ton of product. So far as these inputs are concerned, there are no economies of scale, such inputs being correlated directly with the increase in output.

Table 6. Consumption of certain major inputs per ton of output of indicated nitrogenous products

Product	Natural gas feed a/ (in standard cubic feet)	Electricity (in Kwh)	Water (in gallons)	Steam (in tons)	Sulphur (in tons)
Ammonia	23,100 c/	90.75	5,170	- c/	-
Ammonium Nitrate	-	49.5	1,980	2.8	-
Urea	-	33.0	3,850	1.5	-
Ammonium Sulphate	-	27.5	1,100	-	0.263

Source: Same as Table 4.

a/ Natural gas with caloric value of 1,050 BTU per cubic foot.

b/ It is assumed that water used is recirculated; these figures then refer only to water lost in the operation (make-up water).

c/ An additional volume of 17,600 cubic feet of natural gas is used for fuel per ton of output.

Section 4

Production cost

Estimated costs of production have been constructed for the several products under consideration. These calculations are based on rough approximations and engineering coefficients taken from United States' experience. They do not reflect actual performance of any particular plant and are used here for illustration purposes.

It is intended to use these data as benchmarks to explore the differences in cost components that may arise in an under-developed as compared to a developed country, namely, the United States. Table 7 summarizes the share of the major cost components in production cost.

This table indicates that in the United States depreciation cost ranges between 23 and 28 per cent of production cost. As mentioned earlier, investment is likely to be higher in under-developed countries as compared to developed countries for the reasons enumerated above. If one assumes the same rate of depreciation and the same size of plants, then for a developing country, an additional cost of fixed capital of the order of 10 to 20 per cent would imply a rise in the cost of production of about 2 to 6 per cent.

Because of inadequate maintenance - due to lack of skills and organization - there will be a faster physical depreciation of equipment which will have to be reflected in a higher rate of accounting depreciation in the under-developed countries, and hence a higher production cost would ensue. On the other hand, in the longer run, an under-developed country that has a supply of labour at relatively low cost should be in a position by proper training of labour and organization and more intensive maintenance practices actually to lengthen the physical life expectancy of equipment and machinery. In the longer run, it may thus be expected that depreciation would be spread over a longer period with possible reduction in production cost.[7/]

Another important aspect that may be mentioned is the possible low performance in production in under-developed countries as compared to production standards in advanced countries. This may be attributed mainly to poor management and labour practices. Such cases would result in an appreciable rise in unit production cost because fixed capital charges have to be allocated over a relatively small output.

Table 7. Distribution of major cost components and total production cost in the United States

(per cent of total)

Product	Depreciation	Interest	Natural Gas	Utilities	Operating Labour	Supervision and Plant General	Maintenance	Others	Total	Total (in dollars per ton)
Ammonia	23.5	15.0	29.5[a/]	3.6	5.1	6.9	8.5	7.9	100.0	34.63
Ammonium nitrate[b/]	23.9	15.3	12.5[a/]	15.5	6.1	8.7	9.7	8.3	100.0	37.44
Urea[b/]	27.5	17.6	11.6[a/]	7.7	6.6	9.4	11.4	8.2	100.0	50.09
Ammonium sulphate[b/]	23.3	14.7	6.8[a/]	1.8	7.7	10.4	9.7	25.6[c/]	100.0	38.29

7/ For a further treatment of depreciation in developing countries, see United Nations, Bulletin on Industrialization and Productivity, "Use of Industrial Equipments in Under-developed Countries", No. 4 (Sales No.: 60 II.B.2).

<u>Source</u>: Data on fixed investment, labour and other input requirements used in the calculation are obtained from Tables 4-6 and their source. Calculations of production unit cost were made as follows:

1. The capacities used are: Ammonia 66,000 metric tons, Ammonium Nitrate 82,500, Urea 40,000, and Ammonium Sulphate 50,000.

2. Computations were based on 90 per cent of full capacity, except for Ammonia, 95 per cent.

3. Total fixed investment (grassroots investment) assumed at double the plant investment (battery limits).

4. Maintenance at four per cent of plant investment except for Ammonia, three per cent. For the remaining investment, it was assumed at one-and-one-half per cent.

5. Supervision and plant general 80 per cent of total labour.

6. Depreciation at 10 per cent of plant investment and two-and-one-half per cent of other investment.

7. Interest, insurance and taxes have been calculated at four per cent for interest, one per cent for insurance and one per cent for taxes for plant investment; the same percentages were applied for other investment, except for insurance for which 0.5 per cent was used.

8. Production cost includes neither packages nor packing.

9. Price of natural gas 25 cents per 1,000 cubic feet.

10. Price of electricity 0.8 cents per Kwh.

11. Price of water 10 cents per 1,000 gallons.

12. Price of ammonia $34.63 per ton.

13. Price of steam $1.65 per ton.

14. Price of sulphur $27.50 per ton.

15. Wages for operating labour assumed at $3.15 per man-hour and this includes fringe benefits.

<u>a/</u> This includes natural gas used as feed stock and fuel. The percentages for fuel alone are: for Ammonia 12.7 per cent, Ammonium nitrate 5.4 per cent, Urea 5.0 per cent, and Ammonium sulphate, 2.9 per cent.

<u>b/</u> Composite cost was calculated to introduce the capital, natural gas and other inputs carried over from the ammonia stage.

<u>c/</u> Includes 18.9 per cent for sulphur.

The other important capital charge, namely interest, accounts for 15 to 18 per cent of production cost. The interest rate in the United States was assumed at four per cent; in a developing country this rate would be much higher, possibly double if not triple that rate: this represents an increase in cost of the order of between 25 and 40 per cent.

As indicated in Table 6, a large volume of natural gas is used only in the production of ammonia. For the purpose of this study, the share of natural gas in the production cost of the other nitrogenous products was computed indirectly through their ammonia content. In the United States, the share of natural gas both as raw material and fuel, constitutes a large proportion of production cost, 30 per cent for ammonia, about 12 per cent for ammonium nitrate and urea and seven per cent for ammonium sulphate. In a number of developing countries with abundant supplies of natural gas, as a petroleum by-product, the cost of gas may be very low, particularly when the alternative cost concept is used. In each case, the cost of natural gas tends to pull production cost down. This would affect the production cost of ammonia rather significantly, although as far as the remaining products are concerned, the effect may be limited.

With regard to labour input in these products, it was mentioned earlier that wages in developing countries are, in general, lower than in advanced countries. However, during the early years of operation, it may be necessary to recruit foreign technicians, including some skilled labour at relatively higher salaries to operate the plants. Lower labour performance is another offsetting factor which will tend to result in a higher labour unit cost.8/

8/ In the longer run, through a programme of labour training and better management, the labour cost may be expected to be lower.

As Table 7 shows, plant maintenance may roughly amount to between 9 and 11 per cent of production cost. Proper plant maintenance in underdeveloped countries is an extremely important factor. Most of the plants that have been described in this paper should have an operating rate of utilization of 90 to 95 per cent at full capacity; any decline in this figure will result in a steep rise of production cost because of the high share of fixed cost.

In the longer run, if programmes of regular planned maintenance are organized and enforced, the wage cost of maintenance of the plant should actually be less than in developed countries once the skills have been acquired, because of the lower wage rates. An offsetting effect is the magnitude of the inventories of spare parts that must be carried to guard against an expensive shutdown; these are likely to be much higher in a developing country which is far from the sources of supply of equipment.[9/]

The share of utilities in production cost varies with the products. It is relatively high in ammonium nitrate, 16 per cent, and to a lesser extent in urea, 8 per cent. In ammonium sulphate and ammonia, it is rather low, two per cent and four per cent, respectively. The items included under utilities in this study are fuel, power and water. Cost differential will vary greatly with each country. Countries having access to cheap fuel supply would obviously have a cost advantage; likewise countries endowed with hydropower potential would have a cost advantage in power provided that they have the advantage of economies of scale by operating moderately

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9/ For a further elaboration on problems relating to maintenance in developing countries, see Bulletin on Industrialization and Productivity, op. cit.

large-scale power facilities. On the other hand, in certain countries where economic overhead, including power, will have to be supplied by the plants themselves, the cost of power and other utilities will be relatively high because of the expected smaller scale of operation.

A brief mention of another type of input, namely transportation, is in order because it affects the cost of raw materials and finished goods. Certain plants may have to provide for their own transportation facilities. In such cases, the capital charge of infrastructures and the possible under-utilization of transport facilities may result in higher costs.

Other costs that are probably higher in developing countries as compared to advanced countries are catalysts and chemicals, particularly when imported. Their share in production cost, however, constitutes a fraction of a per cent for most of these products, and only a small per cent in the case of ammonium nitrate, roughly two per cent.

It is possible to obtain savings in production cost when related plants are integrated on the same site. Such savings are obtained through reduction of capital charges because of the lower fixed investment required for the fertilizers complex mentioned above, as well as reduced overhead per ton of product. Furthermore, transportation cost will be reduced substantially for raw materials when produced and used on the same site.

It may be concluded that economies of scale in the form of returns to scale in many components of production cost, namely, fixed investment, labour, maintenance, supervision and general plant expenses are a predominant characteristic in fertilizer production.

The importance of the scale of operation on cost in the developing countries cannot be over-emphasized, since the generally limited local demand tends to impose limits upon the scale of production. Table 8 below indicates that the cost of production may vary by as much as between 20 and 30 per cent.

Table 8. Variation in Average Production Cost, Small versus Large Capacity Plants, United States a/

(Unit Coefficient assigned to smallest capacity)

Capacity Factor	Ammonia	Ammonium Nitrate	Urea
1 b/	1.00	1.00	1.00
2	.87	.89	.89
3	.81	.83	.82
4	.76	.79	.79
5	.71	-	.75
6	.68	-	-

a/ For methods of computation and source, see Table 7.

b/ Small capacities in tons per year: 30,000 for Ammonia, 50,000 for Ammonium nitrate and 20,000 for Urea.

This cost differential, due to scale, may very well offset any advantages that may ensue from lower cost of natural gas, even if one considers its alternative cost as zero. It is important to select large enough capacity plants so that with a relative advantage in raw material costs, it would be possible for such projects to compete more effectively on the international market. It is very likely that local markets may not be large enough to sustain a moderately large scale plant for a particular country, but it may be possible to create big enough markets through pooling regional demand.

The economics of investing in a plant, the capacity of which for some years may be too large for the immediate demand for its products, present a number of problems, most importantly high production cost due to under-utilization of capacity. The selection of the optimum size of plant under conditions of growing demand is considered elsewhere.10/

High transportation cost and, still more, inadequate distribution facilities for fertilizers, may impose a serious limitation on the size of plant and hence limit the cost advantages obtainable from economies of scale. On the basis of unpublished material in the United Nations, transportation cost for nitrogenous fertilizers by railway averaged between five to ten per cent of the price in a developing Asian country. But the inadequate services such as irregular deliveries posed a serious transport problem for the distribution of the product. This arose from the fact that fertilizers were to be delivered in bulk at an appropriate season. Several proposals to alleviate this problem were discussed among which were, first, use of motor transport, second installation of relatively small-scale plants, and, third, establishing transit stores at appropriate locations, to replace the companies' storage, to be filled during the relatively slack periods of transportation

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10/ United Nations, Bulletin on Industrialization and Productivity, "Problems of Size of Plant in Industry in Under-developed Countries", No. 2 (Sales No.: 59 II.B.1).

In order to retain the production cost advantages obtained from relatively large-scale operations, the proposal of transit stores was preferred. Fertilizers shipped and stored during the slack transportation periods were to be sold to farmers during the proper season.

In conclusion, it may be stated that production cost in developing countries is likely to be higher than in advanced countries. The combined capital charges are high, roughly 50 per cent of production cost and they are expected to be higher in developing countries. Further, the likelihood of operating at relatively low capacities tends also to extenuate the high production cost in the developing countries. An offsetting factor is the natural gas, the cost of which may be lower in some developing countries; the higher capital charges and the scale factor, however, may very well offset such an advantage.

In the longer run, however, as the developing countries gain more experience in production techniques and management, the differential in production cost may be grandually narrowed. Further, in developing countries where gas is being flared and large demand is obtaining either locally or through pooling regional demand, competitive production cost may ensue.

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