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UNITED NATIONS INDUSTRIAL
DEVELOPMENT ORGANIZATION

A STUDY OF THE ESTABLISHMENT OF NITROGENOUS FERTILIZER

PRODUCTION IN DEVELOPING COUNTRIES

Models for Production of Ammonia, Urea and Ammonium Nitrate based on Feedstocks (a) Natural gas, (b) Naphtha, (c) Fuel oil, (d) Coal, (e) Electrolysis of water

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1. INTRODUCTION

The present world shortage of fertilizers, which seems likely to
last for the next two or three years, coupled with the quadrupling
in fertilizer prices over the past year or eighteen months, is causing
many developing countries which rely mainly on imports to consider
or re-consider plans for local manufacture.

The major increases in the prices of the petroleum products from
which most nitrogenous fertilizers are manufactured, and particularly
the changes in the relative prices of natural gas, naphtha and fuel
oil, have markedly affected the economic factors governing the selection
of a feedstock for ammonia and fertilizer manufacture. As against
petroleum-based feedstocks coal must now be seriously considered for ammonia
manufacture, and amongst petroleum-based feedstocks, though natural
gas still produces the cheapest fertilizer, the balance between naphtha
and fuel oil which has been distinctly in favour of naphtha in recent
years has now tilted in favour of fuel oil.

The time is therefore appropriate for a re-examination of the
various processes available for ammonia and nitrogenous fertilizer
manufacture. The aim of this paper is, by setting out a comparison
of the various feedstocks and processes, to enable those who are
considering local manufacture to make a preliminary assessment of the
economic factors involved in a decision and to give some guidance
in the choice of a feedstock where this possibility exists.

2. SUMMARY

The report provides up-to-date estimates of the capital and
production costs of five different methods of ammonia manufacture; from natural
gas, naphtha, fuel oil, coal and from electrolytic hydrogen. For each
process costs are given for three sizes of plant, 300 tons* per day (t.p.d.),
600 t.p.d., and 1,000 t.p.d., so that a cost appropriate to the size
of the local market or for export may be available. Capital and
production costs are also given for the conversion of the ammonia from
each process and plant size to urea fertilizer. The manufacture of
ammonia from electrolytic hydrogen differs from the other processes
in that it does not provide as a by-product the carbon dioxide required
for urea manufacture. For this process, therefore, costs are given
for the manufacture of ammonium nitrate rather than urea. To make a

* Throughout this report one ton = 1,000 kgs.

comparison with the other processes possible an "equivalent urea" price has been calculated.

To facilitate a comparison between the different processes and plant sizes, data are given in four main tables, Tables 2 and 3 for ammonia, and Tables 4 and 5 for urea. Detailed capital and production costs are given in the appendices. The production costs have been worked out for specific feedstock prices and specific rates for depreciation and profit, but they are presented in a form which makes the substitution of different prices or financial charges straightforward. Because of its importance the effect of feedstock prices upon urea production costs has been worked out for a wide range of feedstock prices; the results are shown graphically in Figures 1A, 1B and 1C for each feedstock and plant size.

Though this is an appropriate time for a fresh comparison of the different processes for ammonia and nitrogenous fertilizer manufacture it is also difficult time for such a comparison, for two reasons.

The first is that because of inflation and equipmen. fabrication shortages capital costs in Western Europe are at present rising very rapidly. In some countries capital costs have risen by 25/30% in the last twelve months. In such a situation a capital cost estimate is liable to be out of date by the time it is published. The estimates given in this report are based on prices in December 1974; over the next twelve months they can be expected to rise by 10/20%.

The second is that the prices of petroleum products are not yet stable. The prices used in calculating production costs are typical prices for December 1974. These prices may have changed by the time this report is circulated, and they do in any case vary from region to region. To cover this situation production costs have, as stated above, been presented so that a correction can easily be made for different prices, and the effect of price variations has been discussed in the report and presented in graphical form. The aim of the report is to assist developing countries and others interested in deciding whether there is a case for local fertilizer manufacture and in making a preliminary selection of feedstocks for further detailed examination.

3. CONCLUSIONS

The conclusions emerging from this study are:

(a) That where natural gas is available at reasonable prices it is always the preferred feedstock;

(b) That the recent rises in petroleum product prices have made naphtha too expensive as a feedstock for nitrogenous fertilizer manufacture;

(c) That coal and fuel oil are of approximately equal ranking as feedstocks, and that the choice between them depends mainly upon local prices and upon considerations such as local availability and price stability.

(d) As the result of the massive rise in prices of petroleum products and consequent unwelcome increase in fertilizer prices to importing countries, coal has become a more attractive feedstock for fertilizer manufacture. Developing countries with coal reserves now find opening in front of them the possibility of using these coal reserves to produce nitrogenous fertilizers at competitive prices. This is a welcome development in that it provides an incentive for the development of indigenous resources which previously was lacking.

(e) The principal disadvantage of fertilizer projects, from the point of view of a developing country, is that they are capital intensive, the capital per man employed is high. However, there are important compensating advantages to be offset against this. Fertilizer projects, though they may for the first five years or so require expensive support by expatriate personnel, do in the long run contribute to the development of a corps of indigenous skilled and experienced personnel who can make an important contribution to industrial development. Much more important, however, is their role as providers of a basic support to agricultural development. It is generally agreed that the correct and adequate use of fertilizers is the most important and key factor in raising crop yields per acre to an acceptable and attainable level. A local fertilizer plant, preferably based upon indigenous resources, can provide guaranteed supplies of fertilizers at stable prices which make it possible for farmers to plan the development of their resources, given stable crop prices, to meet the needs of a rapidly growing population.

Discussion

In the following section of this report, which presents costs for the manufacture of ammonia, the introductory sections discuss in some detail the raw materials and processes available and the factors affecting capital costs. The aim of these sections is to provide a background discussion of the technical and economic factors which are relevant to a decision on local fertilizer manufacture.

Table 1 summarises the capital and production costs for the manufacture of urea.

TABLE 1 - SUMMARY CAPITAL AND PRODUCTION COSTS FOR UREA

Feedstock	Natural gas			Naphtha			Fuel oil			Coal		
Feedstock price	$0.5 per ,000 scf			$120 a ton			$70 a ton			$8 a ton		
Plant output												
Tons per day	520	1040	1720	520	1040	1720	520	1040	1720	520	1040	1720
Thousand tons per year	160	321	535	160	321	535	160	321	535	150	300	500
Total capital ($M)	61	96	135	66	105	149	71	112	158	86	137	183
Production costs ($/ton)												
Feedstock	11	11	11	63	63	63	39	39	39	11	11	11
Other operating costs	24	19	16	24	19	17	26	21	17	30	23	20
Financial charges*	74	59	50	80	64	53	87	68	58	113	91	73
Total	109	89	77	167	146	133	152	128	114	154	124	104

* Depreciation, 10% of fixed capital: profit, 10% of total capital

4. AMMONIA MANUFACTURE

4.1 Raw Materials

The raw materials (feedstocks) used to make ammonia have their normal and major use as fuels; in the generation of heat for domestic or industrial uses, in the generation of electricity, and in transport via the internal combustion engine; they are also widely used as raw materials for the petrochemical industry. Their consumption for these purposes is very much greater than for ammonia manufacture and their prices are therefore determined by their value and use as fuels or petrochemical raw materials, rather than by their respective merits as raw materials for ammonia. For example, the special properties of gasoline as a motor fuel enable it to command a premium price which makes it far too expensive as an ammonia plant feedstock. Similarly, naphtha, which can be used as a component of gasoline and is a valuable raw material for petrochemicals has recently, because of increasing demand, risen in price much more than other petroleum products.

Broadly speaking, however, the factors which determine their relative prices as fuels are similar to the factors which determine their suitability for ammonia manufacture so that their respective prices do roughly correspond to their value as ammonia plant feedstocks. This is only true to a first approximation. Transport costs, the location of petroleum processing facilities, and different demand patterns in different regions lead to important variations in the fuel price structure from one region to another.

The feedstocks with which we are concerned are, in order of increasing chemical complexity, natural gas, naphtha, fuel oil and coal.

Natural gas, or gas of a similar composition associated with crude oil, has - except in industrially developed countries - to be used within reasonable distance of its source. Naphtha and fuel oil are easily transported by sea and are available world-wide. They are the feedstocks likely to be used by countries without indigenous fuels, which have to rely on imported raw materials. Coal, like natural gas, has to be used within reasonable distance of its source because transport costs are high. The major increase in the price of petroleum products has brought coal very much into the picture as a raw material for ammonia manufacture.

As the chemical complexity of a feedstock increases, and as the amount of impurities increases, so does the difficulty of using the feedstock to make ammonia. The number of process stages, the amount of equipment required, and consequently the capital cost of the plant, increase from natural gas through naphtha and fuel oil to coal. To a first approximation, a plant using naphtha costs 10-15% more than one using natural gas, a plant using fuel oil 30% more, and a plant using coal 75-100% more (cf. Table 2).

A further factor to be borne in mind is that as the number of process stages and the amount of equipment increases so the reliability of the plant decreases. Reliable and satisfactory processes exist for all feedstocks but it is nonetheless wise to make some allowance for this in estimating the annual output of a plant of given daily capacity. This is particularly true for coal-based plants, for which less operating experience is available than for other feedstocks.

A factor of particular importance is the sulphur content of the feedstock. Many of the chemical processes involved in ammonia manufacture only operate efficiently in the presence of a catalyst, which is usually adversely affected by sulphur compounds. For such catalytic reactions it is therefore necessary to remove the sulphur. This is always technically feasible, but it does increase costs, and the greater the quantity of sulphur the greater the cost. A further consideration is that to prevent unacceptable atmospheric pollution only a limited quantity of sulphur compounds can be discharged to the atmosphere. Where the feedstock contains appreciable quantities of sulphur it is usually necessary to provide equipment to recover this as elementary sulphur. This is normally necessary with fuel oil and coal, but not with natural gas or naphtha.

When the manufacture of ammonia is under consideration in any region it is essential to examine the local fuel price structure and the costs of converting the various fuels to ammonia in order to select that fuel and process which give the cheapest ammonia. The aim of this report is to assist in making that selection. The importance of this choice cannot be over-emphasized. Feedstock costs and capital charges normally account for 85-90% of the cost of producing ammonia. Since the capital cost of the plant is basically determined by the choice of feedstock, the selection of feedstock fixes about 90% of the ammonia production costs.

4.2 Processes

4.2.1 General

The manufacture of ammonia consumes relatively large amounts of energy, both as heat and as power for machinery drives particularly for gas compression. Many of the chemical reactions in the process take place at high temperatures and generate much heat. The recovery of the heat produced in these reactions to supply the energy needs of the processes is an important and complicating factor in the design of modern ammonia plants. Part of the heat is recovered by transfer from one gas stream to another, but most of it is used to raise steam at high pressure for compressor drives and also for use as a reactant in the processes. The provision of the necessary heat exchangers and waste heat boilers, and the control of the steam-raising plant, considerably complicate the operation and control of ammonia plants. However, they markedly increase the efficiency of the plant and have led to the development of processes which are practically independent of outside power supplies.

Though heat recovery systems on modern ammonia plants are very efficient, it is not possible to recover all the heat which is generated at various stages of the process. There is consequently a large "cooling load" to be dealt with and this has an important bearing on the location of ammonia plants. Water is the most widely used cooling agent but the demand is so large, about 10,000 M^3/hr for a 1,000 tons a day plant, that only in exceptional circumstances, e.g. when there is a large river or lake nearby, is it possible to use a "once-through" system in which water is pumped from the source through the coolers and back to the source. It is usually necessary to use recirculating cooling water systems in which the heat picked up by the water in the plant coolers is removed by evaporation to the atmosphere in a cooling tower and the water is returned to the plant. With such a system water is required only to replace losses by evaporation and as spray, normally about 3-5% of the circulation rate. Sea-water can be used if absolutely necessary on a once-through system but it is much more corrosive than fresh water and the reduction in cost obtained by dispensing with cooling towers is counter-balanced by the extra cost of using special corrosion-resistant materials in many coolers. It is rarely possible to use sea-water for all cooling purposes. Air

4.2 Processes (continued)

4.2.1 General (continued)

cooling can also be used and it has obvious advantages where water is scarce. In hot countries it may be necessary to finish off the cooling with water, but most of the cooling can be done in air coolers. Smaller amount of water is also required for steam generation and the process itself.

Catalysts, which accelerate chemical reactions, are widely used in ammonia plants. Their performance is adversely affected by quite small concentrations of certain substances, known as "Catalyst poisons". Typical poisons for many catalysts are sulphur compounds and chlorine compounds. If the concentration of catalyst poisons is allowed to rise above avery low level the catalyst becomes inactive and the plant must be shut down to replace it by fresh catalyst. Catalyst is expensive, and so are plant shut-downs. However, shut-downs for catalyst changes cannot be avoided completely. All catalysts have a limited life, partly because poisons can never be completely eliminated and partly because the catalysts undergo slow structural changes which cause a loss of activity.

There are three basic steps in ammonia manufacture: synthesis gas production, gas purification and compression, and ammonia synthesis. In synthesis gas production the feedstock reacts with steam or with steam and oxygen at high temperatures (800° to $1,500^\circ$C) to produce a gaseous mixture of hydrogen and oxides of carbon. In the purification the oxides of carbon, sulphur compounds and other impurities are removed, and the purified gas is compressed to $150/300$ atmosphere. In the synthesis section ammonia is made by passing the compressed gases over a catalyst at $500^\circ/550^\circ$C; it is separated as a liquid by cooling and is stored at low temperatures (-30°C). These three steps are discussed in the following sections.

4.2.2 Synthesis Gas Production

The major differences between the various manufacturing processes occur in synthesis gas production, which becomes progressively more difficult as we pass from natural gas through naphtha and fuel oil,

4.2 Processes (continued)

4.2.2 Synthesis gas production (continued)

to coal. There is a major division between natural gas and naphtha,
which can be gasified with steam alone, and fuel oil and coal which
need oxygen as well as steam. The provision of an air separation
plant to supply the oxygen appreciably increases the capital costs
of plants using fuel oil or coal as a feedstock.

The 'steam reforming" process for the synthesis gas production
of natural gas and naphtha uses catalysts; sulphur, which is present
in these feedstocks in small quantities (less than 0.2% by weight) must
be removed before synthesis gas production. Purified natural gas
or vapourised naphtha is mixed with steam and passed over a catalyst
contained in metal tubes suspended in a furnace. The reaction takes
place at a temperature of 800°-900°C. Synthesis gas production is
completed (and nitrogen is introduced) by passing the hot gas, together
with a controlled quantity of air, over a fixed bed of catalyst.

The synthesis gas production of fuel oil oxygen and steam is
known as "oxygen reforming" or, more usually, "partial oxidation".
It is not a catalytic process and prior removal of sulphur is
not necessary. Oxygen and a fuel oil/steam mixture are fed to a burner
fitted to a vertical cylindrical brick-lined vessel in which the
synthesis gas production reactions take place at a temperature of
about $1,400^{o}$C. The gas from the gasifier contains particles of carbon
in suspension, by weight about 2 to 3% of the feedstock, which must
be removed before subsequent processing. They are removed by injecting
water into the gas. The carbon is recovered from the water by mixing
it with oil. It can then be burnt as boiler fuel or recycled to the
gasifier.

Both processes, steam reforming and partial oxidation, operate
at pressure, thus reducing the energy required for subsequent
compression of the gas. With steam reforming the pressure is
limited to about 30 atmospheres by the operating conditions of the
tubes in the reformer furnace. Partial oxidation is not subject to
this limitation and pressures of 50 to 80 atmosphere · are used.

An important advantage of partial oxidation is that it can use
a wide range of hydrocarbon feedstocks : natural gas, naphtha, fuel oil,
heavy oils. Practically any petroelum fraction which can be pumped to the
gasifier can be used. This gives the process an ability to adapt itself to
major changes in the price structure f the various petroleum products which
steam reforming does not possess.

In steam reforming about 40% of the raw material is used as fuel
to the reformer furnace. If fuels cheaper than the chosen feedstock
are available they can sometimes be used in the furnace. However,
heavy fuel oils are not normally suitable because they contain normally
traces of vanadium and sodium which damage the tubes.

There is probably little difference in reliability between the
two processes. The simplicity of partial oxidation synthesis gas production
is offset by the high temperatures involved, the problems posed in
the supply and use of oxygen and in the carbon separation equipment.

Three established processes are available for the gasification of
coal. The Winkler process gasifies small coal (up to 10 mms) by
maintaining the particles in suspension in a tall, narrow, cylindrical
vessel, in an upward-flowing current of oxygen and steam. To avoid the
formation of large particles the temperature must be kept below the fusion
temperature of the ash; about $1,000^{\circ}C$ is the maximum permissible. The
Koppers-Totzek process is similar to fuel oil synthesis gas production
process; a stream of finely powdered coal and steam is fed, with oxygen, to a
burner located in a vessel in which the synthesis gas production reactions take
place. The synthesis gas production temperature is about $1,500^{\circ}C$. In
the Lurgi process a fixed bed of sized coal (5 to 30 mms) is maintained on a
slowly rotating grate through which oxygen and steam are passed.

The Winkler and Koppers-Totzek processes operate at atmospheric
pressure; the Lurgi process about 30 atmospheres. Because of its
comparitively low operating temperature the Winkler process is used
mainly for reactive fuels like lignite and brown cola. Some ash is
removed from the base of the gasifier but most is carried forward with
the gas and is removed by cyclones and finally by water washing. Because
of its much higher operating temperature the Koppers-Totzek process can
use practically any solid fuel. It can also use fuel oil and other
liquid petroelum products.

4.2 Processes (continued)

4.2.2 Synthesis Gas Production (continued)

The coal must be very finely ground and the power consumption for grinding is significant. About half of the ash is recoverd a slag from the base of the gasifier; the remainder is carried forward in the gas and is removed by washing the gas with water. In the Lurgi process the oxygen/steam mixture must be able to pass through the coal firebed in the gasifier. The coal supplied must therefore be free from dust and small particles, it must not cake, and the temperature must be kept below the level at which fusion of the ash takes place (about $1,000^{\circ}$ to $1,100^{\circ}C$). These requirements restrict the kinds of coal that can be used; it must be carefully sized, it must be relatively free from caking when heated, and it should not have a low ash melting point. The gas produced contains products of coal carbonization, heavy and light tars, oils, phenols, etc., which are removed by condensation and water-washing. The separation of these products and the purification of the resulting aqueous effluents is a complicated and expensive process which is in part offset by the value of the products recovered. The gas also contains an appreciable concentration of methane (about 10/15%) which must be removed and converted to hydrogen or used for steam raising. The oxygen consumption is muon lower than that of the Koppers-Totzek process, with consequent savings in the capital and operating costs of the oxygen plant. The production of the gas at 30 atmospheres pressure also reduces the power required for subsequent compression. In the Winkler and Koppers-Totzek processes the gas, after cooling and removal of entrained solid particles, is compressed prior to the purification processes.

4.2.3 Purification and Compression

There are four basic steps in gas purification : sulphur removal, carbon monoxide conversion (often called "CO shift"), carbon dioxide removal and small quantity of carbon monoxide and carbon dioxide in the final purification.

4.2 Processes (continued)

4.2.3 Purification and Compression (continued)

In the steam reforming sulphur is removed from the feedstock, natural gas or naphtha, before synthesis gas production. The sulphur content of natural gas is usually very small(less than 0.01%); it is removed by absorption on a solid catalyst. Naphtha may contain up to 0.20% of sulphur which is usually removed in two stages. Treatment with sulphuric acid removes most of the sulphur and a catalytic stage similar to that for natural gas completes the removal.

Fuel oil used for ammonia production contains about 3.5% of sulphur, and coal has 0.5% to 2.0%. The total quantity of sulphur is much greater than with natural gas or naphtha and it is removed after synthesis gas production, not before. During synthesis gas production most of the sulphur is converted to gaseous hydrogen sulphide, which is removed by contacting the gas with a solvent. The hydrogen sulphide is removed from the solvent by heating. Atmospheric pollution regulations prevent its discharge to atmosphere. It can be used directly to make su phuric acid or, more usually, it is processed to produce sulphur which is, of course, a saleable product.

The principal constituents of the gas from the synthesis gas production stage are hydrogen, carbon monoxide and carbon dioxide. In CO shift, carbon monoxide is reacted with steam over a catalyst to produce carbon dioxide and hydrogen. In the "high temperature shift" the carbon monoxide content of the gas is reduced to about 3% to 4% by volume. This is satisfactory for some subsequent processes, usually for gas produced by partial oxidation. When steam reforming is used it is normal to add a "low temperature shift", using a sulphur sensitive catalyst, which reduces the carbon monoxide to 0.2% to 0.4%. Carbon monoxide conversion generates heat, which is recovered as steam in a waste heat boiler. The size of the plant depends upon the carbon monoxide content of the gas. Gas from high temperature synthesis gas production (fuel oil or Koppers-Totzek process for coal) has 50% to 60% carbon monoxide; gas from steam reforming has about 10%. The former consequently require a much larger plant.

4.2 Processes (continued)

4.2.3 Purification and Compression (continued)

Carbon dioxide removal is effected by contacting the gas with a solvent. The carbon dioxide is removed from the solvent by heating and the solvent is returned to the process. A number of different processes, using different solvents, are available. They differ mainly in the size of the equipment needed to dissolve the carbon dioxide and to regenerate the solvent, and in the amount of heat required to remove the carbon dioxide from the solvent. Partial oxidation processes using coal or fuel oil produce much more carbon dioxide(about 3 tons per ton of ammonia) than steam reforming processes using natural gas or naphtha (about 1.5 tons per ton of ammonia) and therefore require a much larger plant.

The carbon monoxide conversion plant and the carbon dioxide removal plant do not achieve the complete removal of these substances which is necessary for ammonia synthesis. This final removal is effected either by catalytic conversion to methane (methanation) or by washing the gas with liquid nitrogen at low temperatures. Methanation increases the methane content of the gas supplied to the ammonia synthesis plant. This methane accumulates in the synthesis plant and has to be removed by purging gas from the plant, thereby losing hydrogen and lowering the efficiency. It is therefore necessary to keep the carbon monoxide and dioxide concentrations as low as reasonably practicable. Ammonia plants using methanation always use a low temperature shift to reduce the carbon monoxide content to 0.2% to 0.4%. The liquid nitrogen wash is only used in conjunction with partial oxidation synthesis gas production because the liquid nitrogen can readily be obtained from the air separation plant which supplies the oxygen. A low temperature shift is not necessary with nitrogen wash but it is sometimes used to improve the efficiency of the ammonia plant by lowering slightly the feedstock consumption. One advantage of the liquid nitrogen wash is that it removes methane and other inert gases almost completely and enables the synthesis plant to operate more

4.2   Processes (continued)

   4.2.3 Purification and Compression (continued)
   efficiently.

   When synthesis gas production is by steam reforming the purification
stages usually consist of high temperature shift, low temperature shift,
and methanation.   When synthesis gas production is by partial oxidation
the choice is greater, but the majority of plants omit a low
temperature shift and use a nitrogen wash for final purification.
A nitrogen wash is often used in conjunction with the Rectisol
process for hydrogen sulphide and carbon dioxide removal. This
process uses refrigerated methanol as a solvent.

   The choice of the processes to be used for gas purification is
technically complex.   The difference between the processes is
marginal; it is probably best to leave the choice to the plant
contractor because the most important factor is that he should have
wide experience of the processes selected.

   After purification the gas is compressed from 30/50 atmospheres
up to 200/300 atmospheres for ammonia synthesis.   In modern ammonia
plants this is done in one large centrifugal compressor, driven by
a steam turbine.   At outputs below 600 tons of ammonia a day these
compressors cannot be used and recourse must be made to conventional
reciprocating compressors, usually driven by an electric motor.
This increases the consumption of electric power and calls for
a corresponding decrease in the steam energy recovered from waste heat
if alternative uses cannot be found for it. (This would not be a
problem when the ammonia is converted to urea because the urea
plant consumes steam). The change to reciprocating compressors
increases the capital cost per ton of ammonia.

   4.2.4 Ammonia Synthesis
   Ammonia is made by passing a mixture of hydrogen and nitrogen
at 200/300 atmospheres pressure over a catalyst,at temperatures of
400° to $540^{\circ}C$.   Only about one quarter of the gas is converted to
ammonia in a single passage over the catalyst.   The ammonia is
condensed as a liquid by cooling and the gas is recycled to the

4.2 Processes (continued)

4.2.4 Ammonia Synthesis (continued)

catalyst. The recycling is normally done by the machine which
compresses the purified gas.

Ammonia synthesis plants do not show the differences in process
or plant design that exist in synthesis gas production or in the various
purification stages; all synthesis plants are very much alike.
The differences arise in details of converter design, and in methods
of cooling, i.e. whether cooling is by water alone or whether
refrigeration is used. Most large modern plants use refrigeration.

4.2.5 Electrolytic Process

This process uses electricity to decompose water into hydrogen
and oxygen. It operates at about 30 atmospheres pressure. The
hydrogen contains traces of oxygen which are catalytically converted
to water. Nitrogen from an air separation plant is added, and
the mixed gases are compressed and delivered to a synthesis plant.

The process requires large amounts of electricity, about 11,000 Kwh
for a ton of ammonia, and is economic only where power is very cheap,
say $0.001/0.003 per Kwh. The process is nearly always associated
with hydroelectric power stations in developing areas. The capital
cost is high because there is a limitation in the size of a "cell"
used for hydrogen production. Large numbers of cells are required
and the capital cost per ton of ammonia does not show as large a
decrease as the size of the plant increases as do other processes.

Both electrolysis and air separation produce oxygen as a
by-product. If this can be sold the economics of the process are
of course improved. It is possible to use the oxygen in partial
oxidation processes for ammonia; one ton of ammonia from an
electrolytic process produces enough by-product oxygen for one and a
half tons of ammonia by partial oxidation.

4.3 Capital Costs

In considering the capital cost of any chemical plant it is useful
to think of it as made up of the cost of three components. First of all
there is the process plant itself. Then there are the "offsites", the

4.3 Capital Costs (continued)

auxiliary facilities equipment which is not directly involved in the
process but supplies the essential services, e.g. boilers, electricity
generation or supply and its distribution, cooling water systems,
feedstock and ammonia storage tanks, effluent treatment plant etc.
Finally there are site general costs, including the land itself, roads,
railways, drainage, offices, workshops, stores, laboratories, canteens,
other welfare services, support facilities. An important part of site general costs
are the costs outside the site boundary, i.e. the cost of connecting
the site to the nearest road or rail track, of bringing water or electricity
supplies to the site, and of taking effluents away from it.

When a client requires a preliminary cost estimate most contractors
will readily quote what they call a "battery limits" cost; this is the
complete erected cost of the process plant, excluding offsites and site
general. They will sometimes also give an approximate estimate for
offsites but will rarely be prepared to estimate site general costs
because these depend so much upon site location and upon the client's
wishes. Sometimes some part of site general costs may be included in
the offsites; when preliminary estimates are obtained it is necessary to
have a clear statement of what is included in the estimate and what is
excluded. Any costs quoted in the technical press which are not defined
in terms of battery limits, battery limits plus offsites, or total
plant costs, should be treated with great reserve.

The capital cost of a plant depends mainly upon its size and design
philosophy, its location, and the choice of feedstock.

The relationship between the size of a plant and its cost is
determined by the basic design principles. For example, if a 500 tons
per day (t.p.d.) plant comprises a certain number of vessels, heat
exchangers, pumps, compressors etc., and a 1,000 t.p.d. plant is built
by doubling up on each of these items, the larger plant would cost twice
as much as the smaller one. However, if the 1,000 t.p.d. plant is built
using the same number of items of equipment but increasing each in size
or capacity for the higher output, it would cost much less. The latter
principle is now, when practicable, almost universally adopted in the
design of ammonia plants, resulting in what are known as "single-stream"
plants with capacities of up to 1,500 t.p.d. At these very large
capacities it is not always possible to use single units, particularly

4.3 Capital Costs (continued)

in the synthesis gas production section of oil or coal based plants. The single-stream principle has greatly reduced the cost of ammonia plants, but a price has to be paid for this in terms of reliability. Trouble on a single vessel, heat exchanger or compressor may cause a total shut-down, which would not be required on a two-stream plants initially lost much output due to equipment or instrument failures. Over the years, as operating and maintenance techniques improved, the record has been much better, but in many developing countries it is still far from satisfactory.

The relationship between the size and cost of offsites is roughly the same as for the battery limits plant, but the site general costs are much less affected by the size of the plant. The battery limits plus offsite costs for a 1,000 t.p.d. plant are about twice the costs for a 300 t.p.d. plant but site general costs are probably only one and a half times the costs for the 300 t.p.d. plant.

When plants are mainly single-stream, using the same feedstock and built in comparable regions, the relationship between the costs and sizes of complete plants is approximately given by the relation

$$\text{Cost Ratio} = (\text{Size Ratio})^n$$

For ammonia plants, $n = 0.60/0.70$; an average value of 0.65 may be used. This is only a first approximation, but if the size and cost of a plant are known it may be used to give an approximate cost for similar plants of different sizes.

The capital cost of a plant depends upon its location. In a developing country much of the equipment has to be transported long distances and a large number of expatriates may be required to erect the plant. In arid or hot countries the cost of cooling facilities may be high. It may be necessary to strengthen the local transport facilities to bring in large items of equipment, or to deal with raw materials and the final product. If some of the large vessels cannot be carried by local road or rail it may be necessary to use two small vessels in place of one large one. If the soil cannot take high loads, piling may be necessary. It is general experience that the cost of a plant in a developing country is 20% to 30% greater than the cost of a similar plant in a developed country.

4.3 Capital Costs (continued)

The major effect of the choice of feedstocks on capital costs has
been emphasised in Section 2.1 above. It is evident in Table 2, which
gives fixed capital costs for 300, 600 and 1,000 tons per day (t.p.d.)
ammonia plants. Detailed costs for 1,000 t.p.d. plants are given in
Table A of Appendix 1. Because of inflation, capital costs are at
present rising at an alarming rate and the accuracy of estimates is
necessarily reduced.

TABLE 2 - SUMMARY FIXED CAPITAL COSTS FOR AMMONIA PLANTS ($ millions)

Plant Capacity (t.p.d.)	300	600	1000
Feedstock			
Natural gas	34.3	52.5	75.0
Naphtha	37.7	58.1	83.0
Fuel Oil	43.5	66.4	95.0
Coal	59.8	93.4	123.0
Electric power	59.1	97.7	137.0

Notes

1. The costs are for complete plants erected in developing countries
   on an undeveloped site at prices ruling in December 1974.

2. They cover all costs inside the factory fence, but exclude all costs
   outside the factory fence, e.g. housing, rail and road connexions
   to site, drainage from site, power and water supply to site boundary
   etc.
   They include starting-up costs and a 10% allowance for contingencies.

3. Storage is provided for three days' production of ammonia and twenty
   days' feedstock requirement;

4. The proportion of those costs which can be met by local currency varies
   from about 20% to 40%, depending upon local resources;

5. No allowance is made for inflation during plant construction. If the
   plants take four years to erect and if inflation is 10% to 12% p.a. over that
   period, completed plant costs will be 20-25% higher than the figures
   given above. Interest charges incurred during the construction of
   the plant are not included.

6. The costs for 1000 t.p.d. plants have been obtained by a careful analysis
   and correlation of achieved costs, contractors and consultants estimates,
   and published information. The costs for the smaller plants have been
   derived from the costs for the 1000 t.p.d. plants except for "electric
   power" where, because of lack of information on large plants, they
   are based on costs for the 300 t.p.d. plant.

4.4 Production Costs

The feedstock, power and water consumptions per ton of ammonia are set out below:

	Nat.gas	Naphtha	Fuel oil	Coal	Elec.power
Feedstock	38,000 s.c.f.	0.90 tons	0.96 tons	2.3 tons	-
Power (Kwh)	40	40	40	264	10,700

Water - 15 M^3/ton for all processes

The actual water consumption varies from 10 M^3/ton to 20 M^3/ton depending on the temperature.

The coal consumption varies according to the quality of the coal. For costing purposes a consumption of 2.3 tons/ton is assumed.

The figures apply to 300, 600 and 1,000 t.p.d. plants. (To avoid complicating the cost table it has been assumed that on the 300 t.p.d. plant, which has to use a reciprocating synthesis gas compressor, the compressor is driven by a steam turbine, through a reduction gearing. If enough electric power was locally available the use of an electric motor to drive this compressor would probably save $2 to $4 per ton of ammonia, because the feedstock consumption could then be reduced by about 15%).

Summary production costs for all processes and plant sizes are given in Table 3. Detailed production costs for the 1,000 t.p.d. plants are given in Table B of Appendix 1.

4.4.1 Discussion

Naphtha produces the dearest ammonia. As long as relative prices of naphtha, fuel oil, and coal remain even approximately as shown in the table naphtha cannot compete as a feedstock for ammonia manufacture.

The difference between the remaining three processes is not large. There are few places where power is available at as low a price as $0.003 a Kwh, and the interest of the comparison centres around the relative merits of coal and fuel oil. At the price of $8 a ton for coal and $70 a ton for fuel oil, coal shows a significant advantage at 1000 t.p.d. Feedstock costs account for more than 40%

4.4 <u>Production costs</u> (continued)

4.4.1 <u>Discussion</u> (continued)

of the total cost for fuel oil, but less than 15% for coal. Plants using fuel oil are much more affected by changes in feedstock prices than plants using coal.

The table below sets out the percentage contribution of feedstock and capital charges to ammonia cost for the different processes. The figures for each process are averages for the three plant sizes.

Feedstock	Nat.gas	Naphtha	Fuel oil	Coal	Elec.power
Feedstock costs (% of total)	21	56	42	13	20
Capital charges (% of total)	64	35	48	73	68
Feedstock + capital charges	85	91	90	86	88

The feedstock and capital charges together account, in all processes, for 85-90% of the cost of the ammonia, but their contributions to this total vary significantly. For natural gas, coal and electric power, feedstock covers 15% to 20% of ammonia cost and capital charges 65-75%. For naphtha and fuel oil, feedstock covers 40-60% and capital charges 35-50%.

TABLE 3 - SUMMARY OF AMMONIA PRODUCTION COSTS ($/TON)

Feedstock	Natural gas			Naphtha			Fuel oil			Coal			Elec.power		
Feedstock price	$0.5 per 1000 s.c.f.			$120 a ton			$70 a ton			$8 a ton			$0.003 a KWH		
Plant output															
Tons per day	300	600	1000	300	600	1000	300	600	1000	300	600	1000	300	600	1000
Thousand tons per year	93	186	310	93	186	310	93	186	310	87	174	290	93	186	310
Feedstock	19	19	19	108	108	108	67	67	67	19	19	19	32	32	32
Utilities, cata-lysts,chemicals	3	3	3	3	3	3	3	3	3	5	5	5	2	2	2
Maintenance, labour + 0'heads	15	10	8	16	11	9	19	13	10	24	16	13	22	16	13
Plant cost	37	32	30	127	122	120	89	83	80	48	40	37	56	50	47
Depreciation (10%)	37	28	24	41	31	27	47	36	31	69	54	42	64	53	44
Sub-total	74	60	54	168	153	147	136	119	111	117	94	79	120	103	91
Profit (10%)	37	28	24	41	31	27	47	36	31	69	54	43	64	53	44
Total	111	88	78	209	184	174	183	155	142	186	148	122	184	156	135

Notes:

1. Maintenance is charged at 2.5% of fixed capital, depreciation at 10% of fixed capital and profit at 10% of total capital;

2. Annual production is taken as 310 days full output, except for coal where 290 days are taken;

3. Power is charged at $0.01 per Kwh (except for the electric power process) and water at $0.10 per M^3.

4.

	Feedstock price per unit calories US$/1 million BTU	Heats of combustion (LHV) assumed
Natural gas	0.5	8,900 Kcal/NM^3
Naphtha	2.86	10,500 Kcal/kg
Bunker C fuel oil	1.84	9,500 Kcal/kg
Coal	0.344	ave. 6,000 Kcal/kg
Electric power	0.87	——

4.4 Production Costs (continued)

4.4.2 Effect of Feedstock prices

To enable the reader to adjust the ammonia production costs given in Table 3 for feedstock prices obtaining in his area, or for changes in these prices, the effect upon ammonia cost of changes in these prices is given below. The figures given apply to all plant sizes.

Natural gas: A rise of $0.1/10^3$ s.c.f. raises ammonia cost by $3.8 a ton

Naphtha	: "	"	" $10/ton	"	"	"	" $9.0 " "
Fuel oil	: "	"	" $10/ton	"	"	"	" $9.6 " "
Coal	: "	"	" $1.0/ton	"	"	"	" $2.3 " "
Elec.power	: "	"	" $0.001/Kwh	"	"	"	" $10.7" "

This subject is discussed further in Section 5.

4.4.3 Effect of Reduction in Output

When the plant fails to maintain its designed output, costs per ton of ammonia increase. The cost of feedstock, power and water and catalysts and chemicals is constant irrespective of output, but all other costs rise. Table 3A shows the effect of variations in output on ammonia production costs for 1000 t.p.d. plants.

TABLE 3A - EFFECT OF OUTPUT ON PRODUCTION COSTS FOR 1000 T.P.D. AMMONIA PLANTS

Feedstock	Nat.gas			Naphtha			Fuel Oil			Coal			Elec.power		
Output %	60	80	100	60	80	100	60	80	100	60	80	100	60	80	100
Fixed costs*	22	22	22	111	111	111	70	70	70	24	24	24	34	34	34
Variable costs*	13	10	8	15	11	9	17	13	10	22	16	13	22	16	13
Depreciation	40	30	24	45	34	27	50	38	30	70	53	42	73	55	44
Profit	40	30	24	45	34	27	52	39	31	72	54	43	73	55	44
Total $	115	92	78	216	190	174	189	160	141	188	147	122	202	160	135

* See note 2 of Table B, Appendix 1

The table clearly shows that drastic effect of output reductions on production costs. The effect is naturally most marked for high capital cost plants.

4.4 <u>Production costs</u> (continued)

  4.4.3 <u>Effect of Reduction in output</u> (continued)

    A comparison of Tables 3 and 3A shows that the production costs of a 1000 t.p.d. plant running at an average of 80% capacity, i.e. at 800 t.p.d., are slightly higher than those of a 600 t.p.d. plant running at full output.

5. <u>UREA MANUFACTURE</u>

  The manufacture of urea fits readily into projects involving the manufacture of ammonia from natural gas, naphtha, fuel oil or coal, because the carbon dioxide required, in conjunction with ammonia, is available as a by-product from the ammonia plant. Ammonia plants using natural gas as a feedstock normally produce about three quarters of carbon dioxide required to convert all the ammonia to urea. For ease of comparison this deficiency has not been taken into account in the ensuing cost calculation. In practice it would be necessary to find an alternative use for one quarter of the ammonia produced, e.g. as industrial ammonia, or in the manufacture of ammonium nitrate or NPK fertilizers. If no alternative use for ammonia can be found it would be necessary to use some liquefied petroleum gas or naphtha as feedstock or to manufacture carbon dioxide to meet the deficiency. For a 1720 t.p.d urea plant, carbon dioxide manufacture would increase capital costs by about $4 million and, at 20% capital charges, would increase urea costs by about $4 a ton. (The electrolytic process does not produce carbon dioxide; the ammonia from this process is therefore used to make ammonium nitrate fertilizer. The process is described and costs are given in Section 4).

  5.1 <u>Process</u>

    Urea is made by reacting ammonia and carbon dioxide at temperatures of $180^{o}C$ to $200^{o}C$ and pressures of 130 to 280 atmospheres. The reaction is incomplete and the process problems arise mainly in separating the urea from excess ammonia and carbon dioxide and other reaction products and in returning the latter to the reactor. The problems are complicated by the corrosive nature of the substances coming from the reactor.

5. **UREA MANUFACTURE** (continued)

5.1 **Process**(continued)

The urea solution, after separation from reactants and by-products
is concentrated by evaporation; solid granules are obtained by
spraying the concentrated solution from the top of a "prilling" tower
in which it falls through a rising stream of air which cools
and solidifies the particles.

Special precautions are taken in evaporation to minimize
the production from urea of biuret, a substance which, if present
in significant quantity, can injure germinating seedlings. The
product we have assumed for this report contains not more than 0.9%
biuret and is satisfactory for nearly all fertilizer uses. If urea
is used as a foliar spray the biuret should not exceed 0.3%. A
product meeting this requirement can readily be obtained by providing
for some additional processing.

Four or five established processes are available. The differences
in capital and operating costs are small and the costs given in
this section cover all processes.

5.2 **Capital Costs**

The urea plant is designed to convert all the available ammonia
to urea. Since 0.58 tons of ammonia will produce one ton of urea
the 300 t.p.d. ammonia plant requires a 520 t.p.d. urea plant, the
600 t.p.d. requires 1040 t.p.d. urea and the 1000 t.p.d. requires
1720 t.p.d. urea.

Summarized capital costs for the three sizes of plants are given
in Table 4 below. Table A of Appendix 2 gives detailed capital costs,
and Table 4A combines the ammonia and urea plant capital costs.

TABLE 4 - TOTAL CAPITAL COSTS FOR UREA PLANTS ($ million)

Plant capacity (t.p.d.)	520				1040				1720			
Ammonia feedstock	N.G.	N	F.O.	C.	N.G.	N.	F.O.	C.	N.G.	N	F.O.	C
Fixed capital	25.0	25.0	25.0	25.0	41.0	41.0	41.0	41.0	56.0	56.0	56.0	56.0
Working capital	1.1	2.7	2.0	1.5	2.0	5.2	3.8	2.6	3.0	8.3	5.7	4.0
Total	26.1	27.7	27.0	26.5	43.0	46.2	44.8	43.6	59.0	64.3	61.7	60.0

N.G. = Natural Gas: N = Naphtha: F.O. = Fuel Oil: C = Coal

Notes

1. Notes 1, 2, 4, 5 and 6 to Table 2 apply also to this table;

2. Storage is provided for fifty-seven days' production, fifty in bulk and seven in bags. This accounts for 15-20% of the fixed capital and 40-50% of the working capital. For any specific proposal the amount of storage required should be carefully assessed in relation to the seasonal variation of fertilizer demand. If demand is fairly steady, about thirty days capacity would be adequate, giving significant capital savings.

3. Working capital assumes that urea storage is half full, that payments for sales are received one month after despatch, and that one month's stock of bags is carried. The urea cost used in the calculation excludes depreciation and profit on both ammonia and urea.

In Table 4A below the ammonia and urea plant capital costs are combined to show the total capital required for urea manufacture.

TABLE 4A - COMBINED CAPITAL COSTS FOR AMMONIA AND UREA PLANTS ($ million)

Plant capacity (urea t.p.d.)	520				1040				1720			
Ammonia feedstock	N.G.	N.	F.O.	C	N.G.	N	F.O.	C	N.G.	N	F.O.	C
Fixed capital	59.3	62.7	68.5	84.8	93.5	99.1	107.4	134.4	131	139	151	179
Working capital	1.3	3.2	2.3	1.7	2.3	6.3	4.4	3.0	3.5	10.1	6.8	4.4
Total	60.6	65.9	70.8	86.5	95.8	105.4	111.8	137.4	134.5	149.1	157.8	183.4

5.3 Production Costs

The raw material and services consumptions used in calculating production costs are as follows:

	Ammonia	Carbon dioxide	Power	Steam	Raw water
Consumption per ton of urea	0.58 tons	0.76 tons	140 Kwh	1.0 tons	$4M^3$

The carbon dioxide is obtained as a by-product from the ammonia plant, which also supplies the steam needed.

A summary of production costs for the four ammonia feedstocks and the three plant sizes is given in Table 5. Table B of Appendix 2 gives detailed production costs for the 1000 t.p.d. ammonia/1720 t.p.d. urea plants. A different build-up of urea costs is given in the summary Table 1. This separates the feedstock cost from the other cost components.

TABLE 5 - SUMMARY OF UREA PRODUCTION COSTS ($/TON)

Ammonia feedstock	Natural gas			Naphtha			Fuel oil			Coal		
Feedstock price	$0.5 per 1000 scf			$120 a ton			$70 a ton			$8 a ton		
Plant output												
Tons per day	520	1040	1720	520	1040	1720	520	1040	1720	520	1040	1720
Thousand tons per year	160	321	535	160	321	535	160	321	535	150	300	500
Ammonia	22	19	17	74	71	69	52	49	46	28	23	21
Utilities, bags	6	6	6	6	6	6	6	6	6	6	6	6
Maintenance, labour, overheads	7	5	4	7	5	4	7	5	4	7	5	4
Plant cost	35	30	27	87	82	79	65	60	56	41	34	31
Depreciation (10%)	37	29	25	39	31	26	43	33	28	56	45	36
Sub-total	72	59	52	126	113	105	108	93	84	97	79	67
Profit (10%)	37	30	25	41	33	28	44	35	30	57	46	37
Total	109	89	77	167	146	133	152	128	114	154	125	104

Table 5 (continued)

Notes

1. Notes 1, 2 and 3 to Table 3 apply also to this table.

2. Depreciation and profit are based on Table 4A; i.e. they cover capital charges on both ammonia and urea plants. The figures have been presented in this way to make it easy to adjust them for different depreciation and profit rates.

3. Ammonia is charged at "Plant Cost"; i.e. exclusive of depreciation and profit.

4. Sales expenses are not included.

6. AMMONIUM NITRATE MANUFACTURE

The manufacture of ammonia by electrolysis does not produce, as a by-product, the carbon dioxide needed for urea manufacture. This can be obtained by burning fuel oil and extracting the carbon dioxide from the combustion gases with a solvent; sulphur dioxide, which is formed from sulphur in the fuel oil, must be removed from the carbon dioxide. Approximate cost data for this process are given below:

Urea Production (t.p.d.)	520	1040	1720
Carbon Dioxide required (t.p.d.)	395	790	1300
Carbon Dioxide plant capital ($million)	4.5	6.5	9.0

	Fuel oil	Power	Water	Chemicals	Steam
Process requirements per ton CO_2	0.35 tons	600 Kwh	$5M^3$	0.028 tons	1.8 tons

The steam is obtained from the heat released by the combustion of fuel oil. At a fuel oil price of $70 a ton the cost of carbon dioxide manufacture, including 10% depreciation and 10% profit, adds about $35 a ton to the cost of urea. This additional cost makes the manufacture of urea from "electrolytic" ammonia uneconomic. The alternative is to manufacture ammonium nitrate, which requires only ammonia and air or oxygen, and this alternative has been chosen for the manufacture of nitrogenous fertiliser from electrolytic ammonia.

Ammonium nitrate is widely used as a fertilizer. It contains 34.5% N, as against 46% N in urea, and transport and handling charges are

6. AMMONIUM NITRATE MANUFACTURE (continued)

therefore higher per ton of nitrogen. Except on alkaline soils it is less
likely than urea to be subject to nitrogen loss in the soil. However,
because of its hygroscopicity and its ability to support combustion and,
in extreme situations, to act as an explosive, it requires more precautions
in handling and storage than urea. It is normally stored in bags, not
in bulk, and it is advisable to limit the quantity stored in any one
location.

6.1 Process

The manufacture of ammonium nitrate from ammonia is a two-stage
process. In the first stage nitric acid is made by oxidizing ammonia, oxygen
and air, and in the second stage the nitric acid is "neutralized" with ammonia
to form ammonium nitrate. Since oxygen is available from the separation plant
attached to the ammonia plant, this oxygen can partly be used in the nitric acid
plant. The nitric acid is fed to a "neutralizer" in which it meets a stream of
gaseous ammonia, forming ammonium nitrate solution. The temperature and concentra-
tion of the solution are maintained by condensate injection. In a vacuum evaporator,
which uses the reaction heat for evaporation, the concentration of ammonium
nitrate is increased to 90-95%.

In a "homogenizer" fines and oversize from the product screens are
dissolved and the solution is then further concentrated, by a hot air
stream, to 99.5 - 99.8%. The concentrated solution is sprayed from the
top of a "prilling" tower into a rising air stream which cools and
solidifies the falling droplets. The granules or prills are coated to
prevent caking in storage and are packed in 50 kg. polythene bags.

6.2 Capital costs

A 300 t.p.d. ammonia plant will produce 670 t.p.d. ammonium nitrate
(34.5% N), a 600 t.p.d. plant 1330 t.p.d., and a 1000 t.p.d. plant
2220 t.p.d. At the maximum output a twin-stream plant, consisting of
two 1100 t.p.d. units, is assumed. Table 6 below summarizes capital costs;
details are given in Table A of Appendix 3. Table 7 gives combined capital costs
for ammonia and ammonium nitrate plants.

TABLE 6 - SUMMARY CAPITAL COSTS OF AMMONIUM NITRATE PLANTS ($ million)

Plant capacity (t.p.d.)	670	1330	2 x 1110 = 2220
Plant capacity (thous.t.p.yr)	207	414	690
Fixed capital	23.8	34.5	56.4
Working capital	1.5	2.7	4.3
Total	25.3	37.2	60.7

Notes

1. Notes 1, 2 and 3 to Table 4 also apply to this table (with the substitution of ammonium nitrate for urea)

2. Storage is provided for fifty-seven days' production, in bags. Because it is inadvisable to store so large a quantity of ammonium nitrate in one place it has been assumed that the total stock is maintained in a number of stores located near centres of demand.

TABLE 7 - COMBINED CAPITAL COSTS FOR AMMONIA AND AMMONIUM NITRATE PLANTS ($ million)

Plant Capacity (thous.t.p.yr)	207	414	690
Fixed capital	82.9	132.2	193.4
Working capital	1.6	2.9	4.6
Total	84.5	135.1	198.0

6.3 Production costs

The raw material and services consumptions used in calculating production costs are given below:

	Ammonia	Power	Raw water	Platinum Catalyst	Coating Material
Consumption per ton A.N.	0.45 tons	170 Kwh	5 M^3	80-100 mg	2.0 Kgs.

Production costs for the three sizes of plant are set out in Table 8 below:

TABLE 8 - AMMONIUM NITRATE PRODUCTION COSTS ($ TON)

Plant capacity (t.p.d.) (thous.t.p.yr)	670 207	1330 414	2 x 1110 = 2220 690
Ammonia	25.2	22.5	21.1
Power and Water	1.0	1.0	1.0
Catalysts and Chemicals	1.0	1.0	1.0
Bags	4.7	4.7	4.7
Fixed Costs	31.9	29.2	27.8
Maintenance	2.5	1.7	1.7
Labour and Supervision	0.9	0.7	0.7
Overheads	1.0	0.6	0.4
Variable Costs	4.4	3.0	2.8
Plant Cost	36.3	32.2	30.6
Depreciation (10%)	40.1	32.0	28.1
	76.4	64.2	58.7
Profit (10%)	40.8	32.6	28.7
Total	117.2	96.8	87.4
Equivalent Urea Cost	156.3	129.1	116.5

Notes

1. The product is packed in 50 Kg polyethene bags, 10/1000" thick.

2. The ammonia cost excludes depreciation and profit.

3. Depreciation and profit cover both the ammonia and ammonium nitrate plants.

4. The equivalent urea cost is calculated from the nitrogen (N) contents of ammonium nitrate and urea. Ammonium nitrate contains 34.5% N and urea 46.0% N. Hence, cost of urea = cost of ammonium nitrate x $\frac{46}{34.5}$

7.   COMPARISON OF PROCESSES

7.1 General: Effect of Varying Feedstock Prices

Economic factors always play a major part in a decision about
the building of a fertilizer factory. In particular situations other
factors may be of greater importance, e.g. ensuring fertilizer
supplies, saving foreign exchange, or promoting national development,
but it is still of primary importance that investment should be
as low as is reasonably practicable, that fertilizer should be
produced as cheaply as possible, and that operation of the factory should be
reliable. This section therefore concentrates on the economic aspects
of the selection of feedstock.

The tables so far presented give a detailed comparison of the
production costs, at capital charges of 20% (10% depreciation plus
10% profit) of the various processes at fixed feedstock prices.
These prices have been chosen in the light of current prices.
However, feedstock prices differ significantly from region to region
and are also liable to change from time to time. To cover a range
of feedstock prices and to enable the reader to select prices
appropriate to his own area, the effect of varying feedstock prices
on urea production costs is given in Figures 1A, 1B and 1C, one for
each size of plant. (Section 2.4.2 gives factors for adjusting ammonia
production costs for changes in feedstock prices).

Before discussing the different processes in detail in the light
of these Figures a few general observations are relevant.

Firstly, economic factors include technical considerations. If
a process is less reliable because of technical complexity, this is
reflected in lower output and higher production costs.

Secondly, because the urea process is the same for all sources
of ammonia, it is the ammonia manufacturing processes which are under
discussion.

Thirdly, as the capital costs increase so does the penalty for
loss of output. The increases in cost of production caused by a given
decrease in annual output become steadily greater as we move from
natural gas to naphtha, fuel oil, coal and electric power (see Table 3A).

7.1 General: Effect of Varying Feedstock Prices (continued)

Fourthly, the probable long-term stability of feedstock prices
is an important factor. Indigenous feedstocks have a great advantage
from this point of view.

7.2 Urea and Ammonium Nitrate

To cover the five ammonia production processes we need some
method of comparing the production costs of urea and ammonium
nitrate. This is done on the basis of their nitrogen (N) content.
Urea has 46% N and ammonium nitrate 34.5% N. If ammonium nitrate
costs are multiplied by 46 ÷ 34.5, i.e. by 4/3, we obtain an "equivalent
urea" production cost. Market prices for these two fertilizers
are, in fact, determined mainly by their N content so that the
conversion is a valid one. The capital costs do not need
correction, because the total quantity of fertilizer nitrogen
produced is the same for urea as for ammonium nitrate.

7.3 Natural Gas - Electric Power

The general conclusions to be drawn from Table 5 and the graphs
are the same as those arising from an examination of ammonia
production costs (see Section 2.4.1). The most obvious conclusion
is that Natural Gas produces by far the cheapest urea and would be
chosen as a feedstock whenever it is available.

The electrolytic process for ammonia production requires very
large qunatities of electricity (a 1000 t.p.d. plant has an hourly
demand of approximately 450 MW) at very low prices.   These conditions
effectively confine the process to places where large quantities of
hydro-electric power are available and where there is no large demand
for power for general industrial or domestic use.

7.4 Naphtha versus Fuel Oil

At current prices naphtha produces the dearest urea. For countries
without indigenous fuel resources the natural competitor to naphtha
is fuel oil. If the price of naphtha is more than $15 to $20 a ton
greater than that of fuel oil, naphtha cannot compete with fuel oil.
It seems improbable that the price difference will be as low as this
for some time to come and it therefore seems likely that where
the choice lies between these two feedstocks, fuel oil will be preferred.
The price differential of $15 to $20 a ton only applies at the capital

7.4   Naphtha versus Fuel Oil (continued)

charges of 20% assumed in this report. If capital charges were
increased a greater price differential could be tolerated because
the naphtha-based plant has a lower capital cost.
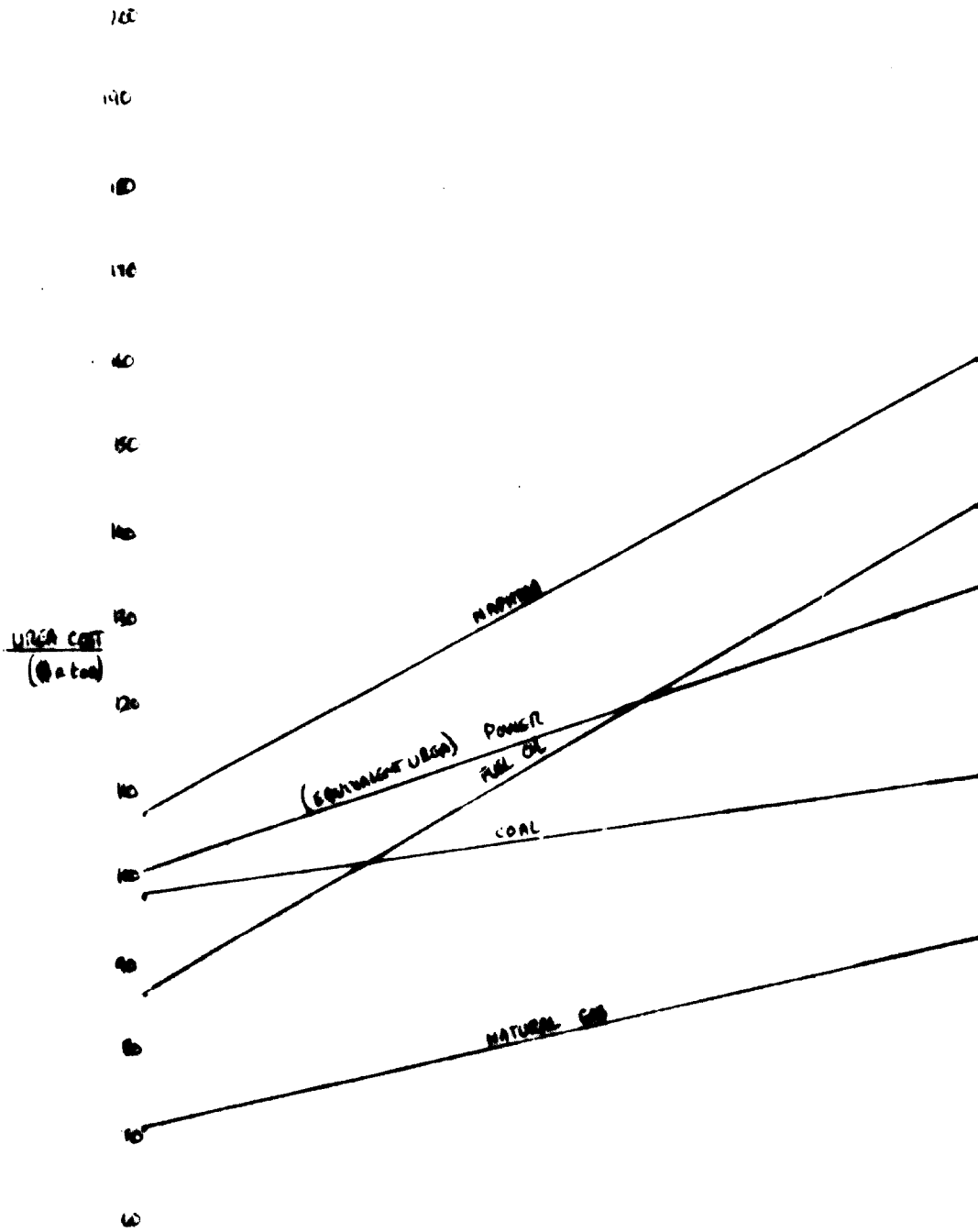
7.5   Fuel Oil versus Coal

Many countries with coal reserves, and coal is by far the most
widely distributed feedstock constituting about 90% of world fuel
resources, will be interested in the comparison between fuel oil
and coal.   At 1720 t.p.d. urea the balance of advantage appears
to be with coal, except at coal prices of $15 to $20 a ton where fuel oil
would probably be preferred. However, with smaller plants the
advantage of coal is less marked as is shown in the table below,
which gives the fuel oil price required to produce urea at the same
cost as urea from coal, at a range of coal prices. (All prices
are in $ a ton).

Coal Price	5	10	15	20
Equiv't fuel oil price: 1720 t.p.d. 44		57	70	83
" " " " :1040 t.p.d. 57		69	82	95
" " " " : 520 t.p.d. 64		77	90	103

In making a choice between these feedstocks factors other than
the purely economic need consideration. If fuel oil has to be imported,
the use of coal will give very large savings in foreign exchange. In
a changing fuel supply situation the use of an indigenous resource
is a considerable advantage and also contributes to national development.
On the other hand, coal-based processes for ammonia production are less
firmly established than fuel oil-based processes, and the synthesis
gas production of coal is technically much more complex than that of
fuel oil. Coal is also a much less standard product than fuel oil and
synthesis gas production processes have to be designed to suit the
grades of coal available. Some allowance has been made for these difficulties
in taking 310 days full output a year for fuel oil and 290 days for coal.

The production costs of coal-based plants rise more steeply
with falling output than the production costs of fuel oil-based
plants. (See Table 3A)

Fig.1A — UREA PRODUCTION COST OF VARIOUS FEEDSTOCK PRICES — 1720 TONS UREA PER DAY

URER COST ($ a ton)

Labels on lines: NAPTHA, (EQUIVALENT UREA), POWER, FUEL OIL, COAL, NATURAL GAS

NAT. GAS	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1.0	1.1	1.2	$ a 1000 s.c.f.
NAPTHA	70	80	90	100	110	120	130	140	150	160	170	$ a ton
FUEL OIL	20	30	40	50	60	70	80	90	100	110	120	$ a ton
COAL	3	4	5	6	7	8	9	10	11	12	13	$ a ton
POWER		0.001		0.002		0.003		0.004		0.005		$ a Kwh

FEEDSTOCK PRICES

Fig.13   UREA PRODUCTION COST OF VARIOUS FEEDSTOCK PRICES

1000 TONS UREA PER DAY

FEEDSTOCK PRICES

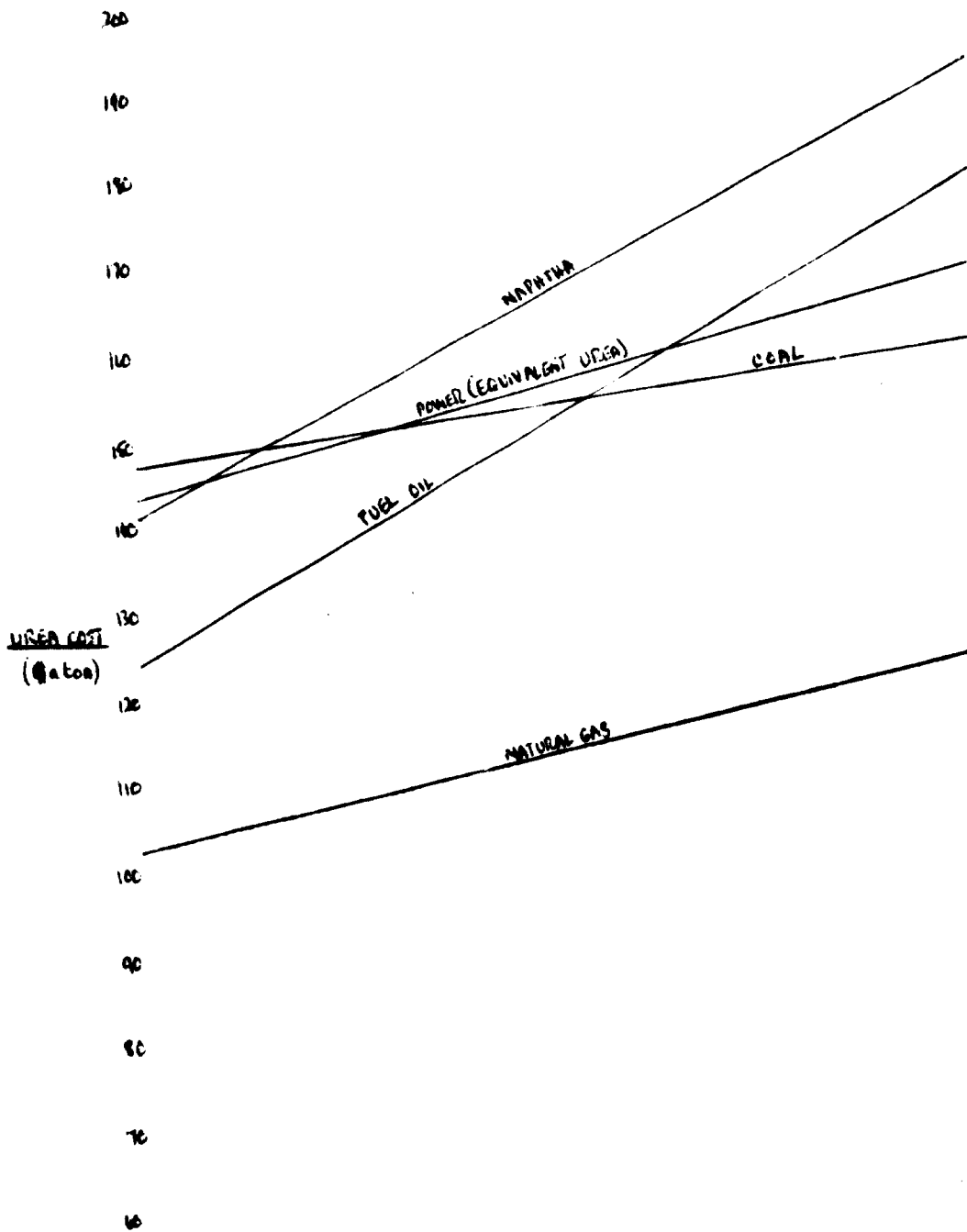Fig.1C UREA PRODUCTION COST OF VARIOUS FEEDSTOCK PRICES
520 TONS UREA PER DAY

UREA COST
($ a ton)

NAT. GAS	0·2	0·3	0·4	0·5	0·6	0·7	0·8	0·9	1·0	1·1	1·2 $ a 1000 s.c.f
NAPHTHA	70	80	90	100	110	120	130	140	150	160	170 $ a ton
FUEL OIL	20	30	40	50	60	70	80	90	100	110	120 $ a ton
COAL	3	4	5	6	7	8	9	10	11	12	13 $ a ton
POWER		0·001		0·002		0·003		0·004		0·005	$ a Kwh

FEEDSTOCK PRICES

7.5 Fuel Oil versus Coal (continued)

Too much should not be made of these technical matters. Coal synthesis gas production presents more technical problems than fuel oil synthesis gas production but these problems are solvable by an experienced contractor, though the process will always make greater demands on the technical expertise and experience of operating and maintenance personnel.

7.6 Return on Capital - Cash Flow

In mid-1972 urea was obtainable on world markets at an f.o.b. price of about $55 a ton. The current price (December 1974) is about $360 a ton. The 1972 price did not give manufacturers a reasonable return on their capital and was maintained by a surplus of urea on world markets. The large rise in oil prices accounts for a large part of the increase but the major part is undoubtedly due to a world shortage of urea. As manufacturing capacity increases and urea becomes more readily available prices must fall and fall substantially. It would be most unwise to use the current inflated prices as a guide in calculating the profitability of a projected plant.

The costs set out in this report assume full output from the plants and they take no account of methods of financing, or of inflation during the construction of the plant. In practice it will take three to four years to work up to full output, for most overseas projects interest charges on loans will have to be met, and there will certainly be inflation costs to cover during plant construction. All these factors operate to increase costs and decrease the 10% profit allowed for in the calculated costs.

A cash flow statement for a given project can take account of these factors, with the exception of inflation, and gives a truer picture of the profitability of a project. It is not practicable to produce cash flow statements for so wide a range of processes and plant sizes as are covered by this report. To illustrate the effects of these factors cash flow statements for 1720 t.p.d. ammonia/urea plants based on coal and on fuel oil are presented in Appendix 4. The assumptions made are set out in detail in Appendix 4, but the major ones are that one third of the fixed capital is supplied as equity, that the remainder is borrowed at an average interest rate of 9% p.a., that urea is sold for $200 a ton, and that outputs for the first four years are 40%, 60%, 80% and 100% respectively of designed output.

Under these conditions both schemes are able to repay borrowed capital, including interest charges, in about $3\frac{1}{2}$ years of operation. The conventional return on capital, i.e. the proceeds of sales less production expenses at full output, expressed as a percentage of total capital, is 48% for fuel oil and 46% for coal. The discounted cash flow returns, based on the cash flow statements, are 22% and 21% respectively for a ten year project life. This means that the total capital for the projects could be borrowed at these rates of interest and completely repaid, together with the interest charges, in ten years.

APPENDIX 1   AMMONIA PLANT COSTS

TABLE A - DETAILED CAPITAL COSTS FOR 1000 TON PER DAY AMMONIA PLANT
($ million)

Feedstock	Nat.gas	Naphtha	Fuel oil	Coal	Electric power
Equipment	31.4	34.7	39.8	54.4	76.0
Spares	3.1	3.5	3.9	5.4	6.0
Transport	3.4	3.8	4.3	6.0	8.5
Delivered Equipment	37.9	42.0	48.0	65.8	90.5
Erection	14.3	16.5	19.5	22.2	12.5
Civil Works	7.8	8.2	9.2	10.8	12.5
Engineering and Management	6.3	6.8	7.6	10.0	7.0
Erected Plant	66.3	73.5	84.3	108.8	122.5
Start-up	1.9	2.0	2.1	3.0	2.0
Sub-total	68.2	75.5	86.4	111.8	124.5
Contingency (10%)	6.8	7.5	8.6	11.2	12.5
Total Fixed Capital	75.0	83.0	95.0	123.0	137.0
Working Capital	0.5	1.8	1.1	0.7	0.3
Total Capital	75.5	84.8	96.1	123.7	137.3

Notes

1. Notes 1 to 6 to Table 2 apply to this table;

2. License fees are included in engineering and management costs;

3. Start-up costs include expenses for training before the start-up of the plant;

4. Because the plants are in developing countries spares have been included at 10% of F.O.B. equipment;

5. Approximate detailed costs for 300 and 600 t.p.d. plants can be calculated from the total fixed capital of Table 2 on the assumption that the percentage contribution of each item is the same as for the 1000 t.p.d. plant.

APPENDIX 1   AMMONIA PLANT COSTS (continued)

TABLE B - DETAILED PRODUCTION COSTS FOR 1000 TON PER DAY AMMONIA PLANTS
($/TON)

Feedstock	Nat.gas	Naphtha	Fuel oil	Coal	Electric Power
Feedstock price	$0.50/1000 s.c.f.	$120/ton	$70/ton	$8/ton	$0.003/Kwh
Feedstock and fuel	19.0	106.0	67.2	18.4	—
Power and Water	1.9	1.9	1.9	4.1	33.5
Catalysts and Chemicals	0.7	0.8	0.5	1.0	0.5
Fixed Costs	21.6	110.7	69.6	23.5	34.0
Maintenance (2.5%)	6.1	6.7	7.7	10.6	11.0
Process Labour/supervision	0.8	0.9	1.0	1.2	0.8
Overheads	1.2	1.2	1.2	1.3	1.2
Variable Costs	8.1	8.8	9.9	13.1	13.0
Plant Cost	29.7	119.5	79.5	36.6	47.0
Depreciation (10%)	24.2	26.8	30.7	42.5	44.2
	53.9	146.3	110.2	79.1	91.2
Profit (10%)	24.4	27.4	31.2	42.6	44.3
Total	78.3	173.7	141.4	121.7	135.5

Notes

1. Notes 1, 2 and 3 to Table 3 apply to this table;

2. The terms fixed and variable costs used in this table refer
    to costs per ton of ammonia produced. If the plant output is
    reduced the "fixed" costs per ton of ammonia remain constant
    irrespective of the quantity of ammonia produced. The variable
    cost per ton of ammonia represent a constant annual expenditure,
    independent of output, and the costs per ton of ammonia therefore
    rise as output is reduced, as of course do also depreciation
    and profit per ton of ammonia.

APPENDIX 2   UREA PLANT COSTS

TABLE A — DETAILED FIXED CAPITAL COSTS FOR UREA PLANTS ($ million)

Plant capacity (t.p.d.)	520	1040	1720
Equipment f.o.b.	8.6	14.0	19.9
Spares f.o.b.	0.9	1.4	2.0
Transport	0.9	1.4	2.2
Delivered Equipment	10.4	16.8	24.1
Erection	3.5	5.9	7.6
Civil works	5.1	8.4	11.2
Engineering and Management	3.5	5.9	7.6
Erected Plant	22.5	37.0	50.5
Start-up	0.2	0.3	0.4
	22.7	37.3	50.9
Contingency (10%)	2.3	3.7	5.1
Total Fixed Capital	25.0	41.0	56.0

Notes 1, 2, 3 and 4 to Table A of Appendix 1 apply to this table.

APPENDIX 2   UREA PLANT COSTS (continued)

TABLE B - DETAILED PRODUCTION COSTS FOR 1720 T.P.D. UREA PLANTS ($/TON)

Ammonia Feedstock	Nat.gas	Naphtha	Fuel oil	Coal
Ammonia	17.2	69.3	46.1	21.2
Power and water	1.8	1.8	1.8	1.8
Bags	4.7	4.7	4.7	4.7
Fixed Costs	23.7	75.8	52.6	27.7
Maintenance (2.5%)	2.6	2.6	2.6	2.8
Process Labour/Supervision	0.6	0.6	0.6	0.6
Overheads	0.5	0.5	0.5	0.5
Variable costs	3.7	3.7	3.7	3.9
Plant cost	27.4	79.5	56.3	31.6
Depreciation (10%)	24.5	26.0	28.3	35.8
	51.9	105.5	84.6	67.4
Profit (10%)	25.2	27.9	29.5	36.7
Total	77.1	133.4	114.1	104.1

Notes

1.   Bags. Urea is packed in 50 kg. polythene bags, 0.010 inches thick;

2.   Annual outputs are 535,000 tons, except for coal-based plants where the lower ammonia output limits urea production to 500,000 tons.

APPENDIX 3   AMMONIUM NITRATE PLANT COSTS

TABLE A - DETAILED CAPITAL COSTS OF AMMONIUM NITRATE PLANTS (0 million)

Plant Capacity (t.p.d.)	670	1330	2 x 1100 = 2200
Equipment f.o.b.	9.1	14.2	25.4
Spares f.o.b.	0.9	1.4	1.7
Transport	1.0	1.6	2.9
Delivered Equipment	11.0	17.2	30.0
Erection	2.7	4.0	6.4
Civil works	3.9	5.5	9.0
Eng. and Management	2.9	3.4	4.3
Erected Plant	20.5	30.1	49.7
Start-up	1.1	1.3	1.6
	21.6	31.4	51.3
Contingency	2.2	3.1	5.1
Total	23.8	34.5	56.4

Notes 1, 2, 3 and 4 to Table A, Appendix 1, also apply to this Table.

APPENDIX 4   CASH FLOW STATEMENTS

Cash flow statements for the production of 1720 t.p.d. urea from
fuel oil and from coal are set out in Tables A and B. The assumptions which
have been made in drawing up these statements are as follows:

1.   Construction time is four years with fixed capital expenditure
     20% in the first year, 30% in the second and third years,
     and 20% in the fourth year;

2.   Equity is one-third of fixed capital. The remaining two-thirds
     plus the interest charges during construction are obtained as
     loans. Most of this loan is presumed to be contractor-financed
     at an interest rate of 8% p.a. The remainder is borrowed from
     other sources at higher interest rates. An average rate of 9%
     p.a. is assumed.

3.   For the first three years of operation annual outputs average
     40%, 60% and 80% of designed output. Thereafter designed
     output is maintained.

4.   The urea selling price is $200 a ton.

5.   Sales expenses are $0.7 million a year at full output.

6.   Loan repayment has a prior claim on any cash balance.

7.   No allowance is made for taxation.

APPENDIX 4   CASH FLOW STATEMENTS (continued)

TABLE A - CASH FLOW FOR 1720 T.P.D. UREA PLANT: FUEL OIL ($ million)

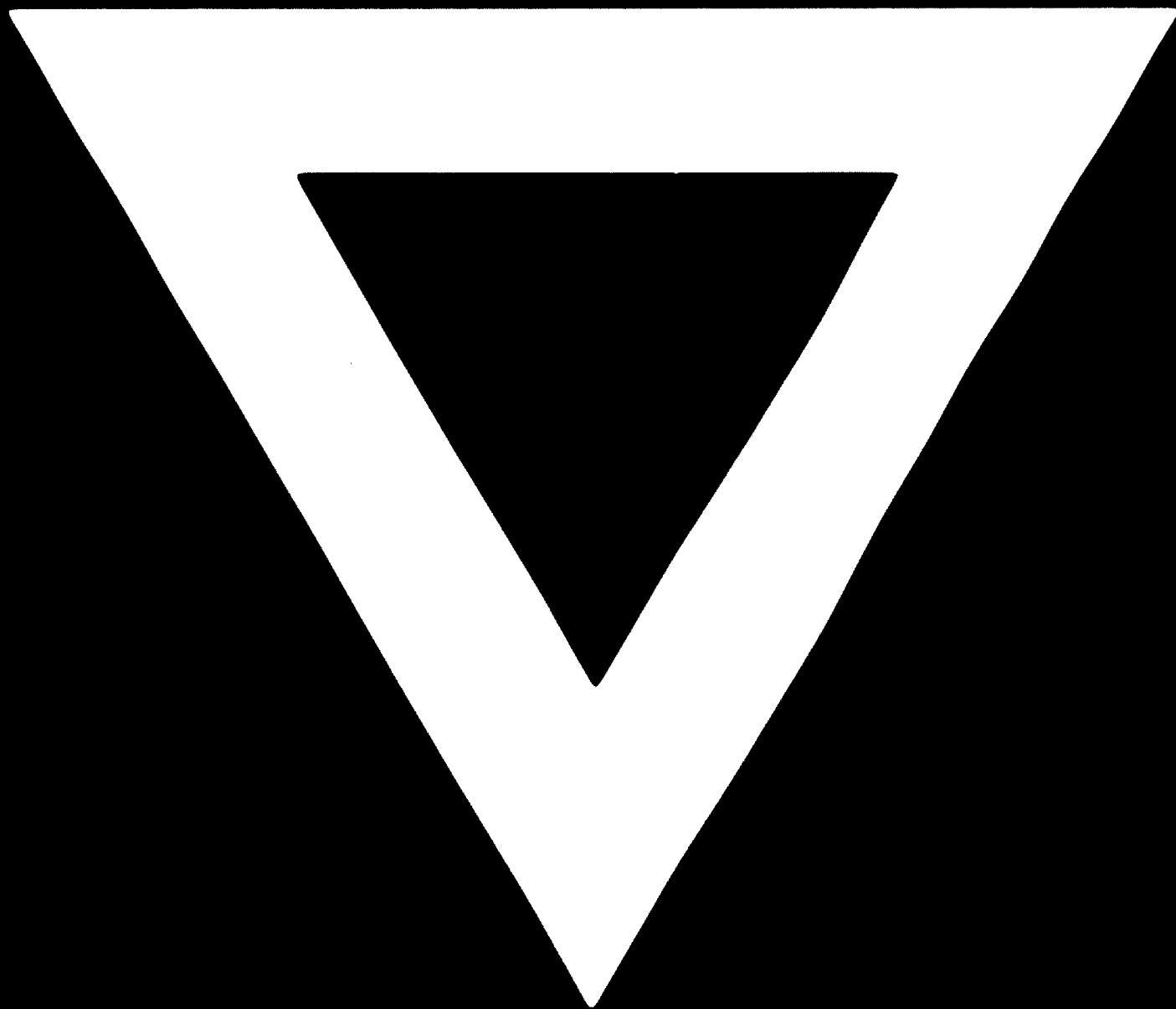| Year	1	2	3	4	5	6	7	8	9 on-wards	Total
Fixed capital	30.2	45.4	45.3	30.2						151.0
Working capital					6.8					6.8
Interest on Working capital (10%)					0.4	0.7	0.7	0.7	0.7	
Loan Interest(9%)		0.1	4.1	7.2	10.3	8.9	5.5	0.9		24.4
Loan Repayment					16.3	33.8	53.	10.7		114.3
Available for distribution								64.1	75.3	
Total Outflow	30.2	46.0	49.7	38.4	33.8	43.4	60.0	76.0	76.0	
Net Trading Profit					27.0	43.4	60.0	76.0	76.0	
Equity	30.2	19.8								50.0
Loan		26.2	49.7	38.4						114.3
Overdraft					6.8					6.8
Total Inflow	30.2	46.0	49.7	38.4	33.8	43.4	60.0	76.0	76.0	

APPENDIX 4   CASH FLOW STATEMENTS (continued)

TABLE B - CASH FLOW FOR 1720 T.P.D. UREA PLANT: COAL ($ Million)

Year	1	2	3	4	5	6	7	8	9 on-wards	Total
Fixed Capital	35.8	53.7	53.7	35.8						179.0
Working Capital					4.4					4.4
Interest on Working Capital (10%)					0.4	0.4	0.4	0.4	0.4	
Loan Interest (9%)		0.7	5.1	9.6	12.1	10.5	7.2	0.5		45.7
Loan Repayment					17.2	36.8	58.0	22.4		134.4
Available for Distribution								60.3	83.2	
Total Outflow	35.8	54.4	58.8	45.4	34.1	47.7	65.6	83.6	83.6	
Net Trading Profit					29.7	47.7	65.6	83.6	83.6	
Equity	35.8	24.2								60.0
Loan		30.2	58.8	45.4						134.4
Overdraft					4.4					4.4
Total Inflow	35.8	54.4	58.8	45.4	34.1	47.7	65.6	83.6	83.6	

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