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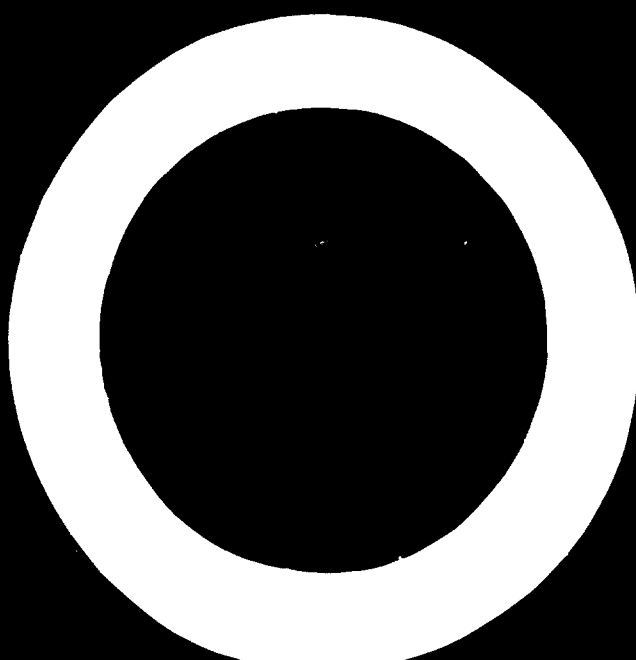
Guide to Building an Ammonia Fertilizer Complex



The cover photograph depicts a 600 tons a day, single-train ammonia unit built by the M. W. Kellogg Company, for Farmlands Industries at Fort Dodge, Iowa.

By courtesy of the M. W. Kellogg Company, a division of Pullman Inc.

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VIENNA

Fertilizer Industry Series

Monograph No. 2

GUIDE TO BUILDING AN AMMONIA FERTILIZER COMPLEX

UNITED NATIONS
New York, 1969

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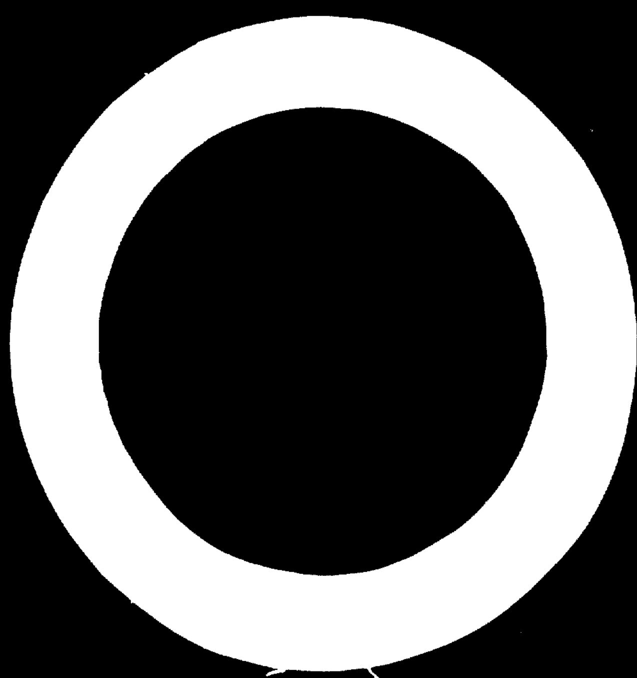
Foreword

This report is the second of a series of monographs in the Fertilizer Industry Series to be published by the United Nations Industrial Development Organization. It will be followed immediately by other studies in the series on: reduction of sulphur needs in the manufacture of fertilizer; the ammonium chloride and soda-ash dual manufacturing process in Japan; and the new process for the production of phosphatic fertilizers using hydrochloric acid.

The increasingly acute shortage of food that has resulted from rapid population growth on the one hand, and from rising living standards on the other, confronts the world with the pressing problem of how to increase agricultural production quickly and efficiently. To this end, the expansion of the fertilizer industry and the rational use of fertilizers, particularly in the developing countries, must be encouraged by every possible means.

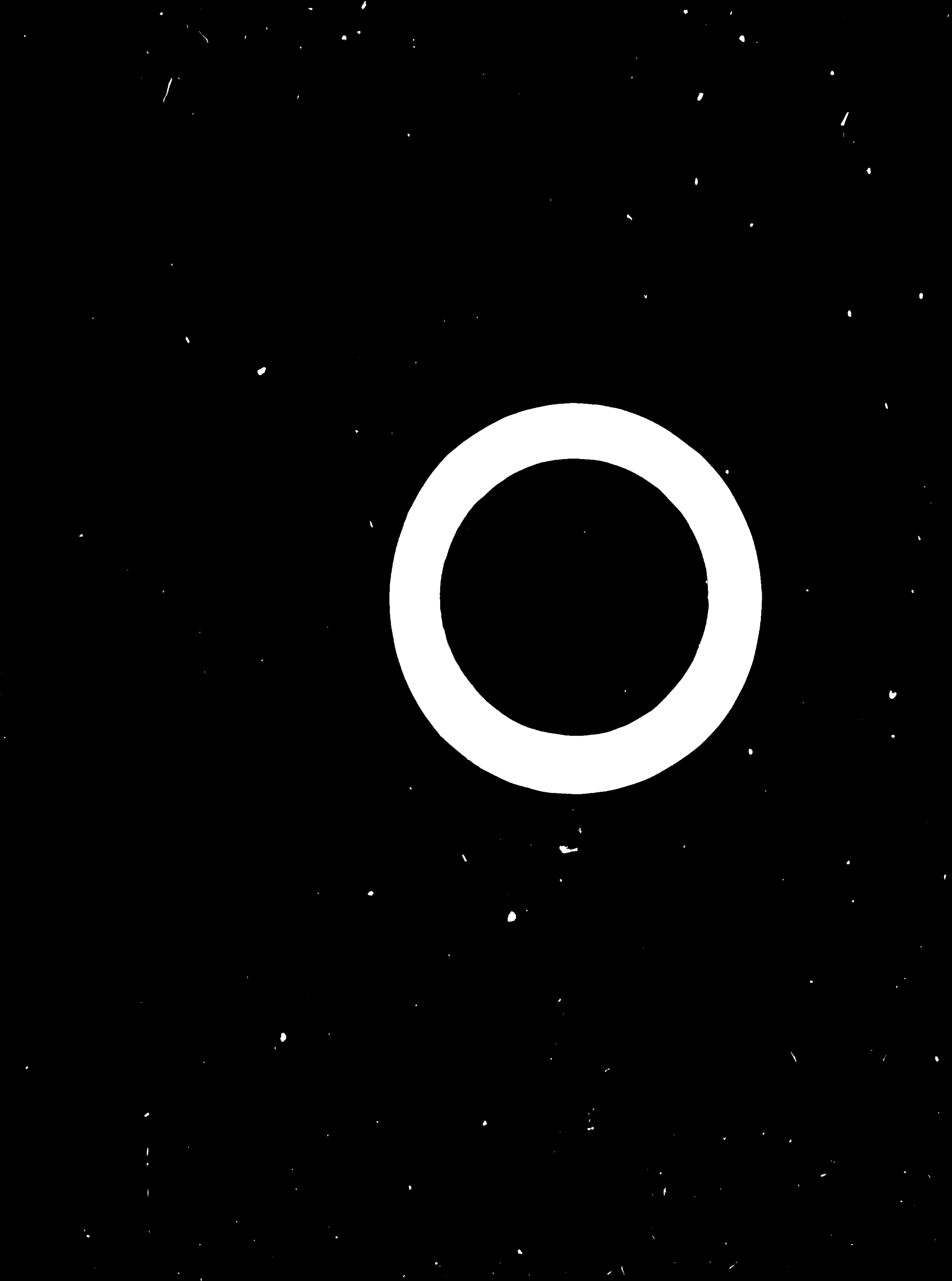
It is the purpose of this series of monographs to assist the developing countries by providing them with the most recent technical and economic information in this field and on the steps that must be taken to establish a fertilizer industry.

The present report was prepared by J. A. Finneran and P. J. Masur, of the M. W. Kellogg Company, New York, serving as consultants to UNIDO.



Contents

Foreword
Introduction
Phase I: Project study 1
Phase II: Putting the project into operation 9
Annex I 19
Annex II 21



Introduction

A petrochemical project, particularly one related to the fertilizer industry, is both a privilege and a burden to those who undertake it. The privilege is to be able to participate in one of mankind's most rapidly developing and crucial efforts today, that of expanding the world's food supplies. The burden, of course, is the knowledge that programmes which have already been adopted and developed concern large-scale investments and prodigious human effort. The results of such undertakings are bound to reflect upon the reputation of the companies concerned or the countries involved. It is for those engaged in this work that this paper has been prepared, in the hope that it will furnish guidance for the success of such an undertaking.

Ammonia production has recently received considerable attention in the technical press. Articles have cast doubt on the technical and economic soundness of giant projects in this field. In specific cases, the concern may be justified, but any chemical plant, for any product, regardless of size, may be technically and/or economically unsound, due to a combination of circumstances.

For a large ammonia plant such as a single-stream installation with a capacity of 600 tons or over per day, there has been a tendency to associate all sorts of problems with the fact that it is a giant or a new type of plant. This reasoning is not necessarily justified because a modern large ammonia plant closely resembles a small one, and the inherent technical pitfalls of a large plant are limited. Many of the difficulties reported would have occurred even in a small plant. However, with virtually no construction of small plants being carried out there is little or no basis for comparison. The economic advantages offered by the larger facilities are so well recognized that the installation of them in certain areas has tended temporarily to outstrip the market. As a result, delays in construction have occurred because of the high demands on suppliers of plant equipment and on labour, which together with the situation of excess capacity, has had its effect on the overall economics of such projects.

This does not mean that the large ammonia plant does not offer a technical challenge, but it is intended to put the problem in perspective. A prospective owner, building on a sound foundation and with the guidance of an experienced contractor, can easily avoid the pitfalls. Numerous cases of a smooth start-up and high on-stream factor prove this to be the case. The purpose here is to point out those factors challenging both the owner and contractor and to cite specifically the part each can play in overcoming them.

For the installation of a large ammonia plant or similar undertaking it is helpful to divide the project into two phases and to enumerate the various stages through which it should go, from the conception of the idea to the operating stage:

Phase I

(*a*) Products and market
(*b*) Raw materials
(*c*) Sites
(*d*) Processes
(*e*) Project cost
(*f*) Evaluation

Phase II

(*a*) Project specifications
(*b*) Proposals and final evaluation
(*c*) Contract
(*d*) Design and construction
(*e*) Operation and maintenance

Phase I indicates those elements that must be determined while the project is still in the study stage. At the end of Phase I the project will be sufficiently defined to know whether or not it is a commercial feasibility. Phase II enumerates the steps to be taken to make the ammonia plant a reality and to ensure its successful operation.

PHASE I

Project study

Though the stages are listed in order, they need not necessarily follow each other in sequence, provided that each item is defined and documented before an evaluation is made and before Phase II begins.

Products and market

There must be a demand for a chemical plant before the project can be initiated. As nitrogen is a basic component of fertilizer, a vital factor in meeting ever-expanding food requirements, the demand for ammonia exists in virtually every country of the world. The installation of ammonia production plants in recent years has therefore skyrocketed. Moreover, technological improvements have enabled unit capacities to increase sufficiently to make a significant saving in production costs. Thus, the spotlight today is on the large ammonia plant, which forms the basis for fertilizer chemical complexes. The performance of the ammonia plant and the important part it plays in the success of any broader undertaking cannot be overestimated.

With assurance that the necessity for a given product exists (in this case nitrogen as ammonia) the study can begin. At the outset, the following factors[1] must be explored in depth:

(a) Specific market area;

(b) Ammonia production capacity required;

[1] For factors *(b)* to *(e)* accurate definitions are required before engineering contractors can supply details of plant investment and operating costs.

(c) Range of associated nitrogen products required by the market;
(d) Quantity of each;
(e) Product specifications;
(f) Estimate of future demands;
(g) Prices of equivalent products available;
(h) Product distribution facilities;
(i) Distribution schedules with special attention to unusual seasonal demands.

A great deal of study and planning is required if problems presented by a varied market are to be met successfully. Early consideration should be given to obtaining outside consultancy services — an adviser or a consultant organization, expert in the field, and familiar with local conditions. Such services can be supplied by a chemical engineering contractor, for example, who can assist in launching the project properly and maintaining continuity of effort throughout Phase I.

Raw materials

Obviously, raw materials are a basic requirement for any chemical processing enterprise. The fact that they are listed in second place does not mean that they are of secondary importance. Chemical plant economics and, therefore, commercial feasibility, are significantly affected by the availability of raw materials as much as by their cost. Such factors will in turn dictate the number of accessible processing methods and will influence the final choice.

The raw material survey should establish the following information:[2]

(a) Raw materials available;
(b) Future possibilities from other sources;
(c) Continuity of source;
(d) Quality;
(e) Variability;
(f) Cost.

The importance of items (a), (b) and (c) is immediately apparent. It is essential to examine, as soon as possible, the characteristics of all the raw materials, including their chemical analysis, physical properties and the conditions under which each is available. For any material, solid, liquid or gas, a specific set of data is required. A typical listing of the main information essential for each is included

[2] For items (a), (d), (e) and (f) accurate definitions are required before engineering contractors can supply details of plant investment and operating costs.

in annex I. In collecting such information, care must be taken to ensure that it is typical of average material and, therefore, representative.

A wide variety of hydrocarbon raw materials can be used as a source of hydrogen for the production of ammonia, ranging from natural gas to coke or coal. In addition, byproduct gases rich in either hydrogen, hydrocarbons or a combination of both can be employed.

It must be remembered, however, that more than hydrocarbon is required to produce ammonia. In the case of catalytic steam reforming, for example, air and water (steam) must be supplied. The air introduces the nitrogen necessary to achieve the three-to-one hydrogen-nitrogen ratio for NH_3 synthesis. The oxygen in the air, by combustion with hydrogen, supplies additional heat with which to complete the steam-hydrocarbon reactions. For partial oxidation, a source of oxygen is required to furnish all the process heat internally and, together with water (steam), to convert the hydrocarbon to carbon monoxide and hydrogen. Partial oxidation is then followed by carbon monoxide shift conversion to carbon dioxide and hydrogen, and the removal of carbon dioxide. In this case, the nitrogen is usually introduced during the final low temperature nitrogen wash system to purify the gas before synthesis. A partial oxidation ammonia plant, therefore, requires a separate source of oxygen and nitrogen, or an air separation plant.

The important part that the chemical composition of any raw material plays in ammonia production cannot be over-emphasized. This is particularly true of the sulphur and hydrocarbon content, for they will influence the steps required during processing.

These steps for raw materials like natural gas and naphtha will vary even in a single process, such as catalytic steam reforming. Sulphur must be removed and, depending on the reactivity of the particular compounds, desulphurization may be simply a matter of adsorption or chemical reaction. For non-reactive sulphur compounds, facilities are required for conversion to a reactive state, such as hydrogen sulphide, followed by removal.

Regarding the hydrocarbon content of any feedstock, again considering catalytic steam reforming, various modifications are necessary. For a feedstock having a high concentration of unsaturated hydrocarbons, hydrogenation is needed to eliminate the possibility of carbon deposition in the reformer. In addition, the carbon-to-hydrogen ratio of the feedstock will determine the size of the carbon dioxide removal facilities for a given synthesis gas production. Proceeding from natural gas to naphtha, this ratio increases, thus requiring larger CO_2 removal facilities.

Where ammonia is to be produced by partial oxidation, the situation is different. Sulphur compounds are removed in conjunction with carbon dioxide removal. However, in such cases the CO_2

by-product contains the sulphur compounds. Therefore, provisions must be made to remove them subsequently, if the CO_2 is to be used for urea manufacture. Large quantities of unsaturated hydrocarbons lead to the production of soot in the partial oxidation route. As for the carbon-to-hydrogen ratio in the raw materials and its effect on the size of the CO_2 removal equipment, the situation would be about the same as with steam reforming. For heavier oils and solid fuels the removal requirements are even greater per unit of synthesis gas produced.

For the additional raw materials (air, oxygen, nitrogen and water), quality is also important. This is particularly true in the case of process water. Because of the close integration of the process flow in large ammonia plants with high-pressure steam generation facilities, boiler feedwater quality is a significant consideration. Raw water quality at the plant site must, therefore, be thoroughly investigated.

This leads to the question of variability within a raw material. Sufficient effort should be made to permit the establishment of variability in the physical and chemical properties encountered, in order to avert serious difficulties or wrong decisions being made.

While the cost of raw materials comes last on the list, it is by no means the least important. All data must be accurate and comprise total costs incurred for the supply of the material at the processing plant. Expenses resulting from handling, storage or transport must also be included.

Sites

Having defined the products of interest, the market involved and the possible choice of raw materials, the question of plant location requires serious study. If a site has already been chosen, the reasons for the choice and the suitability of the location as the project develops must be reviewed.

Ideally, sites will provide the optimum balance between the following factors:*

(a) Availability and cost of raw material;
(b) Proximity to the market;
(c) Distribution facilities (water, railways and the like);
(d) Available utilities and their cost;
(e) Topography and soil conditions;
(f) Atmospheric conditions (average annual and/or seasonal variations);

* For items *(d)* to *(g)* accurate definitions are required before engineering contractors can supply details of plant investment and operating costs.

(g) Regulations (local or otherwise) imposed on the operation from outside

Annex II contains a list of typical data required for more specific information on items (d), (e), (f) and (g)

Processes

Frequently more than one design is possible for a plant manufacturing chemicals This includes ammonia plants Based on the raw materials available the choice is usually between catalytic steam reforming and partial oxidation In exceptional cases where a rich hydrogen gas is available, variations of the above and/or application of low-temperature processing may be possible for the production of ammonia synthesis gas In general, however, for materials such as natural gas, refinery off-gas, liquid petroleum gas and naphtha, catalytic steam reforming or partial oxidation can be employed For these materials in general the catalytic steam reforming process is economically favourable For feedstocks heavier than naphtha, such as fuel oil, coke or coal, catalytic steam reforming is not applicable and partial oxidation is the usual answer Any final choice of process, where alternatives exist, must be based upon a full consideration of the economics involved, including cost of raw materials, investment required, and utility and operating cost.

As indicated under the section on raw materials, the steps required in any process are dependent on both the chemical composition of the feed and the processing alternative under consideration, for example, catalytic steam reforming or partial oxidation. In addition, a choice usually exists for any given unit operation with respect to the over-all processing scheme. For instance, in carbon dioxide removal numerous systems have been developed which will do the job required The question is which would be the best and most economical for the specific case in point. As a rule those involving the lowest investment carry higher operating costs and *vice versa*. The final choice must depend upon a thorough appraisal of the physical and economic factors involved. A correct decision depends upon understanding the part played by these variable factors. The owner should keep this constantly in mind.

While the study continues to define comprehensively the project products, market, materials, sites and the like, the owner must make an economic evaluation of the physical plant to be constructed and the choice of a process that will ensure commercial feasibility. Then, with an accurate and full delineation of the various factors (see footnotes 1 to 3) in hand, and with the lists referred to in annexes I and II, the prospective plant owner is ready to employ the services of a chemical engineering contractor.

Project cost

The project has now acquired an identity even though several processing designs may still be under consideration. The next move is to find the investment and operating costs of the physical facilities for a number of the possible choices of process. Accordingly, the following information is required:

(*a*) Process plant investment;
(*b*) Offsite investment;
(*c*) Operating requirements; and
(*d*) Financing as required.

At this juncture the prospective owner, with the assistance of an engineering contractor, should take the final steps necessary for the completion of Phase I. For items (*a*), (*b*) and (*c*), the engineering contractor has the main responsibility. He will be in a position to furnish the requisite information, provided the project has been researched in depth.

The process plant investment is the cost of construction of a battery limits plant, including contractor's services and fees. This normally consists of the point of entry of raw materials from storage and the point of connexion with all utilities required, as well as the delivery of the product to storage (storage not included) and delivery lines of any process effluent. Usually, items such as a water-cooling tower, circulating pumps, boiler feed-water treatment and pertinent auxiliaries would not be part of a battery limits plant investment. They would normally be included in what are called "offsites". However, in the case of a large-scale ammonia plant, it is common for an exception to be made. Because of the complex interdependence of steam generating facilities that comprise the heat exchange equipment and power recovery units with the process design and operation, the water-cooling tower and boiler feed-water treating facilities are generally included as part of the battery limits plant.

Offsites are the additional facilities that must be provided in order to make the plant a smoothly functioning unit. They include property fencing, raw materials reception, handling and storage, product storage, loading and handling facilities, effluent treatment, buildings, roads, drainage, utilities supply and maintenance equipment.

The main reason for separating plant and offsite investment costs at this point may not be obvious. It is most important to realize that each of these items cannot be absolutely accurately assessed until a complete job specification has been prepared (Phase II) where the total cost of the offsites is usually an asset. Since an estimate of offsite costs can carry a greater degree of uncertainty, it is well to treat such an estimate as a separate item.

The extent of the uncertainty at this point depends mainly on how well the facilities and operations beyond the battery limits plant have been defined. Unless prior consultancy services have been obtained, it often happens that too little attention is paid to these important points. The magnitude and diversity of the offsite facilities for a large central ammonia plant producing, in addition, a series of fertilizer materials such as urea, ammonium nitrate, ammonium sulphate, nitrochalk and nitrogen solutions, must be fully understood.

Operating requirements for the battery limits plant can be provided by the contractor. The raw materials, utilities, labour and maintenance needed to fulfil the normal plant operation can then be established. Similar requirements, such as handling and storage of raw materials or products, will, to a large extent, depend upon the circumstances and wishes of the owner.

Financing is a significant element in such an enterprise and must be considered before an over-all evaluation can be made. As discussed above, not only is there a large central processing plant, but normally also simultaneous processing facilities for by-products and auxiliary requirements in order to complete the operation. The investment costs are generally measured in tens of millions of dollars. Thus the source and cost of financing cannot be underestimated. Engineering contractors can furnish invaluable assistance to the prospective owner in this context and in making arrangements for financing.

Evaluation

The final and critical point of Phase I is the evaluation and decision-making stage. For this reason, it is important that the five elements previously discussed are reviewed in order to be certain that each has been thoroughly considered. Emphasis must be given to such matters as products and market, raw materials and project cost. Any significant error in the information assembled or in the final selection may have serious consequences on the over-all effort.

At this point, the following questions should be considered for final checking:

Has the need for each product been documented?
Has the marketing area been identified?
What are the costs of competitive products?
Has the project cost been determined with acceptable accuracy?
Can the products from the new facility be delivered at a lower cost and with a satisfactory return on investment?
Is a constant supply of raw materials assured?

Have contract terms for the supply of raw material been documented?

Is there any serious risk of early obsolescence of the process as a result of other raw materials becoming available and/or new process developments?

Have the financing arrangements been completely investigated and documented?

Have alternate undertakings for investment with greater potential profitability been considered?

The answers to such questions will have a direct bearing on the decision made. Its validity will rest on the accouracy of the work done in the Phase I study.

Any significant difference between large and small ammonia plants, therefore, is only one of degree. The large plant needs a bigger market, but carries with it a potential for greater profit as a result of lower manufacturing cost. Consequently, it requires comprehensive planning to establish a wider market and entails a greater financial risk. Thus, there is the possibility of greater profit or loss and a wrong decision can prove costly.

PHASE II

Putting the project into operation

Having established the characteristics of the project, the next stage is to bring the physical plant into being. Several major steps must be taken, however, before construction can begin. The preparation of a formal detailed statement of the owner's needs in a plant must be made. Next on the list is an evaluation of proposals from contractors, as well as an investigation into the commercial soundness of the project. Finally the contract is awarded. Of these three steps, the preparation of the complete specifications of the project is the most important. When the owner believes that outside engineering management and services are needed, an engingeering contractor can act under contract to the owner, serving as project manager during this and subsequent stages of project development.

Project specification

The project specification ist the formal document submitted by the owner to the contractor. This document serves as a basis for the contractor's proposal. As far as is practicable, it must clearly, completely and accurately express the owner's intent. On the other hand, it should not prevent the contractor from applying his experience and ingenuity to the project.

The project specification consists of four main elements:

(a) Duty specification,

(b) Commercial specification;

(c) Mechanical specification; and

(d) Process specification.

The duty specification includes such major variables as the specification and cost of raw materials, production capacity and products specification, and project design data, including labour and utility costs and guarantees.

In addition, the owner should offer a guideline which permits the contractor to know whether incremental cost in capital is justified for reducing the operating cost. This is most satisfactorily expressed as an acceptable pay-out time.

The duty specification, in other words, explains what production is required of the plant, without describing how to achieve the required performance.

Two of the items in the duty specification, project design data and guarantees, should be considered further.

The project design data consists of site data on location, such as elevation, soil, topography, atmospheric conditions, temperature, wind velocities, rainfall and snow conditions. Utility data, such as source and characteristics of raw materials, fuel, water and electric power are also included. The project design data must contain, in addition, information on government regulations with reference to safety, labour, effluent and the like, with indications where government approval is required. Finally, project design data should point out the rail and port facilities available for receiving and shipping materials. For an outline of a typical project design data form, see annex II.

Contractors frequently offer two types of guarantee. The performance guarantee assures the owner of over-all plant performance in respect of capacity, product quality and utility consumption. Fulfilment of a performance guarantee is generally demonstrated by a formal test run. Mechanical guarantees and guarantees for the quality of the workmanship assure the owner of the mechanical soundness of the plant and equipment. This guarantee, usually effective for one year, assures the owner that any defective material will be replaced or lowering of standards in the quality of the workmanship corrected.

The second section of the project specifications is the commercial portion. This section describes the specific financial requirements, restrictions on currency, general contractual terms and conditions, and owner's intent with respect to such items as insurance, taxes, import duties etc. It should clearly state the time and place for the tendering of bids and that it is the contractor's responsibility to call the owner's attention to any exceptions the contractor wishes to make.

The third part of the project specification is the mechanical specification. In the simplest project specification, this can be dispensed with and the contractor can use his own. In the majority of cases, however, the mechanical specifications require the use of the various codes developed by technical and code societies, such as the American Society for Mechanical Engineers (ASME) (Pressure Vessel Code), the American Standard Association (ASA) (Piping Standards) etc. A listing of United States codes is included in annex II under item V (Government regulations). These professional codes, or the equivalent, are the minimum used in the process contracting industry today. In certain instances in the private sector, large industrial corporations have developed their own mechanical specifications, which are added to the professional codes. These industrial codes may be more or less restrictive than society codes. There is a clear tendency, however, for even industrially sophisticated organizations to adopt society codes.

It is advisable to include in the mechanical specifications for ammonia plants those requirements dictated by the ability of the owner to train and equip personnel for operation and maintenance. Few sites in the world can equal the Gulf Coast of the United States of America in terms of the availability of personnel and of materials, but a Gulf Coast plant is not necessarily adequate for a less developed site, for these reasons, among others:

(*a*) All operating pumps to have spares installed. Large pump services to have three 50 per cent pumps (50 per cent spare).
(*b*) All reciprocating compressors to have two 50 per cent compressors;
(*c*) Exchanger tubing to be of standard diameters and lengths;
(*d*) Furnace coils to be designed for a minimum of 100,000 hours stress to rupture;
(*e*) Emergency electrical power systems to be provided;
(*f*) The selection of a contractor to include consideration of his ability to provide staff for servicing.

The fourth element of the project specification is the process specification, which describes the particular process to be used. For example, this would call for specific systems for purification of ammonia synthesis gas; or in another instance, a specific process for the gasification of solid fuels. In the ammonia industry a process specification is not usually included. In processes such as ammonia production, in which the contractors have assumed a technical lead, it is generally advisable for the client to leave the process specifications to the contractor, in order to obtain the most economic and up-to-date proposal.

When the process specification in a project specification is absent, the contractor is able to use the best information and experience available to him, to achieve the owner's objectives by the most economical method. In the case of ammonia plants, sophisticated industrial organizations nowadays tend to omit the process specification from their project specification. It is, in fact, this practice which has permitted the contracting industry to make significant advances in the design of large-scale ammonia plants.

There are probably some thirty contractors in the world today who can claim the ability to design, engineer, procure and erect a large-scale ammonia plant. How does an owner select contractors to whom he will submit project specifications? It is obvious that no owner can submit specifications to thirty contractors. The principal factor to be considered is the contractor's experience with ammonia plant construction which can easily be discovered from records, while his competence should be verified by getting in touch with owners of plants that he has built. The owner is well advised at this point to confirm, not only that the contractor has built the plant, but that the plant is operating as the contractor had indicated it would.

It is suggested that the following factors be considered in selecting a contractor:

(a) Experience with ammonia plant construction: ascertain the successful operation of such plants;

(b) Evidence that the contractor is ready to take the job when the prospective plant owner needs it without overloading his engineering, design and procurement capability;

(c) Ability of the contractor to purchase, inspect and expedite in the area of the world in question;

(d) Size and experience of contractor's field force, and competence to provide the proper field administration and supervision of the relevant project;

(e) Capacity to arrange training facilities for owner's personnel, as well as to provide experienced personnel for start-up assistance;

(f) Ability of contractor to supply technical laboratory service to the project from his own laboratory facilities.

Proposals and final evaluation

The contractor's proposal document is frequently composed of two main parts, the technical proposal and the commercial proposal. The technical proposal describes the process, specifications, arrangement and mechanical equipment upon which the contractor bases his offer. The commercial proposal describes the terms and conditions under which the technical offer is made.

In addition to the formal written proposal, it is almost inevitable that a presentation is also made. The purpose of a presentation, usually drawn up by a contractor's team, is to clarify items in the formal proposal.

The proposal document may contain exceptions to the owner's project specifications. These should be clearly set forth in the contractor's proposal and the owner should request that the reason for such exceptions be clearly explained.

Evaluation of a contractor's proposals includes many considerations. Price, a very important factor, has to be weighed against other factors. Financial terms, project schedule, contractor's experience at the particular site and performance guarantees have all to be considered. Bids should be examined for completeness and for compliance with specifications. Exceptions to the owner's specifications should not be rejected outright, but should be carefully examined. Such exceptions frequently turn out to represent features desirable to the owner.

In making his final evaluation the owner of an ammonia plant should consider the questions:

(a) Is the proposed plant similar to one the contractor has previously built? What has been its start-up and performance record?
(b) Are any mechanical or process innovations proposed? If so, are they technically sound and economically justified?
(c) Has a distinction been made between normal and guaranteed operating requirements?
(d) Are the various catalytic services designed with overlap to accommodate upsets? Can the catalysts be easily replaced? Are they readily available?
(e) Start-up of ammonia plants is complex and time-consuming. Has the contractor thought out the start-up procedure?
(f) Is the type of equipment proposed consistent with owner's capability for plant maintenance? Is the machinery of proven design? Are the contractor's service personnel readily available? Spare parts?
(g) Is a performance guarantee included?

Contract award

Immediately prior to the award of the contract, the client frequently requests adjustments to the contractor's final proposal. While adjustments can be made after the contract is assigned, it is in the owner's interest to assure himself that the project as defined in the contract is in accordance with his intent. Changes made afterwards are generally more costly to the owner, and are not welcomed by the contractor, as they interfere with the orderly progress of the job.

A project can frequently be initiated by a letter of intent. This is simply a letter from the owner to a contractor, stating that a contract will be signed. In most cases, the contractor begins engineering work, without a contract, on the basis of an acceptable letter of intent. This is simply a time-saving device.

Preparation of the final contract frequently requires several weeks. The contract must define the responsibility of all the parties involved, and be sufficiently flexible to accommodate changes.

Design and construction

Modern large-scale ammonia plants present certain problems to the contractor, which small units do not. However, it should be understood that the processing steps are essentially the same. For this reason small and large plants remain basically equivalent. Differences that do exist include the size of equipment, the complex integration of steam generating equipment, heat-exchange facilities, energy recovery systems and the use of centrifugal compressors.

Dependent on the actual size of a large plant and its location, certain restrictions may be encountered in shop fabricating some of the vessels required. Because of their size and the consequent limitations on shipment, cases can arise where vessels must be assembled on site.

The second difference involves the highly integrated system for heat recovery, steam generation and energy utilization. Water purity is important because the modern large ammonia plant generates high-pressure steam and a correct design for the boiler feedwater treating facilities is essential for the provision of proper purification. Only in this way can satisfactory performance be assured of the complex heat-exchange system for the generation of process steam and auxiliary steam for power recovery. It is recommended that the design of the boiler feedwater treating facilities be such that it will produce water quality as follows:

	Boiler feedwater (ppm)
Total dissolved solids	0.25
Silica	0.02
Iron	0.01

These rigid specifications have been adopted as one means of minimizing the fouling of heat-exchange surfaces that occurred in the first large plants. Other measures taken have been the use of special low silica refractories and catalysts.

The third major dissimilarity in the design of a large ammonia plant is the application of steam-driven centrifugal compressors, which causes significant reductions in total plant costs. It must be understood, however, that this is a sophisticated piece of machinery, and should be treated with care during the selection and installation stages.

The owner's best assurance that such potential problems are properly handled during the design and construction stage is the contractor's experience in building successful ammonia plants.

A recent survey has revealed that two-thirds of the delays encountered in the start-up of new ammonia plants are the consequences of equipment not being manufactured in accordance with specifications, such as the use of non-specified construction materials, incorrect assembly and failure to comply with allowable tolerances. It is this area of manufacture and construction, usually referred to as quality control, that has deteriorated noticeably in recent years. The reason for this deterioration is generally assumed to relate to the current high shop loads and high loads of industrial construction. Examples of the type of problem which has arisen are:

(a) Failures in welds in reformer furnaces have been found to be the result of the use of incorrect welding electrodes at shop welds. This produced a weld of lower strength and of higher sensitivity to cracks. The welds were replaced and the furnace has since been in operation for several months.

(b) Excessive vibration in centrifugal machinery brought about a plant shutdown. The vibration was caused by the rotor balancing not being performed in accordance with the designer's specifications. The rotor was taken apart and rebalanced, and the machine has been in operation for more than a year.

(c) A shaft failure occurred on a large pump. Cause of the failure was traced to the use of a close clearance ball bearing instead of the normal clearance, as was intended. The pump has now been in successful operation for months.

These instances are cited as examples of the random nature of the difficulties which have been encountered. The problem of quality control will continue to be of concern, and can be kept to manageable proportions only by the continued exercise of diligent inspection. The contractor's experience in shop and field inspection will play a significant part in achieving a successful plant operation.

Quality control as applied to the design of large equipment requires the greatest skill on the part of the contractor's staff. For this reason, contractors have established acceptable vendor's lists for the large items required for modern large ammonia plants. It is evident that tested machinery and fabrication techniques should be used and highly experienced contractors engaged.

To date, large ammonia plants worth more than \$US300 million and requiring more than six million man-hours of construction have been built in ten different countries without one fatal construction accident. This is a record of which the construction industry can be proud.

The building of a large ammonia plant calls for no more exceptional effort than that required for the construction of refineries, power plants etc. Some of the pressure vessels for a plant with 1,000 tons per day capacity are large and heavy requiring special engineering and constructional efforts. For example, large vessels can be assembled on the site rather than in the shop, two vessels can be used rather than a single heavy vessel, special provision can be made for the short overland haul of heavy vessels. Below are the approximate dimensions of some of the main vessels needed for an ammonia plant handling 1,000 tons per day.

	Diameter (ft)	Height (ft)
Shift converter	13	48
CO_2 absorber	11	83
CO_2 stripper	11	58
Synthesis converter	11	64

During the design and construction phase, the owner acts principally as an observer; during this period he should familiarize himself with the contractor's systems for engineering and purchasing and study carefully the contractor's schedule. The owner is often invited to witness shop tests of various items of equipment during manufacture and he should avail himself of this opportunity.

Operation and maintenance

The final stage of the project necessitates a great deal of forethought and preparation on the part of the owner, assisted by the contractor.

The chief elements necessary for the successful outcome of the project are as follows:

(*a*) Plant operating instructions;
(*b*) Operator and maintenance training;
(*c*) Spare parts and start-up materials;
(*d*) Start-up;
(*e*) Maintenance schedules;
(*f*) Safety precautions.

Planning for start-up must begin far in advance of the actual start-up date, and the adequacy of the planning will determine the ease with which the plant can be brought on stream.

Detailed operating instructions should be drafted for the modern ammonia plant. In most instances the contractor will provide operating manuals. It is often advisable however for the owner to prepare more detailed operating manuals, using the contractor's manual as a basis. Start up and shut down procedures must be very carefully considered. The owner should also examine various possibilities that may cause an emergency and lay down the procedure to be followed.

Operator maintenance training is frequently possible on modern large scale ammonia plants. An owner would be well advised to make arrangements for his staff to take advantage of such training with the co-operation of the contractor.

Spare parts and start up materials must be on hand prior to any start up date. The recommended list of spare parts is usually supplied by the contractor.

Start up assistance for ammonia plants can be provided by most contractors. Indeed it is usual for the contractor to provide at least one man, if not two, for each shift for on-the-job training. These contractor operators are usually men who have worked on a number of ammonia plant start-ups and their experience is invaluable.

Actual start up can be divided into two stages. The first is carrying out prescribed procedures recommended by the contractor in physically preparing the plant for operation. These will, in general, be part of the operating instructions provided by the contractor, and will include such items as cleaning and testing. The second step involves bringing the plant on stream and up to capacity.

Maintenance schedules and safety precautions have been listed after start-up to indicate continuing requirements for the successful operation of the plant. The adoption of maintenance schedules and safety practices, however, should form part of the early planning stage.

The importance this part of the project plays in the over-all operation cannot be over-emphasized. The owner must be ready to assume responsibility for operating and maintaining a sophisticated chemical processing plant. Its success will therefore depend largely on the choice of personnel, their training and adherence to sound operating practices, as well as on the maintenance and safety precautions.

A recent survey of start-up experience of large-scale ammonia plants shows that more than half the plants have achieved full production (rated capacity) within two months from the introduction of feed. Taking into consideration the complications of the first start-up, for example, the fact that the various components are being subjected to process conditions of temperature and pressure for the first time and that the start-up involves complex catalyst activation procedures for a series of catalysts, these results are considered to be a good record. They compare favourably with experiences with the older smaller ammonia plants. For example, M. W. Kellogg has a record of 21 plants which have been operating for about 130,000 hours without a fatal accident.

In conclusion, it has been proven that the success of a new plant depends on both the contractor and the owner. The contractor's responsibilities are usually well defined, but the owner's responsibilities are not so easy to clarify. Emphasis must certainly be put on the competence of operators and foremen and a skilled maintenance staff for instruments and machinery. These new large plants probably do not require more highly skilled operators than smaller plants, but they most certainly should not be started up with a minimum staff composed of operators in training. An understanding of the operational requirements of high-pressure steam systems and integrated systems is essential at the foreman and plant-engineer level. It is generally recognized that operating staff well aware of the large daily potential loss of profit incurred in the shut-down of a large plant will often tend to remain on line as long as possible. For these new plants, operators must acquire an understanding of the potential hazards and possibility of damage to equipment in an emergency shut-down, because of the interrelated nature of the systems. This means that all instruments and safety devices must be kept in perfect working order and in calibration. In addition, when maintenance is undertaken, it should be done properly and speedily and the plant left in a clean condition. If the plant is run with only one boiler feed pump, or if rags are left in pump and compressor suctions after maintenance has been completed, the risk of damage and subsequent loss may rise in proportion to the increased inherent profitability of these large plants. This is one important area where the owner can make his contribution to a successful and profitable start-up and a continued high-stream flow.

Annex I

RAW MATERIALS SPECIFICATION GUIDE

Gaseous hydrocarbons

Composition (volume per cent):

- Fixed gases:
- Hydrocarbons:
- Sulphur:
  - *(a)* H_2S
  - *(b)* Organic forms
- Moisture:

Composition (weight per cent):

- Oil:
- Dust:
- Specific gravity:
- Heating value:
- Pressure:
- Temperature:
- Cost in US dollars per unit:

Liquid hydrocarbons

Heating value:
Gravity:
Viscosity:
Vapour pressure:
Conradson carbon residue:
Volatility (boiling range):
Sulphur:
Pour point:
Flash and fire points:
Water and sediment:
Ash:
Corrosion test:
Cost in US dollars per unit:

Cokes and coals

Proximate analysis (wt %)

Moisture:
Volatile matter:
Fixed carbon:
Ash composition:

Coal properties

Weathering index:
Grindability:
Agglomerating properties:
Parts of coal:
Grade of coal:
Size range:
Heating value:
Cost in US dollars per unit:

Ultimate analysis (wt %)

Carbon:
Hydrogen:
Oxygen:
Sulphur:
Nitrogen:
Ash temperatures:
Initial deformation:
Softening temperature:
Fluid temperature:

Annex II

TYPICAL PROJECT DESIGN DATA FORM

I. Utilities

(a) *Steam*
- Quality if saturated:
- Pressure:
- Temperature:
- Cost in US dollars per 1,000 lb:

(b) *Electric power*
- Voltage:
- Phase:
- Frequency:
- Cost in US dollars per kWh:

(c) *Fuel oil*
- Type:
- API Gravity:
- Viscosity:
- LHV — Btu/lb:
- Temperature:
- Pressure, psig:
- Cost in US dollars per barrel:

(d) *Fuel gas*
- Type:
- Molecular weight:

LHV-Btu/ft^3:
Sulphur, grains/100 standard ft^3:
Pressure, psig:
Cost in US dollars per 1,000 ft^3:

(e) *Water*
Types and quality (cooling, fire, drinking, condensate return etc.):
Analyses:
Temperature:
Pressure, psig:
Cost in US dollars per gallon:

(f) *Air*
Service (instrument, utility etc.):
Pressure, psig:
Temperature:
Dew point:

(g) *Chemicals*
H_2SO_4, NaOH, Na_2CO_3, N_2, O_2, H_2:
Strength:
Purity:
Specific gravity:
Pressure:
Cost in US dollars per unit:

II. Raw materials and products data at plot limits

Raw materials — data required given in annex I
General location:
Above or below grade:

Products
Temperature:
Pressure, psig:
General location:
Above or below grade:

III. Waste disposal

Cooling water return, storm water, sanitary sewer etc.
Type conduit:
Location of exit:
Minimum elevation:

IV. Site data

(a) *Topographical map*
Elevation:
True North bearing:

(b) *General data*

Air and water pollution precautions; air corrosiveness; vibration and noise transmittal precautions; tidal data; railroad information; earthquake intensity zone; drainage:

(c) *Wind and atmospheric pressure data (seasonal):*

(d) *Air temperatures (seasonal):*

(e) *Rainfall and/or snow conditions:*

(f) *Soil data:*

(g) *Pile data:*

V. Government regulations

(a) *Codes*

The following American standards are used as the basis for the design, materials, and safety in ammonia plants built in the United States of America. Comparable foreign standards may be substituted provided recognition is given to differences in rating, allowable stress and dimensions of ammonia plants.

Concrete design: American Concrete Institute (ACI) publication ACI 318 "Building Code Requirements for Reinforced Concrete" with details conforming to ACI 315 "Manual of Standard Practice for Detailing Reinforced Concrete Structures".

Boilers: American Society for Mechanical Engineers (ASME) Boiler and Pressure Vessel Code: Section I for design, Section II for materials, and Section IX for welding.

Pressure vessels: ASME Code Section VIII for design and Section II and IX for materials and welding.

Exchangers: ASME Code Sections I or VIII as applicable and The Standards of Tubular Exchanger Manufacturers' Association (TEMA).

Burner tubes: American Petroleum Institute (API) "Recommended Practice for Calculation of Heater-Tube Thickness in Petroleum Refineries", API RP 530 for establishing allowable stresses for tube materials listed therein. USAS B 31.3 "Petroleum Refinery Piping" is used for allowable stresses for pressure parts outside the furnace and for all tube fabrication. USA standards

(USAS) are issued by the American Standards Institution; series A refers to civil engineering and series B to mechanical engineering.

Structural steel, furnace steel, and stacks: American Institute of Steel Construction (AISC) "Specifications for the Design, Fabrication and Erection of Structural Steel for Buldings". Welded stack details are in accordance with the American Welding Society (AWS) „Standard Specifications for Welded Highway and Railway Bridges" D2.O.

Heating, ventilating and air conditioning: Generally in accordance with the Guide of the American Society of Heating, Refrigerating and Air Conditioning Engineers (ASHRAE).

Buildings: in accordance with local building codes.

Plumbing: USAS A40.8 Plumbing Code.

Piping: USAS B31.3 and the standards listed therein for bolting, fittings, valves, flanges, gaskets, piping, tubes, and threads. These standards cover dimensions for interchangeability, pressure-temperature ratings, and manufacturing and testing requirements.

Electrical: National Electrical Code as modified for local conditions.

Safety: USAS A12 for wall openings; USAS A14.3 for fixed ladders; API RP 500 for limits of hazardous areas; API RP 520 as design and layout guide for pressure relieving systems; API RP 2000 for tank venting guide.

Wind and earthquake: USAS A58.1 for wind load. Uniform Building Code for earthquakes.

Ammonia storage tanks: API Std. 650 with Appendix R for refrigerated products when pressure is below 15 psig and ASME Code, Section VIII for over 15 psig.

(b) *Approval required from:*

Federal government, state, country, city and licensed engineer.

VI. Construction facilities

(a) *Utilities:*
(b) *Fabrication and storage areas:*
(c) *Temporary buildings:*
(d) *Transportation:*
(e) *Labour regulations:*

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7. 8. 73