The Potential for Energy Efficiency in the Fertilizer Industry

Roger Heath, John Mulckhuyse, and Subrahmanyan Venkataraman
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(List continues on the inside back cover)
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Roger Heath, John Mulckhuyse, and Subrahmanyan Venkataraman

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ABSTRACT

The major increases in energy prices since the early 1970s have had a considerable effect on the cost structure of the fertilizer industry, since the price of energy is a significant factor in the production costs of many fertilizers. These price increases have encouraged the industry to adopt energy-saving technology, much of which, although previously available, was not justified by previous low energy prices and the new improved energy efficiency designs developed for new plants. By using energy conservation measures, many plants can be made more economical and can improve their competitive position.

This report reviews the potential for energy conservation in the fertilizer industry, describes the organizational aspects of implementing successful energy conservation programs, and gives details of particular conservation measures that may be considered. Since the production of ammonia is the most energy-intensive process for all fertilizer, a major emphasis of the report is on the potential savings in ammonia production, which can amount to as much as 30%, or up to US$45/mt of ammonia. About half of the savings can be achieved by good housekeeping measures, with little or no investment cost; the other half involves a mix of short- and medium-term payback investments.
Les fortes hausses intervenues sur le marché de l'énergie depuis le début des années 70 ont eu des répercussions considérables sur la structure des coûts dans le secteur des engrais. En effet, le prix de l'énergie est un élément important des coûts de production de nombreux engrais. Cette situation a incité les fabricants à économiser l'énergie, en adoptant des techniques qui, pour la plupart, existaient déjà, mais dont l'utilisation ne se justifiait pas tant que les prix de l'énergie étaient bas. En outre, les nouvelles usines ont été conçues de façon à maximiser le rendement énergétique. Ces mesures permettent à de nombreuses usines d'opérer plus économiquement et d'améliorer leur compétitivité.

Ce rapport indique les économies d'énergie qui peuvent être réalisées dans l'industrie des engrais, analyse les questions organisationnelles que soulève l'exécution d'un bon programme d'économie de l'énergie et décrit en détail certaines des mesures qui peuvent être envisagées. Etant donné que la production d'ammoniaque est le procédé qui consomme le plus d'énergie pour tous les engrais, le rapport insiste particulièrement sur les économies qui peuvent être réalisées dans ce domaine, et qui peuvent atteindre jusqu'à 30 %, ou 45 dollars par millier de tonnes. Des mesures d'entretien et des réglages judicieux permettent déjà une économie de 15 %, pour un coût d'investissement faible ou nul. Les 15 % restants exigent des investissements dont la rentabilité se manifeste à court et moyen termes.
EXTRACTO

Los importantes aumentos de los precios de la energía que se produjeron desde principios del decenio de 1970 han tenido una repercusión considerable en la estructura de los costos de la industria de los fertilizantes, ya que estos precios son un factor significativo de los costos de producción de muchos fertilizantes. Estos aumentos han estimulado a la industria a adoptar técnicas que permiten el ahorro de energía, muchas de las cuales si bien ya existían con anterioridad no se justificaban en razón de los bajos precios y los nuevos diseños más eficientes en el aspecto energético preparados para las nuevas plantas. Aplicando medidas de conservación, muchas plantas podrían resultar más económicas y mejorar su posición competitiva.

En este informe se examina el potencial de conservación de energía en la industria de los fertilizantes, se describen los aspectos de organización para la ejecución de programas provechosos y se detallan ciertas medidas de conservación que podrían considerarse. Puesto que en la producción de fertilizantes, la de amoníaco es el proceso que demanda el uso más intenso de energía, se hace especial hincapié en las posibles economías obtenibles en su producción, que pueden llegar hasta el 30% o US$45/t de amoníaco. Aproximadamente la mitad del ahorro puede lograrse con adecuadas medidas internas de conservación, con poco o ningún costo de inversión; la otra mitad implica una combinación de inversiones recuperables a corto y mediano plazo.
ACKNOWLEDGEMENTS

This report was prepared by staff of the Industry Department under the overall supervision of H. S. Kohli (Assistant Director, Policy) and E. L. Segura (Chief, Fertilizer, Refining and Other Chemical Industries Division). The report was written by R. Heath, J. J. Mulckhuyse, and S. Venkataraman of the Industry Department and G. D. Honti and K. Stokes (consultants). Secretarial assistance was provided by A. Mojica, and word processing assistance by M. Greaves, E. George, A. Johnson, A. Tenorio, and W. Peiris. Charts and diagrams were prepared by P. Kimpitak and C. A. Kocak.
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## EQUIVALENT ENERGY UNITS

1 kJ = 0.948 BTU = 0.239 kcal

1,000 cal = 1 kcal = 4.187 kJ = 3.968 BTU

1 kWh = 10,000 BTU (ar 34% Conversion Efficiency)
= 2,520 kcal
= 10,550 kJ

1,000 BTU/short ton = 277.8 kcal/metric ton (mt)

1,000 scf of natural gas = 1.08 GJ
= 1.02 million BTU
= 0.257 Gcal

1,000 Nm³ of natural gas = 40.06 GJ
= 37.97 million BTU
= 9.57 Gcal

1 ton of naphtha = 47.3 GJ
= 44.8 million BTU
= 11.3 Gcal

1 ton of oil equivalent (toe) = 42.7 GJ
= 10.2 Gcal
= 40.5 million BTU
ABBREVIATIONS AND ACRONYMS USED

<table>
<thead>
<tr>
<th>Abbreviation</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Atm</td>
<td>Atmosphere - a measure of pressure</td>
</tr>
<tr>
<td>BFW</td>
<td>Boiler Feed Water</td>
</tr>
<tr>
<td>BTU</td>
<td>British Thermal Unit</td>
</tr>
<tr>
<td>Cal</td>
<td>Calorie</td>
</tr>
<tr>
<td>DAP</td>
<td>Diammonium Phosphate</td>
</tr>
<tr>
<td>EPA</td>
<td>US Environmental Protection Agency</td>
</tr>
<tr>
<td>Gcal</td>
<td>Gigacalorie (= 1 billion calorie)</td>
</tr>
<tr>
<td>GJ</td>
<td>Gigajoule (= 1 billion joule)</td>
</tr>
<tr>
<td>HHV</td>
<td>High (or Gross) Heating Value</td>
</tr>
<tr>
<td>IFDC</td>
<td>International Fertilizer Development Center</td>
</tr>
<tr>
<td>K20</td>
<td>Fertilizer Potassium (Potash)</td>
</tr>
<tr>
<td>Kcal</td>
<td>Kilocalorie</td>
</tr>
<tr>
<td>KJ</td>
<td>Kilojoule</td>
</tr>
<tr>
<td>Kwh</td>
<td>Kilowatt hour</td>
</tr>
<tr>
<td>LHV</td>
<td>Lower (or Net) Heating Value</td>
</tr>
<tr>
<td>MAP</td>
<td>Monoammonium Phosphate</td>
</tr>
<tr>
<td>mt</td>
<td>Metric Ton</td>
</tr>
<tr>
<td>N</td>
<td>Fertilizer Nitrogen</td>
</tr>
<tr>
<td>Nm³</td>
<td>Normal cubic meter</td>
</tr>
<tr>
<td>P₂O₅</td>
<td>Fertilizer Phosphate</td>
</tr>
<tr>
<td>PSA</td>
<td>Pressure Swing Absorption</td>
</tr>
<tr>
<td>Scf</td>
<td>Standard cubic feet</td>
</tr>
<tr>
<td>TFI</td>
<td>The Fertilizer Institute</td>
</tr>
<tr>
<td>tpd</td>
<td>Tons per Day</td>
</tr>
<tr>
<td>TSP</td>
<td>Triple Superphosphate</td>
</tr>
</tbody>
</table>
SUMMARY

1. Energy policies in many developing countries have focussed principally on increasing domestic energy supply, and little has been done to manage energy demand. Yet, in most countries there is substantial scope to improve the energy situation through the more efficient use of the energy resources. Preliminary World Bank and other studies indicate possible savings of 10-25% of current industrial energy consumption through the implementation of energy conservation measures. An important lesson drawn from experience in industrial countries is that in order to achieve these savings, it is necessary to implement a vigorous and comprehensive energy conservation program supported by a realistic energy pricing policy. To design and implement an integrated program successfully, developing countries have often found useful the establishment of a center for energy conservation with sufficient authority to coordinate and implement energy conservation efforts.

2. The chemical industry has an especially unique relationship with energy carriers, since in many chemical processes the feedstocks themselves are energy carriers and chemical transformations that take place during the processing often generate heat energy as a by-product. The more than tenfold rise in energy prices since 1973 has made many plants built 8 to 10 years back economically obsolete. On the other hand, new plant costs have increased substantially so that replacing existing plants would require high capital investments, and in addition investment funds have become
scarce. In this context, there is a need to modify existing plants to improve their energy efficiency. This need is especially pressing for fertilizer plants since energy is a main element of production costs, and fertilizer costs are a significant element to the farmer in the overall costs of food production.

3. This study reviews the general principles and potential areas for energy savings in existing fertilizer production processes for possible application in studying individual plants. The general approach and principles reviewed here, however, can be extended to most chemical and process industries. Specific examples have also been given.

4. By the late 1970s, the world annual energy consumption in the fertilizer industry reached nearly 4.9 billion gigajoules (GJ). Though forming only 1.5% of the total world commercial energy consumption, it is the equivalent of about 114 million metric tons per year (tpy) of fuel oil. About 73% of this energy consumption is in the nitrogen industry, 5% in the phosphate fertilizer industry; 3% in the potash industry; and the remaining 19% is accounted for by packaging, transportation and application (PTA). An overall saving of 10-25% in existing plants is economically possible. Assuming only an average 15% of achievable energy saving, the total savings (excluding PTA) could be as much as 0.59 billion GJ per year with an annual value of about US$2.0 billion.

5. Significant energy savings on a sustained basis in existing fertilizer plants can be achieved only through an organized and systematic
approach which requires effective organizational measures and energy audits for formulating detailed energy conservation programs. These programs usually consist of three parts: good housekeeping (improved operation and maintenance), short-term (revamping) investment measures and long-term (reconstruction) investment measures. While good housekeeping and organizational measures are general and essential in all industrial plants, revamping and reconstruction are always process-specific. In some cases, it is possible to substitute one fuel with another more economical and commercially cheaper fuel. Though this does not necessarily result in energy conservation, significant cost reductions can be achieved.

6. Ammonia manufacture is by far the major energy consumer among the various fertilizers, and thus attention for energy conservation by revamping or reconstruction is focussed on its manufacture. New designs for ammonia manufacture claim energy consumptions below 33 GJ/mt of ammonia, however, many plants built in the last 10-15 years, and still in production, consume over 46.0 GJ/mt.

7. The potential for energy savings in fertilizer plants other than for ammonia production is rather limited though still significant. Plants producing urea, nitric acid, ammonium nitrate, sulfuric acid, phosphoric acid, potash and mixed fertilizers are also reviewed in this report for possible energy saving.
I. INTRODUCTION

1.01 As a result of the more than ten-fold increase in energy prices in the 1970s, most developing countries have pursued active policies for energy management. These policies generally aim to increase domestic production of petroleum and alternative sources of energy and have therefore focussed principally on the energy supply side. In many countries, except for attempts to set realistic energy prices, relatively little has been done in managing energy demand. Yet, in most developing countries, substantial opportunities exist to improve the overall energy balance through more efficient energy utilization. While supply side policies normally take several years to improve the energy balance of a country, energy conservation measures, particularly in industry, can produce quicker results. Therefore, appropriate energy consumption management should be a critical element of any overall national energy program.

1.02 Most industrial plants now in production were designed before 1973, when energy prices began to rise. When initiated, their profitability was maximized by optimizing industrial plant designs that, in general, minimized capital investments and for this purpose accepted high energy consumptions based on low energy costs. At today's energy prices, many highly economic investments are possible which would reduce energy consumption in such plants. These investments range from low cost ones which would optimize the use of existing utilities and equipment (i.e., housekeeping measures such as better control of air/fuel mixes in
furnaces, preventive maintenance, improvements in insulation, elimination of steam leakages, etc.), to more substantial ones involving retrofitting of existing equipment (such as changes in burners) or the addition of new equipment (such as purge gas recovery units, heat exchangers, boilers for waste heat recovery, etc.).

1.03 In a fully free market economy, energy price adjustment to long-term opportunity cost levels should alone, in theory, be sufficient to promote energy conservation, as consumers react to price signals without the need for any special incentives and measures. However, in the experience of many developed countries, industrial and other consumers often react only slowly to increasing energy prices even when economic advantages are obvious, possibly because: (i) there is a reluctance, perhaps due to inertia, to respond to energy price changes, particularly when facilities, otherwise operating well, require costly modifications; (ii) energy conservation investments are complex and often involve innovative devices which are not easily evident to non-specialists, but are identified only through complex and sophisticated analysis of the whole process or plant; (iii) energy conservation investments, which often consist of a large number of measures, have low visibility when compared to new and larger investments; and (iv) the justification and need for such investments have surfaced when most industries are in financial difficulties and are unable to generate the necessary resources internally.

1.04 World Bank and other preliminary studies indicate that as much as 10-25% of the industrial energy consumption can be saved if adequate
conservation measures are implemented. A major lesson from the experience of industrial countries is that in order to achieve such savings on a country wide basis, it is necessary to implement a vigorous and comprehensive energy conservation program. Such a program often consists of several interrelated aspects, which include: (i) a campaign to promote awareness in industry in particular, and among people in general, of the potential for, and benefits of, energy savings; (ii) technical assistance (including energy audits) to enable industrial enterprises to identify and evaluate energy saving opportunities and to provide training to management and technical staff; (iii) appropriate incentives and legislation that would encourage energy saving investments; and (iv) financial arrangements that would provide access to funds for executing identified energy saving investments. To be successful, it is essential that the energy conservation program be accompanied by rational pricing policies both for energy inputs and product prices.

1.05 The Industry Department of the World Bank has prepared a comprehensive report on the potential for, and alternative approaches to, developing such programs for industrial energy saving in developing countries. This report also reviews the policy and institutional measures necessary for promoting such programs. In addition, the Industry Department is preparing a series of reports aimed at managers in those major energy-intensive industries with the most potential for energy conservation. Industry managers need to be made aware of specific technical measures and approaches available for improving energy efficiency in individual industries and plants. This paper is one of the series
designed to meet this need and covers the fertilizer industry. Similar reports have been issued for the cement, steel, and petroleum refinery industries; and are planned for the mining, pulp and paper, and other industries.
II. ENERGY AND THE CHEMICAL INDUSTRY

A. General

2.01 The chemical industry has a unique and special relationship with energy, characterized by the following: (i) feedstocks for many chemical processes are energy carriers, such as natural gas, naphtha, coal or even sulfur, and their prices are therefore determined by the energy market; (ii) chemical transformations during processing (in so-called exothermic reactions) often generate substantial amounts of heat energy that can be recovered as a by-product (steam, electricity); and (iii) process conditions are often difficult (high pressure and/or temperature) and require high energy input for compression, heating, etc. Given the intense use of energy use in the chemical industry, energy recovery from the processes becomes a key to process and plant economics. However, each increment in energy recovery could involve additional equipment and, therefore, investment, providing a range of optimizations for energy recovery. The large energy cost increases since the early seventies have outdated many plants designed prior to that period. In this context, existing plants need to be modified to improve their energy efficiency thus reducing the total plant energy needs. At the same time, rationalization, debottlenecking and other measures, where feasible, need to be adopted to improve on-stream time and plant performance. This can be attractive, especially in view of the increased capital costs in real terms for new plants, i.e., revamping of old ammonia and sulfuric acid plants can be
carried out at low cost to improve operational efficiency and achieve energy savings. A practical problem, however, is the substantial production loss during the long down-time needed to execute such a revamping program. These programs should, therefore, be well planned and executed in steps that coincide with annual maintenance schedules, thus minimizing production loss. The expansion of output from debottlenecking is especially important for fertilizer, a basic input to increased world food production, given the expected continuous increases in world demand. 1/

2.02 This review of energy-saving possibilities in the fertilizer industry discusses general principles and identifies key potential areas for energy saving that could be appropriate for individual existing plants. This report is, therefore, not exhaustive and does not aim to substitute the need for a detailed plant specific energy audit. The general approach and principles reviewed here, would be equally applicable in most other similar chemical and process industries.

B. Basic Theoretical Principles

2.03 Energy conservation relies on three basic thermodynamic laws. A brief review of these laws is useful to identify how and where efforts for energy efficiency improvements are best deployed.

1/ Estimates by the FAO (World Food Report 1983) show that for the agricultural sector of the developing countries (not including China), fertilizers accounted for about 53% of total commercial energy use in the sector for 1980 (20 million toe) and is projected to rise to 57% by 2000 (99 million toe).
2.04 According to the first law of thermodynamics, also called the energy conservation law, energy can be transformed but not lost. Every energy input in a process must appear in some form as energy output. This principle, seemingly obvious now, is fundamental to all engineering calculations. It allows "energy balances" to be drawn to establish different forms and quantities in which energy has been provided and where it has gone.

2.05 The first law does not distinguish among forms of energy. The heat value of a fuel, the electricity generated by hydropower and the temperature rise of cooling water are all manifestations of different forms of the same energy under the first law. The second law of thermodynamics establishes the extent to which energy can be transformed into work. Only a part of the energy is capable of performing work, the amount depending on the energy form, e.g. electric power can theoretically yield its total equivalent in work, while heat can be transformed into work only to a limited extent, depending on the temperature level at which it is generated. The part of energy that can be transformed into work is generally called available energy. The second law allows calculations of the theoretical maximum of recoverable work (available energy) from a given energy transformation process. Different transformation processes have different efficiencies: thermal power plants, using the boiler-turbine route theoretically transform about 40% of the fuel energy to mechanical work, while a gas turbine/steam turbine combination achieves a substantially higher efficiency. So the second law enables comparison of different energy transformation routes and selection of the optimum one.
2.06 While the second law sets the theoretical optimum, the third law of thermodynamics states that, in practice, this optimum can never be achieved. The second law describes equilibrium, or standstill conditions. Industry processes, on the contrary, involve action or movement that needs a driving force, and therefore a departure from equilibrium. A greater departure from equilibrium means higher energy requirements and associated loss of available energy. Losses of available energy are thus twofold: the inherent loss of the chosen process route which cannot be altered (except by adopting another process); and the losses associated with the engineering design, where an economic optimum between investment costs and energy recovery is generally made.

2.07 In order to thoroughly analyze the energy conservation possibility of a given plant or process, all of the above balances (total energy and available energy balances, both theoretical and actual) must be calculated and evaluated. Therefore, it is of utmost importance that every energy conservation project be based on a thorough, detailed and complete energy audit undertaken by competent people who are experienced both in the process and in energy conservation methods.

C. Comparison of Energy Consumption Data

2.08 Available industry and published information on energy consumption figures in the chemical and fertilizer industries should be reviewed with care, for the following main reasons:
(a) **High or gross heating value (HHV) vs. lower or net heating value (LHV).** Many publications, such as the Fertilizer Institute (TFI) report "Energy", give energy figures in HHV values—the basis on which fuels are generally sold. Most technical data sources, on the contrary, are based on LHV values. The difference between the two is the amount of heat that would be released if all the water vapor formed when the fuel is burned were to be condensed. In most cases, this heat cannot be recovered economically. The difference between the two values which depends on the hydrogen content of the fuel is 11% for natural gas, around 7% for crude oil, and 3-4% for coal.

(b) **Battery limit energy consumption vs. overall energy consumption.** Data from the literature as well as from engineering firms usually give the energy needs of strictly battery limit process facilities on full operating rate basis. Raw material and product handling, storage, ventilation, heating, lighting, pollution control and other facilities are excluded. These, as well as the impact of plant shutdowns, are generally factors which could account for up to 10% of overall energy consumption in energy intensive processes and between 5-50% for low energy consumption processes, such as phosphate industries which handle large quantities of solids.
Guarantee consumption vs. yearly average. Bids from engineering firms usually provide guarantee figures based on a short test run to be carried out immediately after commissioning. As the plant ages, and deteriorates slowly, energy consumption increases, e.g., by fouling of heat exchange surface, by reduced catalyst activity, etc. Shutdowns and part-load running also add substantially to energy consumption possibly up to 10% over the guarantee figures.

2.09 Energy consumption figures should therefore be properly defined along with the basic parameters used in their estimation. In this study, all energy figures are based on the higher heating values and include allowances for the major outside battery limits inputs. However, with the exception of figures quoted from the TFI Energy Use Surveys, the base figures for energy consumption of different processes are guarantee figures.
III. ENERGY CONSUMPTION IN FERTILIZER PRODUCTION AND POTENTIAL SAVINGS

A. Energy Consumption in the Fertilizer Industry

3.01 By the late 1970s, the world fertilizer sector (including packaging, transportation and applications) energy consumption was equivalent annually to about 114 million toe as shown in Table I. Though it represented only about 1.5% of the total world commercial energy use, it was the major commercial energy use in the agricultural sector. About 81% of the energy used in the fertilizer sector was for fertilizer manufacture with 73% consumed in nitrogen production, 5% for phosphates and 3% for potash. Developing countries account for about 32% of the total world energy use in fertilizer production.²/

3.02 Energy sources, not only provide heat or motive power as in other industries, but are also the main feedstock for nitrogen fertilizer production. The major source used for ammonia production is natural gas (naphtha, refinery gas, heavy oil and coal are also used to a limited extent); energy sources for phosphate and potash production are required for steam and electricity generation, any convenient fuel is used.

3.03 Table II below gives the energy consumption, fuel oil equivalent value for the energy consumed and the share of this energy value in product

²/ Total world consumption of fertilizer nutrient for 1978/79 in millions of tonnes was 108.83 (53.75 N, 30.62 P₂O₅, 24.46 K₂O) compared against a total of 114.67 for 1982/83 (61.02 N, 30.83 P₂O₅, 22.82 K₂O).
Table I
Estimated Consumption of Energy by the World Fertilizer Sector for 1978/79

<table>
<thead>
<tr>
<th>Region and PTA b/</th>
<th>Energy Consumptiona/ for Fertilizer Production and PTA b/ Million toe/year</th>
<th>Share of Energy Consumption %</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Energy Consumptiona/ for Fertilizer Production</td>
<td>Share of Energy Consumption %</td>
</tr>
<tr>
<td></td>
<td>N</td>
<td>P</td>
</tr>
<tr>
<td>Developed Market Economies</td>
<td>48.8</td>
<td>20</td>
</tr>
<tr>
<td>North America</td>
<td>23.4</td>
<td>19</td>
</tr>
<tr>
<td>Western Europe</td>
<td>21.5</td>
<td>20</td>
</tr>
<tr>
<td>Oceania</td>
<td>1.1</td>
<td>38</td>
</tr>
<tr>
<td>Other Developed M. E.</td>
<td>2.8</td>
<td>23</td>
</tr>
<tr>
<td>Developing Market Economies</td>
<td>21.6</td>
<td>17</td>
</tr>
<tr>
<td>Africa</td>
<td>1.1</td>
<td>21</td>
</tr>
<tr>
<td>Latin America</td>
<td>5.9</td>
<td>21</td>
</tr>
<tr>
<td>Near East</td>
<td>3.4</td>
<td>16</td>
</tr>
<tr>
<td>Far East</td>
<td>11.2</td>
<td>15</td>
</tr>
<tr>
<td>Other Developing M. E.</td>
<td>0.0</td>
<td>-</td>
</tr>
<tr>
<td>Centrally Planned Economies</td>
<td>43.9</td>
<td>18</td>
</tr>
<tr>
<td>Asian CPE</td>
<td>15.3</td>
<td>14</td>
</tr>
<tr>
<td>E. Europe and USSR</td>
<td>28.6</td>
<td>21</td>
</tr>
<tr>
<td>Developed Total</td>
<td>77.4</td>
<td>20</td>
</tr>
<tr>
<td>Developing Total</td>
<td>36.9</td>
<td>16</td>
</tr>
<tr>
<td>World</td>
<td>114.3</td>
<td>19</td>
</tr>
</tbody>
</table>

a/ Totals may not be exact due to rounding.
b/ PTA; Packaging, transportation of raw material and product and application.
Source: IEFDC.

prices for the production of various fertilizers. As can be seen, energy plays a dominant role in nitrogenous fertilizer production. If priced at fuel oil equivalent prices, the energy value represented a large share of the ex-factory prices for both ammonia and urea. For straight phosphatic and potassium fertilizers, however, the energy values form a relatively minor part of the product price ranging from 4% for phosphoric acid to 9% for potash (as potassium chloride). The higher proportions for diammoniumphosphate—DAP (19%) and the compound fertilizer example selected in the table (27%) are due to the nitrogen content in these products.
Table II
Energy Consumption and Values in Fertilizer Production

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Product b/ Cumulative b/</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ammonia</td>
<td>45.6</td>
<td>170</td>
<td>195</td>
<td>87</td>
</tr>
<tr>
<td>Urea (Prilled)</td>
<td>9.3</td>
<td>36.0</td>
<td>134</td>
<td>170</td>
</tr>
<tr>
<td>Calcium Ammonium Nitrate</td>
<td>2.7</td>
<td>17.6</td>
<td>65</td>
<td>72</td>
</tr>
<tr>
<td>Phosphate Rock</td>
<td>1.2</td>
<td>4</td>
<td>40</td>
<td>10</td>
</tr>
<tr>
<td>Wet Process Phosphoric Acid (tonne P₂O₅)d/</td>
<td>(0.4)</td>
<td>3.7</td>
<td>315</td>
<td>(1)</td>
</tr>
<tr>
<td>Triple Super Phosphate</td>
<td>2.0</td>
<td>3.8</td>
<td>145</td>
<td>5</td>
</tr>
<tr>
<td>Diammonium Phosphate</td>
<td>1.0</td>
<td>11.2</td>
<td>220</td>
<td>2</td>
</tr>
<tr>
<td>Potash (Shaft Mining)</td>
<td>2.3</td>
<td>2.3</td>
<td>90</td>
<td>9</td>
</tr>
<tr>
<td>Compound 15-15-15 (Granular)</td>
<td>1.3</td>
<td>11.6</td>
<td>160</td>
<td>3</td>
</tr>
</tbody>
</table>

**Note:**
- a/ Energy consumptions are based on average values reported in the Fertilizer Institute Energy Use Survey (June 1983) for 41 US fertilizer companies.
- b/ The energy value for the "product" is the processing energy required including energy required for processing of any fertilizer raw materials used in the processing. The "cumulative" energy consumed is the energy for processing the product plus the energy required to produce the fertilizer raw materials used, e.g., for urea the energy required to produce urea from ammonia and carbon dioxide—9.3 GJ/mt is added to the energy required to produce the ammonia used—0.585 x 45.6 GJ/mt.
- c/ Product prices are as of August 1984 and are based on: urea, ammonia and compound fob West Europe; calcium ammonium nitrate, fob East Mediterranean; phosphate rock, triple super phosphate and DAP, fob North Africa; phosphoric acid, fob US Gulf; potash, fob Vancouver.
- d/ The phosphoric acid plant (energy importing) is combined with a sulphuric acid plant (energy exporting) based on elemental sulphur.

3.04 Since nitrogen fertilizers account for approximately 73% of the energy consumption in the fertilizer sector (para 3.01) and energy values are dominant in ammonia production costs (the intermediate for almost 100% of nitrogen fertilizer production), this paper will emphasize mainly energy conservation possibilities in ammonia production.
B. Development of the Nitrogen Fertilizer Industry

The nitrogen industry can be said to have commenced with the exploitation of Chilean nitrate mineral deposits in 1850, with production reaching a peak of some 3 million tpy of the mineral in the late 1920s. Synthetic nitrogen production commenced in 1905 with the electric arc process by which nitrogen oxides were formed by the passage of air through an electric discharge requiring 850 GJ/mt of ammonia equivalent—a large energy consumption equivalent to 20 toe. This process was rapidly supplemented by the less energy intensive cyanamide process in which calcium carbide and nitrogen were heated together at about 1,000°C to form calcium cyanamide which was then reacted with water to give ammonia. The modern ammonia industry was founded by Carl Bosch in 1913 with small scale commercial ammonia production from hydrogen and nitrogen using the principle developed by Haber. The reaction of steam with coke produces hydrogen which is then reacted with nitrogen, separated from air and compressed up to 250 atmospheres (atms) and recirculated over an iron catalyst at elevated temperatures. The ammonia formed is removed by cooling and condensation. The Haber Bosch process has remained basically unchanged, though there have been many refinements. What have changed are the processing methods and feedstock sources for the production of hydrogen and nitrogen. Until the early 1940s, synthesis gas was commonly produced through reaction of steam and air with coke, and the cryogenic separation of hydrogen from coke oven gas and nitrogen from air. The steam reforming of natural gas (NG) for hydrogen production was developed in the mid-1930s—initially for the refining industry and subsequently in the
1940s, adopted for ammonia production. Later developments in 1960s extended the steam reforming process to use light hydrocarbon feedstocks such as naphtha. The steam reforming process is now the most important route (Table III) for world ammonia manufacture with 90% of total production capacity based on this process.

Table III
Make-up of World Ammonia Production Capacity as of 1982

<table>
<thead>
<tr>
<th>Ammonia Production Capacity</th>
<th>million tpy</th>
<th>% of Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Natural Gas Reforming</td>
<td>94.5</td>
<td>79</td>
</tr>
<tr>
<td>Naphtha Reforming</td>
<td>10.9</td>
<td>9</td>
</tr>
<tr>
<td>Refinery Gas Reforming</td>
<td>1.9</td>
<td>2</td>
</tr>
<tr>
<td>Fuel Oil Partial Oxidation</td>
<td>4.1</td>
<td>3</td>
</tr>
<tr>
<td>Coal based processes</td>
<td>6.3</td>
<td>5</td>
</tr>
<tr>
<td>Electrolytic processes</td>
<td>1.0</td>
<td>1</td>
</tr>
<tr>
<td>Others</td>
<td>1.0</td>
<td>1</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>119.7</strong></td>
<td><strong>100</strong></td>
</tr>
</tbody>
</table>

Source: World Bank

3.06 The overall effect of process development on energy consumption is shown in Figure A. Energy consumption per unit of product has dropped from about 80.0 GJ/mt ammonia in the early 1940's to about 40.0 GJ/mt for an average plant built in the last 3-4 years. Most of the major ammonia process designers now offer low energy designs that are likely to result in energy consumptions around 33.0 GJ/mt of ammonia. A few plants based on such designs have recently commenced operation and others are under construction. Such designs are not the result of major technical "break throughs" but more the integration of a number of energy conservation features some of which have already been in use in ammonia plant design. Although there may be novel features in the designs (new carbon dioxide
removal systems, low synthesis pressure, etc.) the main novelty is the combination of features. Once these designs have been proven, both as regards energy efficiency and reliability, they are likely to be the standard for all new plant construction. Further major decreases in energy consumption may no longer be achievable since modern energy consumption for present process schemes are close to the theoretical level of 21.0 GJ/mt (the energy content of liquid ammonia) and still closer to the probable practical limit of about 28.5 GJ/mt.

**FIGURE A**

Effect of Process Development on Energy Consumption in Ammonia Manufacture
C. **Effect of Energy Prices on Ammonia Costs**

3.07 As mentioned above, a major share of the world ammonia capacity is based on natural gas as the energy sources. Since natural gas is not a readily tradeable commodity, its price has shown wide regional variations depending on local energy supply demand balances and governmental policies. In many locations, especially in energy importing countries where the substitution of natural gas for fuel oil use (such as in power stations) would result in either decreased fuel oil imports or increased exports, the economic value of natural gas is the heavy fuel oil equivalent value. In countries where gas is abundant and in excess of potential uses as replacement of fuel oil, the economic value of gas is bound to be much lower. Although natural gas price movements and their impact on the ammonia producer are unlikely to be as volatile as oil price movements, in the medium term natural gas prices will tend to rise in many areas to the heavy fuel oil equivalent prices. This has already been the trend in both the USA and W. Europe.

3.08 **Historical energy values (on an equivalent fuel oil basis)** embodied in the production of one ton of urea and ammonia are shown in [Figure B](#). Also shown are the export prices for urea and ammonia, and the naptha cost per ton of ammonia for naptha based ammonia production (all in constant 1983 prices). The situation has changed drastically since the 1960s when the energy value to produce one ton of ammonia was approximately US$43 compared to sale prices between US$80 - and US$200 per mt. Since this period (except for the atypical 1973-75) the differentials between the
FIGURE B

Historical Energy Values in the Production of Ammonia and Urea and Their Historical Export Prices

Legend:
A - Urea Price交通事故 N.W. Europe (buik)
B - Ammonia Price交通事故 N.W. Europe
C - Value of Energy in Ammonia Production of Fuel Oil Prices
D - Value of Energy in Urea Production of Fuel Oil Prices
E - Value of Naphtha Required to Produce 1 Tonne Ammonia
energy values and export prices for both ammonia and urea have been consistently eroded and at present there is a narrow differential between the two. In the case of naphtha based plants, since 1976 the effect of higher naphtha costs (which are directly subject to world oil price movements) and declining or static ammonia/urea export prices, has made naphtha-based ammonia and urea production uneconomic in most locations, except in special circumstances in isolated locations with surplus naphtha and large local fertilizer markets.

3.09 In practice, especially in the developing world, the value of energy inputs for ammonia/urea production may be significantly lower than the equivalent international price of fuel oil (especially in those countries with large surpluses of natural gas where the alternative use is for export as LNG). Furthermore, in many of these countries the ammonia/urea produced substitutes for imports, and therefore its value (due to freight and handling costs for imported product) will be higher than the international fob price. Figure C illustrates the possible comparison of energy and urea values for a producer in the developing world. Energy prices for a producer in the developing world are assumed to parallel the prices to US producers in the high and medium range (US$3.12 to 2.02/million Btus in 1983) and at the lower range (US$0.80/million Btus) to be equivalent to the value of natural gas in energy exporting countries. The same trend of increasing energy costs in relation to product price can be seen (12-30% of product price in 1970 to 36-74% in 1983) although the rate of energy costs increase is much lower than in figure B. Although such producers have been insulated to some
extent from the above rising energy value trends shown in Figure B, they may not continue to be so insulated and the differential between energy value and ammonia/urea prices is also unlikely to revert to levels that prevailed in the 1960s. While the present depressed ammonia/urea prices will most probably improve, ammonia/urea producers should still seek ways to decrease production costs by minimizing energy usage.

**FIGURE C**

Cost of Imported Urea for Developing Countries and Estimated Actual Energy Costs for Urea Production for Producers with Natural Gas Based Ammonia/Urea Plants

Legend:
- Imported Urea Delivered Cost (S. Asia) to an Inland Distribution Center
- Urea Price (f. o. b. N.W. Europe) (bulk)
- Range of Energy Costs for Urea Production in the U.S.
  - Top of Range Small Generally Old Plants on High Cost Gas (US 3.12/million Btus in 1983)
  - Bottom of Range Large Generally Modern Plants on Low Cost Gas (US 2.02/million Btus in 1983)
- Estimated Energy Costs for Producers in Oil Exporting Developing Countries — Gas Cost (US 0.80/million Btus in 1983)


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*Note: The diagram shows the trend of energy costs from 1970 to 1984, with a peak in 1973 and a decline thereafter. The cost of imported urea is also depicted, with a significant increase in the early 1970s and a subsequent decrease.*
D. Potential for Energy Conservation in Ammonia Production

3.10 The energy saving realizable with different measures in existing ammonia plants depends, to a great extent, on the particular plant; and therefore, no general figure would be appropriate. Particular measures that can be undertaken under different conditions, and their costs and benefits, are reviewed in later sections of the report. As a preliminary to evaluating the potential for energy conservation in the ammonia fertilizer industry, it is useful to review the capacity build-up on a world-wide basis since the age of particular facilities is a very good guide to its level of energy usage. Figure D shows the ammonia production capacity built prior to January 1982 and still believed to be operational, although a part may now be idled. As may be seen, about 50% of the capacity in use in 1982 was brought on stream during or prior to 1973, the period of major oil price changes. There are wide regional variations, e.g., 50% of the capacity in the USSR, the country with the largest ammonia capacity was brought on stream prior to 1976 whereas the USA, the country with the second largest ammonia production capacity 50% of the capacity still in operation was brought on stream on or prior to 1969. Overall, on a world-wide basis, 50% of the capacity now in operation is 10 or more years old and allowing for an average three-year implementation period, approximately 60% of the capacity now operational was planned and designed prior to the major oil price increases in 1973.
The various stages in the development of ammonia production based on natural gas from 1952 onwards are summarized in Table IV. Energy consumption dropped about 22% in the ten years between 1952 and 1962 and by a more modest 18% in the following twenty years. On the other hand modern design practices for average plants due to come on stream in 1984 or later would drop energy consumption by an additional 16% from consumption in 1982.
plants. The figures shown are for an average plant design, i.e. a design that has had widespread use, these average figures conceal the fact that there are some designs which have much lower energy consumption figures, and others which have shown much higher figures. It should be noted that both the owners and the engineering contractors have also responded only slowly to the higher energy prices in view of the need to maintain plant reliability even at somewhat higher production costs. Although the major potential for energy conservation is in the older plants, even a modern plant brought on stream in 1982 has energy consumption 16% higher than that in the next generation plants and therefore has significant potential for improving energy efficiency.

Table IV

Ammonia Plant Development: Natural Gas and Power Consumption a/

<table>
<thead>
<tr>
<th>Stage of Development</th>
<th>Year</th>
<th>Plant size, mtpd (single train)</th>
<th>Reformer Pressure, Atmosphere</th>
<th>Synthesis Pressure, Atmosphere</th>
<th>Feed &amp; Fuel, GJ/mt</th>
<th>Power, kWh/mt</th>
<th>Total Energy Consumption, GJ/mt</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Up to 1952</td>
<td>140</td>
<td>0.3</td>
<td>320</td>
<td>47.2</td>
<td>1,328</td>
<td>61.1</td>
</tr>
<tr>
<td>2</td>
<td>1953</td>
<td>145</td>
<td>4.1</td>
<td>320</td>
<td>46.4</td>
<td>1,140</td>
<td>58.6</td>
</tr>
<tr>
<td>3</td>
<td>1955</td>
<td>90-270</td>
<td>8.5</td>
<td>320</td>
<td>41.4</td>
<td>986</td>
<td>51.7</td>
</tr>
<tr>
<td>4</td>
<td>1960-1962</td>
<td>90-325</td>
<td>19</td>
<td>320</td>
<td>39.4</td>
<td>810</td>
<td>47.9</td>
</tr>
<tr>
<td>5</td>
<td>1963</td>
<td>290</td>
<td>27</td>
<td>320</td>
<td>38.7</td>
<td>754</td>
<td>46.7</td>
</tr>
<tr>
<td>6</td>
<td>1965-1975</td>
<td>550-1,550</td>
<td>31-33</td>
<td>150-230C/</td>
<td>40.0-41.4</td>
<td>77</td>
<td>40.8-42.1</td>
</tr>
<tr>
<td>7</td>
<td>1982</td>
<td>1,350</td>
<td>33</td>
<td>215</td>
<td>39.1</td>
<td>20</td>
<td>39.4</td>
</tr>
<tr>
<td>8</td>
<td>1984</td>
<td>1,000-1,350</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>33.0</td>
</tr>
</tbody>
</table>

Source: Based on reference 30 and World Bank data.

a/ These consumption figures are based on guarantee values and assume excellent operating practices, i.e., very good housekeeping, maintenance and onstream times.
IV. IDENTIFICATION OF ENERGY CONSERVATION POTENTIAL IN EXISTING PLANTS

A. General

4.01 Energy saving is not new to the fertilizer industry. Efficient use of raw materials and energy is normally one of the main areas attended to by corporate and plant management, maintenance personnel and operators. Moreover, with the steep increase in fuel and raw material prices during the last decade, production techniques have been improved to achieve more efficient feedstock and energy use, compared to the substantially less efficient plants commissioned 10-15 years ago. However, because of urgent pressures of plant operation, corporate and plant management had generally not paid adequate attention to energy conservation. Prevailing economic conditions now provide the impetus for adopting new methods and techniques to economize on inputs.

4.02 Energy conservation programs at the plant level need an organized and systematic approach if their full potential is to be realized. Effective plant organizational measures and energy audits are necessary to track down losses, to identify possible measurement anomalies, to evaluate audit results both technically and economically, and to work out detailed energy conservation programs. These programs will usually consist of two or three distinct parts: improved housekeeping and maintenance (needing little or no investment); short-term investment (revamping) programs; and long-term (reconstruction) programs. While organizational measures, energy
audits and good housekeeping can be of general applicability to fertilizer plants, revamping and reconstruction measures are always process-specific.

B. Organizational Arrangements

4.03 The organizational arrangements needed at the plant level to collect the required energy consumption information, analyze it adequately to facilitate preparation of an energy efficiency program specific for each plant facility, and monitor the implementation of the identified program, are the following:

(a) Organize a General Energy Audit, along the lines discussed below, by in-house specialists or by an outside agency (an energy audit firm or consultants with expertise in this field is normally required where revamping is considered) based on which energy conservation measures and investments can be designed;

(b) Install an Energy Accounting System to initiate availability of energy utilization data on a regular basis. Initially this system may be rough and approximate, because a more accurate and detailed accounting system will be possible only after unit-by-unit energy audits have been carried out;
(c) **Establish the Position of Energy Coordinator**, who should be responsible either to the production manager or to the works manager. He should be a process engineer with reasonable experience in the fertilizer industry. In addition, it would be desirable for the works manager and/or the production manager to attend a general course on energy saving methods.

(d) **Initiate Unit-by-Unit Energy Audits** as soon as everyone concerned becomes familiar with energy conservation. This analysis, under the supervision of the energy coordinator, should be made by a process technologist, and the energy accounting system referred to in (b) above should be refined for each unit studied. This is a step-by-step procedure, explained further in the next section.

(e) **Install a Follow-up Program** based on the above audits, with clearly established improved energy consumption standards endorsed by the top management. A regular periodic energy accounting is necessary to measure maintenance of these standards, enabling management to constantly monitor the use of energy.

4.04 Organizationally, it is important to have one person in the company, the energy coordinator, as the focal point for all energy-saving activities. It is not necessary to create a department for energy saving.
In fact, the creation of such a department may be counter productive since the operating managers should retain the main responsibility and motivation to achieve energy savings in the plant. The energy coordinator could have an assistant, but may use the existing staff of the technological, engineering, maintenance and project departments, for project preparation and implementation. If these departments do not have the required level of in-house knowledge on energy conservation, outside consultants with knowledge of the process under scrutiny could be utilized.

C. General and Unit Energy Audits

4.05 Several of the larger chemical and fertilizer companies have worked out detailed energy audit procedures for whole complexes and individual units. In complexes where people are not yet sufficiently energy-conscious, it may be especially desirable to start with a general energy audit of the whole complex with the assistance of a specialized outside consulting firm or operating company.

4.06 As noted earlier, the next step is to carry out detailed energy audits of individual units, including offsites and services. These audits should be in adequate depth to result in the identification and evaluation of definite energy saving proposals. In these audits, the following factors should be given close attention:

(a) Establish the overall economics of the plant and the desirability of energy saving. Even after energy savings
are achieved, some of the older plants may still have consumption levels much higher than modern plants and the economic viability of the plant could be doubtful. In this case, it may be more appropriate to close down the plant.

(b) Make an energy balance of inputs and outputs (including drains, stacks, etc.) within about 5% accuracy, to locate major areas of loss and inefficiency, looking especially at the balance of available energy.

(c) Review broadly the plant energy audit with a team (coordinated by the audit leader) consisting of the plant manager, plant engineer, process manager and energy coordinator, to identify major energy saving potentials;

(d) Review in detail the energy audit with a larger team including foremen and specialists in addition to the members mentioned under (c) above; and

(e) Prepare an action program in which costs and benefits are carefully identified and taken into account.
V. ENERGY CONSERVATION THROUGH IMPROVED HOUSEKEEPING AND MAINTENANCE

A. Importance of Good Housekeeping

5.01 In general, most energy losses are not obvious unless equipment performance is regularly measured. In some cases, between 10% and 20% of the total energy bill of a complex could be saved through improved housekeeping measures. There are other cases where the full benefits of energy saving investments are not achieved due to poor housekeeping. Sometimes there are differences between the production and maintenance departments, the former aiming at maximizing production and the latter trying to get sufficient time to check the equipment thoroughly. The level of good housekeeping is also often based on economic optimums, e.g., accepting minor steam leaks instead of shutting down the plant to correct them. Management participation in energy saving measures is therefore crucial. Good housekeeping can save significant amounts of energy, as explained below, through several generally applicable measures.

5.02 Material and energy balances, as mentioned earlier, are very powerful tools in energy conservation. In some cases it is impossible initially to arrive at an energy balance because of unaccountable losses. Strict accounting of all inputs and outputs by itself can eventually lead to savings of up to 5-10% through identification and elimination of losses. A day-to-day balance and accounting of energy use and its review against a practical optimum should be part of the general routine, with
monthly or quarterly inventory checks. Instrumentation may often need to be supplemented to obtain the required measurements.

B. Operating Efficiency, Pollution Control and Energy Saving

5.03 Material and energy waste can often be the result of operation at lower capacity levels or unscheduled shutdowns. In plants with low on-stream or load factors, energy savings of 2-10% can be achieved through operation at higher on-stream factors and fuller loads. In some extreme cases, as reported in the literature, savings between 14% and 35% were achieved by increasing capacity utilization. Hence careful planning, good maintenance and operator training can improve the plant efficiency.

5.04 The operating efficiency (on stream factor and capacity utilization) of the plant should be satisfactory before energy conservation programs are started. Frequent plant breakdowns strain operators and operational management who become unresponsive to any call for improved efficiency in the use of raw materials and/or energy. Such breakdowns can be caused by either one or a combination of the following causes: poor plant design, deficient maintenance, inadequately trained operators and inexperienced operational management. In general, production losses caused by such breakdowns far outweigh, in money terms, any energy and raw material inefficiencies.

5.05 Pollution control is not often considered as a means of saving energy since most pollution control and abatement equipment consume
additional energy. However, any pollution abatement measure that recovers and recycles materials also has an important energy saving aspect since any material, be it a nitrogen compound phosphate, a potassium or a sulfur-compound, has an energy equivalent corresponding to the amount of energy used to mine, beneficiate, process and transport it. In general, all designs of pollution abatement systems require a careful review of the energy balance, since energy savings by recovery of raw materials and products can easily be offset by additional energy (mostly electricity or steam) used to operate the system. The energy balance can also become negative if pollution standards are over strict. Some examples of energy saving by reduced pollution are in ammonia plants, i.e., purge gas recovery and recycling, recovering contaminated condensate and stripping the ammonia or its use as such in other plant facilities (e.g., hydrolyzing and stripping of urea plant effluents). At some sites it may even be feasible to combine several ammonia-containing effluent streams for treatment in one stripping unit. Decreasing the nitrogen oxides (NOx) emissions from nitric acid plants by extended absorption, and the sulphur dioxide (SO2) emission from sulfuric acid plants by extra conversion and absorption, are other examples of such energy savings. These could be especially attractive if plant capacity increase is desired at the same time. In Florida, an old 800 tpd capacity sulfuric acid plant was expanded to 1850 tpd by modifying it into a double conversion-double absorption plant and at the same time, meeting the new U.S. Environmental Protection Agency (EPA) emission standards. Another example of raw materials saving (and consequent energy savings) by stricter emission controls is possible in plants which produce solid materials. The loss of raw materials and intermediate products in
these plants is often high; losses of 5% of nitrogen and phosphate compounds are quite common, but can be avoided by careful operation and redesign of the gas cleaning equipment and a total recycle of effluents in the plant under review or, if such total recycle is not possible, recycling through other plants at the same site.

C. Steam Systems

5.06 Improvements in the plant steam system is one of the most promising energy-saving areas. Over and above the installation of steam metering and accounting, that should be part of developing a general energy balance, the following possibilities should be investigated:

(a) Check the whole steam system on a regular basis for losses, including insulation, flange tightness and steam traps. Losses due to bad insulation, leakage at flanges, and defective steam traps, etc. can result in up to 10% steam loss;

(b) Ensure adequate condensate recovery and utilization. Recovered condensate can be used for many low-level heat requirements either directly or by flashing; and

(c) Optimize the utilization of the steam system, including a review of steam availability and demands at various pressure and temperature levels for optimum utilization.
While generally only small changes may be needed, some of these may require small- or medium-size investments, e.g., installing turbines or condensate flashing equipment.

D. Improved Equipment Performance

5.07 Substantial energy savings can be achieved by improving the performance and operating conditions of key equipment. Boilers, heaters and reformers offer two distinct energy conservation possibilities, as follows:

(a) **Increase efficiency over design value.** Older less efficient units designed earlier with capital investment savings in mind, are characterized mainly by high stack temperature and/or high excess air. Possible improvements, design changes and additional investment, to recover heat from stacks should be considered and integrated into the whole plant energy system.

(b) **Improve operating performance to reach and maintain the design parameters.** Instrumentation to monitor continuously the main parameters determining the efficiency; stack gas temperature, oxygen and combustible content should be installed and operating values kept at optimum levels. Besides instrumentation, use of more efficient burners even with no other equipment changes can be beneficial.
5.08 Equipment which have operating temperatures below 5°C or over 60°C, offer many energy saving possibilities, principally in terms of avoiding heat losses, as follows:

(a) **Repair and maintenance of existing insulation.** Insulation can also be upgraded to improve the performance over the original design basis. The use of infrared photography for locating hot or cold points is a particularly effective tool for locating areas that require attention.

(b) **Checking at regular intervals or monitoring continuously the heat transfer** on all main coolers, condensers, heaters, etc. In operation, heat transfer rates gradually deteriorate due to fouling. Very simple means are needed for checking this. Cleaning at regular intervals or installing automatic cleaning equipment can raise the total plant efficiency at virtually no cost. The principle of regular monitoring and corrective action applies to other types of equipment, such as towers, filters, etc.

5.09 Performance of machines, gearboxes, drives and other mechanical equipment can also impact on specific energy consumptions. Usually in the older plants, these items are not designed for energy efficiency. With time their efficiency tends to decline even further since they are seldom checked. Systematic control of actual performance, comparison with design values, and restoration to original condition are the first steps in
improving their energy efficiency. After that, or, in many cases even instead, it will be worthwhile to alter or replace some of the equipment. For example, older mixers in many plants consume twice as much electric power as normally needed to perform a given task. Improperly fitted or inadequately selected driving motors are sometimes responsible for affecting adversely the quality of the whole plant's electric network, leading to frequent shutdowns. Another example covers design modifications. In some of the new big ammonia plants, all the small steam turbines driving different compressors, pumps, etc. are replaced by electric motors and one large turbine is used in addition to the three main compressor drives to expand the steam from the 40-30 atms. level to condensation and generate power. This large turbine is more efficient than the small ones. So in spite of the unavoidable transformation losses in power generation, distribution and use, this modification can achieve up to a 30% efficiency gain in steam utilization.

E. Utilities

5.10 Utilities are another key area for energy saving in fertilizer plants. Three major categories of utilities are discussed below:

(a) **Power generation and distribution** is a very sensitive point in all fertilizer plants, not only because of its own energy efficiency, but also because of the disastrous influence on plant performance of frequent power failures, as is the case in many plants especially in developing countries. While
outside factors are often responsible for these failures, the plant's own power system can often be inadequate and faulty. A systematic review, and in most cases relatively minor changes, can improve plant power system reliability and thereby raise indirectly the plant energy efficiency, and also contribute directly to energy conservation with better power utilization.

(b) **Cooling water systems** form one of the key weak spots in most plants. Inadequate cooling water treatment systems lead to serious fouling problems, and even worse, to expensive and dangerous corrosion. Make-up water and circulating water purification, use of appropriate additives, corrosion inhibitors and good maintenance of cooling towers, pumps, etc. are of utmost importance. It is not possible to quantify the advantages gained with these measures but the consequences of neglecting them can result in multi-million dollar replacement of critical equipment, shutdowns, production losses, and high specific energy consumptions.

(c) **Steam systems** already discussed in para 5.06, form the remaining major area requiring attention.

F. **Instrumentation**

5.11 Without exact measurement of operating conditions and energy inflows and outflows, no effective energy conservation program is
possible. Automatic control of operations is of great help to maintain the best operating parameters. In many plants, however, instrumentation is not serviced properly, sometimes even allowed to deteriorate to cover up bad operation. Most fertilizer plants, even modern ammonia plants, can be operated efficiently without highly sophisticated computerized control systems, but a well-designed measuring, monitoring, data logging and automatic control system is important in general housekeeping and especially in energy conservation. Periodic checks for good working order and regular servicing of the instrumentation system are absolutely necessary for good plant efficiency.

5.12 One further refinement can be economically attractive: the new hierarchical, distributed digital control systems based on microprocessors offer a reliable, easily adaptable low-cost approach to closer control and better efficiency.
VI. REVAMPING AND RETROFITTING TO IMPROVE ENERGY EFFICIENCY

6.01 This chapter discusses possible longer term measures (revamping and retrofitting) to achieve energy efficiency in fertilizer plants. These measures and investments are process-specific and therefore are presented here by type of plant, including ammonia, urea, nitric acid, ammonium nitrate, sulfuric acid, phosphoric acid and mixed fertilizer plants.

A. Ammonia Plants

6.02 Table V, provides a broad categorization of the present world ammonia capacity and energy use:

<table>
<thead>
<tr>
<th>Period When Capacity Brought On-stream</th>
<th>Capacity Million mt/year</th>
<th>Energy Consumption GJ/mt</th>
<th>Energy Value US$/mt ammonia at Fuel Oil Equivalent Prices (US$160/ton)(^a/)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Prior to 1955</td>
<td>2.42</td>
<td>59</td>
<td>219</td>
</tr>
<tr>
<td>1955-1960</td>
<td>1.69</td>
<td>51.7</td>
<td>192</td>
</tr>
<tr>
<td>1960-1962</td>
<td>3.18</td>
<td>47.9</td>
<td>178</td>
</tr>
<tr>
<td>1963-1965</td>
<td>6.79</td>
<td>46.7</td>
<td>174</td>
</tr>
<tr>
<td>1965-1975</td>
<td>53.49</td>
<td>41.4</td>
<td>154</td>
</tr>
<tr>
<td>1975-1982</td>
<td>46.93</td>
<td>39.4</td>
<td>146</td>
</tr>
<tr>
<td>Total</td>
<td>114.50(^b/)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Source: World Bank

\(^a/\) Average ammonia fob price in 1984 was about US$195/mt.
\(^b/\) Total capacity includes 5.15 million mt/year for which the start-up date is unknown.
6.03 If it is assumed that an energy conservation investment program can give an energy decrease of 15% (reduction due to good housekeeping etc. are not taken into account here since the specific energy consumption figures in Table V are based on guarantee values) and allowing US$16/mt ammonia for other production cost\(^3\)/ not including depreciation, plants brought onstream earlier than 1965 will have energy costs per unit of ammonia which are close to the average fob price of ammonia. These plants, therefore, will need to be reviewed carefully since continued operations may not be economic.

6.04 On the above basis, approximately 14.0 million tons/year of ammonia capacity should be replaced by new and more efficient plants. This may well be attractive in many instances since most of the other facilities on a fertilizer complex (infrastructure, utilities, urea plants, ammonium nitrate plants) may have many years of economic life still available.

6.05 Table IV listed the major stages in the development of the steam reforming processes for ammonia production. (A description of a modern ammonia plant is given in Annex 1.) A number of major trends have been responsible for the almost continued improvement in energy consumption for new plants as shown in Table IV. It is important to understand these trends in order to form a judgment as to the likely improvement in energy consumption that can be economically justified for a particular plant.

\(^3\)/ From TFI Ammonia Production Cost Survey year ended June 1983.
(i) **Plant Size.** Although not strictly an energy conservation feature, the increase in plant sizes was instrumental in reducing specific energy consumption in ammonia plants, since the economies of scale in construction costs made energy conservation features more attractive as investments for larger plants. Although plant sizes steadily increased up to 1963, the large jump in plant size occurred after 1963 with the development of the centrifugal compressor which was not only lower priced than the previously used reciprocating compressors, but also permitted closer integration of the plant energy system when driven by steam turbines using steam produced in the plant. As a result, as can be seen in Table IV the electric power requirement dropped from about 800 Kwh/ton of ammonia (the reciprocating compressors were generally electric motor driven) to 20 Kwh/ton for a modern plant.

(ii) **Metallurgy.** The development of alloys with better strength at high temperatures enabled the use of steam reforming pressures considerably above atmospheric pressure with consequent reduction in the synthesis gas compression, the major power consumer in the ammonia plant.

(iii) **Energy System Integration.** A typical modern ammonia plant generates about 5.2 tons of high pressure steam per ton of ammonia while the primary reformer requires about 2.0 tons of medium pressure process steam; this allows co-generation
economies to be achieved by letting down the high pressure steam through a turbine to the primary reformer pressure. The power requirement of a typical modern ammonia plant is about 810 kWh per ton (a 1,350 tpd plant thus has a power requirement of about 46 MW) of which about 790 kWh/ton is generated in the ammonia plant energy system. Energy efficiency favors the use of higher steam pressures and temperatures and indeed steam pressures and temperatures of up to 123 atms and 510°C respectively are used. Such steam systems require stringent choice of materials, high maintenance standards and close control of operating conditions. Some centrifugal plants were therefore built for better reliability using steam generation pressures of 62 atms and less but with a resulting penalty of about 6.0–7.0% on total energy consumption.

(iv) **Catalysts.** Reforming catalyst developments now permit higher reforming pressures and lower steam/carbon ratios—thereby lowering fuel requirement. The adoption of low temperature shift conversion 1963 in conjunction with methanation catalysts not only improved efficiency but simplified operations through elimination of copper liquor scrubbing. Developments in ammonia synthesis catalyst and converter designs have reduced power requirements and improved heat recovery from the ammonia synthesis section.
(v) **Reliability.** In general the reciprocating compressor based reformer plants were very reliable—due to their simpler construction—the early centrifugal plants in general suffered severe reliability problems in their initial years of operation and as a result, there is even now a very cautious approach to innovation in the industry. Poor reliability, with consequent frequent start-ups and shut downs increases energy consumption. Over the last few years, however, both equipment reliability (especially the major compressors and turbines) and understanding of problem areas in design and operation have improved significantly.

6.06 There is, therefore, a limit to the level of energy saving that can be economically justified especially for some of the plants designed before 1963 (see Table IV), since the introduction of all the features that could improve energy efficiency would in effect represent a substantial replacement of the plant. Based on available published information and the experience of engineering firms, the economically feasible upper limit to energy conservation through retrofitting in 1000 mtpd ammonia plants running under good operating conditions (i.e., good housekeeping, well trained operators, plant well maintained) is about 20%. It is significantly less for smaller size plants due to the effect of scale down factor on investment requirements. In evaluating the economics of retrofitting ammonia plants built before 1963, it is essential to assess, as accurately as possible the residual plant life available after the retrofitting. The residual life should be sufficient to justify the
investments, since it could otherwise make better economic sense to build new capacity.

Energy Saving Retrofits That Operating Plants Have Successfully Demonstrated

6.07 The following examples list several retrofits of ammonia plants that have been adopted and demonstrated in practice. Investment costs where available are in 1983 prices and refer to a plant of 1,000 tpd ammonia capacity. The cost figures, where available, relate to developed countries and should be viewed as only indicative since such costs are heavily dependent on particular plant designs. In addition to energy savings, many of the indicated measures also lead to capacity increases and to reliability improvements.

Purge Gas Treatment

6.08 Since the object of steam reforming of natural gas is the production of hydrogen, recovering hydrogen in the purge gas from the synthesis section and recycling it back to the process, reduces overall energy consumption by reducing the reformer fuel requirement and the load on the CO₂ removal system, and also by saving some compression power. Diffusion, cryogenic or molecular sieve purge gas recovery units can recover hydrogen from the purge gas at suitable pressures for recycle to the syngas compressor. The industry has widely adopted purge gas recovery, since it is an energy conservation feature that does not interfere with the
operation of the main plant either during construction or when on-line.
These units can save some 1.8 GJ/mt of ammonia and typically cost US$1.4 million installed. Depending on the particular case, it may be necessary to change the burners that were previously fired with purge gas, due to the changed fuel characteristics.

**Synthesis Converter**

6.09 It may sometimes be attractive to retrofit with an additional ammonia converter in parallel with the existing one to save significant gas recycle and some refrigeration compressor power and to debottleneck the ammonia synthesis loop. The additional ammonia converter reduces pressure drop and recycle rate so that the recycle compressor power requirements decrease, and increases ammonia concentration in the converter effluent due to the influence of the larger catalyst volume. Where such retrofitting has been adopted, the additional converters were available at low cost under specific circumstances. This option is not generally viable. Energy savings of some 1.12 GJ/mt per ton of ammonia are possible.

6.10 Numerous plants have been retrofitted with radial flow converters with dual radial beds combined with feed effluent heat exchangers which offer the same advantages as para 6.09 above. This retrofit offers about 0.7 GJ/mt per ton energy saving.
Molecular Sieves

6.11 At least one contractor offers as a retrofit a molecular sieve in the syngas make-up stream to the synthesis loop. Molecular sieves remove residual water and carbon dioxide and allow fresh make-up gas to be fed directly to the ammonia converter saving pressure drop and decreasing the recycle rate by lowering the ammonia concentration in the converter feed which permits a greater conversion over the catalysts. Most existing plants introduce the syngas make up down stream of the converter so that condensed ammonia product can wash out residual moisture and carbon oxides. Molecular sieves can be debottlenecking as well as energy saving devices. They save approximately 0.6 GJ/mt per ton for a cost of about US$1.8 million installed.

High Level Waste Heat

6.12 In some old ammonia plants a condensate stream quenches the gas stream exit from the secondary reformer to lower the temperature of the gas to the shift-conversion. All modern plants use a reformed gas waste heat boiler instead of a condensate quench in order to recover the considerable amount of heat available. If the carbon dioxide removal system can be upgraded so that less energy is required for regeneration, then the quench duty can be partially or wholly supplied by a retrofitted reformed gas waste heat boiler. Energy savings in the carbon dioxide removal system are then translated into steam generated by the waste heat boiler. At least one plant has been retrofitted with a reformed gas waste heat boiler.
6.13 Numerous plants have been retrofitted with steam generators in their synthesis sections to utilize high level heat in the converter exit gas. This is particularly attractive in conjunction with paras 6.09–6.11 since these modifications lead to more high temperature heat availability which makes high-pressure steam generation attractive.

**Carbon Dioxide Removal**

6.14 The rich (carbon dioxide bearing) solution in chemisorption carbon dioxide removal systems must be regenerated using low-level heat—most of which is in the process gas stream, and sometimes also using additional low pressure steam. Most existing ammonia plants have either potassium carbonate or monoethanolamine (MEA) chemisorption systems. The overriding consideration for retrofits is to identify utilization for the low-level heat in the process gas stream that would be saved with more efficient systems since in most situations this has no other use. Reducing the process steam supplied to the reformer is one easy option for some old plants now using excessive steam, since this reduces the low level heat available. Eliminating low pressure steam-producing turbines is sometimes another straightforward option. Such savings can amount to 4.1 GJ per ton. These large values represent fuel savings especially when the ammonia plant can export low-level heat for process use. When low pressure steam export is not possible, only 60 to 80% of the heat savings in the carbon dioxide removal section translate into fuel savings. Where monoethanolamine systems are used, numerous plants have added retrofitted corrosion inhibitor systems which decrease the heat duty of the carbon
dioxide system by about 34% and show a payout period time of about 3 months. Power recovery turbines on the rich stream to the regeneration tower can recover some of the energy in the high pressure stream as it is let down to atmospheric pressure to the extent of about 10 kWh/mt of ammonia at a cost of about US$0.35 million.

Combustion Air Preheater

6.15 Many older plants have high heat losses in the flue gases going to the stack. Combustion air preheaters can be retrofitted to recover waste heat from the reformer flue gas and typically reduce stack temperatures from 250°C to 150°C. Many companies are known to have installed these systems. The heat recovered depends on the stack temperature, the reforming severity and the degree of auxiliary firing in the flue gas section. Savings will typically fall in the range of 0.8-1.2 GJ/mt of ammonia. Engineering companies are now offering package air preheater units for this purpose.

6.16 A retrofitted combustion air preheater, however, costs significantly more than one installed in a new plant. The cost for a 1,000 mtpd ammonia plant with a downfired reformer was about US$3.5 million, but is expected to be less with the package units now available. Although the industry has retrofitted at least 6 units, ammonia producers should evaluate proposals with caution because differences between plants may lead to substantially higher costs. Some items impacting on cost of such retrofitting are: reformer stack relocation; availability of space for
ducting, fans, air preheaters; type of reformer. In addition to the new preheater, the following equipment would need to be changed: forced draft fans and drivers, burners and burner tiles, ducting; possible changes to induce draft fan and driver and the reformer stack. A side benefit from introducing a combustion air preheater is the easier control of furnace firing, due to the control system required, resulting in the reduction of the excess air to design levels, and therefore reducing the fuel required.

\textbf{Surface Condenser Cleaning}

6.17 Several ammonia plants have been retrofitted with on-line cleaning devices in the turbine condensers to achieve substantially improved turbine efficiencies. These devices are very simple and easy to operate and typically consist of flexible plastic spheres that are circulated through the heat exchanger tubes. While typical design condenser vacuum in ammonia plants is 100 millimeters of mercury (mm Hg) there are plants operating at vacuum as poor as 250 mm Hg, mainly due to the heavily fouled cooling water systems and typically losing about 9% in turbine efficiency. Even for systems where the cooling water quality and control is good, such devices can be worthwhile. On-line cleaning systems cost about US$50,000 and show pay-back period of less than one year. The same system has also been used advantageously in ammonia condensors where also performance is very susceptible to fouling.
Use of Flare Gas

6.18 During start-ups and controlled shutdowns there are long periods when synthesis gas is produced by the plant but has to be flared. Some plants have made provision to burn this flare gas instead of the normal fuel gas either in a package boiler or in the reformer furnace. Cost is approximately US$0.15 million with a pay-back period of about 18 months.

Compressor Drives

6.19 Since the early days of centrifugal compressors there have been major improvements in steam turbine and compressor designs leading to lower energy consumption and much improved reliability. At least one ammonia plant has replaced the major compressor turbine units, to achieve these improvements.

Decrease in the Amount of Reaction Steam

6.20 A decrease in the amount of reaction steam to the primary reformer is often done in conjunction with improved shift conversion catalysts and reduced steam requirements of the carbon dioxide regeneration system. In most cases it is not possible to make this change in isolation and achieve worthwhile savings since the change will have an effect on the total energy balance of the plant.
Feedstock Saturation

6.21 A hot water stream produced by low level heat can be used to saturate the natural gas feed to the primary reformer or in some cases the process air to the secondary reformer and has been retrofitted to saturate the gas stream to the low temperature shift convertor in conjunction with a reduction of the steam carbon ratio to the primary reformer. Steam for process use is in this way effectively created using a heat source at a lower temperature than is necessary to generate steam in a conventional boiler. There is the additional advantage that process condensate can be used (instead of ultra pure boiler feed water) and impurities present (ammonia and methanol) which are otherwise a pollution problem, are destroyed. Some retrofits are being implemented. The energy saved is a function of the reforming pressure and the waste heat available but would be typically 0.6 GJ/mt per ton of ammonia.

Selective Oxidation of Carbon Monoxide (CO)

6.22 The disadvantage of the methanator unit of the ammonia plant is the use of valuable hydrogen to convert the residual carbon oxides (CO) to methane. Some plants are now reported to be operating using oxygen or air for selective oxidation of residual CO over a catalyst at low temperature. This step reduces hydrogen loss in the methanator and also reduces inerts in the make up gas to the synthesis loop thereby saving energy and increasing capacity. The system is not yet in widespread use and its suitability for a particular plant should therefore be carefully evaluated.
Coal Gasification Unit for Synthesis Gas Preparation

6.23 TVA has built, on an experimental basis, a coal gasification unit with a capacity equivalent to 135 m tpd ammonia to replace natural gas requirements of an existing ammonia plant. Preliminary data indicate that with gas costs at US$4.50/million Btu's (US$182/mt equivalent fuel oil cost or US$4.25/GJ) and coal at US$30/mt (US$44/mt equivalent fuel oil cost) the coal gasification retrofit for a 900 mtpd plant can produce ammonia at US$226/mt or about 90% of the cost based on a new natural gas reforming plant. TVA plans to continue operation of the experimental unit to develop design improvements and generate better cost estimates. In Japan, Ube Ammonia Industry has retrofitted an existing steam reforming ammonia plant based on LPG of 1,250 mtpd capacity with a Texaco coal-based gasification ammonia plant with a reduced capacity of 1,000 mtpd at a reported cost of Yen 28 billion. The production cost for one ton of ammonia it is reported will decrease from Yen 58,000 (US$247) for LPG to Yen 38,000 (US$162) for coal. In any event, given the size of the investments involved, the use of coal gasification should be studied carefully for the specific case before its implementation.

B. Urea Plants

6.24 Urea, a nitrogenous fertilizer with a nutrient value of 46% nitrogen, is prepared by reacting ammonia with carbon dioxide (see Figure E) -an exothermic (heat producing) process. However, in practice, there is a negative energy balance since mechanical energy is needed to compress
carbon dioxide, pump ammonia and recycle gas and/or liquid. Heat is also needed to decompose the carbamate\(^4\) and evaporate water from the urea solution before prilling (or granulating). Additional energy is also now required to process waste streams, i.e., hydrolyze urea and strip ammonia in pollution abatement systems.

**FIGURE E**

Typical Urea Production Process

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\(^4\) Carbamate is formed very rapidly in the urea reactor from ammonia and CO\(_2\) this then dehydrates slowly to form urea. This dehydration reaction is never complete (between 60-80% complete), so it is necessary to recover the ammonia and CO\(_2\) from the carbamate and return these to the reactor.
6.25 The practical lower limit of energy required for converting ammonia to urea (battery limit value) is around 2.9 GJ/mt of urea (6.7 GJ/mt of N); modern efficient plants operate at around 4.2 GJ/mt of urea, excluding energy needed to process waste streams and other outside battery limit purpose. The TFI report, quoted in para 3.03 above, indicates that the average energy consumption for US plants for prilled urea is 9.2 GJ/mt of urea and 5.7 GJ/mt of urea for the lower value of the inter-quartile range. There is, therefore, scope for energy conservation, even after allowing for the reduction in the energy needed to produce ammonia which will in turn reduce the total energy needed to produce urea. All the latest technological improvements in urea production have led to significant reduction in per unit ammonia consumption to close to the theoretical levels and have led to significant reductions in total energy needed per ton of urea.

6.26 Modern urea plants differ greatly from the older ones which account for the very high average consumption figures. The new stripping technology reduced the energy requirements of the two energy intensive process steps: carbon dioxide compression and carbamate recirculation. New carbamate decomposition and condensation systems and more efficient evaporation equipment contributed greatly to this improvement. These improvements, however, do not lend themselves easily to retrofitting. Most viable energy conservation measures available for old urea plants relate to improvements in the evaporation section where the urea solution is concentrated prior to prilling on granulation and minimizing material losses. A more efficient evaporator system can reduce the steam consumption by 1.0-3.1 GJ/mt of urea.
C. **Nitric Acid Plants**

6.27 The reaction of ammonia with oxygen to form nitric acid is strongly exothermic (see Figure F). Therefore, in principle, a great part of the energy invested in ammonia production should be recoverable, as only about 16% of the energy content of the ammonia appears as energy content.

*Figure F*

**Typical Nitric Acid Production Process**

- Ammonia
- Vaporization
- Reacting
- Filter
- Mixing
- Conversion to NO
- Cooling
- Conversion to NO₂
- Oxidation & Absorption
- Nitric Acid
- Mechanical Energy Recovery (% compression)
- Tail Gas

**Notes**
1. Tail gas may require pollution abatement treatment unless extended abatement is used.
2. Some processes operate with relatively low pressure in NO conversion & further compression before absorption.
of the nitric acid produced. Even the best of modern nitric acid processes, however, cannot achieve more than 20-21% energy efficiency; that means, only 14-15% of the ammonia formation energy is recovered as export steam and 80% is either simply lost to the environment or used for process purposes (compressor drives). The peculiarities of the present processes do not allow for better efficiency except in some very special cases. Only the heat released when burning the ammonia on the platinum-alloy catalyst can be economically recovered. The remainder could be extracted from the system only at near ambient temperature and therefore, cannot be used.

6.28 Older plants have less efficient heat recovery systems and are either self-sufficient or dependent on external energy. Another serious problem with these plants is atmospheric pollution due to the high NO\textsubscript{x} content in the stack gas. The reduction of pollution, if properly done, reduces energy consumption, although it cannot be justified on this basis alone. Other methods to improve thermal efficiency are generally outside the scope of revamping, but small improvements can always be made in the heat recovery system, in the compressor train, or in the operational parameters.

6.29 Utilization of near ambient heat is sometimes possible for domestic heating or in greenhouses. This general possibility is also available for nitric acid plants. One known example is in Denmark (Frederika) where at first 42 GJ/h, later 200 GJ/h of waste energy was delivered in the form of hot water for the town heating network.
D. Ammonium Nitrate Plants

6.30 In principle, the reaction heat liberated by the neutralization of ammonia with nitric acid should be sufficient to evaporate the water brought in with the acid (see Figure G). Actual processes, however, need external energy. The total energy balance for the whole production line comprising the nitric acid plant, neutralization, evaporation and prilling-granulation should be considered together, since the low pressure steam export of the nitric acid can be put to best use in the ammonium nitrate plant. The practical optimum today for the whole nitric acid/ammonium nitrate production from ammonia is around 2.0 GJ/mt of ammonium nitrate. The actual average industry figure is around 3.2–4.2 GJ/mt.

FIGURE G
Typical Ammonium Nitrate Production Process
6.31 Ammonium nitrate plants are particularly suited for energy conservation measures that would also solve the pollution problems. Typical modifications are: (i) heat recovery through ammonia vaporization or other low level users; (ii) vent scrubbers and/or high efficiency mist eliminators and (iii) use of recovered contaminated condensate in the nitric acid plant. The equipment used in the neutralization and evaporation section is relatively inexpensive: it is very simple and has a very high throughput. In older, less efficient plants, savings of between 0.4-1.7 GJ/mt of ammonium nitrate are possible. The total costs of new equipment (neutralization and evaporation) for a 750 mtpd plant is less than US$3 million with a payback period of 2-4 years.

E. Sulfuric Acid Plants

6.32 Sulfuric acid (Figure H on the next page) is required for producing about 80% of the world's phosphate fertilizer. About 65% of the world's sulfuric acid production is from elemental sulfur and 17% from pyrites while the remainder is from smelter gas and reconditioned spent-acid. The energy released in the production of sulfuric acid from elemental sulfur is 5.4 GJ/mt of sulfuric acid (somewhat less when pyrite is used). Part of this energy can be used for power generation and other uses in the sulfuric acid plant and the surplus exported to adjacent plants as steam or electric power. In actual practice, according to a TFI Energy Use Survey, an average of 2.2 GJ/mt of surplus energy is recovered in usable form, with variations ranging between 1.8 GJ/mt and 2.5 GJ/mt. The most recent plants produce an energy surplus of around 2.9 GJ/mt of acid.
FIGURE H

Typical Sulfuric Acid Process with Double Absorption
6.33 As noted, the energy recovered as steam is used either in adjacent plants (e.g., phosphoric acid) or to generate electricity. The main sulfuric acid process equipment is relatively inexpensive but needs considerable overhauling every year. This makes it easy to introduce improvements in existing plants. The main areas for energy saving possibilities in these plants are:

(a) **Main heat recovery system.** Installation of waste heat boilers, steam turbines and power generators. If these units have not yet been installed, they should be considered and adopted; in many old plants it may be economical to replace the old heat recovery system by a new and more efficient one.

(b) **Use of a new catalysts.** New more active catalysts with lower pressure drops in the process allow for increased sulfur dioxide \( (SO_2) \) gas strength (up to 12%). This measure has the advantage of increasing steam production, as more energy is recovered from the gas stream, while at the same time reducing the steam consumption of the main compressor turbine, because of the smaller gas volume and the lower pressure drops over the catalyst.

(c) **Recovery of energy from the gas stream to the absorption tower.** This was limited in the past by corrosion caused by acid condensation. Specialist companies have developed for
this purpose low temperature economizer systems with potential for significant energy recovery.

(d) Air Compressor Rearrangement. Where the main compressor is upstream of the drying tower, a different arrangement can be considered by moving it downstream of the tower. This suction drying tower arrangement has better energy efficiency as the compression heat can be converted into steam. However, special care is required to remove any acid mist from the gas stream.

(e) Boiler Feed Water. More steam can be generated by heating up the boiler feed water (BFW) with low grade heat which is generally lost in the cooling water. However, care should be taken to avoid contamination of the BFW with leaking acid.

(f) Filtration. Installation of a liquid sulfur filter (if this is not used at present) and/or the installation of a hot gas filter (if the pressure drop can be afforded). The latter is not required if refinery sulfur is used; but, even with bright Frasch sulfur, it can be economically attractive.

(g) Recovery of low level heat. Large quantities of heat are normally lost in the cooling water. In contrast to the nitric acid, where the cooling must be carried out at the
lowest possible temperature level, in sulfuric acid plants this temperature can be quite high (up to 100-120°C). If an all-year user can be found for this low level heat, the usual evaporating acid coolers (which cause many problems in the plant) can be replaced by plate-type heat exchangers and up to 2.1 GJ/mt of acid can thus be recovered with an investment of about US$2,000/mt per day of acid production capacity.

F. Phosphate Fertilizer Plants

6.34 The modern phosphate industry dates from the mid 19th century with the development of the superphosphate process by which insoluble calcium phosphate (from bones originally) was converted with sulphuric acid into soluble phosphate—single superphosphate (SSP). Although of low analysis—typically 18% P₂O₅—SSP is very simple to produce and maintained a dominant position until the 1960's. SSP has now been replaced to a great extent by phosphatic fertilizers based on phosphoric acid; notably, triple superphosphate—TSP (46% P₂O₅) made by reacting phosphoric acid with phosphate rock, and ammonium phosphates—MAP and DAP (48-54% P₂O₅).

6.35 Phosphoric Acid. Wet process phosphoric acid is made by reacting sulphuric acid with finely ground phosphate rock to form filter phosphoric acid (normally about 30% P₂O₅) and calcium sulphate (usually gypsum CaSO₄·2H₂O) (see Figure I on the next page). The calcium sulphate is filtered from the acid which is then concentrated from about 30% to 54%
either for sale as merchant-grade acid or for further concentration into superphosphoric acid (70\% P₂O₅). Although there are many different proprietary processes, most processes in operation work according to the gypsum process which means that calcium sulphate formed in the reaction is in the dihydrate form.

**FIGURE I**

Typical Phosphoric Acid Production Process

- Phosphate Rock
- Grinding
- Reaction
- Filtration
- Concentration to 54\% P₂O₅
- Concentration (Not Always Necessary)
- Fertilizer Uses
- TSP
- MAP
- DAP
- Compound Fertilizers

Gypsum to Utilization or Disposal
Fluorine Compounds to Utilization or Disposal

Water
6.36 Ammonium Phosphate. The most popular process for production of ammonium phosphate is the method commonly known as the slurry granulation; phosphoric acid is neutralized in a series of tanks with ammonia where some water is removed by the heat of reaction. Either monoammonium phosphate—MAP (11-54-0) or diammonium phosphate—DAP (18-46-0) can be produced. Granulation is carried out in a blunger, a pugmill, or a rotating drum.

6.37 Several variations of the process have been developed in which rotary drums are used to granulate the material and ammoniation is carried out during granulation. In some cases, potash and supplementary nitrogen in the form of urea or ammonium nitrate can also be added to produce a range of ammonium phosphate based compounds.

6.38 About 60% of the world's phosphate fertilizer is made from phosphoric acid. The estimated energy use for the various grades of phosphoric acid and for various processes is shown in Table VI.
TABLE VI
ENERGY USE FOR PHOSPHORIC ACID PRODUCTION a/

<table>
<thead>
<tr>
<th>Process</th>
<th>Dihydrate, Dry Rock Feed</th>
<th>Dihydrate, Wet Rock Feed</th>
<th>Dihydrate, Wet, Unground Rock Feed</th>
<th>Hemihydrate, Wet, Unground Rock Feed</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>(GJ/mt of P2O5)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Rock Preparation b</td>
<td>3.69</td>
<td>1.51</td>
<td>1.51</td>
<td>1.51</td>
</tr>
<tr>
<td>Sulfuric Acid c</td>
<td>-3.69</td>
<td>-3.69</td>
<td>-3.69</td>
<td>-3.69</td>
</tr>
<tr>
<td>Filter acid d</td>
<td>4.12</td>
<td>3.60</td>
<td>2.60</td>
<td>2.18</td>
</tr>
<tr>
<td>Concentrated to 42% P2O5 e</td>
<td>2.85</td>
<td>2.85</td>
<td>2.85</td>
<td></td>
</tr>
<tr>
<td>Total for 42% P2O5</td>
<td>6.97</td>
<td>4.27</td>
<td>3.27</td>
<td>0</td>
</tr>
<tr>
<td>Concentrated to 54% P2O5</td>
<td>3.35</td>
<td>3.35</td>
<td>3.35</td>
<td>3.35</td>
</tr>
<tr>
<td>Total for 54% P2O5</td>
<td>10.32</td>
<td>7.62</td>
<td>6.62</td>
<td>3.35</td>
</tr>
<tr>
<td>Concentrated to 70% P2O5</td>
<td>3.14</td>
<td>3.14</td>
<td>3.14</td>
<td>3.14</td>
</tr>
<tr>
<td>Total for 70% P2O5</td>
<td>13.46</td>
<td>10.76</td>
<td>9.76</td>
<td>6.49</td>
</tr>
</tbody>
</table>

Source: TFI and World Bank

a. Assumptions: 94% P2O5 recovery; 3.32 mt of phosphate rock and 2.78 mt of H2SO4/mt of P2O5 recovered.
b. Mining, beneficiation, and (when required) drying.
c. Based on use of elemental sulfur with zero energy charge.
d. Including grinding when required.
e. Based on TFI average of 6.29 GJ/mt P2O5 for production of merchant grade from filter grade. Filter grade assumed to be 28% P2O5 and merchant grade 54% P2O5. Energy use assumed to be proportional to water evaporation. For hemihydrate process 43% P2O5 acid is obtained directly from the filter.

Most of the plants now in operation are of the dihydrate type (the particular form of calcium sulphate that is produced in the reaction stage of the process at moderate temperatures and phosphoric acid concentration). As shown in the above table, the modern hemihydrate (the form of calcium sulphate produced in the reaction stage at high temperature and phosphoric acid concentration) has a much lower energy consumption than the dihydrate process.

6.39 In existing phosphoric acid plants, in general, not much energy savings may be expected. There are some exceptions, however:
(a) **Wet rock phosphate feed** can be used as is, instead of
dried phosphate rock, if the plant is located on a mine
site, Table VII. This saves about 2.5 GJ/mt of $P_2O_5$ as
compared with using dried, ground rock. At least two
dihydrate processes as well as most hemihydrate processes
can be adapted to use wet, unground rock provided the
maximum particle size is less than about 1 mm. Most
commercial rocks meet this criterion. Using wet rock is
economical when the plant is near the mine but not when the
rock must be shipped over any distance.

(b) **A roller ring mill instead of a ball mill** could be
considered if the dry rock grinding mill is being replaced.
A roller ring mill with an air separator can substantially
reduce power cost per ton of milled rock. Furthermore,
depending on the rock used, it is not always necessary to
grind the phosphate to the fineness prescribed in the basic
design, thus saving electricity.

(c) **Hemihydrate process.** Phosphoric acid is usually produced at
28-30% $P_2O_5$ concentration and, as a next step, is further
concentrated to 45-54% $P_2O_5$ content (merchant-grade). For
this concentration, low pressure steam from the sulfuric
acid plant is used (approximately 1.9 ton steam/ton of
$P_2O_5$). It is possible, however, to produce acid of 44% strength (or higher) directly by the hemihydrate processes.
For this purpose, the plant has to be retrofitted. At the
same time, an alternative use has to be found for the low pressure steam if this originates from the sulfuric acid plant. Often, this low pressure steam may not have any other alternative use, and therefore the retrofitting may not be justified.

(d) A change to vacuum flash cooling for phosphoric acid plants using air cooling for temperature control in the reactor section, could reduce the electrical energy required for moving the large amounts of air, while at the same time decreasing considerably the amount of air to be scrubbed, which also results in less energy consumption.

(e) A redesign of the agitator in the reaction tanks can improve the completion of the reaction (less-insoluble/P₂O₅ losses) and reduce, at the same time, energy consumption. In this connection, it may be useful to check the points where sulfuric acid is added; a modification could improve P₂O₅ efficiency by up to 2%.

G. Mixed or Compound Fertilizer (NPK) Plants

6.40 Compound fertilizers can be classified based on the process used in their production, as follows:

(a) Granulation of dry mixed material in which chemical reactions are not an essential part of the process.
(b) Granulation of dry materials with the addition of ingredients that react chemically, usually ammonia and phosphoric acid or phosphoric acid and sulphuric acid.

(c) Slurry granulation in which materials to be granulated are in the form of a slurry.

(d) Melt granulation in which all or part of the mixture to be granulated is in the form of a hot fluid melt, usually containing less than 2% water, which solidifies on cooling.

(e) Blending or dry mixing of granular materials.

(f) Nitrophosphate materials in which mixed fertilizers are made by reacting phosphate rock with nitric acid, separating calcium nitrate by cooling and filtration and producing a granular product using slurry granulation.

6.41 Energy requirements for granulation normally vary between about 1.0 to 0.2 GJ/mt depending on the type of operation. The lower end of the range applies to the energy requirements for blending of granular materials, without taking into account the energy needs to granulate the components of the blend.

6.42 The mixing and granulation of fertilizer materials is basically a simple operation in which energy is not a major cost component. Energy is
used mainly as electricity for the operation of the rotary drums, screens and conveying equipment. Energy in the form of gas or oil is also usually required to dry the compound fertilizer after granulation. Energy savings in the granulation process can be effected by detailed attention to the transport and handling of materials both in and outside the plant. Principal measures include:

(a) Minimization of product recycle ratio by maintaining the optimum temperature/moisture relationship in the granulator.

(b) Maintaining optimum combustion conditions in the drier by maintaining a correct fuel/air relationship, and by preventing cold air leakage into the drier inlet.

(c) Recycling of cooling air from the cooling drum to the drying furnace.

(d) Avoiding unnecessary handling of material (inside and outside the plant, including storage).

6.43 The most important development in recent years to save energy in the granulation process, both for ammonium phosphate and mixed fertilizer plants, has been the use of energy from the chemical reaction of the product components to assist both the granulation and the drying process and minimize the need for outside heat. The increasing availability of
ammonia and phosphoric acid as raw materials for the production of compound fertilizers has accelerated this trend, given that their reactions are exothermic. For some compound fertilizers hot melt mixtures can be produced which when sprayed into a granulator and cooled can produce compound granular materials which require no further drying. The chemical reaction between mineral acids and ammonia is carried out in a pipe reactor or in a small stirred tank pressure reactor in which the heat of reaction removes water from the system. One advantage of the tank reactor is that it is possible to recover the energy in the form of low pressure steam (contaminated) which can be utilized elsewhere. A number of proprietary tank and pipe reactors are now available and are being installed in new granulation plants or by retrofitting existing plants. If it is possible to eliminate the drying stage and minimize recycle requirements, energy requirements of the pipe reactor, compared with a conventional slurry-granulation process are as indicated below. The indicated savings are equivalent to about US$4/mt per ton of product, at international prices for energy.

<table>
<thead>
<tr>
<th></th>
<th>Slurry Granulation Process</th>
<th>Pipe Reactor Process</th>
</tr>
</thead>
<tbody>
<tr>
<td>Electricity</td>
<td>50 kWh</td>
<td>25 kWh</td>
</tr>
<tr>
<td>Fuel Oil</td>
<td>20 kg</td>
<td>4 kg</td>
</tr>
<tr>
<td>Steam</td>
<td>5 kg</td>
<td>1 kg</td>
</tr>
</tbody>
</table>

Although the overall cost of producing blend mixed fertilizers is probably little different from producing compound fertilizers from raw
materials such as ammonia and phosphoric acid or mixed acids there are many occasions where the use of bulk blending can offer energy savings. For example, any intermediate fertilizer materials for compound fertilizer products such as urea, diammonium phosphate and triple superphosphate are only available in granular or prilled form and the regranulation of these materials to produce other compound fertilizers requires further energy input. In this case, blending without regranulation will be more economic.

6.45 When granulated compound fertilizers are produced using nitrophosphate processes, there is probably little advantage compared with blending regarding overall energy savings, based on processing costs alone. The main advantage of the nitrophosphate process is, of course, that it reduces or eliminates the need for sulphur which can offset the higher energy requirements of the process. The ability to maintain satisfactory world sulphur balances and low sulphur prices is now mainly dependent on production of Frasch Sulphur, which is energy intensive. New sulphur mines require more than 10 GJ/mt per ton of sulphur produced.
VII. ENERGY SAVINGS IN NEW PLANTS

7.01 Although energy efficient ammonia plant designs have been available for some time, they have not yet been adopted widely. Moreover, over the past 10 years, plant design in general has changed little as regards energy efficiency. To some extent this has been due to the industry's memory of the difficulties experienced with the early centrifugal plants—the great innovative period of the ammonia industry in the last 30 years—and the relatively minor effect on plant viability of energy savings when compared with the major effect of lost production if such features gave rise to reliability problems. The situation today—especially in the developed countries, with energy costs now a major proportion of the sales value of ammonia and very considerable experience within the industry of ammonia design and operating problems—makes attractive a careful review of the risks and benefits of building new generation plants even if they are not commercially proven on a widespread basis. As can be seen from Table IV, the potential energy savings from the new generation plants (Stage 8) is 6.4 MJ/mt or more compared with a traditional plant (Stage 7) or about US$25/mt lower energy costs (using equivalent fuel oil values). This would amount to about US$7.4 million per year for a 1,000 mtpd ammonia plant; on the basis of 1983 prices, it would correspond to the sales value of the output of the plant for 50 days. On the other hand, it is necessary to carefully examine and quantify the risks in the new design; some of the factors that should be evaluated are the firmness of the capital costs, the increase in complexity, the need for new equipment or components not commercially proven for the required
application, and the risk of implementation delays due to unforeseen design and construction problems stemming from the new design.

A. Ammonia Plants

7.02 The first step in the evaluation of a new ammonia project is, of course, an analysis of the raw material to be used. In countries and locations where natural gas is available, it is the preferred feedstock and best suited for ammonia production. Use of other feedstocks is generally less energy-efficient and requires larger investments. In the absence of natural gas, refinery gas, fuel oil and coal can be considered. The energy efficiency decreases in that order and the economics require a careful review. At today's and expected international prices, naphtha based plants would be uneconomic at most locations.

Natural Gas-Based Plants

7.03 Most of the new plants to be built in the next decade will be natural gas-based steam reforming plants. Some important ammonia contractors now offer designs that are claimed to bring energy consumptions down to about 33 GJ/mt of ammonia for steam reforming based on natural gas.

7.04 Typical process conditions for steam reforming and gas purification are still about 30-40 atms combined with synthesis pressures of 70-330 atms. It is not possible to give general valid rules to
generate a process flow-sheet with process conditions fixed for all circumstances. In every case, it is necessary to determine what the optimum conditions are under the given circumstances (taking into account existing steam systems), temperature of cooling water, winter/summer conditions, steam export and electricity generation and, of course, the cost of gas and other fuels, such as coal for separate steam production. Nevertheless, a brief review of the new process schemes offered can be useful.

(a) Classical Flow Sheet

7.05 Some contractors and process owners have improved the well-known and proven flow sheet of ammonia plants without introducing new elements and claim low energy consumptions of about 33 GJ/mt of ammonia. Main features of the improvements are: low amount of reaction steam per ton of ammonia produced (70% of normal), new and better catalysts, physical carbon dioxide removal which has a lower energy requirement, and a more extensive heat recovery system. Although many steam reforming plants operate with low steam to carbon ratios these have been mainly in the town gas industry and not for ammonia production for which the new generation plants will use such low rates for the first time. It has to be noted that use of physical carbon dioxide removal methods will provide less carbon dioxide for urea production, an important factor where the only product is urea.
(b) **Cryogenic Purification**

7.06 Low energy consumption plants using cryogenic purification have been available for some time. The main features of the process are: mild reforming in the primary reformer, with excess air introduced in the secondary reformer to transfer the load to the secondary reformer and elimination of excess nitrogen by partial condensation at very low temperature. This gives a very pure synthesis gas needing only a very small amount of purging. Against savings in the different process steps has to be considered the higher air compressor duty--sometimes driven by a gas turbine with the exhaust gases used as hot combustion air to the primary reformer.

(c) **Pressure Swing Absorption (PSA)**

7.07 Pressure Swing Adsorption can be applied as a replacement for most of the gas purification train, giving pure hydrogen and, as by-product, a fuel gas for the primary reformer. This is of particular interest for small ammonia plants (less than 500 tpd) since the units can be skid mounted. However, pure carbon dioxide gas will not be available for urea production.

(d) **Low Pressure Ammonia Synthesis**

7.08 With the historical increase in reforming pressures and the decrease in synthesis pressures, there is the attraction of eliminating the
synthesis gas compressors altogether and make both synthesis gas and ammonia all at the same pressure. Although for natural gas reforming plants this goal is still distant, some modern designs will operate with synthesis pressures as low as 70-80 atms.

7.09 Several design companies have patented various processes where the heat in the flue gases from the primary reformer, used now for steam superheating and preheating process streams, could be diverted partly to reform more methane. While the theoretical possibility exists, industrial realization will require the solution of many engineering and design problems.

**Partial Oxidation**

7.10 When natural gas is not available, partial oxidation of fuel oil or coal is most often the available option. New developments tend to improve the process schemes available for both fuels. Several improvements have been proposed in the classical partial oxidation flowsheet. Some of these improvements include the use of sulfur resistant CO shift catalyst, better heat recovery after the partial oxidation reactor, use of enriched air instead of pure oxygen and elimination of liquid nitrogen wash.

7.11 Partial oxidation is feasible at pressures around 100 atm. Several monopressure processes (synthesis gas preparation and synthesis, all at the same pressure) have appeared in the literature using different purification routes, including liquid nitrogen wash at high pressure, but no industrial application has so far been attempted.
Integrated Ammonia/Urea Plants

7.12 Several schemes have been proposed for integration of ammonia and urea plants. Since no commercial experience is available, it is difficult to assess how far the fears concerning such process integration are well founded. However, at least half of the claimed energy savings can also be gained with an integration of the steam systems of the ammonia and urea plants. Another possibility of integration is the combination of ammonia and methanol production since methanol plants produce excess hydrogen which can give, depending on which option is chosen, between 5% and 20% energy saving. Several projects for an integrated methanol/ammonia complex are being studied at the moment. The process integration raises no problem from the technical point of view. Market considerations, however, must be taken into account; only if a secured outlet for the full capacity of both methanol and ammonia is found, can the full benefit of the energy saving be enjoyed. If, for the same reason, production of one of the products has to be decreased, energy savings are affected. Besides these considerations, there is also the obvious disadvantage that any technical trouble in one product line can cause production loss on the other lines. Therefore, from a practical point of view of energy saving, a fully integrated plant is more prone to reliability problems leading to decreased production.

B. Urea Plants

7.13 The new generation urea plants are all based on the carbon dioxide stripping process either as isobaric or non-isobaric double
stripping or modified single stripping. The decrease in energy consumption by the introduction of the stripping designs is approximately 25%. The latest designs claim another 6% saving. By increasing the conversion and the stripping efficiency, perhaps a further 5% can be saved which appears to be the optimum level at the current energy prices. As pointed out above (para 7.12), a further reduction is possible if the steam system is integrated with that of an ammonia plant or if the steam balance of the complex does allow the installation of a gas turbine for driving the CO₂-compressor and using the exhaust gas from the turbine in an ammonia reformer.

C. Acid Plants

7.14 For nitric acid and sulfuric acid plants, both important generators of energy, existing technologies offer big improvements against an old plant's performance (para 6.28). Dual pressure or mono-high pressure systems with extended absorption satisfy both the energy conservation and pollution control requirements in the nitric acid industry. The same applies to the double conversion systems in the sulfuric acid field. In choosing a phosphoric acid process, a careful evaluation must be made between a hemihydrate (-dihydrate) and dihydrate process depending on the steam balance of the complex and the price of electricity (i.e., maximum use of steam to generate electricity against use low pressure steam for phosphoric acid concentration), investment costs and operational problems.
VIII. CONCLUSIONS

8.01 Fertilizer is a major input for increased agricultural production in the development programs of developing countries. Procurement and delivery of fertilizers to the farmers in the most economic manner is an important component of such programs. Many developing countries—where economically justified, also have their own fertilizer production facilities to ensure reliable and timely supplies. Improved performance of these facilities to reduce their production costs is an essential part of any program to reduce delivered fertilizer costs to the farmer. As noted in the report, in many fertilizer processes, energy is a major element in the cost of production.

8.02 The World Bank has been involved in providing assistance to the fertilizer sector in over 20 developing countries. As part of this involvement, the World Bank has participated in reviewing the potential for energy efficiency and production optimization in several fertilizer complexes. As a result of such reviews, the World Bank has assisted six countries in developing programs primarily aimed at energy conservation in the fertilizer plants. Our experience shows that the industry managers and the governments in some developing countries are becoming aware of the substantial energy saving potential in the fertilizer industry and its implications in reducing the delivered cost of fertilizers to the farmers. It would possibly take some time before this potential can be substantially realized in most other developing countries, unless the governments develop and promote comprehensive measures which will encourage the industries to
develop and implement appropriate investment plans. International financing institutions such as the World Bank can play an important role in assisting developing countries in designing and implementing energy conservation programs that would result in more efficient fertilizer production.
ANNEX I. AMMONIA PROCESS DESCRIPTION
(based on natural gas steam reforming)

1. Natural gas for feedstock is desulphurized, if necessary, by heating to 380°C-400°C and then passing it through a catalyst bed to convert all sulphur compounds to hydrogen sulfide and then through a bed of zinc oxide; the essentially complete removal of sulphur compounds is important since sulphur acts as a poison for the downstream catalysts. The natural gas at about 40 atm of pressure is then mixed with medium pressure steam and heated by flue gas from the primary reformer furnace to about 500°C. The relative proportion of steam to natural gas is an important process parameter (the so called steam-carbon ratio). The heated gas mixture then passes into catalyst-filled tubes that are suspended in the primary reformer furnace. As the mixture passes down the tubes, chemical reactions occur under the influence of the catalyst whereby hydrogen, carbon monoxide and carbon dioxide are formed, some of the methane in the natural gas is left. Since the reactions are endothermic (absorb heat) and conversion of the methane is favoured by high temperatures, most of the fuel required in the process is burned in the primary reformer furnace.

2. The mixture of steam, methane, hydrogen, carbon dioxide and carbon monoxide leaves the primary reformer at about 33 atm and 835°C and passes to the secondary reformer, which is a vessel containing a bed of catalysts of similar composition to the primary reformer. At the entrance
to the secondary reformer the primary reformer effluent is mixed with air from the process air compressor which has been heated to about 465°C by the flue gas from the primary reformer. Heat is liberated by the reaction with the oxygen in the air providing the high temperature and heat input necessary for the completion of the reforming action. The nitrogen in the air supplies the nitrogen required in the ammonia synthesis.

3. The reformed gas leaving the secondary reformer (a mixture of nitrogen, hydrogen, carbon dioxide, carbon monoxide, a small proportion of unreformed methane, steam and traces of argon from the air) is at about 1,000°C, and must be cooled and purified to essentially a mixture of hydrogen and nitrogen, so called synthesis gas. The considerable energy in the gas stream exit the secondary reformer is transferred into the plant high pressure steam system to the maximum extent feasible. Purification is accomplished first of all by reaction of the carbon monoxide and steam to give hydrogen and carbon dioxide – the shift reaction – in catalyst filled vessels. This exothermic reaction takes place in two stages: the first high temperature shift at about 370°C and the second low temperature shift at about 220°C since lower temperatures favour maximum conversion. The carbon dioxide is then removed from the reformed gas by chemisorption into a liquid solution of either an ethanolamine or potassium carbonate, this solution is regenerated by flashing to atmospheric pressure and stripping with low pressure steam for which the energy source is the heat content of the gas stream after the low temperature shift conversion. Traces of
carbon dioxide and residual carbon monoxide are finally removed by conversion to methane through the exothermic methanation reaction over a nickel catalyst.

4. The gas after cooling is then compressed in the synthesis gas compressor makeup section from about 26 atm to 150-200 atm. The gas is essentially hydrogen and nitrogen except for small quantities of methane and argon that are chemically inert to the synthesis process, and traces of water vapour which unless removed would, like oxides of carbon, act as a poison of the synthesis catalyst. Removal of the water vapour is by mixing the make up synthesis gas with the circulating gas downstream of the synthesis converter so that as the gas stream is cooled and chilled to condense out liquid ammonia, the ammonia effectively scrubs out the water vapour and traces of carbon oxides.

5. Only about 25% of the hydrogen and nitrogen at the inlet to the synthesis converter is converted to ammonia over the synthesis catalyst. It is thus necessary after extraction of the ammonia by condensation to recirculate the gas, with fresh make up gas, back into the converter. The recirculation compressor accomplishes this job and is mechanically part of the synthesis gas compressor. After leaving the recirculation compressor, the synthesis gas is heated to about 400°C by hot gas, which is leaving the synthesis converter before entering the first of three catalyst beds. Since the reaction is exothermic and completion is favoured by low
temperatures (although the speed of reaction decreases) it is necessary to cool the gas stream before it enters the second and third beds. The gas stream leaves the converter at about 310°C (after heating the incoming gas) and is then cooled in a number of stages to about -24°C such that the ammonia condenses out and the concentration in the gas is reduced from about 13% to 2%. Because the residual methane and traces of argon in the make up gas accumulate in the synthesis loop, it is necessary to take a small purge of gas from the synthesis loop (equivalent to about 7% of the make up gas) to control the level of the inerts (argon and methane) in the loop. The purge gas, after removal of ammonia, is used as fuel to the primary reformer. Product ammonia is cooled to -33°C at which temperature it can be kept in insulated storage at atmospheric pressure.

6. The heart of the system is, however, the energy recovery and the integration of this with process steam requirements and the steam required to drive the various compressor pumps and fans. High pressure (HP) steam at about 100 atms is raised in cooling the high temperature gas leaving the secondary reformer, and again exiting the high temperature shift convertor. This is, however, insufficient for all requirements so that about 25% of the total HP steam is raised in an auxiliary gas fired boiler. Lower grade heat is recovered from the process gas stream by heating boiler feed water, and by providing the heat to regenerate the carbon dioxide removal solution. The other major source for heat recovery is from the flue gases leaving the primary reformer and the auxiliary
boiler. These are used to: (i) preheat the process air to the secondary reformer so that the temperature in the secondary reformer is high enough to reform almost all the methane in the process gas; (ii) the steam natural gas mixture prior to the primary reformer so that the size of the primary reformer is minimized; (iii) superheating the HP steam to about 485°C since the higher the pressure and temperature of this steam the more power can be provided from the steam turbines for a given steam quantity—supplemental gas fired burners are required at this point to provide additional heat input comprising about 5% of the total gas requirements; (iv) preheating boiler feed water; (v) combustion air preheater for preheating the air to the primary reformer, auxiliary boiler and the steam superheater burners. By the end of this latter stage the flue gas has been reduced in temperature to about 150°C.

7. All of the HP steam is then expanded through the synthesis gas compressor back pressure turbine to about 38 atms providing almost 75% of the power required to drive the synthesis gas compressor. This compressor requires about 45% of the total power requirement of about 810 kwh/mt of the ammonia plant (only about 20 kwh/mt is provided by outside electric power). From the 38 atms medium pressure steam (MP), the steam required for the reaction stream to the primary reformer, about 1.9 tons/mt of ammonia out of the 5.2 tons/mt ammonia of steam produced, is subtracted, with essentially all the rest being used in condensing turbines to provide power for the balance required for the synthesis gas compressor (95 kwh/mt
ammonia), process air compressor (180 kwh/mt), refrigeration compressor (140 kwh/mt), cooling water pumps (50 kwh/mt), and the other pumps and fans (totalling about 60 kwh/mt). The larger turbines may have a thermodynamic efficiency of about 75% whereas with the smaller turbines this can be as low as about 30%. About 17% of the total energy used for the ammonia production is removed by cooling water from the surface condensers of the turbines.

8. The above description is for one of the more common types of ammonia plants built in the last few years. Although natural gas reforming plants are basically similar, there are many differences in the engineering solutions used for the particular process steps. Exhaust gas from a gas turbine driving the process air compressor (which still has a high oxygen content) may be used to provide combustion air to the primary reformer. Excess air may be fed to the secondary reformer to transfer some of the referring load from the primary to the secondary reformer. This then requires removal of the excess nitrogen in a cryogenic unit (separation of the nitrogen by low temperature liquifaction). Low energy CO₂ systems may be used although these usually do not produce so much CO₂ which is important if the only product is urea. The synthesis gas may be purified from water, carbon oxide traces, methane and argon, before entering the synthesis loop. This will enable a reduction in the purge gas stream and
therefore the conversion per pass over the synthesis catalyst is increased (as the make up gas can be fed directly to the convertor inlet) with a consequent reduction in the compressor horse power and also the possibility of generating HP steam in the synthesis loop.
REFERENCES

The following are publications by the World Bank on energy in general and energy conservation in various industries:


5. *Energy Sector Assessment Program*. A series of reports on issues and options in the energy sector for different countries. The World Bank/UNDP.

A vast amount of literature on energy saving is available. Most of it, however, refers to new design. Following is a partial list which provides information on energy use in fertilizer plants and practical information on energy conservation potential in existing plants:


19. Lang, "Replacing Older Gas Compressor Drivers May Pay Out Fast," Oil and Gas Journal (March 5, 1984).


World Bank
Publications
of Related
Interest

A Brief Review of the World Lube Oils Industry
A. Ceyhan, H. Kohli, L. Wijetilleke, and B.R. Choudhury
This report assesses the structure, background, and outlook for the world lube oils industry. Presents the historical
and projected lube oils demand and trends in manufacturing technologies and production capacity and provides
an indicative assessment of the economics of lube oil production with detailed market and economic data.

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