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ENVIRONMENTAL CONSIDERATIONS OF SELECTED ENERGY CONSERVING MANUFACTURING PROCESS OPTIONS: Vol. XV. Fertilizer Industry Report

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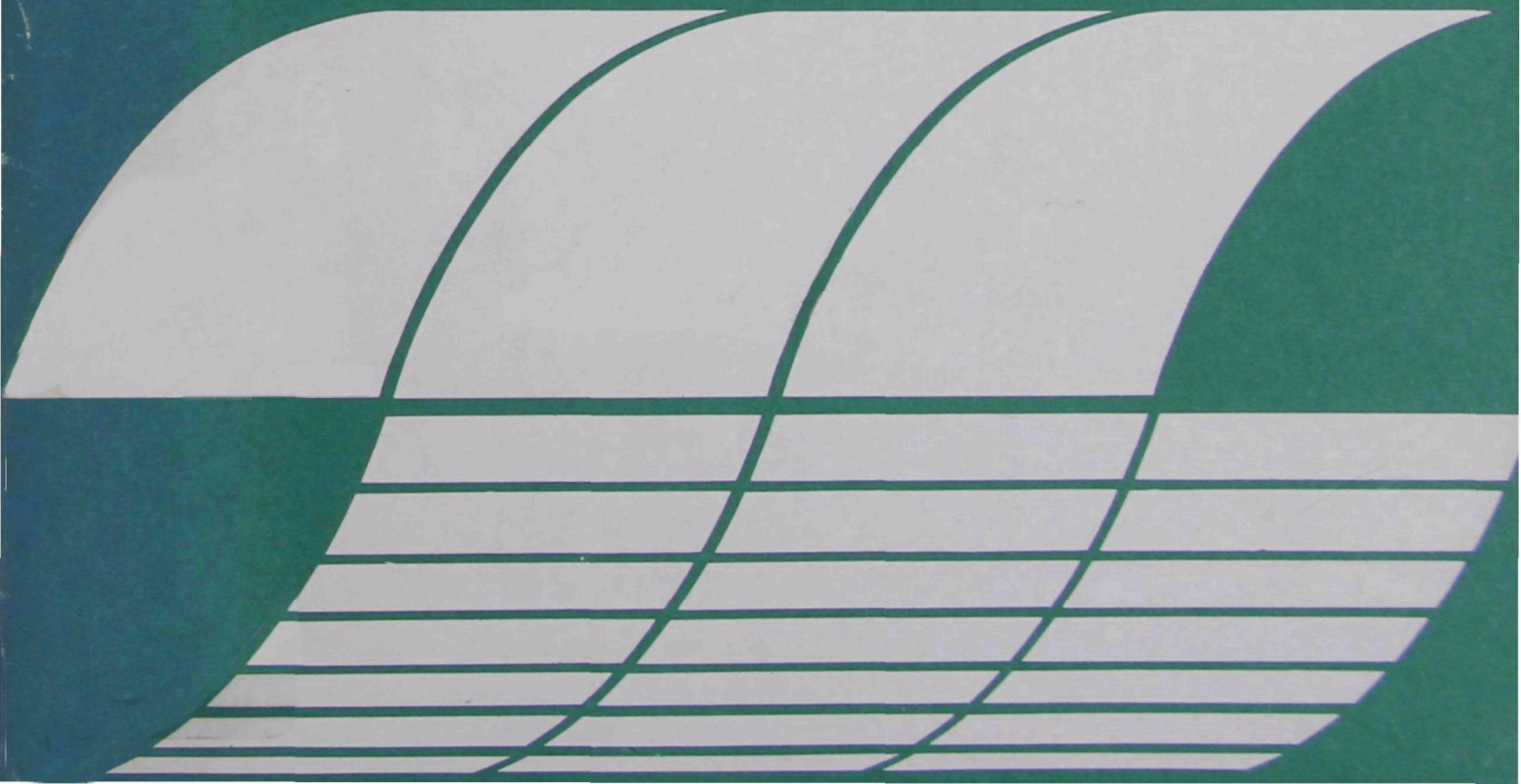

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December 1976

ENVIRONMENTAL CONSIDERATIONS OF SELECTED ENERGY CONSERVING MANUFACTURING PROCESS OPTIONS

Volume XV

FERTILIZER INDUSTRY REPORT

EPA Contract No. 68-03-2198

Project Officer

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FOREWORD

When energy and material resources are extracted, processed, converted, and used, the related pollutional impacts on our environment and even on our health often require that new and increasingly more efficient pollution control methods be used. The Industrial Environmental Research Laboratory - Cincinnati (IERL-Ci) assists in developing and demonstrating new and improved methodologies that will meet these needs both efficiently and economically.

This study, consisting of 15 reports, identifies promising industrial processes and practices in 13 energy-intensive industries which, if implemented over the coming 10 to 15 years, could result in more effective utilization of energy resources. The study was carried out to assess the potential environmental/energy impacts of such changes and the adequacy of existing control technology in order to identify potential conflicts with environmental regulations and to alert the Agency to areas where its activities and policies could influence the future choice of alternatives. The results will be used by the EPA's Office of Research and Development to define those areas where existing pollution control technology suffices, where current and anticipated programs adequately address the areas identified by the contractor, and where selected program reorientation seems necessary. Specific data will also be of considerable value to individual researchers as industry background and in decision-making concerning project selection and direction. The Power Technology and Conservation Branch of the Energy Systems-Environmental Control Division should be contacted for additional information on the program.

David G. Stephan
Director
Industrial Environmental Research Laboratory
Cincinnati

EXECUTIVE SUMMARY

The function of the fertilizer industry is to provide farmers with the three basic plant nutrients -- nitrogen, phosphorus, and potassium -- in a form and proportion suitable for particular crops and soils. This requires the production of intermediate products through chemical reaction, mixing or blending, and an extensive distribution system. In this report, the definition of the fertilizer industry excludes the mining or manufacture of raw materials, such as ammonia, phosphate rock, sulfur, and potash. In fact, most of the industry's energy consumption (78×10^{12} Btu/yr) is in the manufacture and mining of raw materials, and not in the subsequent processes. However, the fertilizer industry treated in this report consumed 52×10^{12} Btu in 1973. Almost half was as electric power. The remainder was mostly natural gas, but natural gas use is declining in favor of fuel oil and LPG.

We foresee no process changes being made in the fertilizer industry (as defined herein) solely from the desire to conserve energy. The major cost components in the fertilizer industry are raw materials; investment and working capital-related costs are second; and other items such as energy and labor are usually insignificant. While changes in product mix and processes are likely over time, such changes will be the result of factors other than energy conservation.

There are two areas where environmental regulations and energy conservation are in conflict. These are:

- The reduction of nitrogen oxide emissions from nitric acid plants; and
- Switching from natural gas to fuel oil for firing fertilizer dryers, where emissions are presently controlled by bag filters.

The most widely used process for control of nitrogen oxide emissions in nitric acid plants is the catalytic decomposition of nitrogen oxides to nitrogen and oxygen. This process is capital- and energy-intensive, and is particularly expensive for those few nitric acid plants that cannot recover the energy in the form of steam. The problem is aggravated because natural gas is the required energy source, and most plants are limited in the quantities of gas they can purchase. Natural gas use for pollution

control reduces the amount available for other purposes, thus effectively reducing production. The annual natural gas requirement for pollution control of a 300-ton-per-day nitric acid plant could be used to produce 6,600 tons of ammonia, including process fuel requirements, or about 11,000 tons of ammonia if used only for feedstock.

Other abatement systems are becoming available and hold the promise of lower investment and operating costs, significantly lower energy requirements, and no need for natural gas as the energy source. However, these other processes currently suffer in various ways from problems of maintenance, of stringent operating conditions ("Molecular Sieve"), inapplicability to low-pressure nitric acid processes ("Grade Paroisse"), and too little actual experience (CDL/Vitok).

We found that only 10-20% of the ammoniation granulation fertilizer plants in the country use bag filters to collect the considerable dust generated by the process; others use wet scrubbers. The need to shift to fuel oil because of the scarcity of natural gas has caused problems in operating the bag filters, because of the premature clogging of the filter for a variety of reasons, including incomplete combustion of fuel oil, increased soot and ash formation, and deposition of sulfate salts on the bags. We have found that these problems can be overcome, short of replacing the bag collectors with wet scrubbers or short of shutting down the plant. It will require upgrading the burner equipment, gaining experience, and improving operating procedures.

Areas for further research or other types of action are:

- Determining the applicability of the new processes to control nitrogen oxides emissions from sources other than nitric acid plants;
- Developing methods of alleviating the problems of startup, shutdown, and malfunction of the nitrogen oxide abatement equipment; and
- Disseminating information on techniques for using bag filters in conjunction with oil-fired dryers.

This report was submitted in partial fulfillment of contract 68-03-2198 by Arthur D. Little, Inc. under sponsorship of the U.S. Environmental Protection Agency. This report covers a period from June 9, 1975 to January 16, 1976.

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During the course of the study we also had occasion to contact many individuals within industry and trade associations. Where appropriate we have made reference to these contacts within the various reports. Frequently, however, because of the study's emphasis on future developments with comparative assessments of new technology, information given to us was of a confidential nature or was supplied to us with the understanding that it was not to be credited. Therefore, we extend a general thanks to all those whose comments were valuable to us for their interest in and contribution to this study.

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ENGLISH-METRIC (SI) CONVERSION FACTORS

To Convert From	To	Multiply By
Acre	$Metre^2$	4,046
Atmosphere (normal)	Pascal	101,325
Barrel (42 gal)	$Metre^3$	0.1589
British Thermal Unit	Joule	1,055
Centipoise	Pascal-second	0.001
Degree Fahrenheit	Degree Celsius	$t_C^\circ = (t_F^\circ - 32)/1.8$
Degree Rankine	Degree Kelvin	$t_K^\circ = t_R^\circ/1.8$
Foot	Metre	0.3048
$Foot^3$/minute	$Metre^3$/sec	0.0004719
$Foot^3$	$Metre^3$	0.02831
$Foot^2$	$Metre^2$	0.09290
Foot/sec	Metre/sec	0.3048
$Foot^2$/hr	$Metre^2$/sec	0.00002580
Gallon (U.S. liquid)	$Metre^3$	0.003785
Horsepower (550 ft-lbf/sec)	Watt	745.7
Horsepower (electric)	Watt	746.0
Horsepower (metric)	Watt	735.5
Inch	Metre	0.02540
Kilowatt-hour	Joule	3.60×10^6
Litre	$Metre^3$	1.000×10^{-3}
Micron	Metre	1.000×10^{-6}
Mil	Metre	0.00002540
Mile (U.S. statute)	Metre	1,609
Poise	Pascal-second	0.1000
Pound force (avdp)	Newton	4.448
Pound mass (avdp)	Kilogram	0.4536
Ton (assay)	Kilogram	0.02916
Ton (long)	Kilogram	1,016
Ton (metric)	Kilogram	1,000
Ton (short)	Kilogram	907.1
Tonne	Kilogram	1,000

Source: American National Standards Institute, "Standard Metric Practice Guide," March 15, 1973. (ANS72101-1973) (ASTM Designation E380-72)

I. INTRODUCTION

A. BACKGROUND

Industry in the United States purchases about 27 quads* annually, approximately 40% of total national energy usage.** This energy is used for chemical processing, raising steam, drying, space cooling and heating, process stream heating, and miscellaneous other purposes.

In many industrial sectors energy consumption can be reduced significantly by better "housekeeping" (i.e., shutting off standby furnaces, better thermostat control, elimination of steam and heat leaks, etc.) and greater emphasis on optimization of energy usage. In addition, however, industry can be expected to introduce new industrial practices or processes either to conserve energy or to take advantage of a more readily available or less costly fuel. Such changes in industrial practices may result in changes in air, water or solid waste discharges. The EPA is interested in identifying the pollution loads of such new energy-conserving industrial practices or processes and in determining where additional research, development, or demonstration is needed to characterize and control the effluent streams.

B. CRITERIA FOR INDUSTRY SELECTION

In the first phase of this study we identified industry sectors that have a potential for change, emphasizing those changes which have an environmental/energy impact.

Industries were eliminated from further consideration within this assignment if the only changes that could be envisioned were:

- energy conservation as a result of better policing or "housekeeping,"
- better waste heat utilization,
- fuel switching in steam raising, or
- power generation.

*1 quad = 10^{15} Btu

**Purchased electricity valued at an approximate fossil fuel equivalence of 10,500 Btu/kWh.

After discussions with the EPA Project Officer and his advisors, industry sectors were selected for further consideration and ranked using:

- Quantitative criteria based on the gross amount of energy (fossil fuel and electric) purchased by industry sector as found in U.S. Census figures and from information provided from industry sources. The fertilizer industry purchased 0.078 quads out of the 12.14 quads purchased in 1971 by the 13 industries selected for study, or 0.3% of the 27 quads purchased by all industry (see Table I-1).

- Qualitative criteria relating to probability and potential for process change, and the energy and effluent consequences of such changes.

In order to allow for as broad a coverage of technologies as possible, we then reviewed the ranking, eliminating some industries in which the process changes to be studied were similar to those in another industry planned for study. We believe the final ranking resulting from these considerations identifies those industry sectors which show the greatest possibility of energy conservation via process change. Further details on this selection process can be found in the Industry Priority Report prepared under this contract (Volume II).

On the basis of this ranking method, the fertilizer industry appeared in thirteenth place among the 13 industrial sectors listed.

TABLE I-1

SUMMARY OF 1971 ENERGY PURCHASED IN SELECTED INDUSTRY SECTORS

	Industry Sector	10^{15} Btu/Yr.	SIC Code In Which Industry Found
1.	Blast furnaces and steel mills	3.49[1]	3312
2.	Petroleum refining	2.96[2]	2911
3.	Paper and allied products	1.59	26
4.	Olefins	0.984[3]	2818
5.	Ammonia	0.63[4]	287
6.	Aluminum	0.59	3334
7.	Textiles	0.54	22
8.	Cement	0.52	3241
9.	Glass	0.31	3211, 3221, 3229
10.	Alkalies and chlorine	0.24	2812
11.	Phosphorus and phosphoric acid production	0.12[5]	2819
12.	Primary copper	0.081	3331
13.	Fertilizers (excluding ammonia)	0.078	287

[1] Estimate for 1967 reported by FEA Project Independence Blueprint, p. 6-2, USGPO, November 1974.

[2] Includes captive consumption of energy from process byproducts (FEA Project Independence Blueprint)

[3] Olefins only, includes energy of feedstocks: ADL estimates

[4] Amonia feedstock energy included: ADL estimates

[5] ADL estimates

Source: 1972 Census of Manufactures, EPA Project Independence Blueprint, USGPO, November 1974, and ADL estimates.

C. CRITERIA FOR PROCESS SELECTION

In this study we have focused on identifying changes in the primary production processes which have clearly defined pollution consequences. In selecting those to be included in this study, we have considered the needs and limitations of the EPA, as discussed more completely in the Industry Priority Report mentioned above. Specifically, energy conservation has been defined broadly to include, in addition to process changes, conservation of energy form (gas, oil, coal) by a process or feedstock change. Natural gas has been considered as having the highest energy form value followed in descending order by oil, electric power, and coal. Thus, a switch from gas to electric power would be considered energy conservation because electric power could be generated from coal, existing in abundant reserves in the United States in comparison to natural gas. Moreover, pollution control methods resulting in energy conservation have been included within the scope of this study. Finally, emphasis has been placed on process changes with near-term rather than long-term potential within the 15-year span of time of this study.

In addition to excluding from consideration better waste heat utilization, "housekeeping," power generation, and fuel switching, as mentioned above, certain options have been excluded to avoid duplicating work being funded under other contracts and to focus this study more strictly on "process changes." Consequently, the following have also not been considered to be within the scope of work:

- Carbon monoxide boilers (however, unique process vent streams yielding recoverable energy could be mentioned);
- Fuel substitution in fired process heaters;
- Mining and milling, agriculture, and animal husbandry;
- Substitution of scrap (such as reclaimed textiles, iron, aluminum, glass, and paper) for virgin materials;
- Production of synthetic fuels from coal (low-and high-Btu gas, synthetic crude, synthetic fuel oil, etc.); and
- All aspects of industry-related transportation (such as transportation of raw material).

D. SELECTION OF FERTILIZER INDUSTRY PROCESS OPTIONS

1. Process Options Selected

After excluding ammonia manufacture (treated in a separate report) from the fertilizer industry sector, the remaining energy use is relatively low, and thus, the low priority accorded the industry in this study. Furthermore, much of the energy conservation potential will entail areas excluded from this study such as "housekeeping," better heat recovery from waste streams, and fuel switching. However, in the course of work done for the Federal

Energy Administration in 1974 (Economic Impact of Shortages on the Fertilizer Industry, No. PB 240418, January 1975), we uncovered two problem areas where energy conservation and pollution control were in conflict. After discussion with the Project Officer, it was decided that these two problem areas would be investigated in greater depth, even though they do not precisely fit the definition of "process changes for energy conservation purposes." These two areas are:

(1) The reduction of nitrogen oxide emissions from nitric acid plants. In this study, we have considered the major emission control options of:

Catalytic Reduction,
Molecular Sieve,
Grande Paroisse,
CDL/Vitok, and
Masar.

(2) Switching from natural gas to fuel oil for firing fertilizer dryers where emissions are presently controlled by bag filters. In this study, we have considered the options of:

Better equipment/technique, and
Installing scrubbers.

Excluded from our analysis were the mining aspects of the fertilizer industry. Major mining operations are conducted by and for the industry to produce phosphate rock, sulfur, and potash. These are included in SIC Group 14, "Mining and Quarrying of Non-Metallic Minerals, Except Fuels." Fertilizers included in this study are included in SIC Groups 2873, 2874, and 2875.

2. Method of Analysis

a. Nitric Acid

We first reviewed the literature to determine the available processes for pollution abatement in nitric acid plants and reviewed this list with those in the industry who are knowledgeable in this area to determine which processes held the most promise. Suppliers of the most promising air pollution control devices were contacted, and technical and economic information on these processes was obtained. We also contacted several of the users of these air pollution devices to determine their experience with them. This information was then used to prepare our analysis. Our engineering judgment was used to assess the feasibility of these processes, applicability to new and existing plants, technical problems which may be encountered, and to make economic comparisons among them.

b. Fertilizer Drying

Our concern was only with those fertilizer granulation plants which use bag filtration as a method of particulate control. We contacted several fertilizer manufacturers and determined that three major companies account for about half of such plants in the country. These companies were contacted to

determine their experience in converting such dryers from natural gas to fuel oil, and their opinions were elicited as to how the problems could be overcome. We also held discussions with a furnace manufacturer and a producer of bag filters to obtain similar information. This information was combined with our own prior knowledge on the costs of conducting the various options provided us to prepare an analysis which will show whether such conversion from natural gas to fuel oil is feasible, how it might best be accomplished, and the cost.

The industry description in this report is based on 1974, the last representative year for the industry for which good statistical information was available. Recognizing that capital investments and energy costs have escalated rapidly in the past few years and have greatly distorted the traditional basis for making cost comparison, we believe that the most meaningful economic assessment of new process technology can only be made by using 1975 cost data to the extent possible. Consequently, in estimating operating costs, we have developed costs representative of the first half of 1975 using constant 1975 dollars for our comparative analysis of new and current processes.

II. FINDINGS, CONCLUSIONS, AND RECOMMENDATIONS

A. ENERGY CONSERVATION MEASURES IN CONFLICT WITH POLLUTION CONTROLS

1. Nitric Acid

The manufacture of nitric acid generates significant emissions of nitrogen oxides to the atmosphere. The most widely used process for pollution control is the catalytic decomposition of these nitrogen oxides to nitrogen and oxygen. This process is energy intensive and is particularly expensive for those nitric acid plants which cannot recover the energy in the form of usable steam. The problem is aggravated because natural gas is the required energy source. Most plants are limited in the quantities of gas they can purchase, and such natural gas is critical and non-substitutable for the manufacture of ammonia, which in most cases occurs at the same site. Natural gas use for pollution control reduces the amount available for other purposes, thus effectively reducing production. The natural gas requirement for pollution control of a 300-tpd-nitric-acid plant is 232.6×10^9 Btu per year. This amount could be used to produce 6,600 tons of ammonia, including process fuel requirements, or about 11,000 tons if used only for feedstock.

The catalytic reduction process produces steam, which may be used elsewhere in the plant complex, and it may be argued that this reduces the energy input at some other point. Such argument may not be valid for two reasons: first, not all plants have use for the steam; and, second, such steam, if needed, could otherwise be provided with a fuel other than natural gas.

Other abatement systems are becoming available and hold the promise of lower investment costs, lower operating costs, significantly lower energy requirements, and no need for natural gas as the energy source. Also, because the catalytic reduction process is usually too expensive to operate in plants using low-pressure processes to produce nitric acid, two or three of the alternate processes allow more economical recovery for such plants. However, the other processes suffer from problems of maintenance of stringent operating conditions (Molecular Sieve), inapplicability to low pressure nitric acid processes (Grand Paroisse), and too little actual experience (CDL/Vitok).

Investment in a 300-ton-per-day nitric acid plant with no pollution control would be about $5,500,000; while the cost of manufacture, including profit, would be $56.48 per ton. The catalytic reduction process for controlling nitrogen oxide emissions would require an additional investment of $1,384,000 and would add $6.16 per ton to the manufacturing cost, including profit. These costs are quite significant, representing a 25% addition in investment and an 11% increase in the total cost of manufacture.

The four alternative processes studied improve on these costs. The Molecular Sieve and Grande Paroisse processes entail investments on the order of $1.2 million and $1.0 million, respectively, and add $4.01 and $2.30 per ton to the cost of nitric acid. These figures are still significant, but are lower than for the catalytic reduction process.

The newer processes should result in even better economics. The CDL/Vitok requirements and Masar processes should have investment of $575,000 and $663,000, respectively, and add $1.58 to $1.92 per ton to the manufacturing cost.

Energy requirements are also much lower in each of the four alternatives to the catalytic reduction process. Not only is energy use lower in the other processes, but there is no requirement for natural gas. Energy is consumed as electricity only in three of the options, with electricity and fuel oil needed for the Molecular Sieve option. These processes are compared in Table II-1.

2. Fertilizer Mixing

In the drying of mixed granular fertilizers, considerable dust is generated, which must be removed from the process air stream before it is vented to the atmosphere.

In switching from natural gas to fuel oil for firing the fertilizer dryer, manufacturers have encountered operating difficulties with the bag filter. The problem arises from premature clogging of the filter for a variety of reasons, including incomplete combustion of the fuel oil, increased soot and ash formation, and, in the case of high-sulfur fuel oil, deposition of sulfate salts on the bag. To avoid these problems, some plants have switched to propane rather than to fuel oil. The scarcity and high price of propane make this an infeasible alternative for an extended period of time.

We estimate that only about 20% of the estimated 200 ammoniation-granulation plants being considered use bag filters to collect the dusts; the remainder use scrubbers. Thus, while the switch from natural gas to fuel oil will present problems to a few plants, the problem is not highly significant when viewed in an industry-wide context.

The options available to those plants that now employ bag filters to control particulate emissions and who must convert to fuel oil are:

- Upgrade the burner equipment and operating procedures to minimize or eliminate the problems just described;
- Install alternate control equipment, such as a wet scrubber to reduce particulate emissions; or
- Shut down.

TABLE II-1

COMPARISON OF ENERGY, POLLUTION CONTROL, ECONOMICS, ENERGY USE FOR ALTERNATIVE NITRIC ACID PROCESSES

	No Control (Base Case)	Catalyst Reduction	Molecular Sieve	Grande Paroisse	CDL/ Vitok	Masar
Energy Consumption (10^6Btu/ton product)						
Gross	1.6	4.0	2.0	1.7	1.8	1.6
Net of Steam Credit	0.9	2.0	1.3	1.0	1.2	1.0
Investment ($ Thousands)						
Base 300 tpd Plant	5500	5500	5500	5500	5500	5500
Pollution Control	-	1384	1200	1000	575	663
Total	5500	6884	6700	6500	6075	6163
Operating Costs ($/ton product)*						
Base 300 tpd Plant	56.48	56.48	56.48	56.48	56.48	56.48
Pollution Control	-	6.16	4.01	2.30	1.58	1.92
Total	56.48	62.64	60.49	58.78	58.06	58.40

*Includes a 20% pretax return on investment.

Based on the results of our analysis and discussions with mixed fertilizer producers, we believe that it will be possible to upgrade burner equipment and operating procedures and to avoid the other two alternatives.

B. PRACTICES/PROCESSES REQUIRING ADDITIONAL RESEARCH

For nitric acid plants, it will be beneficial in terms of energy conservation to use processes other than catalytic reduction. Fortunately, such other processes require less capital and lower operating costs. Thus, the industry will likely opt for such alternatives of free choice and will not require outside influence.

It would be useful to study the applicability of these new processes to control NO_x emissions from sources other than nitric acid plants.

While control is adequate at steady state, it is not adequate during startup and shutdown. Also, the pollution control device is complex and may have to be shut down even though the basic plant continues to operate. Methods of alleviating these problems are worthy of further study.

For fertilizer drying, the most appropriate action is to disseminate information on techniques for using bag filters in conjunction with oil-fired dryers.

III. FERTILIZER INDUSTRY OVERVIEW

A. DESCRIPTION

The essential function of the fertilizer industry is to produce a variety of solid and liquid fertilizer products containing one or more of the three essential chemical plant nutrients -- nitrogen, phosphorus, and potassium. In this chapter, we describe the basic chemical processes associated with the production of the principal materials, the overall structure of the industry, and factors relating to energy consumption in the various processing operations. Also included are comments relative to the non-fertilizer use of certain of the basic chemicals whose primary use is for fertilizer.

1. Industry Sectors

a. Nitrogen Fertilizers

Ammonia is the basic raw material for virtually all nitrogen fertilizers, in addition to its direct use as a fertilizer material. Furthermore, substantial quantities are also used for the production of non-fertilizer materials, including plastics, resins, nitric acid, etc.

The principal fertilizer products produced from ammonia include urea, ammonium nitrate, ammonium phosphate, and complete mixed fertilizers. Nitric acid is produced from ammonia. Ammonium nitrate is the reaction product of nitric acid and ammonia. Substantial quantities of ammonium nitrate are used for explosive purposes in surface mining applications. Similarly, urea finds significant uses outside of the fertilizer industry, principally as an animal feed, and as a component of thermo-setting resins.

International trade in nitrogen fertilizers is significant for the U.S. industry. Because of geographical and individual company considerations, there are generally simultaneous, and in many cases balancing, exports and imports of anhydrous ammonia and the principal nitrogen fertilizers. Because of the potential limited availability of natural gas for further ammonia plant expansions, the United States may become a major net importer of nitrogen fertilizers in the not-too-distant future. However, the potential for shifting to coal as a feedstock may obviate the need for such import dependence. (This is discussed further in the Ammonia Industry Report, Vol. XII of this study.)

b. Phosphates

The United States is one of the few countries with major reserves of phosphate rock, which is the basic raw material for phosphate fertilizers and industrial phosphates. Major commercial deposits are currently being operated in Florida, North Carolina, Tennessee, and the Mountain states. Most of the rock mined is transformed into derivative products, but large volumes are also exported as is.

To be useful as a fertilizer, the phosphate values in phosphate rock must be transformed into a soluble form. This is generally done by treating the rock with sulfuric acid to produce either superphosphate or phosphoric acid. Superphosphate is a fertilizer which is used as such or as a component of a mixture containing other nutrients. It has a low nutrient concentration, and, because of this has lost market share to higher analysis products based on phosphoric acid. Phorphoric acid is used to produce a variety of solid derivatives, including triple superphosphate, various grades of ammonium phosphates, and complete mixed fertilizers.

A major part of phosphoric acid production is located adjacent to the mining operations. However, there are substantial manufacturing facilities for phosphoric acid located elsewhere, principally in the New Orleans area and in the upper Midwest.

c. Potash

Potassium, the third major plant nutrient, is found in significant commercial deposits in Carlsbad, New Mexico, as well as in lesser quantities in Utah and in various brine operations, including the Great Salt Lake and Searles Lake in California. The principal potash mineral currently being mined is muriate of potash (potassium chloride), and sulfate of potash. Both can be used as mined (after some refining) directly as a fertilizer material.

The development of a major potash deposit in Saskatchewan has served to shift the center of North American potash production from the United States to Canada. The reserves in Saskatchewan are vast in quantity and of substantially higher grade than the Carlsbad deposits, whose life is limited and whose grade is declining. Therefore, the U.S. consumption of potash is increasingly dependent on Canadian materials, although Carlsbad continues to operate. However, recent price increases, together with political uncertainties in Saskatchewan, have served to reinforce the continued development of the Carlsbad potash operations.

A minor amount of the potash that is mined -- perhaps 10% -- is used for various non-fertilizer uses, such as in the production of potassium hydroxide, refined potassium salts, and other miscellaneous potassium chemicals. Fertilizer potash is used either directly as a fertilizer or as a raw material for the production of mixed fertilizers.

d. Mixed Fertilizer Production

Until the mid-1950's, the predominant form of fertilizer used by the U.S. farmer was as a mixture of two or three of the major plant nutrients supplying nitrogen, phosphorus, and potassium. These were most commonly based on superphosphate produced by the limited acidulation of phosphate rock with sulfuric acid. To this was added nitrogen and potash materials (such as ammonium sulfate, ammonium nitrate, and muriate of potash). Mixed fertilizers still constitute an important portion of overall fertilizer use, although the use of single-nutrient materials has displaced a major part of mixed-fertilizer demand.

However, because of increasing demand for higher nutrient content in fertilizers, the manufacture of mixed fertilizer has tended away from those based on normal superphosphate (20% P_2O_5) to materials produced from phosphoric acid (54% P_2O_5) and its derivatives. Requisite quantities of additional nitrogen materials such as ammonia, ammonium nitrate, and muriate of potash are added to the liquid phosphoric acid, which is then dried and granulated to produce a significantly higher concentration of nutrients than is possible with those products based on normal superphosphate.

Mixed fertilizers produced from phosphoric acid are generally manufactured in the same complex where the phosphoric acid is produced -- largely in Florida, but with significant production in North Carolina, the New Orleans area, and the upper Midwest.

There is also a limited but growing use of liquid mixed fertilizers, in which the nutrients exist either in dissolved form in clear solutions, or as stable suspensions of solid particles. These are often produced in a two-step operation, in which a base solution of ammonium phosphate is produced in a large central "hot-mix" plant. The finished product containing additional quantities of nitrogen and potash is then produced in smaller "cold-mix" plants located close to the marketplace.

e. Distribution and Blending

Major changes have taken place in the mode of distribution, principally through the emergence of "bulk blending" stations as the principal means of marketing fertilizer materials.

Until the emergence of bulk blending in the early 1960's, traditional distribution of fertilizer involved the movement of bagged mixed fertilizers, from medium-sized production plants producing between 25,000 and 200,000 tons per year of mixed fertilizer, to farm buyers, through general retail farm supply organizations. Thus, the farmer purchased through such outlets as feed and seed stores, grain elevators, etc. Single nutrient materials, such as ammonium sulfate and muriate of potash, were used in addition and were also handled in bags through the same outlets.

However, in the early 1960's, the advantage of bulk handling of fertilizers became apparent and the emergence of bulk blending developed quickly. In bulk blending, a few basic high analysis materials containing single nutrients (or, in the case of ammonium phosphates, both nitrogen and phosphorus) are shipped in bulk form to retail bulk blending units. Here they are combined physically in mixtures suited to the particular needs of individual farmers. To avoid segregation during mixing and handling, they are generally in granular form of relatively uniform size. Simple physical mixing operations take place and the material is generally applied in bulk through the use of broadcast spreading trucks. Thus, at no point in the distribution chain are the materials handled in any but bulk form.

With the availability of a wide variety of blends of the three nutrients at the retailing station, the demand for basic products shifted from the chemically mixed fertilizer materials to major blending materials such as ammonium nitrate, triple superphosphate, diammonium phosphate, and muriate of potash.

As this mode of distribution developed, many of the major manufacturers developed their own organization of bulk blending stations, thus emerging as the direct seller to the farmer. A typical large fertilizer organization might develop a chain of 100 to 200 such bulk blending stations. These would typically handle from 1,000 to 5,000 tons of material per year and generally sell within a radius of 15 miles.

Bulk blending, together with liquid mixed fertilizers, has displaced a great portion of former quantities of chemically mixed fertilizers. Nevertheless, substantial volumes of mixed fertilizers are in continued use, particularly of the higher grades, such as 10-20-10 or 15-15-15.

2. Integration

The U.S. fertilizer industry is characterized by a substantial amount of integration, both vertical and horizontal. Most basic producers of raw materials, such as phosphate rock, potash, and ammonia, are also involved in chemical upgrading to finished fertilizer products, and in many instances have well-developed distribution and marketing organizations that have direct retail contact with the ultimate farmer/consumer. Many companies are basic manufacturers of more than one nutrient raw material. The degree of horizontal integration of the major companies is indicated in Table III-1.

There has been considerable retrenchment of vertical integration extending to retail outlets. During the expansion period of the mid-1960's, many basic fertilizer producers developed programs for retailing major volumes of their product through wholly owned or controlled retail outlets. However, most major companies were unable to operate retailing operations profitably, and many subsequently disposed of these outlets. However, companies which are still active at the retail level include Agrico, Allied Chemical, W.R. Grace, and The First Mississippi Corporation. Farmland Industries and CF Industries, which are both major farm cooperative organizations, of course have a built-in retail system through their county farm co-ops, which are ultimately the owners of the parent industries.

TABLE III-1

INTEGRATION OF LEADING AMMONIA PRODUCERS

	Ammonia (thousand tons N)	Phosphate Rock (thousand tons)	Phosphoric Acid (thousand tons P_2O_5)	Potash[4] (thousand tons K_2O)
CF Industries	1,069	1	1,250	440
Farmland Industries	1,081	-	455	
Agrico	1,030	9,100	735	
Allied Chemical	979	-	160	
Collier Carbon	628	-	14	
Chevron	621	-	-	
Mississippi Chemical	602	-	200	
Amoco	588	-	-	
Vistron	470	-	-	
U.S. Steel	466	2,800	265	
IMC	278	12,500	750	2,710
Occidental	177	5,500	610	
Mobil	-	4,500	125	
Texas Gulf	-	4,000	685	550
American Cyanamid	278	3,000	263[2]	
W.R. Grace	358	2,300	325	
Beker	244	2,300	565	
Gardinier	268	2,000	590	
Total of Above Companies	9,137[3]	48,000	6,992	3,700
(% of Capacity)	59%	78%	77%	33%
Total of Top Ten Companies	7,534[3]	48,000	6,814	9,322
(% of Capacity)	49%	78%	75%	84%
Total Capacity	15,524	61,884	9,044	11,058

Source: Derived from TVA listing.

[1] Long-term contract with IMC.

[2] Has tolling arrangement for roughly 35% of Freeport capacity.

[3] Excludes duPont, with capacity of 636, because it does not serve the fertilizer industries. It is included in Total Capacity.

[4] Includes Canada.

3. Energy Use

Aside from the manufacture of ammonia and mineral raw materials, the use of energy by the fertilizer industry is relatively small compared to other industries in this study. Energy use in fertilizer manufacture in 1973 is provided in Table III-2. Energy used to produce fertilizer products was 52 x 10^{12} Btu's, almost half of which was in the form of electric power. This amount excludes the energy to produce the raw materials, ammonia (covered in a separate report), phosphate rock, potash and sulfur. These raw materials consumed 574 x 10^{12} Btu's, indicating that the fertilizer included in this discussion represented only 8% of the total energy used by the industry. Energy use includes that used in the manufacture of fertilizers only and excludes energy used to produce the products for non-fertilizer uses.

For the most part, the fuels used are for generating steam and for drying furnaces. Electricity is used to operate motors, compressors, pumps, materials handling equipment, and grinding equipment.

4. Plant Characteristics

Of primary importance in this report are nitric acid and granular mixed fertilizer plants. Therefore, only these two types of plants are discussed.

a. Nitric Acid

There are approximately 125 nitric acid plants in operation in the United States. Because nitric acid is produced from ammonia, most nitric acid plants are located adjacent to ammonia plants within an overall nitrogen products complex. However, since the transport of ammonia is not difficult, there are a number of nitric acid plants which are not associated with ammonia manufacturing facilities and receive their raw material by rail, water, or pipeline transport.

There is a fairly wide spectrum of plant sizes within the nitric acid industry. There are some 24 plants with capacities below 100 tons per day, and the remaining units are fairly evenly distributed within the size range of 100-500 tons per day. Approximately 45% of the capacity consists of plants in excess of 300 tons per day, with some plants running as large as 500 tons per day.

b. Mixed Fertilizers

Prior to 1960 there were approximately 200 mixed-fertilizer plants located throughout the country, often in association with normal superphosphate plants. These produced low-analysis mixed fertilizers based on the ammoniation of normal superphosphate. As economics has favored fertilizers more concentrated than could be made using normal superphosphate, a number of these plants have been shut down or converted to make higher-analysis fertilizer based on phosphoric acid.

TABLE III-2

ENERGY USE IN FERTILIZER MANUFACTURE - 1973

	Fuel	Power		Total	
	10^{12} Btu	10^{6} kWh	10^{12} Btu[1]	(10^{12} Btu)	(%)
Raw Materials					
Ammonia	491.7	584	6.1	497.8	79
Phosphate Rock	15.9	1,643	17.3	33.2	5
Potash	9.6	379	4.0	13.6	2
Sulfur	29.0	76	0.8	29.8	5
Sub-Total	546.2	2,682	28.2	574.4	92
Fertilizers					
Urea	7.7	460	4.8	12.5	2
Ammonium Nitrate	9.5	390	4.1	13.6	2
Phosphoric Acid	0.0	647	6.8	6.8	1
Triple Superphosphate	1.4	110	1.2	2.6	0
Diammonium Phosphate	4.6	286	3.0	7.6	1
Normal Superphosphate	0.0	65	0.7	0.7	0
Mixed Fertilizers	5.0	350	3.7	8.7	1
Sub-Total	28.2	2,308	24.2	52.4	8
Total	574.4	4,990	52.4	626.8	100

[1] At 10,500 Btu/kWh.

Source: Arthur D. Little, Inc., "Economic Impact of Shortages on the Fertilizer Industry" report to the Federal Energy Administration, January, 1975.

There are about 160 of these old plants still operating, though probably no more than 40-50 of them are still based on normal superphosphate. These typically have annual production ranging from 20,000 to over 100,000 tons per year, with 50,000 to 60,000 tons being the average. Additionally, there are 25 to 30 more modern fertilizer plants based on phosphoric acid, with capacities ranging from 100,000 to 500,000 tons per year. These involve the drying and granulation of mixed fertilizer formulations based on additions to phosphoric acid.

An up-to-date listing of granulation plants is not available. A list was prepared in 1973 by the Potash Institute of North America, and appears as Table III-3. It cannot be determined from this listing, however, which of these plants are still operating as granulation plants or which are associated with operating superphosphate or sulfuric acid plants.

B. OUTLOOK

1. Nitrogen Fertilizers

The rate of growth in the consumption of fertilizer nitrogen in the United States has dropped off significantly over that which prevailed for the years prior to 1970. We have summarized prior consumption data in Table III-4, together with our estimates of the U.S. consumption in 1980 and 1985.

The annual rate of growth for the period 1960 to 1970 averaged 10.5% per year. This dropped off significantly following 1970. For the four-year period from 1970 to 1974, the average annual growth was 5.3%. In 1975, consumption declined 6% from the previous year. The decline in the rate of growth of nitrogen consumption in recent years may in part be due to a saturation in the market after many years of very high growth. However, more important reasons were worldwide shortages of nitrogen fertilizers and very significant price increases.

The recent performance of nitrogen fertilizer consumption casts some doubt on future growth rates. However, there is a fundamental need for increasing quantities, and we believe that an average growth rate of 6% per year through 1985 is realistic. Therefore, we have included in Table III-4 our estimates of nitrogen fertilizer consumption in 1980 and 1985, on the basis of a 6% annual growth rate for the next ten years.

On the basis of these consumption figures, an additional 7.7 million tons of nitrogen will be needed in 1985, compared with that consumed in 1975. This is roughly equivalent to 28 of the 1,000-ton-per-day ammonia plants. A number of these are under construction; however, additional projects will have to be initiated to meet the demand which we expect to develop by the mid-1980's.

TABLE III-3

GRANULATION PLANTS IN UNITED STATES

Alabama

U.S.S. Agri. Chem.-Charokee
Swift-Birmingham

Goldkist-Hanceville
Miss. Chemical-Decatur
Centrala-Dempolis

Arkansas

Agrico-Walnut
Arkla-Helena
Olin-North Little Rock

California

Chevron-Richmond
Occidental Chem-Lathrop
Colier Carbon & Chem-Nichols
Swift-L.A.
Valley Nitrogen-Helen
Valley Nitrogen-Elison

Florida

Kaiser-Tampa
Swift-Winter Haven

Georgia

Columbus Nitrogen-Moultrie Macon
W.R. Grace-Colquitt (New Albany)
I.M.C.-Americus, Augusta
Kaiser-Bainbridge
Royster-Macon, Athens (2)
Swift-Albany,Savannah
U.S.S. Agri Chem.-Albany, Columbus

Pelham Phosphates-Pelham

Goldkist-Cordele, Goldkist
So. States Phosphate

Illinois

Borden Chemical-Streator
U.S.S. Agri Chem.-E. St. Louis
Chicago Hgts.

Allerton Supply-Allerton
Perkinson Co.-Decature
Effingham Equity-Effingham
A.B. Chrisman, Inc.-Meredosia

Indiana

Texaco-Butler, Peru
U.S.S. Ag. Chem.-Jeffersonville

Kova Fert.-Greensburg

IFBCA-Indianapolis, Columbia

Iowa

Arco-Ft. Madison
Chevron-Ft. Madison

Kentucky

Royster
Texaco-Louis.&Nashville
Borden-Russellville

Bluegrass Plant Fd.-Cynthiana
Burleybelt Fert.-Lexington
Ohio Valley Fert.-Maysville

So. States-Louisville, Owensboro,
Russelville

Louisiana

Agrico-Donaldsonville
Swift-Shreveport

TABLE III-3

GRANULATION PLANTS IN UNITED STATES (Cont.)

Maine

Brockville Chem.-Preque Isle

Agway-Detroit

Maryland

Agrico-Baltimore
W.R. Grace Co.-Baltimore
Kerr McGee-Baltimore, Cambridge
Swift-Baltimore
U.S.S. Ag Chem.-Baltimore
Miller Chem.&Fort.-Whiteford
Lebanon Chem. Corp.-Baltimore

W.D. Tillghman-Salisbury
Lebanon Chem.-Baltimore

So. States-Baltimore

Mass.

Coranco-Lowell

Michigan

Agrico-Saginaw
Borden Chem-Saginaw, Holland
Riga (3)

Minnesota

Howe, Inc.-Minneapolis
Rochester Fert.-Rochester

Mississippi

Royster-Jackson
Swift-Jackson

Miss. Chemical-Yazoo City Pascaquola

Missouri

Farmland Chem.-Joplin
Missouri Farmers Assn.-Palymra,
Springs

Nebraska

Federal-Omaha

New Jersey

Texaco-Cranbury

Chamberlain & Barclay-Cranbury
Star Fish & Bone-Bridgton

Agway-Yardville

New York

Agrico-Burralo
Royster

Agway-Albany, Batavia, Big Flats,
Lyons, Canastock

N. Carolina

Agrico-Greensboro
Borden Chem.-Kinston (2)
Swift-Wilmington (?)
W.R. Grace-Wilmington
I.M.C.-Winston Salem
Kaiser-Wilmington
Kerr McGee-Williamston
Royster-Wilmington, Charlotte
U.S.S. Ag. Chem.-Greensboro

Wilmington Fert.-Wilmington
Weaver Fert.-Winston Salem
Pearsall & Co.-Wilmington
New Barn Oil & Fert.-New Barn

Farmers Chem-Tunis

Ohio

Swift-Orrville
Agrico-Cairo, Wash. Ct. House
W.R. Grace-Findlay, Columbus (2) Alliance
Plant Life Services-Marion
Federal-Columbus
Kerr McGee-Fostoria
Landmark-Mt. Gilead

Scotts-Marysville
Marion Plant Life-Marion

TABLE III-3

GRANULATION PLANTS IN UNITED STATES (Cont.)

Pennsylvania

Kerr McGee-Philadelphia

Reichard-Allentown
Lebanon Chem.-Lebanon, Allentown
Miller Chemical-Hanover

Agway-York, Kittanning

So. Carolina

W.R. Grace Co.-Charleston
I.M.C.-Hartsville
Kerr McGee-Florence-Jericho
Swift-Columbia (Charleston?)

Tennessee

Agrico-Memphis
Texaco-Humboldt,Nashville
W.R. Grace-Memphis
U.S.S. Ag.Chem.-Nashville
Memphis
Swift-Memphis

Tenn. Farmers' Coop-Lavoigne,
Jackson

Texas

Texas Farm Products
Nipak, Inc.-Littlefield-Kerens
Swift & Co.-Houston
Borden Chem.-Texas City
Occidental Chem.-Houston,
Plainview

Farmers Fert.-Texarkana
Red Barn-Freeport
Texas Farm Prod.-Nacogdoches

Virginia

Borden Chemical-Norfolk (2)
Danville
Royster-Norfolk
Swift-Norfolk

Charles Priddy Co.-Norfolk
Richmond Guano-Richmond
The Vance Co.-Chilhowis

So. States-Chesapeake, Va., Richmond

Wisconsin

Federal Chem.-White Water
Royster-Madison

Koos-Kenosha

F.S. Services-Prairie du Chien

Source: Prepared by Potash Institute of North America - May 1973

TABLE III-4

FERTILIZER NITROGEN CONSUMPTION
(000 tons N)

1960	2,738
1965	4,639
1970	7,459
1971	8,134
1972	8,016
1973	8,339
1974	9,157
1975	8,608
1980 (@6%/yr)	12,254
1985 (@6%/yr)	16,400

Source: U.S. Department of Agriculture and Arthur D. Little, Inc, estimates.

Increasing attention is being given to solid urea as the most attractive nitrogen fertilizer product. Recent analyses indicate that urea can be as competitive as anhydrous ammonia, in terms of price per unit of nitrogen applied to the ground. A number of companies are erecting additional urea production facilities and emphasizing its use as a fertilizer material. Therefore, solid urea's share of the total fertilizer nitrogen market will likely increase significantly. This will largely be at the expense of ammonium nitrate, and this tendency will also limit further growth in the use of anhydrous ammonia as a direct application fertilizer material, on a percentage-of-market basis.

It is likely that the shortage of natural gas will limit the number of additional ammonia plants that can be constructed in the United States, at least in the short term. Therefore, additional nitrogen required may be supplied from plants outside the United States. A number of plants under construction in Canada, Mexico, Venezuela, and Trinidad may have surplus capacity most logically suited for the U.S. market. These would be the primary off-shore sources if import requirements do develop. However, more distant sources, such as the USSR, North Africa, and the Arabian Gulf, may also be potential suppliers.

2. Nitric Acid

Nitric acid finds its greatest use (about 75%) in the production of ammonium nitrate, which is used primarily for fertilizers, but substantial quantities are also used for explosives. Additional smaller quantities of nitric acid are used for the production of nitric phosphate fertilizers, munitions, the manufacture of several organic chemical intermediates, and for stainless steel pickling. Production for recent years, based on Department of Commerce figures, is shown in Table III-5.

TABLE III-5

NITRIC ACID PRODUCTION
(thousand tons of 100% nitric acid)

Year	Production
1966	5,514
1967	6,463
1968	6.992
1969	7,223
1970	7,603
1971	7,638
1972	7,981
1973	7,690
1974	8,192
1975	6,964 (based on 9 months production)

The growth in the period 1966-1974 represented approximately 5% per year annual increase. The substantial drop in 1975 was probably due to the drop in industrial activity during the recession, together with an approximate 6% decline in nitrogen fertilizer use.

The future outlook in demand would suggest a somewhat reduced annual rate of growth. Ammonium nitrate's displacement of dynamite as an above-ground blasting agent is essentially complete, and further growth in this direction will probably proceed at the same general rate of increase as the use of explosives. In the fertilizer area, major attention is being focused on urea as the primary solid nitrogen material of the future, and it is doubtful that actual volumes of ammonium nitrate used in agriculture will increase substantially. For this reason, a 4% annual growth rate through the 1980's is an appropriate forecast for nitric acid. On this basis, and using 1974 production as the base year, future demand is estimated as shown in Table III-6.

TABLE III-6

FUTURE NITRIC ACID DEMAND
(thousand tons of 100% nitric acid)

Year	Production
1974	8,191
1980	10,360
1985	12,600

U.S. nitric acid capacity was estimated in 1975 at 9.7 million tons of 100% nitric acid. There are approximately 125 nitric acid plants at 84 locations in the United States. It is possible that effective capacity may be significantly below this figure, because some plants have been shut down or even dismantled. Nevertheless, the total figures do suggest that there is significant excess capacity. All but a few of these plants use a pressure process.

Assuming effective capacity may be in the neighborhood of 9 million tons per year, an additional 1.4 million tons capacity will be needed by 1980, and a further 2.2 million tons of capacity by 1985.

One factor that could affect future production of nitric acid is the availability of ammonia. However, even if domestic ammonia production increases are limited by the gas situation, imported ammonia should be available to meet additional nitric acid requirements.

3. Mixed Fertilizers

During the depressed conditions of the fertilizer industry in the late 1960's and early 1970's, many of the granular mixed fertilizer plants throughout the country were closed down. This was a result of a decline in the use of particular types of fertilizers. Many companies had a dozen or so plants, each of which was operating at well below capacity. Thus, a consolidation occurred, with the less efficient or most poorly located plants being closed. Now the use of complete mixed fertilizers has stabilized, and it is likely that those plants still remaining will continue to operate. A number of them are being renovated so that they will be capable of making higher-analysis products by using phosphoric acid rather than normal superphosphate.

There is some question as to whether it may not be preferable to produce such high-analysis mixed fertilizers in large plants, rather than in small plants near the markets. Such a decision would hinge on many factors, and each company will have its own decision to make. Nonetheless, if significant costs must be incurred in adding pollution control equipment or in other renovations, it could result in the closing of many of the old plants.

IV. COMPARISON OF CURRENT AND ALTERNATIVE PROCESSES

A. REASONS FOR CHOOSING OPTIONS TO BE ANALYZED IN DEPTH

The major use of energy in the fertilizer industry sector is as a feedstock and fuel for ammonia production, which in this study is analyzed separately. In addition, the phosphorus-phosphoric acid industry is also considered separately. In the remainder of the fertilizer industry, we uncovered two areas having potential impact on energy conservation and pollution control:

- Air pollution control in nitric acid plants, and
- Conversion to fuel oil for drying in mixed fertilizer plants equipped with bag filters.

1. Air Pollution Control in Nitric Acid Plants

The principal way of reducing nitrogen oxide emissions from a nitric acid plant is the catalytic reduction of the oxides to molecular nitrogen and oxygen. The process requires considerable investment and is energy intensive. Furthermore, the process requires that the major energy source be natural gas, which is in short supply both in the nation and to specific nitric acid plants. For these reasons, we have reviewed alternatives to the basic air pollution process to determine whether other methods are available that will not require natural gas, and to determine the costs of such options. Options reviewed in detail are:

- Molecular Sieve,
- Grande Paroisse,
- CDL/Vitok, and
- Masar.

2. Conversion to Fuel Oil for Drying in Mixed Fertilizer Plants Equipped with Bag Filters

We have chosen the two options of upgrading dryer burner equipment/technique and installation of a scrubber, because these are the only two viable control options for the ammoniation granulation plants that now use bag filters rather than scrubbers to control dryer and cooler emissions.

Neither of the options considered here are, strictly speaking, process changes. The changes under consideration relate only to the air pollution control options. The bases for the control options are illustrated in Figure IV-1, which shows a simple bag filter and a plate-type scrubber. The bag filter has the advantages of:

- generating no wastewater,
- allowing easy recycle of product, and
- greater efficiency of particulate control (see Figure IV-2).

On the other hand, it has the disadvantages of being attacked by acid mist and being easily clogged unless considerable attention is given to its care during plant operation. This is particularly true when hygroscopic dusts (such as fertilizer) are present in the gas stream being filtered. To avoid condensation, the gas temperature must be maintained about 70°F above the dewpoint of the highest boiling gaseous contaminant or reaction product. Consideration must also be given to the products of gas phase reactions in the dryer. For example, solid ammonium chloride may be formed through the reaction of gaseous ammonia with hydrogen chloride (formed by the reaction of sulfuric acid with potash). One producer reported that it took nearly a year to optimize operation conditions for use of the bag filter.

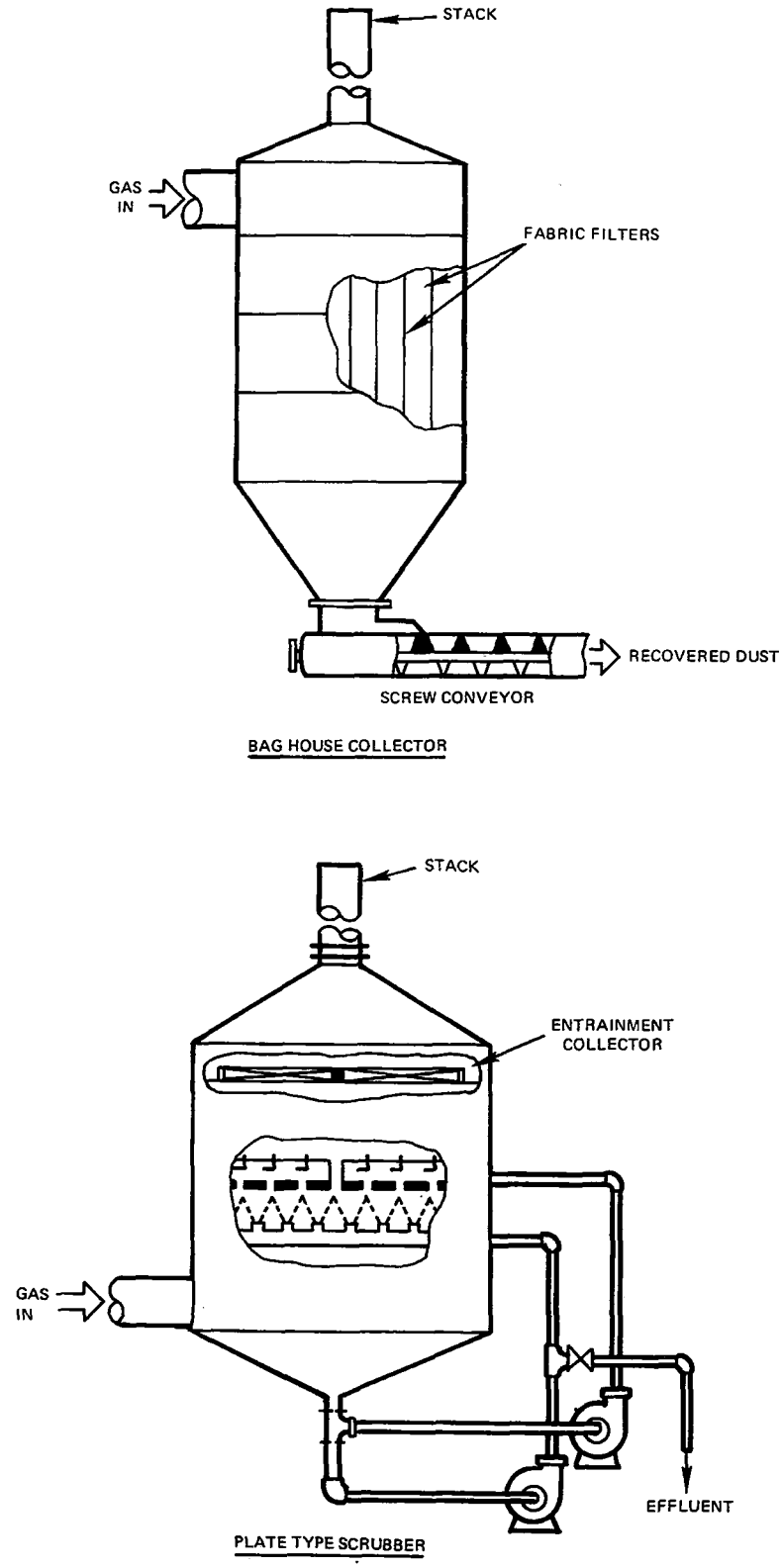
B. COMPARISONS OF CURRENT AND ALTERNATIVE PROCESSES

1. Nitric Acid

a. Base Line Technology for Nitric Acid Manufacture

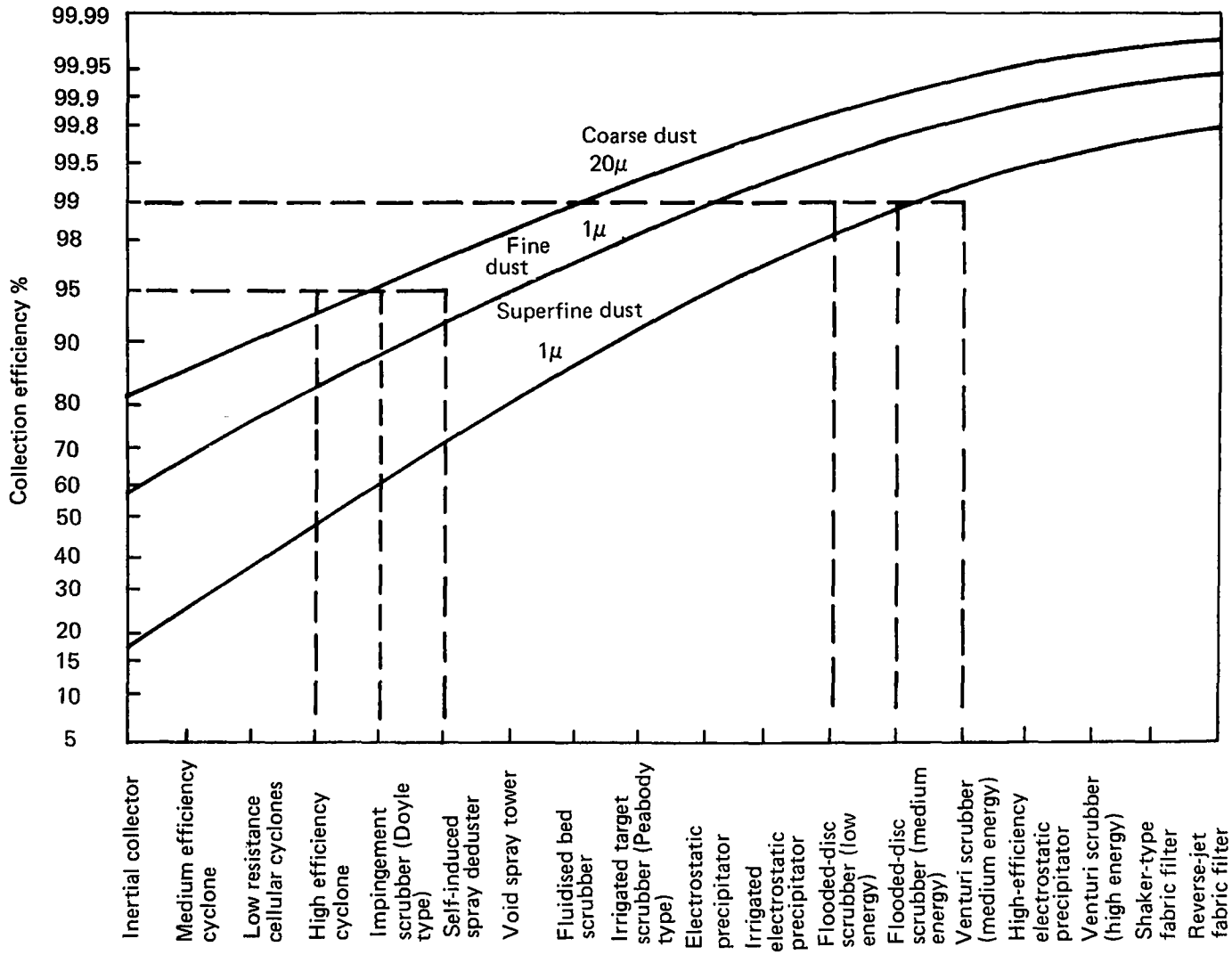
(1) Nitric Acid Process

Nitric acid is an important material in the manufacture of fertilizer-grade ammonium nitrate and explosives. The acid is produced by oxidation of ammonia, usually under high pressure and temperature over a platinum catalyst, forming nitric oxide (NO). The gaseous products from the reactor and oxygen, are cooled to form NO_2, and are sent to an absorption tower to form the acid product. The process forms an acid of approximately 60 - 65% strength, which is sufficient for ammonium nitrate production, and may be upgraded to 99% strength by one of several concentration processes. Both the ammonia reactor and the absorption tower are operated under high pressure, which favors heavy production of NO and NO_2 with minimum equipment. Oxidation of ammonia and final reduction of tail gas compounds are highly exothermic reactions which produce the heat and energy needed to satisfy demands in other parts of the plant. The flow diagram of a typical 300 tpd nitric acid plant utilizing the pressure process is given in Figure IV-3, which shows catalytic reduction used for NO_x abatement. The process change considered here is the NO_x abatement system. The base case is the nitric acid industry with no abatement.



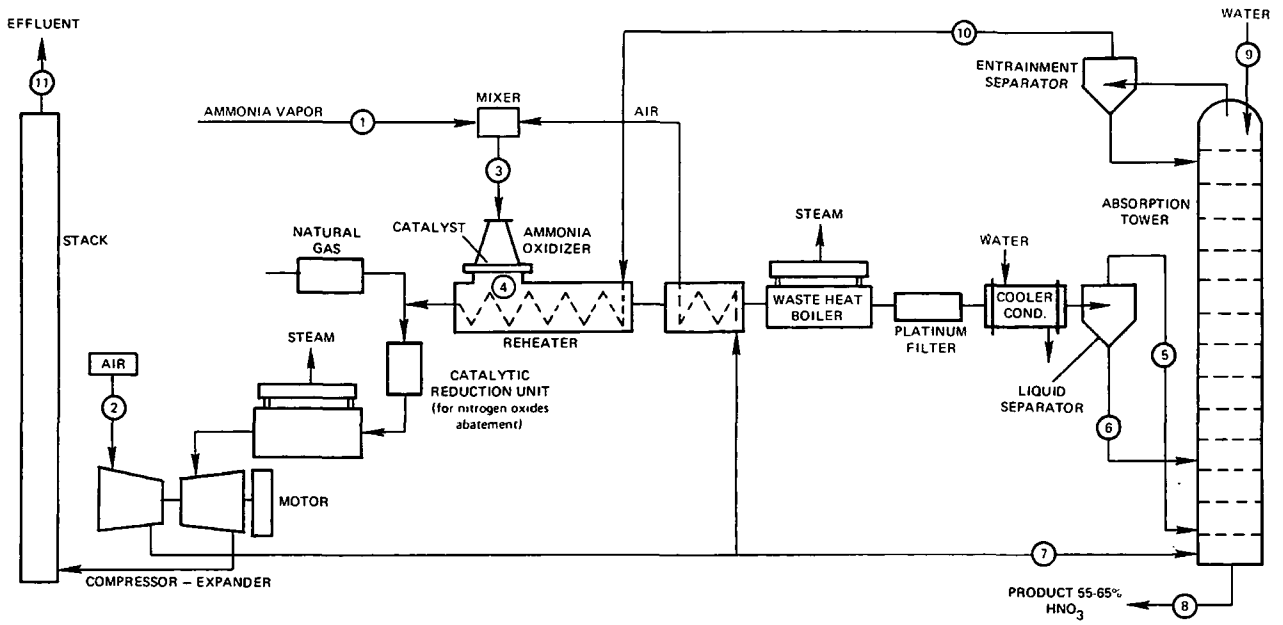
Source: Tennessee Valley Authority

Figure IV-1. Bag House Collector and Plate Type Scrubber



Source: Towards Cleaner Air – A Review of Britain's Achievements. Central Office of Information for the British Overseas Trade Board, London, 1973.

Figure IV-2. Particulate Collection Efficiencies for Various Types of Control Equipment



	10	
	Tail Gas	Stack Effluent
Flow, (lb/hr)	103,000	106,500
Temperature, (°F)	85	450
Pressure, (psig)	92	0
NH_3, (Vol %)	–	–
NO, (Vol %)	0.10	0.10
NO_2, (Vol %)	0.15	Nil
O_2, (Vol %)	3.0	Nil
H_2O, (Vol %)	0.6	3.8
HNO_3, (Wt %)	–	–
H_2), (Wt %)	–	–
N_2, (Vol %)	96.15	94.2
CO_2, (Vol %)		2.0

Source: Atmospheric Emissions from Nitric Acid Manufacturing Processes, USHEW, Publication No. 999-AP-27, 1966.

Figure IV-3. Flow Diagram of a Typical 300-Ton-Per-Day Nitric Acid Plant Utilizing the Pressure Process

The cost of making nitric acid is largely dependent on the price of the ammonia raw material. Using a figure of $100 per ton, ammonia represents over half the cost of manufacture, including a 20% margin to cover income taxes, profits, and general selling and administrative expenses. A detailed cost estimate is provided in Table IV-1. Fixed investment is estimated to be $5.5 million for a 300 tpd plant, or $54 per annual ton.

(2) Emissions from Nitric Acid Plant

The main source of atmospheric emissions from the manufacture of nitric acid is the absorption tower tail gas, which contains unabsorbed oxides of nitrogen. These oxides are largely in the form of nitric oxide and nitrogen dioxide. In addition, trace amounts of nitric acid mist are present in the gases as they leave the absorption system. In the pressure process, the gases are reheated for power recovery purposes and are discharged to the atmosphere at 400 - 500°F; any nitric acid mist present is then changed to its vapor state to discharge into the atmosphere. In the atmospheric system, tail gases discharged to the atmosphere are cold, and therefore, any entrained particles of nitric acid in this gas stream would appear as a mist. The quantity depends on the extent of entrainment and the efficiency of entrainment separators.

The tail gas is reddish-brown; the intensity of the color depends on the concentration of nitrogen dioxide present. The concentrations of 0.13% to 0.19% and higher by volume of nitrogen dioxide produce a definite color in the exit plume. Effluent gases containing less than 0.03% nitrogen dioxide are essentially colorless. (Nitric oxide, as distinguished from nitrogen dioxide, is colorless.)

Nitrogen oxide emissions from nitric acid plants are given in Table IV-2. The tail gas from the pressure process may be considered to have the average composition given in Table IV-3. Total NO_x emissions from a nitric acid plant are shown in Figure IV-4.

Small amounts of acid mist may be present in the emissions from some nitric acid plants. A small quantity of entrained acid is generally present in the gases leaving the absorption system. In the pressure process, the tail gases are reheated and expanded before being released to the atmosphere at 400-500°F; this treatment results in vaporization of any traces of acid mist that may have been present in the gases from the absorber. Emissions from acid storage tanks may occur during tank-filling operations. The gases displaced are equal in volume to the quantity of acid added to the tank.

(3) Emission Control Standard

In the United States, the limits on nitric oxide and nitrogen dioxide (commonly considered together as NO_x) emitted from nitric acid plants are 3 lb/ton of 100% acid for new plants (federal standard) and, on the average, 5.5 lb/ton of 100% acid for old plants (state standards). This is equivalent to approximately 200 ppm and 400 ppm, respectively, by volume in the tail gas.

TABLE IV-1

PRODUCTION COSTS

Product: Nitric Acid

Location: Louisiana

Annual Capacity: 102,000 Tons

Fixed Investment: $5,500,000

Annual Production: 102,000 Tons

	Units Used in Costing or Annual Cost Basis	$/Unit	Units Consumed per Ton of Product	$/ADT of Product
VARIABLE COSTS				
Raw Materials				
• Ammonia		$100/ton	0.292 ton	29.20
Energy				
• Natural Gas		$2/MCF	1.6 MCF	3.20
Energy Credits				
• Steam		$3/10^3 lb	700 lb	(2.10)
Water				
• Process (Consumption)		$0.75/10^3 gal	280 gal	0.21
• Cooling (Circulating Rate)		$0.03/10^3 gal	18,300 gal	0.55
Direct Operating Labor (Wages)	8 men	$12,700/yr		1.00
Direct Supervisory Wages	4 foremen 1 superintendant	$18,000/yr $25,000/yr		0.95
Maintenance	5% of Investment			2.70
Labor Overhead	30% of Operating Labor & Super.			0.59
• Catalyst		$185/oz	0.00802 oz	1.48
• Chemicals & Operating Supplies				.50
FIXED COSTS				
Plant Overhead	70% of Operating Labor & Super			1.37
Local Taxes and Insurance	2% of Investment			1.08
Depreciation	11 years			4.90
TOTAL PRODUCTION COSTS				45.70
Return on Investment (pre-tax)	20% of Fixed Investment			10.78
POLLUTION CONTROL				
TOTAL				56.48

TABLE IV-2

NITROGEN OXIDE EMISSIONS FROM NITRIC ACID PLANTS

Type of Control	Control Efficiency (%)	Emission NO_2[a] lb/ton Acid	Emission NO_2[a] Kg/MT Acid
Weak Acid			
Uncontrolled	0	50-55	25-27.5
Catalytic Combustor (natural gas fired)	78-97	2-7	1-3.5
Catalytic Combustor (hydrogen fired)	97-99.8	0-1.5	0-0.75
Catalytic Combustor (75% hydrogen (25% natural gas)	98-98.5	0.8-1.1	0.4-0.55
High-Strength Acid		0.2-5.0	0.1-2.5

[a]Based on 100 % acid production

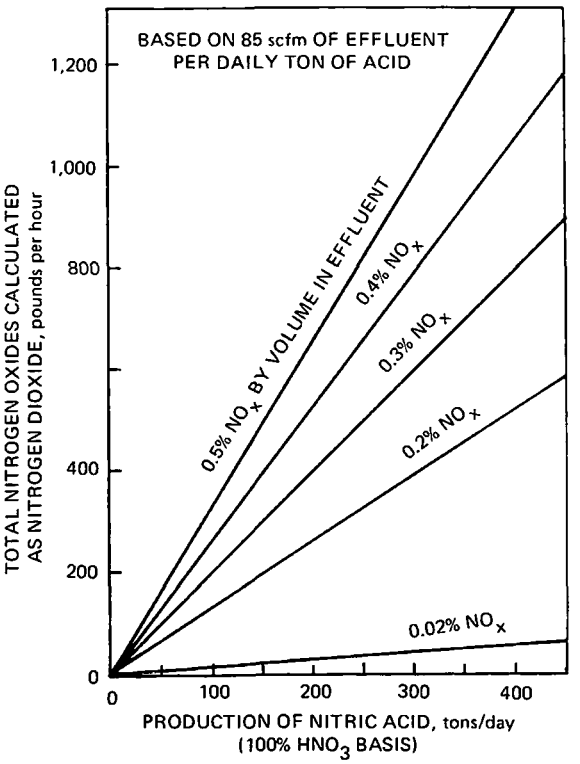
Source: Compilation of Air Pollution Emission Factors, Second Edition, US EPA Publication No. AP42, March 1975.

TABLE IV-3

AVERAGE COMPOSITION OF TAIL GAS FROM THE PRESSURE PROCESS

Total Nitrogen Oxide ($NO + NO_2$)	0.3%
Oxygen	3.0%
H_2O	0.7%
N_2, etc.	Balance

Source: Atmospheric Emissions from Nitric Acid Manufacturing Processes, USHEW, Publication No. 999-AP-27, 1966.



Source: "Atmospheric Emissions from Nitric Acid Manufacturing Processes," USHEW, Publication No. 999-AP-27, 1966.

Figure IV-4. Total NO_x (Calculated as NO_2)/Hour vs Daily Production of Nitric Acid

Adoption of air pollution control is a recent practice in the nitric acid industry. The process change considered in this study is the application of alternative NO_x abatement systems. Therefore, the base case is considered as a nitric acid plant without NO_x abatement.

b. NO_x Abatement Technology

In this section, we consider the following NO_x abatement systems:

- Catalytic Reduction Method,
- Molecular Sieve Process,
- Extended Water Absorption or Grande Paroisse Process,
- CDL/Vitok Process,
- Masar Process, and
- Alkali Scrubbing Process.

In addition to the above processes, there are the SABAR process, Chemico Hycon process, and several European processes.

(1) Catalytic Reduction Process

In the catalytic reduction process, the residual tail gas from the absorber, essentially nitrogen, is demisted and then preheated with steam. The hot tail gas is then further heated by passing it through the shell side of the heat exchanger train utilized to cool the hot process gas.

Before being introduced into the hot gas expander, the reheated tail gas is passed through a combustor that contains catalyst. The oxides of nitrogen are reduced to N_2 and O_2 in the combustor. Natural gas or hydrogen is used as the fuel in the combustor. The flow diagram is shown in Figure IV-3. Hydrogen or natural gas, or a mixture of the two, are used as fuels. The stack effluent is usually clear and colorless, indicating reduction of all nitrogen dioxide to nitric oxide, at least to less than 0.03% by volume. In most cases there is substantial, if not total, removal of oxygen by combustion with the fuel.

- Current Status of the Catalytic Reduction Process - The catalytic process is well established and has been installed on several nitric acid plants. It can also be retrofitted on an existing plant if it uses a pressure process and practices power recovery. If the plant uses a low-pressure process, the capital cost of the catalytic reduction process will be too high. If the plant operates at high pressure and does not practice power recovery, the operating costs of the NO_x abatement will be too high, because there will be no use for the steam, and the plant may adopt an alternate NO_x abatement device or may shut down.

- Effluent Control - The only flow stream from the combustor is the tail gas. If the combustor temperature is maintained according to specifications, the exhaust gases will meet the stationary source standards. Maintenance of operating conditions is also important to prevent carry-over of the catalyst, overheating of the catalyst, etc.

- Economic Factors - The estimated capital cost and the operating cost of the catalytic process for NO_x abatement are given in Table IV-4. Investment cost is high, as are the investment-related operating costs. Charges for catalyst and fuel are also significant, although the fuel costs are largely offset by a steam credit if the steam can be utilized.

- Energy Requirements - The energy requirements for a catalytic process for NO_x abatement are given in Table IV-5, which indicates that method is an energy intensive process. Particularly critical is the fact that this energy must be in the form of natural gas, which is in short supply.

- Technical Considerations - A significant amount of fuel is used in the catalytic reduction process. A major portion of the heating value of the fuel is recoverable in the form of steam. Thus, there is a net export of steam from such a plant, and it may be possible to use the heating value of the steam in other operations at the same location. Attention must be paid to the uses of steam.

TABLE IV-4

CAPITAL AND OPERATING COSTS FOR DIFFERENT NO_x ABATEMENT SYSTEMS IN A 300 TPD NITRIC ACID PLANT

	Catalyst Reduction	Molecular Sieve	Grande Paroisse	CDL/ Vitok	Masar
Capital Investment,[1] ($)	1,384,000	1,200,000	1,000,000	575,000	663,000
Operating Costs					
Operating Labor, (hr/yr)	360	360	360	360	360
($/yr)	2,200	2,200	2,200	2,200	2,200
Maintenance Labor,	315	315	315	315	540
($/yr)	2,200	2,200	2,200	2,200	3,775
Labor Overhead (incl. fringe benefits & supervision, $/yr)	4,400	4,400	4,400	4,400	5,975
Catalyst or Molecular Sieve	77,800	45,600	--	--	--
Cooling Water, (gpm)		500	300	1,020	--
($/yr)		7,330	4,420	14,980	
Steam, (lb/hr)	(15,833)	250	--	715	1,310
($/yr credit)	(387,590)	6,120	--	17,500	32,070
Electricity, (kW)	128	322	90	265	20
($/yr)	20,890	52,550	14,690	43,250	3,260
Boiler Feed Water, (gpm)	35				
($/yr)	12,850				
Fuel, (10^6 Btu/hr)	28.5	2.0	--	--	--
($/yr)	465,120	32,640			
Nitric Acid, (tpd)	--	(6.6)	(6.0)	(6.0)	(5.28)
($/yr)	--	(112,200)	(102,000)	(102,000)	(89,760)
Urea, tpd					1.37[2]
($/yr)					74,528
Ammonium Nitrate, (tpd)					1.25
($/yr)					(42,500)
Depreciation (11-yr life)	125,900	109,090	90,910	52,300	60,300
Return on Investment (@ 20%)	276,800	240,000	200,000	115,000	132,600
Taxes & Insurance, (@ 2%)	27,700	24,000	20,000	11,500	13,260
Total Annual Cost, ($/yr)	628,270	413,930	236,780	161,330	195,708
Annual Cost, ($/ton)	6.16	4.06	2.32	1.58	1.92

[1] Investment estimates exclude interest during construction, owners expenses, and land costs.

[2] Includes credit for 0.0017 tons of urea/ton of nitric acid produced present in the spent solution (D.SITPD).

Source: Arthur D. Little, Inc. estimates.

TABLE IV-5

ENERGY REQUIREMENTS IN NO_x ABATEMENT SYSTEMS FOR A 300 TPD NITRIC ACID PLANT (10^9 Btu/Yr)

	Basic Nitric Acid Plant	Catalytic Reduction	Molecular Sieve	Grande Paroisse	CDL/ Vitok	Masar
Steam (Credit)	(71.4)	(129.20)	2.04	-	5.83	10.69
Electrical	-	10.97	27.59	7.71	22.71	1.71
Natural Gas	163.2	232.56	-	-	-	-
Oil	-		16.32	-	-	-
	91.8	114.33	45.95	7.71	28.54	12.40

Source: Arthur D. Little, Inc. estimates.

TABLE IV-6

BASIS FOR TABLES IV-4 AND IV-5

(Plant Capacity @ 300 tpd and 102,000 tons/yr)

(March 1975 Dollars, ENR Index = 2,126)

1. Operating Labor @ $6.1/hr
2. Maintenance Labor @ $7.0/hr
3. Overhead @ 100% of labor (including fringe benefits and supervision)
4. Cooling Water @ $0.03/1,000 gal
5. Boiler Feedwater @ $0.75/1,000 gal
6. Natural Gas @ $2.00/$10^6$ Btu
7. Oil @ $2.00/$10^6$ Btu
8. Depreciation @ 11 yr straight line
9. Return on Investment @ 20% of capital cost
10. Taxes and Insurance @ 2% of capital cost
11. Nitric Acid @ $50/ton
12. Urea @ $160/ton
13. Ammonium Nitrate @ $100/ton
14. 1 kWh = 10,500 Btu
15. Electricity @ $0.02/kWh

The requirement of catalyst use may be solved with proper attendance. The service life of the catalyst, contamination or overheating, may present problems if operating conditions are not properly maintained.

(2) Molecular Sieve Method

This method is based on the principles of absorption, oxidation, and regeneration of the molecular sieve. An oil-fired heater is used to provide heat for regeneration. The process has high efficiency for removal of NO_x gases. The NO_x outlet concentration is generally below 50 ppm.

The pressure drop in the molecular sieve is significant, and averages 5 psi.

- Current Status of Process - The process has been applied to three plants in the United States having capacities of 55 tpd and higher. The process has operated successfully in controlling the NO_x emissions.

- Effluent Control - The only flow stream from the molecular sieve process is tail gas. If operating conditions are maintained according to specifications, the NO_x concentration in the tail gas is below 50 ppm.

- Economic Factors - The capital and operating costs of the molecular sieve method for NO_x abatement are given in Table IV-4. The process is capital intensive, and the annual costs associated with replacing the molecular sieve materials and electric power costs are also significant. Unlike the catalytic reduction process, nitric acid is recovered and can be credited to the operating costs.

- Energy Requirements - The energy requirements for the molecular sieve method for NO_x abatement are given in Table IV-5. Power requirements are high because of the added compression requirements and the need to regenerate the sieve.

- Technical Considerations - The absorption techniques involve swing operation. This may be a problem, because the burner in the nitric acid plant requires good, steady-state operation to minimize platinum losses and to prevent explosions from improper ammonia-air mixtures.

  It is necessary to replace molecular sieves after a certain number of operating hours. Maintenance of proper operating conditions is important to avoid degradation of the sieves. In some cases, the cost of sieve replacement may be significant. Also, the molecular sieve method uses relatively high energy compared to the other NO_x abatement methods (except the catalytic method).

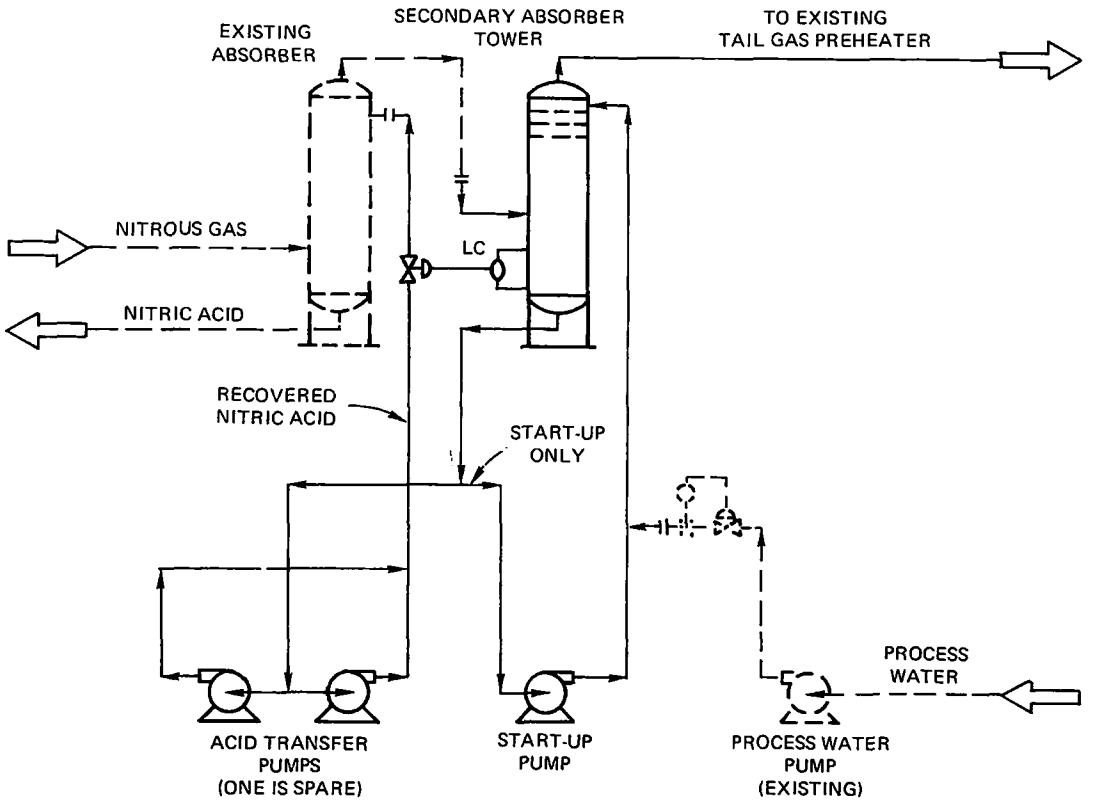
(3) Extended Water Absorption or Grande Paroisse Process

In the Extended Water Absorption or Grande Paroisse Process, tail gas from the existing absorber tower, which typically contains between 1,500 and 5,000 ppm NO_x, is routed to the secondary absorber for additional "extended absorption" of nitrogen oxides. The tail gas is contacted counter-currently with process water, and additional acid produced in the secondary absorber is pumped to the existing absorber. A startup acid pump is included to circulate a large quantity of weak acid through the secondary absorber to fill the absorber trays as quickly as possible during startup.

Figure IV-5 is a simplified flow sheet for the process as installed in a typical nitric acid plant. The exit solution is used to feed the existing absorber, eliminating any liquid stream from the NO_x abatement process. The process has no effect on the quality of the nitric acid produced.

- Current Status of the Grande Paroisse Process - The Grande Paroisse process is well-developed in Europe, and has been used in the design and construction of over 30 plants throughout the world to date.

  In the United States, the Grande Paroisse NO_x abatement process has been applied to five plants having production capacities of 125, 240, 300, 315, and 360 tpd. One additional plant having a capacity of 1,000 tpd using the Grande Paroisse process is under construction.



Source: J. F. Pritchard Co. Catalog

Figure IV-5. Grande Paroisse NO_x Abatement Process

- Effluent Control - The only flow streams from the absorber are tail gas and weak nitric acid solution. The tail gas meets the EPA NO_x standards. The weak acid is used as a feed makeup water to the nitric acid absorber.

- Economic Factor - The capital cost and the operating cost of the Grande Paroisse NO_x abatement process are given in Table IV-4. The process is capital intensive. Costs which are not investment-related are minor and are more than offset by the credit for nitric acid recovered.

- Energy Requirements - The energy requirements for the Grande Paroisse process for NO_x abatement are given in Table IV-5. It uses less energy than any of the other processes, with the possible exception of the Masar process.

- Technical Consideration - The Grande Paroisse process has been accepted where the cost of feedstock and utilities is noticeably higher (Europe). The process may be used in a new plant or may be retrofitted in an existing plant. The process is based on the conversion of NO to useful NO_2, rather than to nonproductive nitrogen. The rate of reaction varies directly with the square of the pressure. Therefore, the operating pressure determines the success of the NO_x abatement in the tail gas. The preferred absorber pressure for an existing plant is above 100 psia and for a new plant it is above 150 psia. The capital cost increases significantly if the operating pressures are reduced (to maintain the same NO_x concentration in the tail gas).

(4) CDL/Vitok Process*

The process uses the principle of scrubbing tail gas with nitric acid under conditions which reduce the nitrogen oxides to the desired level. Both physical absorption and stripping and chemical oxidation absorption are used. The reaction may be catalyzed in some applications to reduce the size of the equipment required. No chemicals other than water and nitric acid are required for the process, thus avoiding additional new waste disposal problems and cost. The nitric acid is not consumed, being an internal recycle, and the water is only that required for the manufacture of the acid, and this becomes a part of the product. All the nitrogen oxides removed from the tail gas are converted to nitric acid at concentration levels that can be commercially utilized.

- Current Status of the CDL/Vitok Process - The CDL/Vitok process has been applied to one commercial plant having a capacity of 350 tpd. The NO_x content in the tail gas is less than 3 lb/ton of nitric acid. Also the process was tested for one year in a demonstration size plant in an ammunition plant.

*Maryland, B.J., "The CDL/Vitok Nitrogen Oxides Abatement Process," presented at the Environmental Symposium of the Fertilizer Institute, January, 1976, New Orleans.

It is expected that the CDL/Vitok process will be applied to four plants next year. These plants have a rated capacity of 60, 60, 150, and 250 tpd.

- Effluent Control - The only effluent stream from the CDL/Vitok process is tail gas. The tail gas will meet the NO_x stationary source standard.

- Economic Factor - The capital cost and the operating cost of the CDL/Vitok process for NO_x abatement are given in Table IV-4. The CDL/Vitok process has the lowest capital and operating costs.

- Energy Requirements - The energy requirements for the CDL/Vitok processes are given in Table IV-5. It uses approximately 25% of the energy of the catalytic reduction process.

- Technical Considerations - The CDL/Vitok process is similar to the Grande Paroisse process. The two processes differ in operating conditions: the CDL/Vitok process uses a higher liquid-to-gas ratio and a lower operating temperature. It is claimed that only one absorber is required for the CDL/Vitok process. However, the increased liquid flow rate may affect the tower capacity.

(5) Masar Process

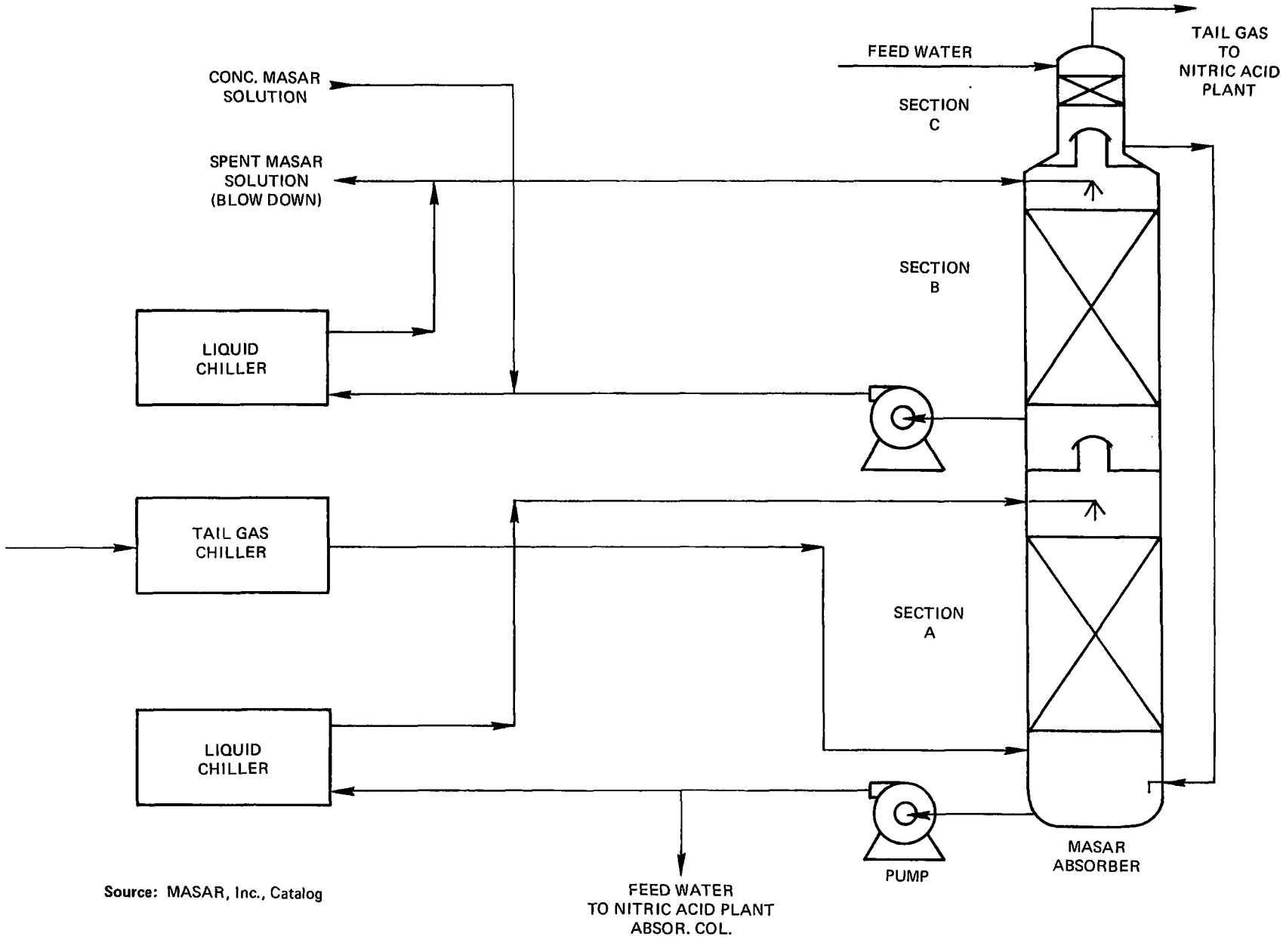
The Masar process (see Figure IV-6), as applied to nitric acid plants, takes the tail gas from the exit of the absorption tower and passes it to a gas chiller where it is cooled. During the cooling operation, condensation occurs, with the formation of nitric acid. The chilled gas and condensate passes into section A of the Masar absorber.

The Masar absorber is divided into three sections, A, B, and C.

- Masar Absorber Section A - In this section, the chilled gas and condensate represent feed gas stream, and chilled feed water (from Section C) represents liquid stream. The feed water stream, mixed with weak nitric acid, flows down in Section A countercurrent to the tail gas to scrub NO_x from the tail gas.

  The liquid stream is circulated through a chiller, E, to remove reaction heat. The bleed stream from the Section A is weak nitric acid and is fed to the nitric acid absorber in the main plant to serve as its feed water.

- Masar Absorber Section B - The tail gas passes into Section B of the Masar absorber, where it is scrubbed with a circulating urea-containing solution. A urea/water solution (concentrated Masar solution) is made up in a storage tank and metered into the recirculating system at a rate necessary to maintain a specified minimum urea residual content. As the solution scrubs the tail gases, both nitric and nitrous acids are formed, and the urea in



Source: MASAR, Inc., Catalog

Figure IV-6. Masar Process for NO_x Abatement

gases, both nitric and nitrous acids are formed, and the urea in the solution reacts with the nitrous acid. As the solution is circulated, the nitric acid content rises and some of the urea present hydrolyzes and forms some ammonium nitrate. To maintain the system in balance, some of the circulated solution (spent Masar solution) is withdrawn. Disposition of this solution is discussed below. The recirculated solution is also pumped through a chiller, F, to remove the heat of reactions and to maintain the desired process temperature in Section B.

- Masar Absorber Section C - The tail gases from Section B pass into Section C, where they are scrubbed by the feed water stream. The feed water is chilled in Section C by countercurrent flow of chilled gas. The chilled water from the bottom of Section C is used as feed water in Section A.

  The tail gases then leave the Masar absorber and pass on to the existing mist eliminator and heat exchanger train of the nitric acid plant. In the application of this process at Illinois Nitrogen, the cooling medium used in the gas chiller is liquid ammonia. The vaporized ammonia is subsequently used as the feed to the plant ammonium nitrate neutralizer. For non-ammonium nitrate producers, mechanical refrigeration could be used or the ammonia vapor could be used in the nitric acid converter directly.

- Current Status of the Masar Process - The Masar process is now being used in three U.S. nitric acid plants: two 350 tpd capacity, and one 250 tpd capacity.

- Effluent Control - The effluent streams from the Masar process are tail gas and spent Masar solution.

  The tail gas has met regulatory standards with regard to NO_x abatement. The NO_x in the tail gas exhaust from one operating plant has been between 100 and 200 ppm for a one-year operation period. Some data show NO_x in tail gas as low as 57 ppm.

  The spent Masar solution contains urea and ammonium nitrate. This is spent in the form of a weak solution. Approximately 25% of the urea in the feed is present in the spent solution. The ammonium nitrate concentration is two to three times the concentration of urea in the spent solution. The solution can be utilized in preparing fertilizer solution. Companies that do not make fertilizer solutions may sell the solution to companies that do or to farmers for direct application.

- Economic Factors - The capital cost and the operating cost of the Masar process for NO_x abatement are given in Table IV-4.

  The credit for the spent Masar solution is determined by using $160/ton for urea and $100/ton for ammonium nitrate.

If the spent Masar solution is used in the fertilizer industry, there will be some cost associated with handling the solution. Alternatively, the solution may be sold to farmers. In the latter case, the price may be lower.

- Energy Requirements - The energy requirements for the Masar process are given in Table IV-5. It uses only about 10% as much energy as does the catalytic reduction process.

- Technical Considerations - Essentially 80% of the NO_x recovered is available in direct usable form (weak nitric solution), as discussed previously. The remainder is abated with the use of urea. This leads to the discharge of spent Masar solution, containing urea and ammonium nitrate. Application of the spent Masar solution should be determined.

  The process requires refrigeration. Selection of the cooling medium is important. Alternatively, mechanical refrigeration may be used.

(6) Alkali Scrubbing Process

Alkaline scrubbers also reduce the emission of nitrogen oxides effectively. Data for five plants are presented in Table IV-7. The two-stage, sodium hydroxide-water scrubber performed exceptionally well, with an overall reduction of 91% in nitrogen oxides content. The data on the sodium carbonate scrubber show a very high (2.5%) nitrogen oxides concentration in gases entering the sodium carbonate scrubber; this high value might indicate that the principal purpose of the scrubber was to produce nitrite and nitrate salts rather than to reduce emissions below the usual 0.15 - 0.40% nitrogen oxides concentration characteristic of untreated tail gas. Alkaline scrubbing is used only if the production of nitrates is desired.

TABLE IV-7

EMISSIONS DATA FOR NITRIC ACID PLANTS
HAVING ALKALINE SCRUBBING EQUIPMENT

	Scrubber	
Type of Control	$NaOH + H_2O$	Na_2CO_3
No. of Stages	2	1
Percent Reduction in Nitrogen Oxides	91	94
Pounds of Nitrogen Oxides Emitted per ton of Acid Produced (100% Basis)	4	27-54

Source: Atmospheric Emissions from Nitric Acid Manufacturing Processes, USHEW, PHS-999-AP-27, 1966.

2. Conversion to Fuel Oil in Mixed Fertilizer Plants Equipped With Bag Filters

a. Wet Scrubber Currently Installed for Control of Particulate Emissions

Currently, approximately 80% of the estimated 200 ammoniation granulation fertilizer plants use wet scrubbers to control particulate emission levels. These plants are expected to have relatively few problems in switching from natural gas to fuel oil for drying. The capital cost for new burners, oil tanks, piping, and miscellaneous equipment is about $10,000 for a typical dryer. Most plants have already installed stand-by fuel oil equipment, so the investment has already been incurred. There are no significant differences in operating costs, aside from the fuel cost differential itself.

b. Base Line Technology Used for Comparison (Bag Filters Currently Installed)

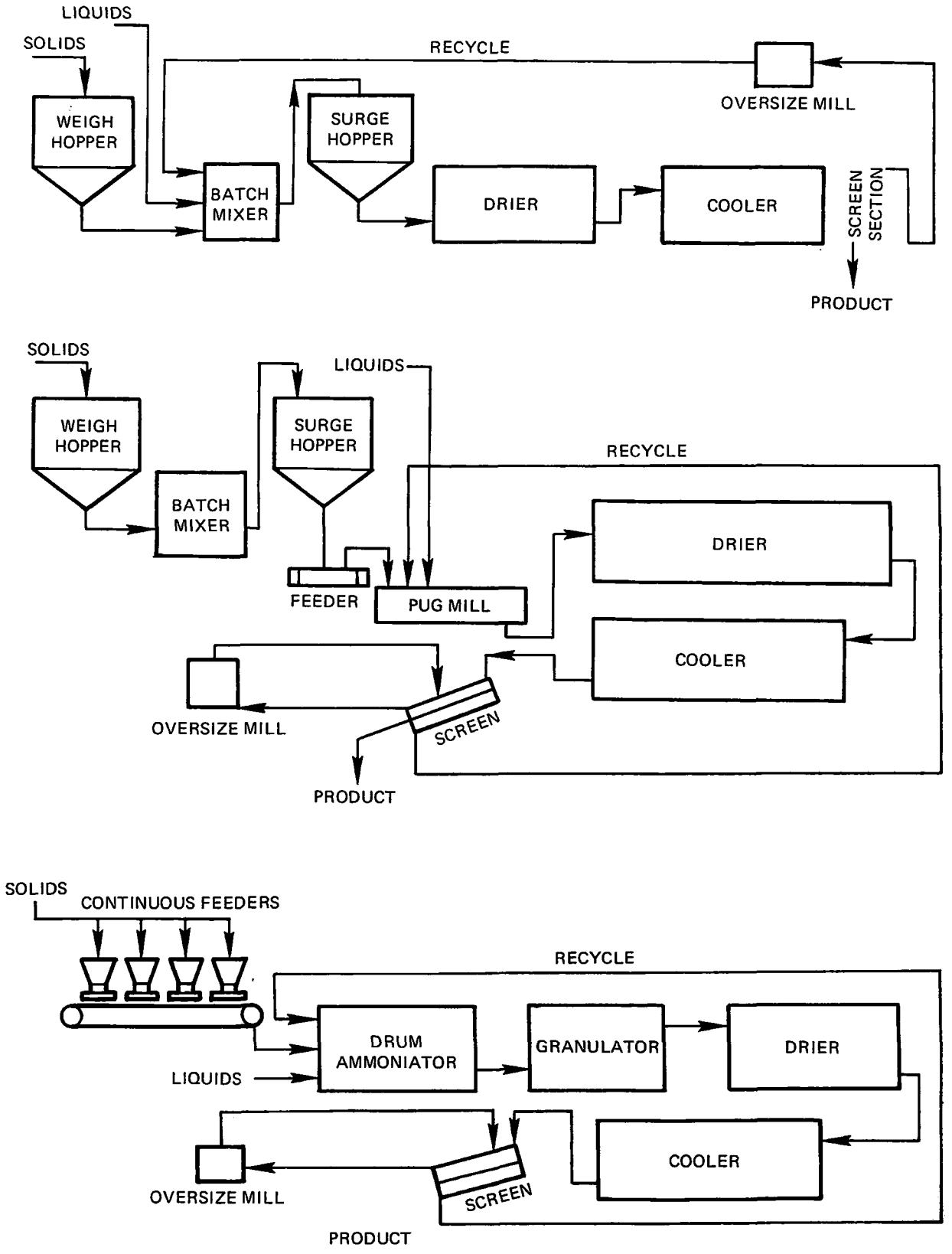
For purposes of analysis, the base line plant is a 47,000 metric-ton-per-year ammoniation granulation plant using a natural gas-fired dryer and equipped with a bag house filter to control particulate emissions.

Of the three types of ammoniators illustrated in Figure IV-7, the rotary-drum design is most common. Figure IV-8 presents a simplified flow diagram for an ammoniation granulation plant, while Figures IV-9 and IV-10 show additional details of the material handling and dust collection systems, respectively. The base case plant has no water effluent and consumes from 200,000 to 400,000 Btu per ton of product for drying.

Table IV-8 presents additional production statistics for the base line plant. Uncontrolled and controlled emission factors (and the total amounts of controlled emissions) are presented in Tables IV-9 and IV-10, respectively. The allowable emission rate per ton of product for new plants is 2.1 pounds. The uncontrolled emission rate in Table IV-9 is 4.6 pounds per ton, indicating a 60% efficiency requirement. For existing plants, the average of state emission regulations for plants of less than 30 tons per hour is $3.59\ P^{0.62}$, where P is the production rate in tons per hour. For plants of 30 tons per hour or greater, the formula is $17.31\ P^{0.16}$. In cases where gaseous effluents exceed existing EPA standards, installation of an auxiliary scrubber is required. The composition and quantity of stack gas will vary considerably depending on product formulation and production control.

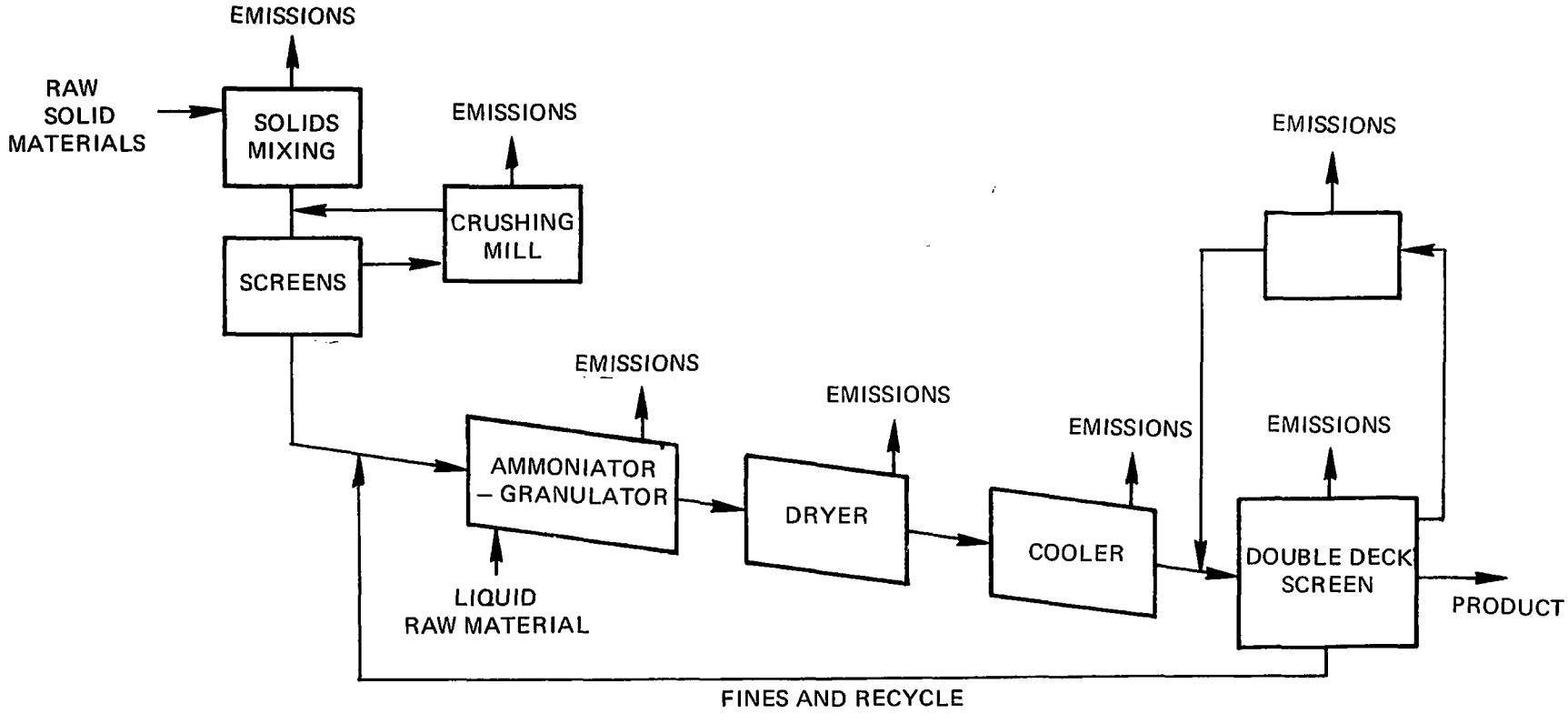
c. Installation of Scrubber on Bag House-Equipped Plants When Converting From Natural Gas to Fuel Oil

As discussed earlier, some fertilizer dryers fired by natural gas employ bag houses for air pollution control. In the base case, when fuel oil has been substituted for natural gas, operational problems have sometimes resulted from the plugging of the bag house filter media with products



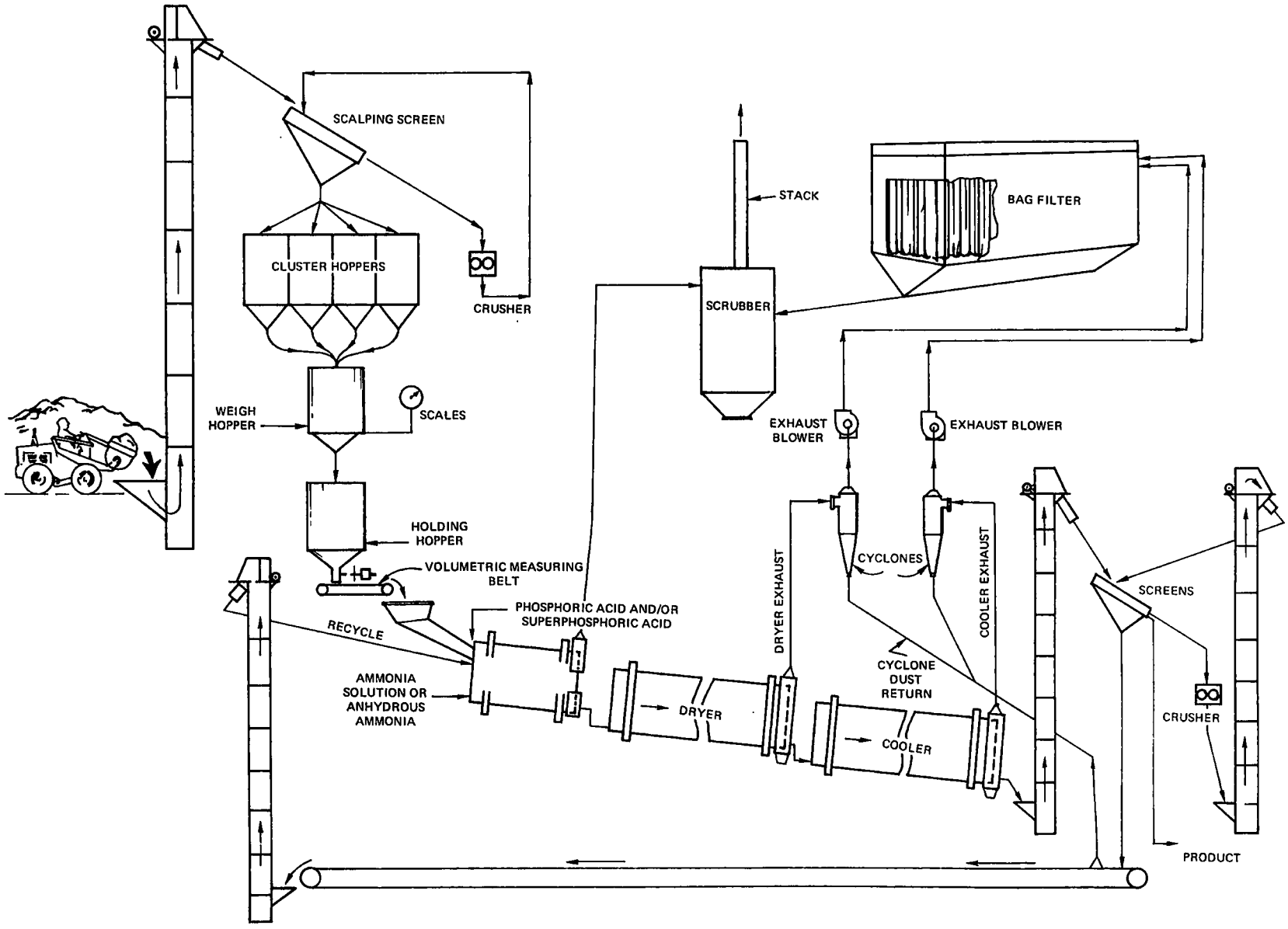
Source: Sauchelli, V., Manual on Fertilizer Manufacture, Industry Publications, Inc., Caldwell, New Jersey, 1963.

Figure IV-7. Batch-Mixer, Pug-Mill and Rotary-Drum Ammoniation



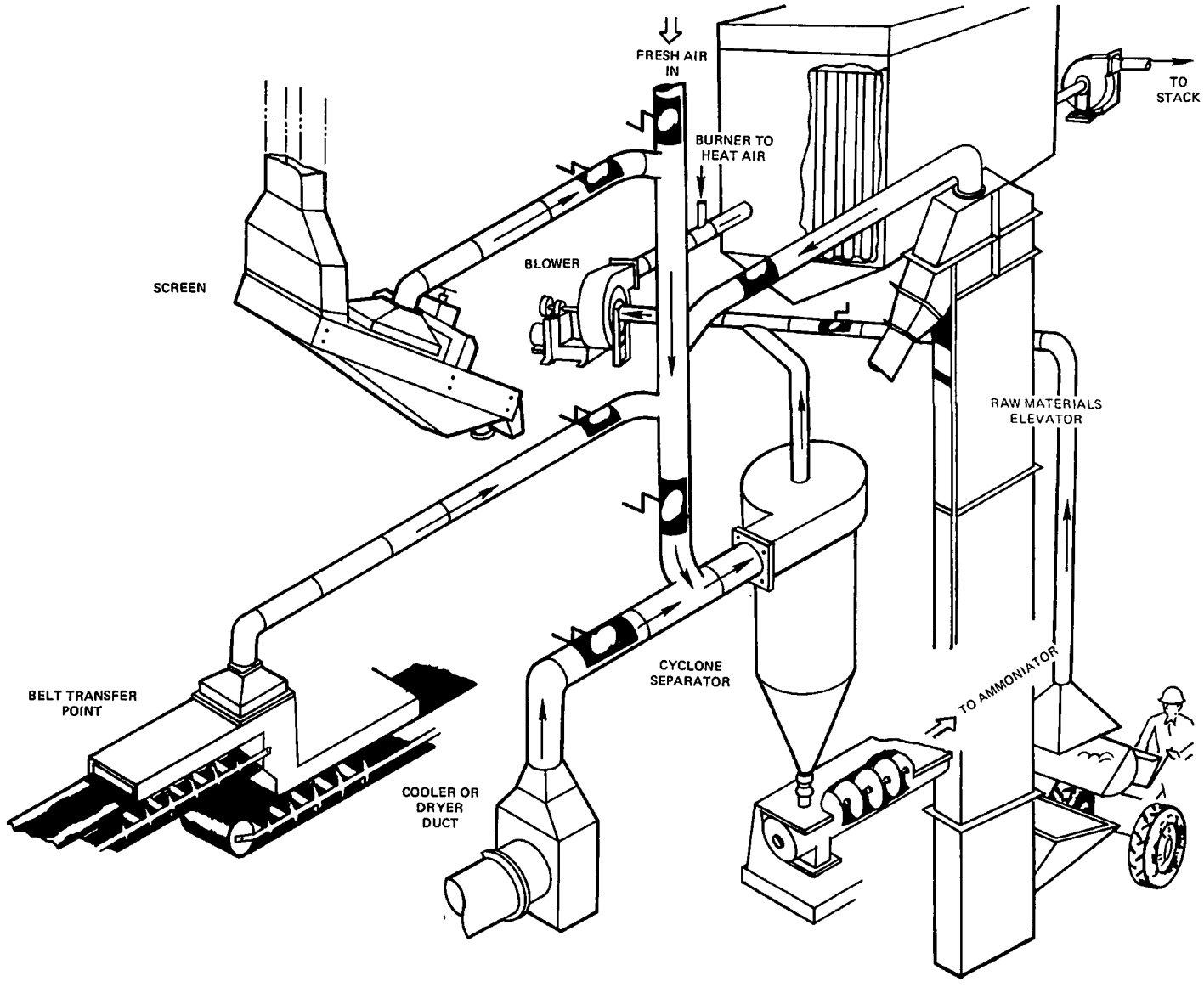
Source: Monsanto Research Corporation

Figure IV-8. Simplified Flow Diagram of an Ammoniation Granulation Plant



Source: Tennessee Valley Authority

Figure IV-9. Detailed Schematic Diagram of Rotary-Drum Ammoniation Plant



Source: Tennessee Valley Authority

Figure IV-10. Detail of Granulation Plant Dust Collection System

TABLE IV-8

AMMONIATION GRANULATION PRODUCTION STATISTICS - 1973

Number of Plants	195
Total Annual Production, million tonnes (tons)	9.14 (10.08)
Annual Plant Production Rate, tonnes/year (tons/year)	9,000- 90,000 (10,000-100,000)
Average Annual Production Rate, tonnes/year (tons/year)	46,870 (51,690)
Plant Design Hourly Production Rate, tonnes/hour (tons/hour)	4.5-90 (5-100)
Average Annual Operating Period, hours/year	3,894
Actual Average Production Rate, tonnes/hour (tons/hour)	12.04 (13.27)

Source: Monsanto Research Corporation

TABLE IV-9

UNCONTROLLED EMISSION FACTORS FOR AMMONIATION GRANULATION PLANTS

Emission Source Cateogry	Emission kg/tonne (pound/ton) Ammonia	Total Chlorine	Total Fluorine	Total Phosphorus	Particulate
Material storage and handling	0	0	0	0	0.5 ± 300%[a] (1.0 ± 300%)
Ammoniator granulator	0.503 ± 104% (1.006 ± 104%)	0.030 ± 186% (0.060 ± 186%)	0.0013 ± 57% (0.0025 ± 57%)	0.0011 ± 87% (0.0022 ± 87%)	0.175 + 356%[b] (0.350 ± 356%)
Dryer and cooler	0.316 ± 44% (0.633 ± 44%)	0.014 ± 175% (0.028 ± 175%)	0.0083 ± 70% (0.0167 ± 70%)	0.0316 ± 133% (0.0633 ± 133%)	0.23 ± 48% (0.46 ± 48%)
Screen and oversize mill	0	0	0	0	0.25 ± 300%)[a] (0.5 ± 300%)
Bagging and loading	0	0	0	0	0.25 ± 300%[a] (0.5 ± 300%)
Total plant	0.819 ± 66% (1.639 ± 66%)	0.044 ± 175% (0.088 ± 175%)	0.0096 ± 61% (0.0192 ± 61%)	0.0327 ± 133% (0.0655 ± 133%)	1.40 ± 300% (2.91 ± 300%)

[a]These values are a result of engineering estimates of similar processes because no source test data is available and the values may vary by a factor of three.

[b]The large error is due to only two data points which statistically results in a large spread for 95% confidence range. The standard deviation in the two data points is ±40%.

Source: Monsanto Research Corporation

TABLE IV-10

EMISSION FACTOR AND TOTAL MASS OF CONTROLLED EMISSIONS FROM FERTILIZER MIXING PLANTS

	Ammoniation Granulation Plants[a]	
Emission Species	Emission Factor, kg/tonne	Total Mass, tonnes/year
Ammonia	0.123 ± 66%	1,120 ± 740
Total chlorine	0.0066 ± 175%	59 ± 103
Total fluorine	0.0014 ± 61%	13 ± 8
Total phosphorus	0.0049 ± 133%	45 ± 60
Particulate	0.21 ± 300%[c]	1,920 ± 5,760

[a]Based on a minimum control efficiency of 85%. All plants have control equipment which is 85% to 99.5% efficient.

Source: Monsanto Research Corporation

of incomplete combustion. However, there is a strong indication that such problems can usually be overcome by modifying the combustion process. If this measure is generally successful, it will still be possible to use bag houses when fuel oil is used. However, should the use of bag houses prove to be incompatible with the use of fuel oil, wet scrubbers will have to be employed. The capital and operating costs for a wet scrubber capable of handling a gas stream of 13,000 cfm and at 38,000 hours of annual operation are shown in Table IV-11.

In the operation of a wet scrubber, the scrubber water is typically recycled after each pass through the scrubber. Since a portion of the water is evaporated on each pass, makeup water must be added. To prevent the buildup of absorbed materials in the scrubber water, a small portion of the scrubber water flow must be purged from the system. This purge stream is a contaminated wastewater stream and a potential source of water pollution. An estimation of the characteristics of this wastewater stream is shown below:

TABLE IV-11

MIXED FERTILIZER PLANT SCRUBBER COSTS
(Production Basis: 52,000 tons/yr)

CAPITAL INVESTMENT	$70,000
INDIRECT COSTS	
Depreciation (@ 9.1%/yr)	6,360
Return on Investment (@ 20%/yr)	14,000
Taxes and Insurance (@ 2%/yr)	1,400
TOTAL INDIRECT COSTS	$21,760
DIRECT OPERATING COST	
Operating Labor	3,500
Maintenance Labor and Materials	3,500
Electricity	5,700
TOTAL DIRECT OPERATING COST	$12,700
TOTAL ANNUAL COST	$34,460
UNIT COST ($/ton of fertilizer)	$0.66

Source: Arthur D. Little, Inc. estimates.

- Wastewater Flow Rate (during actual drying time) = 7,660 gallons/day

- Estimated Wastewater Composition (based on 90% scrubber efficiency)

Constituent	Concentration (mg/liter)
Ammonia	275
Chloride	150
Fluoride	75
Phosphorus	275
Suspended Solids	100

Ammonia, fluoride, and phosphorus are the principal pollutants of concern in the wastewater stream. Their concentration levels must be reduced prior to discharge into a receiving stream.

To remove the pollutants, lime treatment (with aeration) can be employed. The addition of lime will raise the pH of the wastewater, thus converting ammonium ions into ammmonia gas, which can then be stripped from the wastewater by aeration. Lime will also cause the fluoride ions and phosphorus (as phosphate ions) to precipitate out of solution as calcium fluoride and calcium phosphate. The reactions and aeration can be performed in conventional

mixing basins and the settling of precipitates can be performed in a conventional clarifier. The final effluent from the lime treatment must be neutralized with sulfuric acid prior to discharge. The estimated composition of the treated effluent is approximately:

Ammonia	30 mg/liter
Chlorine	150 mg/liter (no removal)
Fluoride	15 mg/liter
Phosphorus	20 mg/liter
Suspended Solids	20 mg/liter

An estimate of the costs of treating the scrubber water is presented in Table IV-12.

TABLE IV-12

MIXED FERTILIZERS - FUEL OIL ALTERNATIVE
SCRUBBER WATER TREATMENT COSTS
(Production Basis: 52,000 tons/yr)

CAPITAL INVESTMENT	$50,000
INDIRECT COSTS	
Depreciation (@ 9.1%/yr)	4,600
Return on Investment (@ 20%/yr)	10,000
Taxes and Insurance (@ 2%/yr)	1,000
TOTAL INDIRECT COST	$15,600
DIRECT OPERATING COST	
Operating Labor ($6.10/hr + 100% of labor for overhead)	7,300
Maintenance Labor and Materials	2,000
Chemicals (lime and acid)	1,500
Electricity (@ $0.02/kwh)	600
Sludge Disposal (@ $5.00/metric ton)	500
TOTAL DIRECT OPERATING COST	$11,900
TOTAL ANNUAL COST	27,500
UNIT COST ($/ton of fertilizer)	$0.53

Source: Arthur D. Little, Inc. estimates.

The treatment system will result in the following consumption of chemicals and energy:

Hydrated Lime	5.4 tons/year
Sulfuric Acid-100% Basis	10 tons/year
Electrical Energy	30,000 kWh/yr (0.64 kWh/metric ton of fertilizer)

In addition, an estimated 100 tons per year of sludge having a solid concentration of 10% will be generated. This sludge may contain as much as 0.5% fluorides and 2.0% phosphates in addition to soluble ammonia; consequently its disposal into landfills must be done with care to insure that leaching into ground or surface waters does not occur.

d. Continued Control of Particulate Emissions With Bag Houses When Converting From Natural Gas to Fuel Oil

For those ammoniation granulation plants that now have bag filters it appears that the problem of filter bag clogging may be corrected through proper attention to equipment design and operation.

Many ammoniation granulation plants have already installed dual-purpose burners and fuel oil storage systems to cope with the interruptable natural gas service which they have been forced to accept. A few producers have chosen to use propane when natural gas is shut off, rather than invest in fuel oil equipment. For those plants with fuel oil equipment, no incremental investment is required for conversion to fuel oil. However, operating costs increase slightly, because cleaning of the bag filters must be done six time per year (with ideal burner performance) rather than four times per year as with natural gas.

Most of the problems occur during startup, before equilibrium operating temperatures are reached. This can be alleviated by preheating the fuel oil, by using proper, well-adjusted burners, and by preheating the dryer before charging the material to be dried. In some cases, particularly where the dryer exit gases may cool before entering the bag house, an auxiliary burner may be required (Figure IV-10).

The estimated operating costs for a bag house on the base line ammoniation granulation plant are shown in Table IV-13. The incremental costs for installing fuel oil storage equipment and dual burners are presented in Table IV-14. If fuel oil equipment is already installed, the incremental costs are much lower, as indicated in Table IV-15. As may be seen by comparing these costs with the incremental costs required for installation of a scrubber system, ungrading the equipment and operating procedures for use of fuel oil with the bag house is considerably less expensive. In cases where difficulty is experienced because of incomplete combustion of the fuel oil, industry observers suggest that an afterburner or other special burner design, such as an infrared burner now under development (Burdett Company, private communication) could solve this problem. The cost of such burners for the base case fertilizer drying plant would be about $15,000.

TABLE IV-13

MIXED FERTILIZER PLANT BAG HOUSE COSTS
(Production Basis: 52,000 tons/yr)

CAPITAL INVESTMENT	$80,000
INDIRECT COSTS	
Depreciation (@ 9.1%/yr)	7,280
Return on Investment (@ 20%/yr)	16,000
Taxes and Insurance (@ 2%/yr)	1,600
TOTAL INDIRECT COST	24,880
DIRECT OPERATING COST	
Operating Labor ($6.10/hr + 100% OHD)	4,000
Maintenance Labor and Materials	4,000
Electricity (@ $0.02/kWh)	1,800
TOTAL DIRECT OPERATING COST	9,800
TOTAL ANNUAL COST	34,680
UNIT COST ($/ton of fertilizer)	$0.67

Source: Arthur D. Little, Inc. estimates.

TABLE IV-14

FERTILIZER DRYING, COSTS FOR MAIN AND AUXILIARY BURNERS
(Production Basis: 52,000 tons/yr)

CAPITAL EQUIPMENT	
Main Burner (4×10^6 Btu/hr), Storage and Related Equipment	$9,500
Auxiliary Burner (0.2×10^6 Btu/hr) and Related Equipment	500
TOTAL	$10,000
INDIRECT COSTS	
Depreciation (@ 9.1%/yr)	910
Return on Investment (@ 20%/yr)	2,000
Taxes and Insurance (@ 2%/yr)	200
TOTAL INDIRECT COST	$3,110
DIRECT OPERATING COST	
Operating Labor	500
Maintenance Labor and Material	500
TOTAL DIRECT OPERATING COST	1,000
TOTAL ANNUAL COST	$14,110
UNIT COST ($/ton)	$0.27

Source: Arthur D. Little, Inc. estimates.

TABLE IV-15

FERTILIZER DRYING, INCREMENTAL COST OF BURNING FUEL OIL WITH BAG FILTERS
(Production Basis: 52,000 tons/yr)

CAPITAL INVESTMENT	
Auxiliary Burner, Piping and Misc.	$500
INDIRECT COSTS	
Depreciation (@ 9.1%/yr)	45
Return on Investment (@ 20%/yr)	100
Taxes and Insurance (@ 2%/yr)	10
TOTAL INDIRECT COSTS	155
DIRECT OPERATING COST	
Operating Labor	2,000
Maintenance Labor and Materials	2,000
TOTAL DIRECT OPERATING COST	$4,000
TOTAL ANNUAL COST	$4,155
UNIT COST ($/ton of fertilizer)	$0.08

Source: Arthur D. Little, Inc. estimates.

V. IMPLICATIONS OF POTENTIAL CHANGES

A. AIR POLLUTION CONTROL IN NITRIC ACID PLANTS

The manufacture of nitric acid produces significant emissions of nitrogen oxides to the atmosphere. The most widely used process for pollution control is the catalytic decomposition of the nitrogen oxides to nitrogen and oxygen. This process is energy intensive and is particularly expensive for those few nitric acid plants which cannot recover the energy in the form of usable steam. The problem is aggravated because natural gas is the required energy source. Most plants are limited in the quantities of gas they can purchase, and such natural gas is critical and non-substitutable for the manufacture of ammonia, which in most places occurs at the same site. Natural gas use for pollution control reduces the amount available for other purposes, thus effectively reducing production. The natural gas requirement for pollution control of a 300 tpd nitric acid plant is 232.6×10^9 Btu per year. This amount could be used to produce 6,600 tons of ammonia.

The process produces steam, which can be used elsewhere in the plant complex, and it may be argued that this reduces the energy input at some other point. Such argument may not be valid for two reasons:

1. Not all plants have use for the steam; and

2. Such steam, if needed, could otherwise be provided with a fuel other than natural gas.

The other abatement systems becoming available hold the promise of satisfactory control of emissions and at lower investment costs, lower operating costs, significantly lower energy requirements, and no need for natural gas as the energy source. Also, because the catalytic reduction process is usually too expensive to operate in plants using low-pressure processes to nitric acid, two or three of the alternate processes allow more economical recovery for such plants. The other processes suffer from problems of maintenance of stringent operating conditions (Molecular Sieve), inapplicability to low-pressure nitric acid processes (Grand Paroisse), and too little actual operating experience (CDL/Vitok and Masar).

The economics of the pollution control options are provided in Table V-1. Investment in a 300 tpd nitric acid plant with no pollution control is about $5.5 million, and the cost of manufacture, including profit, is $56.48 per ton, although this cost is strongly affected by the price of ammonia, which we have

TABLE V-1

CAPITAL COST AND OPERATING COST
FOR
NO_x ABATEMENT SYSTEMS FOR A 300 TPD NITRIC ACID PLANT

	Catalyst Reduction	Molecular Sieve	Grande Paroisse Process	CDL/ Vitok	Masar
Capital Cost	1,384,000	1,200,000	1,000,000	575,000	663,000
Operating Labor	4,400	4,400	4,400	4,400	4,400
Maintenance	4,400	4,400	4,400	4,400	7,550
Catalyst or Sieve	77,800	45,600			
Cooling Water		1,980	1,840	14,980	
Steam (credit)	(387,590)	6,120		17,500	32,070
Electricity	20,890	52,550	14,690	43,250	3,260
Boiler Feedwater	12,850	-			
Fuel	465,120	32,640			
Depreciation	125,900	109,090	90,910	52,300	60,300
Return on Investment	276,800	240,000	200,000	115,000	132,600
Taxes and Insurance	27,700	24,000	20,000	11,500	13,260
Nitric Acid (credit)		(112,200)	(102,000)	(102,000)	(89,760)
Urea					74,528
Ammonium Nitrate					(42,500)
Net Operating Cost, ($/yr)	628,270	408,580	234,200	161,330	195,708
($/ton)	6.16	4.01	2.30	1.58	1.92

valued at $100 per ton. The catalytic reduction process thus adds 25% to the investment and 11% to the cost of manufacture. The molecular sieve and Grande Paroisse processes have almost as much investment, but add only 7% and 4%, respectively, to the operating costs. The newer CDL/Vitok and Masar processes appear to offer significant savings in both investment and operating costs.

Energy requirements are also much lower in each of the four alternatives to the catalytic reduction process (see Table V-2). Of particular interest is that only the catalytic reduction process requires natural gas.

B. FERTILIZER DRYING

1. Continued Use of Bag House With Improved Design and Operation

For the ammoniation granulation plants considered, which are already equipped with bag houses, the impact on pollution control and energy requirements for upgrading design and operation is negligible. Performance of the bag filter will be improved through proper attention to operation and design. The key factors in successful use of fuel oil are a properly designed and adjusted burner and combustion chamber and pre-heating of all exhaust gas before it enters the bag filter. Pre-heating the fuel oil before it enters the combustion chamber may also help to achieve full combustion; however, this investment (several hundred dollars) should not be necessary for No. 1 or No. 2 fuel.

TABLE V-2

ENERGY REQUIREMENT IN NO_x ABATEMENT SYSTEMS
FOR A 300 TPD NITRIC ACID PLANT
(10^9 Btu/yr)

	Catalytic Reduction	Molecular Sieve	Grande Paroisse	CDL/ Vitok	Masar
Steam (Credit)	(129.20)	2.04	-	5.83	10.69
Electrical	10.97	27.59	7.71	22.71	1.71
Natural Gas	232.56	-	-	-	-
Oil	-	16.32	-	-	-
	114.83	45.95	7.71	28.54	12.40

In terms of economic impact, the added cost of upgrading equipment to handle fuel oil is relatively small when compared to the original bag house investment. The incremental cost of approximately $0.08 per ton of product represents about 0.05% of current product price (approximately$160 per ton, January 1976). As such, this added cost is viewed as having a negligible impact on the industry. The cost premium for fuel oil over natural gas (per Btu) has not been considered here, because the switch to fuel oil is a result of factors beyond the operation control. This could be a significant cost.

2. Conversion From Bag House to Wet Scrubber With Fuel Change From Natural Gas to Fuel Oil

It is unlikely, in view of the costs involved, that an ammoniation granulation plant operator would choose to install a wet scrubber when he has already invested in a bag house for pollution control. Assuming that there is no scrubbing equipment now in place, the incremental investment for installation of a scrubber and the necessary effluent treatment equipment, at $1.19 per ton, would be more than ten times as expensive as the upgraded bag house system described above. In addition, the energy requirements for a wet scrubber of comparable efficiency would be considerably higher than for the bag house system. The fuel requirements for fertilizer drying would be nearly identical (slightly less for the scrubber), but the power requirements for scrubber operation are approximately three times as great as for operation of the bag house.

In summary, the amount of fuel required for drying would be about the same for either option, while the operating power would be much greater for the scrubber. In terms of both the required incremental investment and the performance per unit of operating power, the upgrading of current bag house equipment is the preferred alternative for a typical plant equipped with bag filters (see Table V-3).

TABLE V-3

COMPARISON OF SCRUBBER AND BAG HOUSE COSTS AND ENERGY CONSUMPTION FOR TREATING MIXED FERTILIZER PLANT GASEOUS AND PARTICULATE WASTES
(Production Basis-50,000 short tons/yr)

	Incremental Annual Cost ($/ton)	Incremental Annual Energy Consumption (million Btu)
Scrubber Alternative		
Scrubber	$0.66	$2,990
Scrubber Effluent Treatment	0.53	315
Total	1.19	3,305
Less Variable Cost of In-Place Bag House	.19	960
Total Incremental Cost and Energy	1.00	$2,345
Bag House Upgrade Alternative		
Burner Conversion and Auxiliary Equip	$0.08	760[1]
Apparent Advantage of Bag House Upgrade	12X	3X

[1]Assumes 0.2×10^6 Btu/hr for 3800 hours of operation annually.

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(Please read Instructions on the reverse before completing)

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16. ABSTRACT

This study assesses the likelihood of new process technology and new practices being introduced by energy intensive industries and explores the environmental impacts of such changes.

Specifically, Vol. XV deals with the fertilizer industry and examines two areas in which energy conservation and pollution control are in conflict: the reduction of nitrogen oxide emissions from nitric acid plants and switching from natural gas to fuel oil for firing fertilizer dryers where emissions are presently controlled by bag filters. Vol. III-XIV deal with the following industries: iron and steel, petroleum refining, pulp and paper, olefins, ammonia, aluminum, textiles, cement, glass, chlor-alkali, phosphorus and phosphoric acid, and copper. Vol. I presents the overall summation and identification of research needs and areas of highest overall priority. Vol. II, prepared early in the study, presents and describes the overview of the industries considered and presents the methodology used to select industries.

17. KEY WORDS AND DOCUMENT ANALYSIS

a. DESCRIPTORS	b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group
Energy Pollution Industrial Wastes Fertilizer Ammonia, Phosphorus Nitric Acid	Particulate Control Manufacturer Processes Energy Conservation Granulated Fertilizers Air Emission Control Nitrogen Oxide Control	13B

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