THE IMPACT OF AIR POLLUTION ABATEMENT ACTIVITIES OF COAL-BURNING ELECTRIC POWER GENERATING PLANTS ON THE FERTILIZER INDUSTRY

Thesis for the Degree of Ph. D.
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David M. Bell

has been accepted towards fulfillment
of the requirements for

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ABSTRACT

THE IMPACT OF AIR POLLUTION ABATEMENT ACTIVITIES OF COAL-BURNING ELECTRIC POWER GENERATING PLANTS ON THE FERTILIZER INDUSTRY

By

David M. Bell

Society is becoming increasingly sensitive to damages caused by air pollution. The sulfur oxides, a major component of flue emissions, are very damaging to many materials and to plant and animal life. Although legislation designed to solicit control of sulfur oxide emissions has already been enacted, more persuasive controls in the form of direct regulation can be expected to originate from the Environmental Protection Agency in the near future.

Numerous processes designed to recover sulfur oxides from the flue gas of electric power generating plants, which account for over one-half of all sulfur oxide emissions, are in varying stages of development. Many of those processes produce by-product sulfuric acid while a few produce ammonium sulfate and a few produce throwaway products. Both sulfuric acid and ammonium sulfate have value to the fertilizer industry.

A comprehensive linear programming model based on the prominent characteristics of the fertilizer industry as it relates to the Michigan market was developed. This model was manipulated to examine the impact production of by-product ammonium sulfate and sulfuric acid would have on the optimal organization of the fertilizer industry. The model was designed so other problems of interest to participants in the fertilizer industry, and to those who consume its products could be studied as well.

The long-run optimal organization of the fertilizer industry is based on three high-analysis products: anhydrous ammonia, monoammonium phosphate and granular potassium chloride. Most of the latter two are used in dry blends while anhydrous ammonia is used for direct application. By producing and distributing these products optimally, the cost of supplying the amount of N, P_2O_5 and K_2O consumed in Michigan in 1970 can be reduced by 32.4 percent from the amount farmers actually paid.

Three uses for by-product ammonium sulfate were examined: direct application, granulation and bulk blending. Although the use of ammonium sulfate for direct application was superior to the two alternative uses, it competed with N provided in the optimal product mix at very low prices only ($\leq$ \$2.00 per ton). However, if some value were imputed for its sulfur content, and if it competed with products currently being used, it would sell at significantly higher prices.

Both sulfuric acid, a primary input into the wet process, and electricity, a primary input into the elemental phosphorus-furnace acid processes, are currently used to produce phosphoric acid. However, the analysis indicates that at the currently low price for sulfuric acid, approximately \$12.50 per ton, electricity cannot compete economically with sulfuric acid. Therefore, it can be expected that the sulfuric acid process will account for an increasing share of the production of phosphoric acid. Although this and other factors will cause the consumption of sulfur to increase annually in the United States, the potential supply of sulfur is so great that sulfur prices can be expected to be relatively low for some time to come.

By-product sulfuric acid produced in Michigan cannot be used

efficiently in the fertilizer industry. But the high concentration of manufacturing in the North combines with its remoteness from sulfur sources in the Gulf Coast area to provide a good market price for sulfuric acid for those power plants that may choose to produce it.

Since Michigan power plants can generate considerably more revenue by producing sulfuric acid than by producing ammonium sulfate, they can be expected to invest in those abatement processes that produce the by-product sulfuric acid. Consequently, firms in the fertilizer industry that improve their economic position by reorganizing consistent with the optimal organization of the fertilizer industry need not be unduly concerned about the possible effect of by-product ammonium sulfate.

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CHAPTER I

INTRODUCTION

Estimates of damages resulting from air pollution in the United States range as high as 20 billion dollars annually (Kneese, 1966, p. 529). Of all the pollutants, sulfur oxides, most of which are emitted from the electrical power generating industry, are quite possibly the most costly. They attack both plant and animal life. Incidents have been recorded where vegetation 50 miles from the source of sulfur oxide emissions has been injured (The Effects of Air Pollution, 1966, p. 15). Humans have been victimized individually as well as en masse. Sulfur oxides attack materials as well; few metals, stones, or fabrics are exempt. Because of the high cost borne by society, pressure for abatement of sulfur oxide emissions is increasing.

Several processes have been developed for recovering sulfur oxides from power plant smokestacks. One of these processes uses anhydrous ammonia as an input and produces ammonium sulfate and/or sulfuric acid. Many of the other processes produce only sulfuric acid. Both ammonium sulfate and sulfuric acid have value to the fertilizer industry. Ammonium sulfate is useful as a fertilizer material itself, and is also used in the manufacture of other fertilizer materials. Sulfuric acid is used primarily in the acidification of phosphate rock, the initial step in the production of phosphate fertilizers.

Since ammonium sulfate and/or sulfuric acid could be obtained

as by-products in abatement of undesirable emissions from the power generating industry, their price could theoretically fall below zero since there may be a cost of disposing of the by-products. Consequently, their price could fluctuate over a wide range, almost insuring the movement of some of the products into the fertilizer industry.

If a portion of the cost of producing ammonium sulfate and/or sulfuric acid were borne by the fertilizer enterprise, power generating firms would maximize profits by equating the marginal cost of producing each by-product with its marginal revenue. If, on the other hand, the electricity generating component of the firm bore the production costs, and the two by-products were transferred to the fertilizer enterprise at zero cost, the firm would maximize revenues, and therefore profits, by pricing these by-products at those points where their respective price elasticities of demand are equal to one, since this is where marginal revenue equals marginal cost (both of which would be equal to zero). If these by-products produced through the abatement of power generating plant emissions were priced at a level to allow their use as primary inputs in fertilizer production, the organization of the fertilizer industry would be expected to change.

Objectives

This study investigates both the environmental quality issue as it relates to power production and the fertilizer industry, and identifies the potential relationship between the two. Such facets as the economics of abatement, the cost of pollution, the pollutants and their impact, the sources of pollutants, and potential remedies are discussed. Of particular concern, however, is the analysis of the

various impeti that may stimulate the flow of by-product ammonium sulfate and sulfuric acid into the fertilizer industry, the amount of these two by-products that could be used as primary inputs in fertilizer production, and their impact upon the organization of the fertilizer industry.

Specifically, the objectives of this study are:

1. Identify the potential situations that could provide the stimulus necessary to initiate production of by-product ammonium sulfate and/or sulfuric acid from air pollution abatement activities;
2. Determine the amount of each of the two by-products that could be produced from abatement activities in the United States and in Michigan, and the amount of other fertilizer products that could be produced from these two by-products;
3. Project the consequences on the organization of the fertilizer industry (product mix, facilities used, etc.) of these by-products entering the fertilizer market at selected input prices; and
4. Examine some of the issues relevant to pollution abatement activities and the use of the resulting by-products in the fertilizer industry.

Methodology

Essential to the analysis of the problem is the determination of the potential quantity of fertilizer products that could originate from pollution abatement efforts of power plants in the United States and in Michigan. Estimates of the potentially recoverable sulfur oxide emissions for the United States will be secured. For Michigan, power plants that are of sufficient size to warrant abatement procedures

will be identified and the amount of sulfur oxides emitted from each plant determined. The potential supply of ammonium sulfate and sulfuric acid will be based on existing technical processes and their efficiency in capturing the sulfur oxides.

A systems model is used to determine the amounts of the recovered by-products from the abatement of power plant emissions that can be expected to flow into the fertilizer industry. The model is designed to represent the realities of the industry and remain consistent with a set of relevant theories of economics, marketing, and systems science.

The model is based on the theory of linear programming, a mathematical technique that will give the optimal solution to problems defined by a linear objective function subject to a set of linear constraints. Mathematically, the problem of linear programming may be stated as one of optimizing (minimizing, in this model) an objective function of the following form:

$$Z = \sum_{j=1}^{n} C_j X_j \qquad \text{where } n = 1,2,\ldots,N$$

subject to restraints of the form

$$\sum_{j=1}^{n} a_{ij} X_j \quad \begin{matrix} \leq \\ = \\ \geq \end{matrix} \qquad \text{where } i = 1,2,\ldots,M$$

and $X_j \geq 0$ for $j = 1,2,\ldots,N$

where X_j is the quantity of the jth variable of interest (activity) when there are N variables; C_j is the per unit contribution to the objective function; a_{ij} is the coefficient of the jth variable in the ith restraint when there are M restraints; and b_i is the ith requirement when there are M requirements in all (Naylor, 1963, p. 21). The Michigan model contains 2,654 activities (N=2,654), 757 restraints

(M=757), and 15,616 non-null a_{ij}'s in the basic matrix.[1]

The model was designed to represent the fertilizer industry of the United States as it relates to the utilization of fertilizers in Michigan. Consequently, essentially all of the components of the Michigan sector of the industry are included, while only those components of the regional and national industry that are relevant to Michigan markets are included.

Six basic functions in the industry are included: production, storage, handling, transportation, sales, and application. These functions are those necessary to convert mixed materials to fertilizer products, and move them to the soil of Michigan. Of the 31 products included in the model, 12 are strictly intermediate products.[2] These include nitric acid, nitrogen manufacturing solution, elemental phosphorous, green phosphoric acid (wet process), white phosphoric acid (furnace process), ammonium polyphosphate liquids (10-34-0), superphosphoric acid, run-of-mine potassium chloride, standard potassium chloride, run-of-pile triple superphosphate, and sulfuric acid.[3] Twelve products may serve as intermediate products, or may go directly to farms for application. They include anhydrous ammonia, ammonium nitrate, nonpressure nitrogen solution, low pressure nitrogen solution, urea, ammonium sulfate, normal superphosphate, diammonium phosphate,

---

[1]When special problems are studied, the number of restraints, activities, and a_{ij}'s may change because of the additions or deletions needed to represent a certain relationship or phenomenon.

[2]Intermediate products are those that are used in the production of other fertilizer products.

[3]Sulfuric acid can be purchased, as well as produced, within the industry.

granular triple superphosphate, monoammonium phosphate, rock phosphate, and granular potassium chloride. Seven products are used for direct application only: aqua ammonia, coarse potassium chloride, granulated mixed fertilizers, bulk blended fertilizers, hot mixed liquid fertilizers, cold mixed liquid fertilizers, and suspensions.

While most products have fixed levels of N, P_2O_5, and K_2O, the formulations and grades of the mixed products may vary. Bulk blends have 140 formulations representing 18 nutrient ratios. These ratios account for more than 80 percent of the fertilizer actually blended in Michigan in 1970. Granulation, hot and cold mixed fertilizers, and suspensions have 29, 15, 22, and 16 formulations, respectively.

Six production and processing locations that are possible sources of the fertilizers that can terminate in Michigan have been identified. The three primary production areas for N, P_2O_5, and K_2O are Donaldsonville, Louisiana; Tampa, Florida; and Saskatoon, Saskatchewan, respectively. Alternative production locations include a Midwest location (Peoria, Illinois), a central Michigan location (Lansing), and outstate Michigan locations. The locational alternatives make analysis of relative locational efficiencies possible.

Some products can be produced by more than one technical process. Only processes that were significantly different are included, however. For example, dry materials can be blended by several different processes ranging from labor intensive processes to capital intensive ones. To represent this continuum of processes, a labor intensive, a capital intensive, and an intermediate process midway between the labor intensive and capital intensive processes were included within the model.

Products may be stored at the manufacturing and processing

locations, at terminals, at the retailers or at farms, or they may not be stored at all. Usually, however, storage must be provided to reconcile the seasonal use of fertilizer with nonseasonal production.

Rail, barge, pipeline, and trucks are the primary means of transporting fertilizers interstate and intrastate. For local hauls from the retailer or mixer to the farm, applicators, trucks, wagons, nurse wagons or bobtails[4] may be used.[5]

When the product alternatives are incorporated with the alternatives of process, location, modes and routes of transportation, storage and sales, a complex system results. Figure I-1, the product schematic for anhydrous ammonia, shows some of the approximately 713,000 separate channels ammonia may take.

Although the model is designed to reflect the important interrelationships that will govern those interactions that the flow of by-product ammonium sulfate and sulfuric acid may cause, it is also much broader in scope. A system of controls was incorporated so that numerous situations could be evaluated under a multitude of assumptions.

Initially, three basic situations are examined. The first situation is the simulation of the actual conditions that occurred in the Michigan industry in 1970. The model was controlled to closely duplicate the product mix, the product flow, facilities used, and so forth. This analysis identifies, within the framework of the model, the current organization of the Michigan fertilizer industry. The

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[4]A nurse wagon is a trailer with a tank used to transport liquid fertilizers from the retailer to the applicator in the field. A bobtail is a tank truck (similar to those used to haul propane) used for the same purpose as the nurse wagon.

[5]The model is thoroughly described in (Bell, 1971). The data used in the model is presented in (Henderson, 1971).

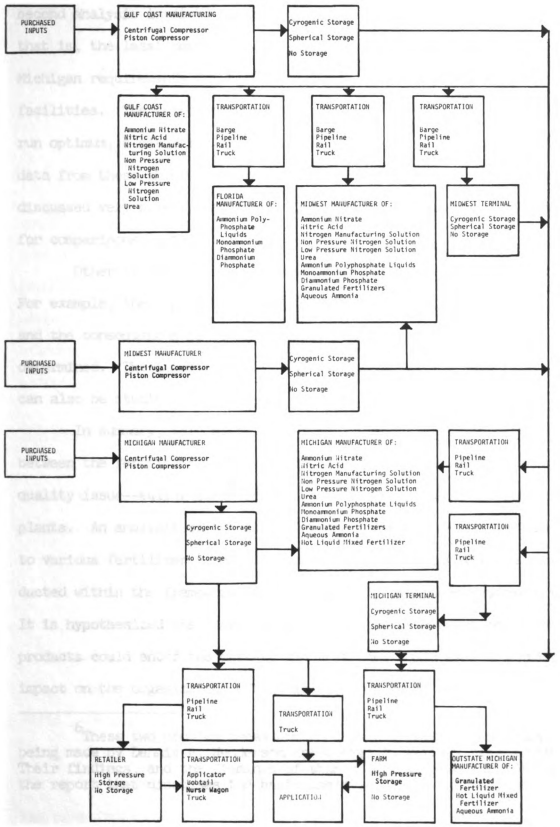

Figure I-1. Product schematic: anhydrous ammonia

second analysis involved the determination of the short-run optimum; that is, the least cost method of fulfilling the respective 1970 Michigan requirements for N, P_2O_5 and K_2O, utilizing only existing facilities. The third analysis was the determination of the long-run optimum, a situation in which new facilities may be built. The data from these three analyses are presented in Appendix A, and are discussed very briefly in Chapter III. These data serve as a basis for comparisons in this study.

Other situations can be investigated with the model as well. For example, the impact of shifts in the nutrient ratio of consumption, and the consequences of consumption of nonoptimal products can be determined. The impact of shifts in capital costs and wage rates can also be studied.[6]

In summary, this study will focus on the interrelationships between the fertilizer industry and one aspect of the environmental quality issue--sulfur oxide emissions from electrical power-generating plants. An analysis of the impact of the conversion of sulfur oxides to various fertilizer materials and their distribution will be conducted within the framework of the previously described systems model. It is hypothesized that large amounts of these by-product fertilizer products could enter the market, and that they would have a significant impact on the organization of the industry in doing so.

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[6]These two problem areas are the subject matter of studies being made by Dennis R. Henderson and George R. Perkins, respectively. Their findings, and the findings of this study, will be included in the report that discusses the basic analysis.

CHAPTER II

AIR POLLUTION AND THE FERTILIZER INDUSTRY

On February 10, 1970, President Nixon sent to Congress a 37-point program to rescue the nation's environment. Calling air "our most vital resource" and its pollution "our most serious environmental problem," he proposed amendments to the Clean Air Act to enlarge the scope of the national program to abate air pollution. With this stimulus, control of air pollution has become a national goal of high priority.

The Economics of Pollution

Decision makers are faced with the problem of determining the amount that should be spent on pollution abatement. From an economic stantpoint, this problem fits neatly into a theoretical framework.

One might expect, a priori, that the relationship between the level of pollution and the cost of damages caused by pollution can be expressed by a nonlinear function (Figure II-1 represents such a relationship). At low levels of pollution, damage is at a minimum. But as the pollution level rises there is a very rapid rise in damage costs. As the saturation point is approached the function may become nearly vertical.

One might also expect, a priori, that the relationship between the expenditures on pollution abatement and the resulting level of pollution can be represented by a nonlinear function (Figure II-2 plots

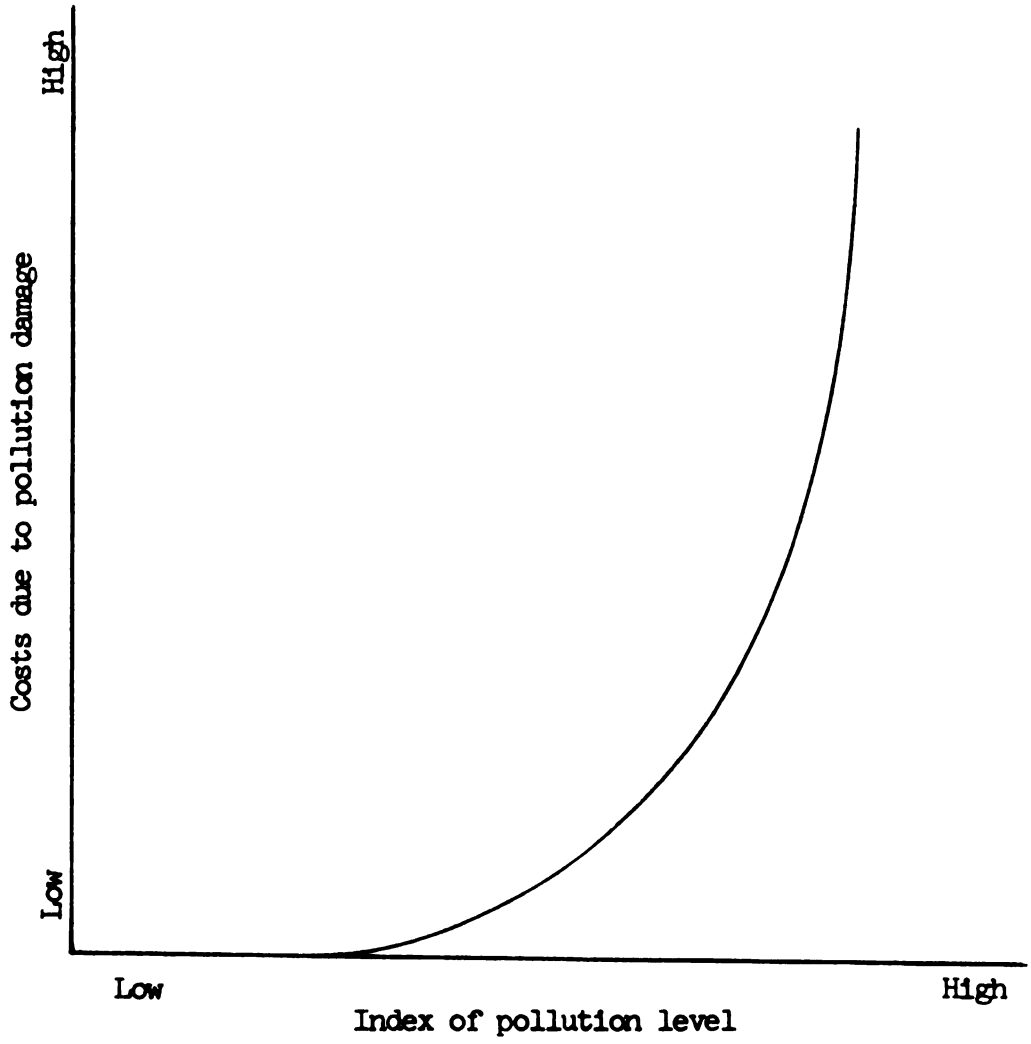

Figure II-1. Air pollution damage costs

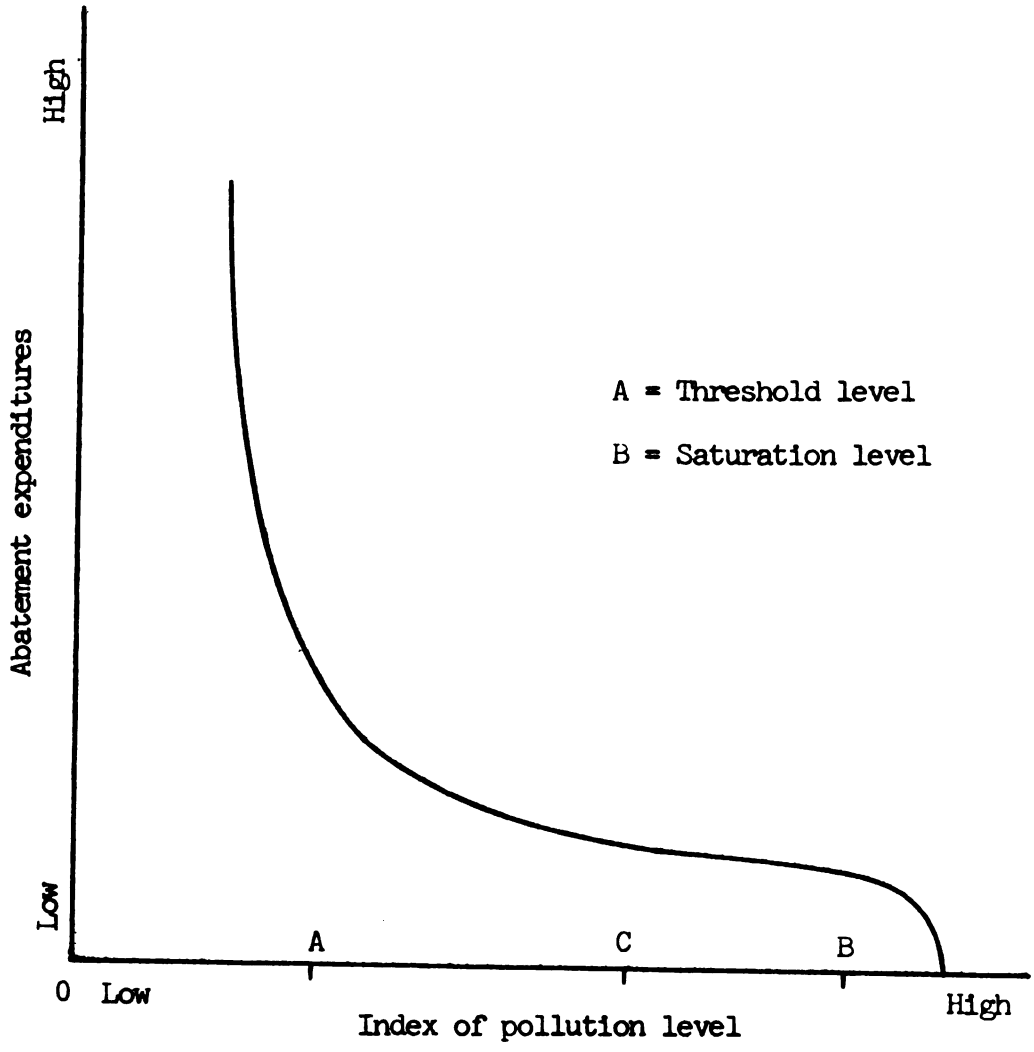

Figure II-2. Air pollution abatement costs

such a relationship). If one moved from Point C to Point A, the threshold level (in other words, the level at which air pollution would be at a low level and just recognizable), expenditures for increased levels of abatement would have to increase more rapidly to reach successive and more difficult to obtain levels of cleaner air, given a constant state of production technology. At lesser levels of expenditures for abatement activities, one would encounter an acceleration in pollution damages. If this abatement function were the actual function decision makers faced, we would expect low returns for small expenditures, then a long span of increasing returns (around the C area) and, finally, diminishing marginal returns to abatement activities as the air approached the threshold level.

The total cost of air pollution is comprised of these two components: the losses that result from air pollution damages, and the cost of expenditures to control it. The total cost curve can be derived by simply vertically adding these two cost curves (Figure II-3).

The socially optimal level at which to set the pollution standard is that which achieves the minimum on the total cost curve for air pollution (Point M, Figure II-3). While the theoretically optimal standard is easily identified on the total cost curve, the empirical problem is that of identifying the actual total cost curve, i.e., the empirical derivation of its component curves, the costs due to damages, and the costs of abatement activities.

Measuring the Cost of Air Pollution Damage and Abatement

While it is normally assumed that the damages from air pollution are costly to society, the actual costs attributable to air pollution

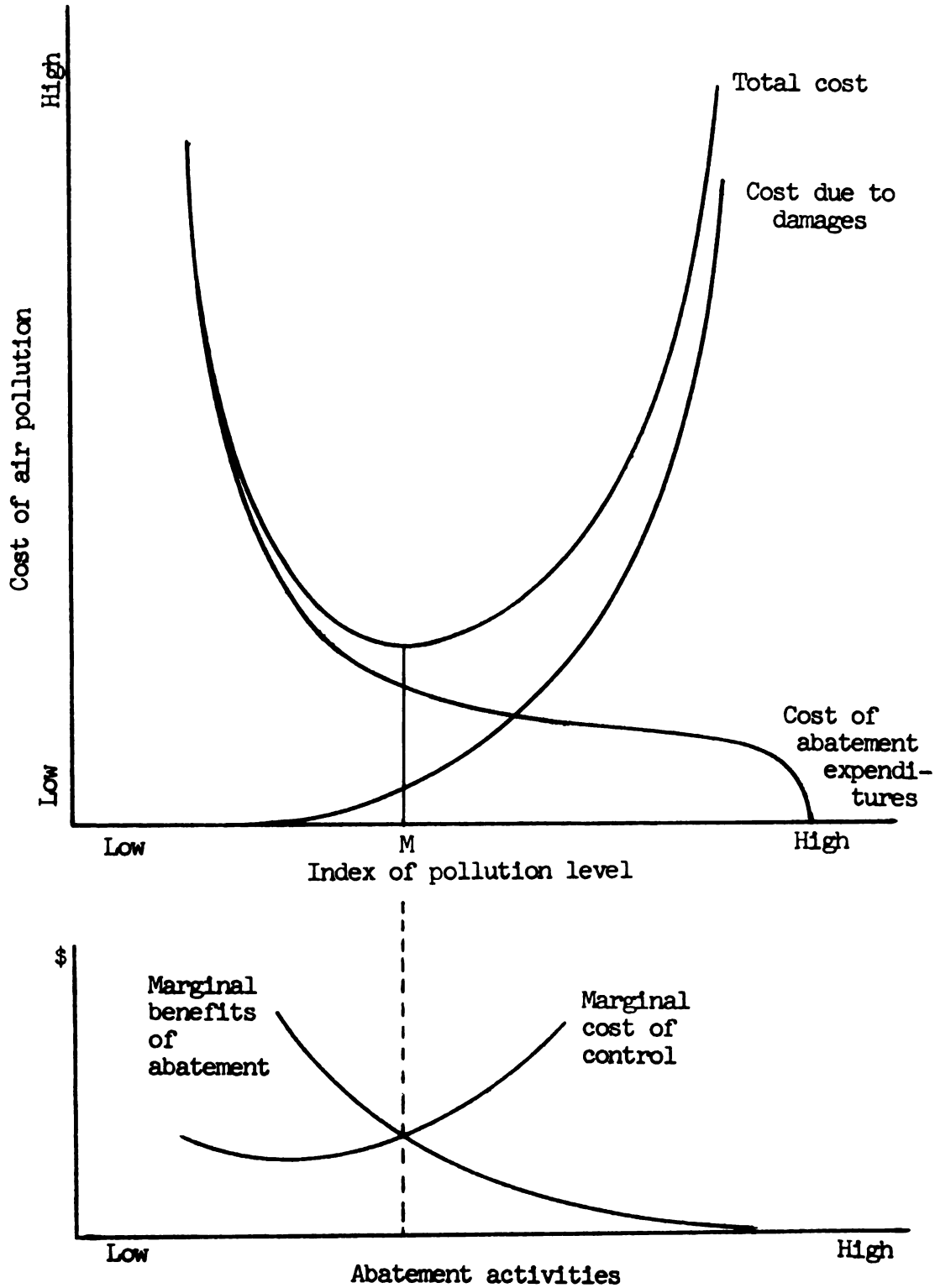

Figure II-3. Total and marginal costs of air pollution

are extremely difficult to determine. Several theoretical approaches are available to determine the cost of air pollution (Ridker, 1967). They correspond to the different levels or stages that can be distinguished. First, the pollution has certain direct and immediate effects such as paint damage, throat irritation, and plant damage. Measurement of these direct effects would require description of the damage per unit of each object affected as a function of the intensity of air pollution. This relationship could be presented as:

$$D_i = f_i(S), \; i = 1,2,\ldots,N$$

where D_i is a measure of the ith type of damage per unit of object affected by the pollution, and S is a measure of the pollution. Then a monetary weight appropriate to measure the importance of the particular effect, and an indication of the number of units of the objects affected must be obtained.

On the assumption that the monetary weights and the number of units affected stay constant as the level of pollution varies, the total cost of pollution can be obtained by multiplying the damage function by the appropriate cost per unit damage, C_i, and the number of units affected, Q_i, and then summing over all types of damage, yielding $\sum_{i=1}^{n} C_i Q_i f_i(S)$, the total cost of direct air pollution damage. The derivative of this function with respect to S is the marginal cost, the additional cost of achieving each succeeding unit reduction in the pollution level (Ridker, 1967, pp. 15-20).

The second theoretical approach to measure the cost of air pollution is based upon the assumption that the direct effects of the pollutants give rise to certain adjustments which individuals and firms

make to reduce the direct impact. For example, an asthmatic person may move to another climate or perhaps filter the air in his home. Such actions have the effect of transferring the direct loss from air pollution to other categories, where it appears in a different form. And although it may reduce the loss, it cannot eliminate it.

Procedures for measuring the cost of adjusting to air pollution, although difficult to carry out, are theoretically straightforward. First, each logically possible category of adjustment that can be used to minimize the effects of air pollution must be identified, and behavior falling into these categories measured. Then all important variables that could also explain this behavior must be identified and measured. Finally, for each category of behavior, statistical analysis must be applied to separate the effects of the pollution from the other factors that could also explain the behavior. The resulting damage function must then be combined with estimates of unit costs and quantities and aggregated over different categories of behavior to obtain a cost-of-pollution function (Ridker, 1967, pp. 20-23).

The third measurement scheme is based on the assumption that the only completely adequate way to measure the social losses of pollution is to take into account social interactions--the effect of one person's actions on another. For the purpose of measurement, the most important interactions are probably the effects that occur because people are linked together through a market system. Theoretically, the market effect represents transfers of benefits and costs between economic units. For example, an increase in pollution levels will depress the value of houses in that area and cause an increase in the value of houses in unaffected areas. By measuring the changes in market value that result

from changes in pollution, the cost of pollution can be obtained[1] (Ridker, 1967, pp. 23-28).

It is obvious that significant measurement problems are evident in these three procedures. Each has been tried on limited scale, and each encountered great difficulty. Although a comprehensive analysis has yet to come, estimates of the damage of air pollution have been abundant. The estimates range from four to 20 billion dollars annually.[2] However, the value of any estimate of current pollution damages to decision makers can certainly be questioned.

Recalling that the total cost of pollution is the sum of pollution cost plus abatement costs (Figure II-4), it is apparent that the relevant portion of the total cost curve is in the portion close to the minimum (Point B, Figure II-4). If one assumes pollution levels are well above the level that corresponds to Point B on Figure II-4, the total damages may well correspond to the area around Point A on Figure II-4.[3] Indeed, knowing precisely the location of A is not too important. Rather efforts should be directed toward identifying the level and shape of the curve around Point B on Figure II-4, since this

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[1]There are significant theoretical problems involved in this approach; for a discussion see (Ridker, 1967).

[2]Kneese points out discernable reasons for this wide range: (a) the figures given are guesses based on slender evidence; (b) they differ in inclusiveness (Kneese, 1966, p. 529).

[3]The staff of the Committee on Public Works certainly believes that the U.S. is in the area around Point A on Figure II-4. They report, "...it is clearly evident that the cost of property damages alone from air pollution is great—far greater than the amounts devoted to its abatement by industry and all levels of government;" in A Study of Pollution—Air, staff report of the Senate Committee on Public Works, 88th Congress, 1st Session, September 1963, p. 20. Although it does not necessarily follow, the implication seems to be that there is little chance of the costs of abatement activities exceeding the benefits.

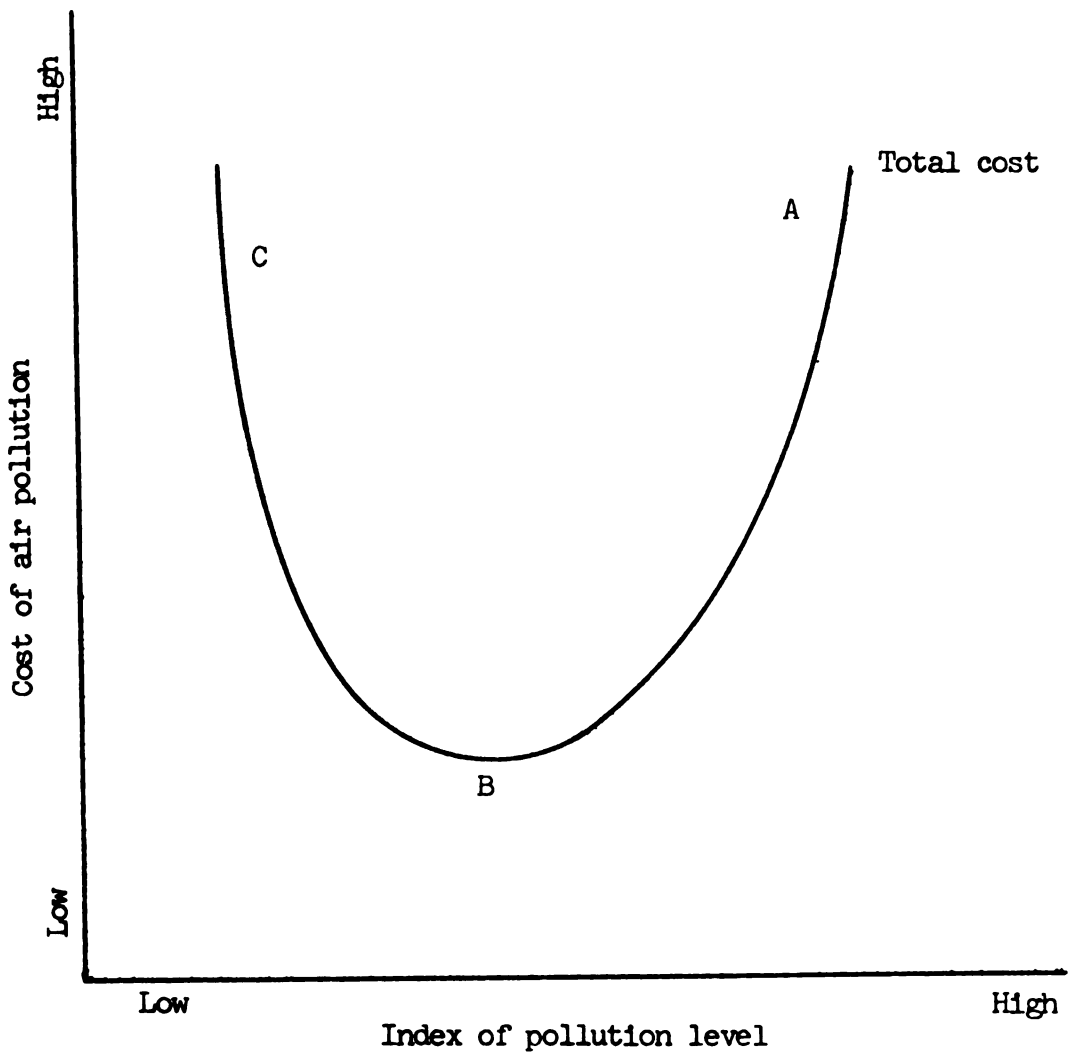

Figure II-4. Total cost of air pollution

is the relevant portion of the curve in determining the level of expenditures that are economically relevant in decisions concerning the abatement of air pollution.

Just as determining the cost of pollution damages is a difficult task, so is the task of determining the cost of abatement. Reliable estimates of costs of abatement at the macro level are scarce. Estimates of costs for specific processes have been made, but even they vary considerably. Often the control system is tied into production changes, or is added to older plants. In other situations, the controls are an integral part of a new installation and their costs cannot independently be accurately estimated. Each situation will have its own peculiarities which result in a unique set of costs.[4] Sampling design problems originate when aggregate supply response analyses are contemplated.

The Pollutants

The pollutants of the atmosphere are primarily gases and solids. The solids, referred to as particulates, are minute particles that remain suspended in air. The particles may be lead, arsenic, asbestos, beryllium, cadmium, or flourides, for example. The primary gaseous pollutants include carbon monoxide, sulfur dioxide, sulfur trioxide, photochemical smog,[5] nitric oxide, nitrogen dioxide, and hydrocarbons. The well-known 1967 estimates by the U.S. Department of Health, Education, and Welfare give the following figures for total discharge of

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[4]Estimates of the increased cost of electricity that will result from abating sulfur oxides vary greatly, ranging from six percent (Stites, 1970, p. 222) to 33 percent (Slack, 1971).

[5]Photochemical smog is a mixture of gases and particles manufactured by the sun chiefly out of the combustion products of such organic fuels as gasoline.

these pollutants in millions of tons per year: carbon monoxide, 72; sulfur oxides, 26; nitrogen oxides, 13; hydrocarbons, 19; and particulate matter, 11—a total of 141 million tons per year.

However, these figures mean little unless each pollutant can be assigned a weighting factor indicating its relative importance as a hazard and a source of annoyance. Based on expenditures appropriated for federal research grants, one might conclude that sulfur oxides pose the greatest threat to the environment. Even though automobiles contribute some 60 percent of the total mass emissions of air pollutants, HEW has allocated several times as much funding for research grants directed toward sulfur oxide control as on grants directed toward the abatement of the pollution from auto exhausts (Sherwood, 1970, p. 183). Health authorities appear to consider sulfur dioxide, and the accompanying sulfur trioxide, as the most serious single air pollution threat.

Sources of Sulfur Oxides

The combustion of fossil fuels accounts for 85 percent of the total sulfur oxides emitted to the atmosphere, with coal accounting for 60 percent of this amount ("Sulfur Oxides: Drawing a Bead on Air Pollution," 1968, p. 281).[6] Electric power plants account for over one-half of all sulfur oxide emissions ("Sulfur Oxide Control: A Grim Future," 1970, p. 187). The 274 million tons of coal annually burned by electric power plants produce 13 million tons of sulfur oxide, while the 156 million barrels of oil used annually account for one

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[6]Other sources include refinery operations, smelting of ores, coke processing, sulfuric acid manufacturing, coal refuse banks, and refuse incineration (Spaite, 1966, p. 162).

million tons, and 2,739 billion cubic feet of gas burned annually account for 3,500 tons of sulfur oxides.

To provide further perspective, the sulfur from electric power-generating plants are compared to the sulfur industry. Electric power-generating plants in 1970 were estimated to have emitted ten million tons of sulfur in the form of oxides (Hangebrauck, 1970). Sulfur consumption for all purposes in the United States in 1970 was only 10 million tons. The sulfur emitted from electric power plants in 1970 was equivalent to 30.7 million tons of sulfuric acid, which slightly exceeds the 30.6 million tons of sulfuric acid produced by the United States sulfur industry in 1970. The United States fertilizer industry, the primary consumer of sulfuric acid, used only 18.5 million tons of sulfuric acid in 1970 (Manderson, 1968).

Sulfur oxide emissions are not likely to diminish either, even if effective controls are implemented.[7] Estimates by the National Air Pollution Control Administration show rapidly increasing emissions (in the absence of controls) reaching 126 million tons per year by the year 2000 (Table II-1). Electric power-generating plants will account for an increasing share of these total emissions.[8] The estimate of power plant emissions of 94.5 million tons in 75 percent of the estimated total emissions for the year 2000 (Table II-1).

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[7] Rohrman, et al., in studying future emissions of sulfur oxides, used estimated demands on the industries producing sulfur oxide pollution to project the overall emission rates to be expected under varying degrees of control of emissions. Figure II-5 shows an estimate of what can be expected at two levels of control as compared with present practices: (1) with good progress in development and application of control methods (Case I); and (2) with control methods developed and applied on a crash basis (Case II) (Rohrman, 1965).

[8] This results from the phenomenon of a doubling of power needs every eight to ten years in the United States.

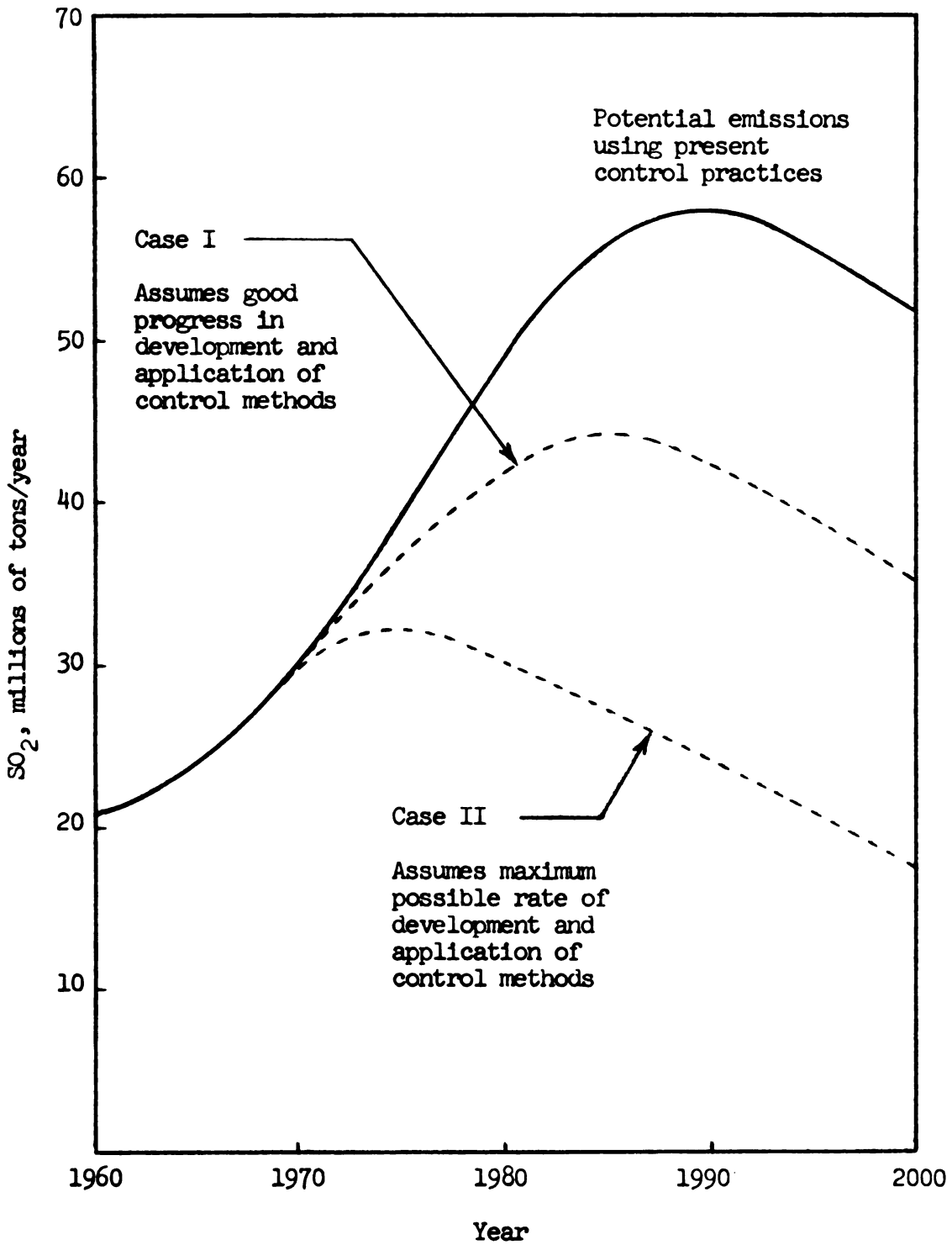

Figure II-5. Potential sulfur dioxide emissions in the United States

Table II-1. Estimated potential sulfur dioxide pollution without abatement for the United States

	Annual emissions of sulfur dioxide, in million tons			
	1970	1980	1990	2000
Power plant operations (coal and oil)	20.0	41.1	62.0	94.5
Total emissions	36.6	60.9	86.4	125.8
Power plant emissions as percent of total	55.6	67.5	71.8	75.1

Source: February 1970 estimates by National Air Pollution Control Administration (Middleton, 1970, p. 172).

In 1969, 21,432 million tons of the 35,674 million tons of bituminous coal shipped to Michigan went to power utilities (Gallagher, 1971, p. 357).[9] Much of this went to seven major power plants. In 1975, these plants are expected to burn approximately 19 million tons of coal. This volume of coal would contain about 584 thousand tons of sulfur (Table II-2). If all of the sulfur burned to sulfur dioxide, there would result 1,076,200 tons of that air pollutant.[10] If scrubbing devices are successful in removing 90 percent of the sulfur oxides, 1,606,730 tons of sulfuric acid or 2,164,749 tons of ammonium sulfate (or some linear combination in between) would result from the scrubbing operations as by-products (Figure II-6).[11]

The 2,164,749 tons of ammonium sulfate contains approximately

[9] Small amounts of anthracite coal was also consumed by utilities in Michigan.

[10] Usually some of the sulfur is emitted as sulfur trioxide and sulfuric acid.

[11] The conversion of sulfur oxides to sulfuric acid and ammonium sulfate will be presented later in this chapter.

Table II-2. Estimated coal consumption and sulfur content of seven major power plants in Michigan in 1975[a]

Plant	Location	Consumption tons/year	% sulfur	Sulfur tons
B. C. Cobb	Muskegon	1,334,000	1.7	22,678
Board of Water and Light	Lansing	953,000	2.5	23,825
Campbell	West Olive	1,687,000	3.2	23,825
Karn	Essexville	1,432,000	2.2	31,504
Monroe	Monroe	8,000,000	3.5	280,000
St. Clair	St. Clair	4,800,000	3.0	144,000
Whiting	Luna Pier	988,000	2.8	27,664
Total		19,185,000		583,655

[a]Compiled from: (Rector, 1970) and (Esch, 1971).

454,597 tons of nitrogen (N). If the ammonium sulfate were used to manufacture an ammonium phosphate-sulfate, with a 20-20-0 analysis, the 2,042,216 tons of fertilizer product would contain 408,443 tons of N and an equal amount of P_2O_5. The amount of N in the ammonium sulfate is 3.2 times the total amount of N consumed in Michigan in 1970. If the ammonium phosphate-sulfate product were produced, it would provide 2.9 and 2.6 times the 1970 Michigan consumption levels of N and P_2O_5, respectively.

The amount of sulfuric acid needed to produce the wet process phosphoric acid, which is utilized in Michigan under the optimal organization of the industry, is 260,565 tons. Scrubbing the effluent from these seven Michigan power plants would provide 4.2 times that amount.

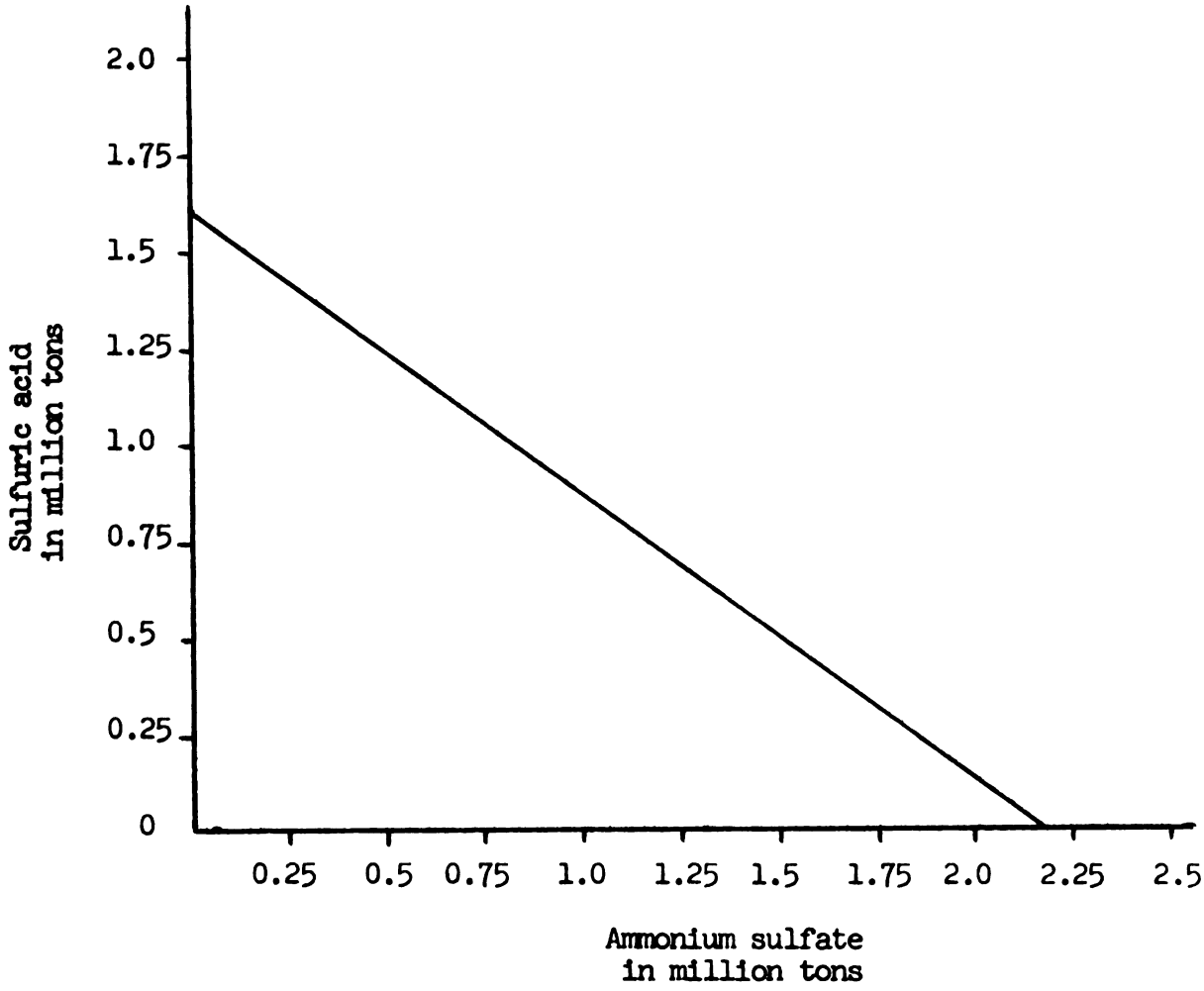

Figure II-6. By-product sulfuric acid-ammonium sulfate production frontier from scrubbing seven major power plants in Michigan in 1975

Pollution Abatement: Market Versus Collective Action: Expectations

Smoke has often been used as a classic example of a negative external effect. Essentially all economists agree that the discharge of pollutants into the atmosphere imposes on some members of society costs which are inadequately imputed to the sources of the pollution by free markets, resulting in more pollution than would be desired from the point of view of society as a whole. Since the cost of pollution to society is not reflected through the market, it is not an important decision variable for the economic unit producing the pollutant. This creates a misallocation of resources since the full cost of producing the economic good (electricity in the case of the electric power-generating firm) is not reflected in the cost curves for the firm in question. Consequently, the firm draws into production more resources than is socially desirable; i.e., the marginal cost of electricity is understated.

The problem of abating air pollution is determining the best manner for reflecting the cost of air pollution in the firm's decision-making framework. Essentially all legislation that has been enacted to date fails to internalize those costs. At best, it only solicits abatement activities by offering incentives such as tax exemption or subsidies on investments in abatement equipment. Firms must still bear the bulk of the cost of controlling emissions, and few have volunteered to do so.

Consequently, a more persuasive approach must be taken; an approach that removes the voluntary aspect of former legislation. But there is real question as to whether or not the American people are legally, politically, technologically, economically, and socially

ready for the nonvoluntary approach. This is important because the rate of development of nonvoluntary controls, the form of those controls, and the resulting sulfur oxide abatement activities are a function of each of those areas. The remainder of this section examines the various components of this issue and determines their implications for various policy alternatives. Finally, it identifies likely development in nonmarket controls for the abatement of sulfur oxide emissions.

Citizens may protect their right to clean air by use of several different common laws currently in existence in every state, including private and public nuisance laws, trespass laws, the Constitutionally protected right to live, and laws relevant to the trust of the nation's natural resources. It is argued that in cases where natural resources are being unduly damaged as a result of some firm's emission of pollutants, courts may rule that the firm stop polluting. Society holds the "common property" natural resources in trust and courts can stop any activity that it feels involves unjustified use of those resources.

The Constitution protects the right to live. Yet firms that fill the atmosphere with matter that acts as poison are killing humans. A situation may be determined a nuisance if it causes inconvenience, discomfort, annoyance, damage or harm to a person or to the public (Van Doren, 1971, p. 16). A firm could be guilty of trespassing if it prevents a person from fully using his land or property (Speck, 1970, p. 85).

Some states have enacted laws designed to protect personal rights from firms that might otherwise infringe on those rights by polluting the atmosphere. These laws are primarily adaptions of time-honored common law and statutory concepts. The Environmental Protection Act

of 1970 passed in Michigan is such an act (Appendix G). It is

> An act to provide for actions for declaratory and equitable relief for protection of the air, water and other natural resources and the public trust therein; to prescribe the rights, duties and functions of the attorney general, any political subdivision of the state, any instrumentality or agency of the state or of a political subdivision thereof, any person, partnership, corporation, association, organization or other legal entity; and to provide for judicial proceedings relative thereto.

One can easily imagine situations where each one of these statutes may be used to protect personal rights. However, such procedures for controlling pollution leave much to be desired. First, it places the issues in courts—courts that are already so overloaded that it is questionable whether or not justice is being served. Secondly, it is difficult for plaintiffs to prove "beyond doubt" that a given firm is responsible for a given loss. In some cases, clear scientific evidence must be shown, and even the high correlation between cigarette smoking and lung cancer would not be considered clear scientific evidence. Third, the outcome of any case may not be in the public interest. In a case involving private rights, the public interest cannot be given proper consideration. Consequently, a decision in favor of the plaintiff may not be in the social interest. For example, a plant that is the basis of the economy in an area may be required to stop polluting because a household is being showered with pollutants. Such an order may cause it to shut down, in which case the social loss may be great. On the other hand, a firm that is causing great social loss through its pollution emissions may be required by the court to pay damages to the plaintiff, in which case it may continue to pollute. It cannot be expected that the courts would become an economic decision maker in these situations. Finally, a law such as Michigan's Environmental Protection Act of 1970

would supersede regulations or directives established by the State Air Pollution Control Agency. Consequently, a firm which operated under the approval of the agency could be taken to court under the Environmental Protection Act. The appropriate court may then determine the reasonableness of the agency-issued standard and, if it found the standard deficient, could direct the defendant to adopt a more stringent device or procedure (Johnson, 1971, p. 6).

The use of common laws and the courts may serve to control certain situations where it can be clearly demonstrated that a firm, or firms, are responsible for losses suffered by a citizen. However, such an approach cannot be used effectively as a universal means of pollution control.

Alleviation of air pollution is, among other things, a political problem (Hill, 1968). Traditionally, politics is the art of compromise. But air pollution, in the severity that it is developing in many localities, is about as subject to compromise as is pregnancy. Public decision makers are faced with complex problems with numerous facets, each with a sound argument. And the public will be split on all sides, often with an individual taking opposite sides. For example, a group may appear before a senate subcommittee testifying to the evils of air pollution and recommending a clamp-down of certain firms.[12] The same group will return home to stoke their coal furnaces and burn their leaves, and argue their right to do so. Individuals will wage verbal war against a polluting firm, and yet will not be willing to sacrifice the jobs nor pay the higher prices that may result from the firm's

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[12]For a brief review of the effects of sulfur oxides, see Appendix F.

abatement activities.

Generally, an issue as complicated as air pollution control poses significant risks to political decision makers. Legislators would have to interpret the vibrations, and their political careers may rest on that interpretation. They would have to carefully weigh the political viability of each alternative. However, legislators appear to have successfully eliminated much of the risk involved in air pollution control by establishing the Environmental Protection Agency at the federal level, and air pollution control agencies at the state level, and by charging the agencies with the responsibility of establishing the necessary rules and regulations, and empowering them with the tools necessary to carry out their objectives. Of course, the legislators did not sacrifice all control. They are still responsible for appropriating funds, and this single responsibility gives them considerable control. In addition, just as the legislature created the agency, it can alter it or even eliminate it. Although the establishment of the environmental protection agencies may have reduced the importance of personal political objectives as a variable in developing pollution control, the basic issues remain.

The influence of industrialists and environmentalists is an important factor determining the rapidity with which the agencies will establish regulations and the effectiveness of those regulations. One might expect the agencies to side with industry, for the interests of big industry seem to be highly intertwined with the political system. On the other hand, the cause of the environmentalists is real; the great cost and trend of current pollution activities can neither be denied nor ignored.

The environmentalist's position will continually strengthen as (1) pollution levels continue to increase, (2) better data on the cost of pollution becomes available, (3) as technological advances make abatement easier and less costly, and (4) as industry increases its willingness to accept abatement regulation. This last factor is an important one. Big industry exerts considerable influence on legislators, and much of this influence will be felt by the agencies. Until industry determines the control of sulfur oxides is desirable, it will serve as an important barrier to the development of effective controls.

A primary problem in developing effective regulation is that of establishing a pragmatic relationship between the various levels of government. The 1963 Clean Air Act specified that the prevention and control of air pollution at its source is the primary responsibility of state and local governments and the primary role of the federal government is to support the state and local governments with technical and financial assistance.

However, the problem of jurisdiction is particularly acute in the case of air pollution since the geographic spread of pollutants recognizes no political boundaries. For example, it has been estimated that one-fourth of the people in the United States live in approximately 23 standard metropolitan areas (as defined by the Census Bureau) that cross state lines and 28 others which extend up to a state line (Edelman, 1968, p. 564).

The Air Quality Act of 1967 was designed to overcome this problem. It establishes procedures whereby states may join together to form an air quality control region. Thus, in situations where the pollution

crosses state boundaries, the respective states can jointly attack the problem.

Under the 1967 Act, the federal agency will establish minimum standards, as well as provide financial and technical assistance. The states, which maintain primary control, must set standards at least as strict as the federal standards. They may establish more restrictive controls. Although local governments may enact controls more restrictive than either state or federal standards, it cannot exempt firms from those standards.

Although essentially no one questions the basic precept that local and state governments are responsible for pollution control while the federal government functions in a supportive role, the trend is to the contrary. In the beginning, the federal Air Quality Act authorized only studies and grants. It now directs the Administrator of the Environmental Protection Agency to promulgate criteria for the guidance of the states, to designate air quality control regions, and to set federal air quality standards in the event a state's efforts are insufficient. As Senator Muskie states it,

> The federal role is that of setting national goals, providing the necessary scientific, technical, and financial support to launch an effective air quality enhancement program, providing the framework for regional institutions to plan for and to implement such programs, and having available the necessary enforcement authority in those cases where jurisdictional impasses or the breakdown of local authority make it impossible to protect health or welfare of communities and states (Muskie, 1968).

This growth in federal activity does not originate from its zeal for power. Rather it originates from necessity; it originates from the inactivity of states.

Although the inactivity of states probably originates from

several factors, the economic consequences of a state's aggressive pollution control measures alone would likely be a sufficient deterrent. Abatement controls, once established and enforced by a state, would require that a firm bear all costs of production. Whereas previously the firm was allowed to pass some of its production costs on to society simply by discharging waste, it now must either discharge that waste in a manner that does not depreciate the welfare of others, or must stop producing the waste. Either procedure will require investments by the firm and will involve some operating costs (assuming the firm will continue operating). This will increase the fixed and variable cost of producing each level of output and, consequently, the firm's average fixed cost, average variable cost, average total cost, and marginal cost will have risen at each level of output (Figure II-7). If the firm was marketing its product in a purely competitive interstate market, and if other states did not enact similar regulations, the consequences of the pollution control could be catastrophic. By equating its new marginal cost with its marginal revenue ($MC_1 = P_0$ in Figure II-7), the firm's level of output would decrease and it would now be realizing a loss. Although a firm may be able to withstand a loss in the short run, it would have to cease production in the long run.

If the firm marketed in an imperfectly competitive interstate market, its output would again fall, but it would not necessarily be operating at a loss.

Consequently, aggressive air pollution control by any one state, without similar activities in all other states, could have dire effects on firms, their owners and employees in that state, and could have considerable impact upon the economy of the state. To prevent such a

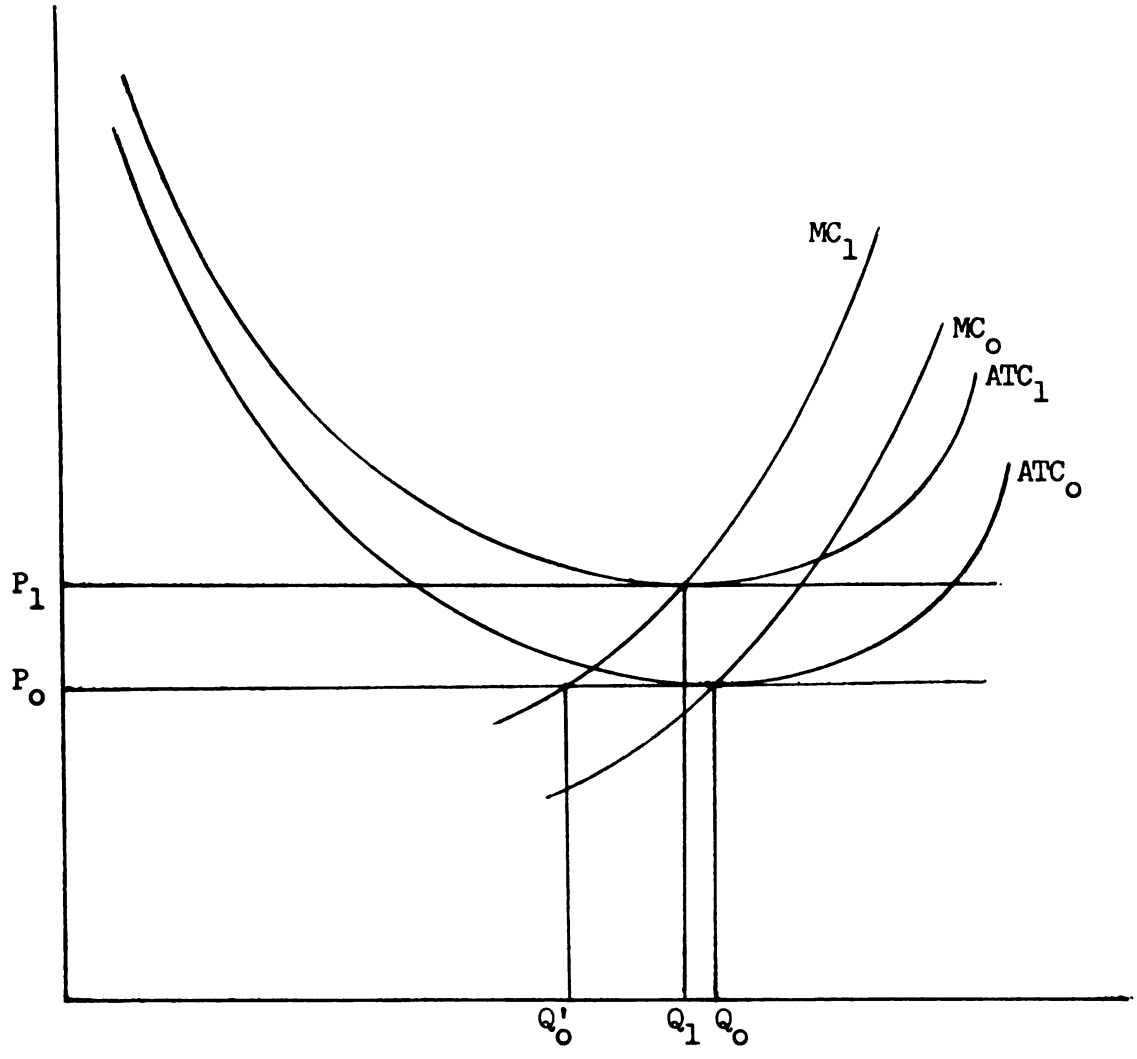

Figure II-7. The impact of pollution controls on a firm's cost curve

situation, the state need only wait for federal regulations to force all states to initiate similar regulations in unison. Such a procedure would result in a general price increase for the product (to P_1 in Figure II-7), but would not significantly affect the relative position of firms in any one state.

This economic phenomenon, which prevents a state from being the leader in controlling air pollution, may also cause it to lag in enforcement of standards required under federal controls. Firms not required to internalize all costs of production would gain an economic advantage over the firms in other states where federal standards are enforced. Consequently, the firm and those associated with it (except possibly for those suffering from the pollution) would gain economically as would the state. For this reason, the federal agency will not only have to establish the standards; it may also have to enforce them.

Three approaches are generally available for regulating firms in an effort to lower pollution levels: 1. charge the polluter for his production of the undesirable product (pollution); 2. pay him for his production of the desirable good (clean air); or 3. force him to stop polluting through direct regulation. These three approaches will be discussed along with a fourth alternative that is relevant in the case of power-generating plants.

The most common method for dealing with air pollution to date has been the direct regulation of emissions. Direct regulation includes a combination of licenses, permits, registration, zoning, and the enforcement of air quality and effluent standards. Proponents of direct regulation emphasize its effectiveness. Not only are regulations easy to administer, policing is easy since noncompliance can easily be determined.

Another primary advantage of direct regulation is that it permits the government to take interim steps even though it has little information on relevant pollutants measurements. It is argued that government agencies have the right to force abatement (at least temporarily) of emission of pollutants from any given firm in situations where it is known to contribute to overall pollution levels, even if the government does not know to what extent the firm is contributing. This argument is based on the contention that suspected negative health effects from air pollution is sufficient basis for abatement action.[13]

Economists are disturbed with such proposals, however, since the action could result in greater social cost than do the pollutants. They argue that only after the relevant data is secured can rational decisions be made. While this may well be true, Crocker points out:

> Given the uncertain quality of available physical, biological, and economic information, and the potentially high costs associated with the gathering of additional information about atmospheric pollution problems, the control authority, in order to impress receptors and emitters with the necessity of regarding the air's two value dimensions[14] as scarce economic resources, appears to be justified in setting minimal standards (Crocker, 1966, p. 79).

It can also be argued that by imposing standards, polluters are forced to reduce emissions, and in situations where the technology is either lacking or nonexistent, this incentive would be sufficient to stimulate truly innovative research and development of abatement technologies.

As expected, direct regulation, a simplistic approach, is not

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[13] A representative statement of this view is U.S. Senate, Air Quality Criteria, A Staff Report of the Subcommittee on Air and Water Pollution, Committee on Public Works, 90th Congress, 2nd Session, July 1968.

[14] Crocker identifies the two value dimensions as life and property supporting capacity, and waste disposal capacity (Crocker, 1966, p. 64).

without cost. While it is effective in dealing with the grossest forms of pollution, it would be difficult to use for equalizing incremental abatement costs among emitters in a relatively precise manner. Although it can be argued that direct regulation can be administered in a flexible manner, evidence shows that it usually is not. Thus, an objection to direct regulation is that its alleged inflexibility results in higher costs than would more selective measures.

An alternative approach to direct regulation is payments, which not only includes direct payments of subsidies, but reduction in collections as well. Examples include subsidization of certain control devices, exemption of pollution control devices from local property taxes, and tax credits for investment in control equipment.

A possible payments system would involve grants to polluters to motivate them to restrict emissions to an optimal level. The grant would vary with atmospheric conditions, effluent location, quantity of effluent, and quality of effluent. However, the more typical proposal under the payments heading relates to tax relief or subsidies used in conjunction with direct control.

There is a strong practical argument against most of the schemes under the payments heading. They are simply payments for the wrong thing. The payment should depend on the amount of pollution discharge, and not on an activity that is directly or indirectly related to the discharge of pollutants. For example, a payment to firms for decreasing the discharge of pollutants is better than a tax credit for investment in pollution control devices because the latter creates a bias against

alternative means of reducing emissions.[15] More efficient control can normally be obtained by incentives that depend on the variable it is desired to influence rather than by incentives that depend on a related variable.

Some 'charge' proposals suffer from the same shortcomings. Charges are often based on related activities rather than on the amount of pollution discharge. For example, an excise tax on coal is less desirable than a tax on the discharge of pollutants resulting from burning coal because the former distorts resource use in favor of other fuels and against devices to remove pollutants from smokestack gases. If, however, this problem is avoided, the charge approach has strong theoretical basis.

In an effort to reach minimum total cost for pollution, emissions should be reduced until the marginal cost of further reductions equals the marginal benefits derived. By using the charge approach, this procedure can be followed. The control agency would evaluate the damage done by the emission of incremental amounts of pollutant into

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[15] A prime example of this problem is Michigan's Tax Exemption Act 250 (1965) administered by the State Tax Commission which provides for the exemption from locally assessed real and personal property taxes for facilities installed primarily for the control of air pollution.

Another problem has developed as a result of this act. This problem centers around the installation of process equipment which effects a reduction in air pollution, but which may not have been installed primarily for the purpose of air pollution control. For example, firms have submitted applications for tax examptions on equipment to convert from coal firing to gas firing, a sure way to reduce emissions. But in reviewing applications, the state health department denied exemption on those types of installations. Of the $218,900,000 investments submitted in 429 applications for exemption, only $119,100,000 worth of exemptions have been granted. Appeals to the state's tax commissioner, the final authority, have resulted in the support of state health department's decision indicating that process changes are not in themselves eligible for tax exemption (Second Annual Report, 1970, p. 124).

the air at any given location and time and assess the emitters a corresponding amount. The economic unit can then decide on the best adjustment to make in light of the costs and benefits they perceive. If the firm can reduce emissions at a cost that would be less than the charge, it would do so to avoid being assessed the charge. If it cannot reduce emissions at a cost less than the charge, it would elect to pay the fee, but would nevertheless have a continuing incentive to reduce emissions. Thus, the optimum level of pollution abatement would be approached by the method that is least costly to society as a whole.

The practical problems associated with this method, however, are prohibitive, at least for the near future. These problems include fee collection, data collection and evaluation, measurement of damages, identification of the polluters and allocation of damages, particularly when synergistic effects occur; that is, when the combination of two or more pollutants cause more damage than either pollutant could cause alone.

The fourth alternative for controlling emissions is relevant in the case of electric power-generating plants and has its basis in the fact that they are regulated utilities. It is asserted that the regulating agency could create a situation in which electric power-generating plants would find it advantageous to control their emissions.

The regulating agency performs three roles when it regulates power-generating plants. It acts as a proxy for the legal mechanism, the price mechanism, and the voting mechanism. As a substitute for the legal mechanism, the agency protects the legitimate claims of the utilities' shareholders with respect to the level and rate of earnings that the firm enjoys. Earnings are allowed on the basis of

$$R = 0 + (V-D)r \qquad 1$$

where R = return, 0 = operating costs, and the return to capital is given by the product of the rate of return 'r' times the rate base, the original value of the plant and equipment 'V' less accumulated depreciation 'D'.

As a substitute for the price mechanism, the agency must determine how the new capital that is presented for inclusion in the rate base will influence the output and distribution of goods and services throughout the economy. This problem is further complicated by the fact that the agency must also try to ascertain whether or not the adjustments that will take place as a consequence of their actions represent a move toward improving the community's welfare.

Finally, as a substitute for the voting mechanism, the regulating agency must treat the utility as an object of the community's social preferences. In the case of air pollution, the agency becomes the vehicle through which the community expresses its preferences to the management of the utility.

If the regulators perceive that society is seriously concerned about the damages caused by the effluents from electric power generating, and that society is willing to pay for abatement measures in the form of higher electrical rates, they have the right to allow such expenditures for abatement devices as acceptable costs in providing electricity.

The firm could then invest in the pollution abatement equipment and add it into its rate base. Likewise, the cost of operating the equipment would also be allowed. The allowable earnings would then be

$$R' = 0 + 0_{EC} + (V+V_{EC}-D)r$$

where O_{EC} is the operating cost of controlling emissions and V_{EC} is the value of the equipment needed to control emissions. Since R' would be greater than R in equation 1, the utility would be allowed to raise its electrical rates so that it could realize revenues equivalent to R'.

Further incentives for the power plant would depend on the value of the by-products in the fertilizer industry and on the tolerance of the regulators. Assuming the utility could sell or transfer the by-products at zero cost (or at a negative cost if a disposal cost is allowable) to another enterprise or to a subsidiary, that division could then market the by-products, thereby generating revenue to that enterprise. If the regulators considered this revenue external to the power-generating enterprise, the revenue generated by the sale of the by-product would not be included in R' above and the total revenues of the firm would be increased.

Thus, if investments and operating costs are allowed in the regulated portion of the business, and if the by-products can return sufficient revenue outside the regulated portion of the business, profits of the firm would be enhanced, emissions of sulfur oxides from the power plant would be reduced, and significant amounts of ammonium sulfate and/or sulfuric acid could be routed into the fertilizer industry.

Because of the complexity of the problem, all four approaches will be used to control sulfur oxide emissions. Sulfur oxides are emitted into the atmosphere from a great variety of facilities including power plants, refineries, smelters, coke processors, sulfuric acid plants, and even from refuse incineration. Directing attention

to power plants alone does not reduce the problem appreciably. Size of power plants varies greatly. For example, one power firm in Michigan operates a 7,500-KW plant as well as a plant at least as great as 1,490,000 KW. There are plants currently being built and plants 50 years old. Some plants can burn only coal, while others may burn a variety of fuel. And there is a great variety of firing technologies used in these plants.

The importance of this characteristic of great variety lies in the implications it has for physical emission control techniques that may be applicable. No one process is applicable to all facilities. Indeed, any given control technique may be limited to very few types of facilities, and for those types of facilities where the process is applicable, the costs may vary considerably. Unfortunately, for numerous plants, no economical control technique may be available. This variety will serve to complicate the problem of regulating sulfur control. Consequently, a simplified approach must be taken, and it is becoming increasingly apparent that the direct regulation and/or directives[16] approach will make up the bulk of the regulations, and that emission requirements will be the primary criteria.

The trend to this approach has been established in foreign countries as well as in the United States. Japan, which suffers from critical levels of air pollution, uses emission controls to reduce sulfur oxide levels. Under their current regulations, sulfur oxide emissions must be less than

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[16]A regulation applies to all firms that fall in the class defined within the regulation regardless of the type of firm, its products, location, resource base, etc. A directive is a rule or decision that applies to one firm, and is normally based on the unique characteristics of the situation with which it is concerned.

$$q = k \times 10^{-3} He^2$$

where q = quantity of SO_2 in CM M/hour at STP

He = effective stack height in meters

and k = a constant which varies by regions and currently ranges between 5.26 and 26.3 (Profile Study of Air Pollution Control Activities in Foreign Countries, 1970, p. 99).

Essentially the only effective air pollution controls in use in the United States qualify as direct regulation, i.e., licenses, permits, registration, and most use emission standards as the primary criteria. Control of particulate emissions from a variety of sources and control of motor vehicle emissions have led the way. The states of New York and California and the cities of Toledo, Newark, and Chicago have motor vehicle emission controls. Control of particulate emissions from fuel-burning plants, refuse-burning equipment and from manufacturing processes has been initiated in eight major cities, five counties or areas, and in four states.

Control of sulfur oxide emissions appears to be following a similar pattern, with standards already established in the cities of New York and St. Louis, and in metropolitan Dade County, Florida; the county of Los Angeles; the San Francisco Bay area; and the county of Sarasota, Florida. For example, Los Angeles County specifies that emissions of sulfur dioxide shall not exceed 0.2 percent by volume at the point of discharge. The Missouri Air Conservation Commission adopted the Air Pollution Control Regulation for St. Louis Metropolitan Area which states that emissions of sulfur dioxide from plants that produce 2,000 million or more Btu's per hour shall be less than 2.3 pounds per million Btu's of heat. The San Francisco Bay Area limits

emissions in excess of 2,000 ppm.

Some of these agencies also use other criteria and other approaches. The Pollution Control Ordinance of metropolitan Dade County, Florida, and the San Francisco Bay Area Air Pollution Control District uses ground-level concentrations of sulfur dioxide as the criteria rather than smokestack emission concentrations. Although Los Angeles County has a smokestack emission limit, it also restricts the use of high-sulfur fuels between April 15 and November 15 of the year (this is an indirect control, as the limitations are placed on the quality of the input, rather than the effluent quality). New York City limits the sulfur content of coal to one percent by weight.

Many states currently use the payment approach for firms that invest in abatement equipment. However, it usually takes the form of exemption from taxes. There are likely to be subsidies, however, in cases where the only alternative would be to cease operations. For example, a small marginal firm may have high concentration of sulfur dioxide in its smokestack plume. Because of the characteristics of its furnaces, and its financial situation, a regulation to curb emissions may force it to discontinue production. However, rather than allow this to happen, a state or federal grant or loan may be available to provide the firm with enough financial strength to continue operations.

The payments approach cannot generally be used as a means of establishing emission controls. There is no natural source for generating the funds necessary to carry out such a program. Any money that is granted will probably have to be collected from the public through usual taxing procedures. Another shortcoming to this approach is that often the technique of abatement is specified and the firm in question

loses its option of determining the process that could result in least cost. Although this need not be the case, it often is. Even though the payment approach cannot be used as a primary means of control, it can be expected to be used in situations where grave consequences that may otherwise result wish to be avoided.

The effluent fee approach will be used to some extent early in abatement programs. However, it will without doubt take a less efficient form, such as a tax on high-sulfur fuels, rather than the economically optimal approach of taxing on the basis of the damage caused by emissions. This approach can be expected because, in the short run (i.e., in the next couple of years, at least), consumption of low-sulfur fuel will be the only technically feasible method of controlling emissions. The theoretically optimal approach will not be used because of measurement and administrative problems. Once proven processes are available for removing sulfur from flue gases, one would hope to see the tax on high-sulfur fuels removed.

The removal of sulfur dioxide from the emissions of power plants should be easy to regulate. Public utility regulators have encouraged power plants to invest in pollution control equipment by allowing investments and operating expenses for pollution control as justified expenses in producing electricity. Thus, power firms are allowed to pass the cost of abating emissions on to the consumers of electricity in the form of higher electrical rates. The firm would not face the problems relevant to interregional competition since each firm's market seems to be well-defined geographically.

In conclusion, all four approaches will be used to improve ambient air qualities. Although direct regulation will be used most

heavily for controlling emissions, payments and effluent charge schemes will also have an important role. Once reliable processes are developed for removing sulfur dioxide from flue gas, power utilities can be expected to control their emissions even in the absence of direct regulation, payments, or effluent fees.

Control of Sulfur Oxide Emissions from Electric Power-Generating Plants

Several alternatives are available for alleviating the problems of power plant emissions. These alternatives fall into three basic approaches: (1) diminish the damages that result from the sulfur oxide emissions; (2) reduce the use of high-sulfur coal; and (3) extract the sulfur that accompanies coal.

Two proposals have been made for reducing the impact of the emissions from power plants. Basically, they both have the effect of removing the sulfur oxides from urban or heavily populated areas. One proposal, the relocation of power plants--preferably to the location of the source of coal--has interesting implications. While it serves the purpose of removing the source of sulfur oxides from the urban area, it would reduce the quality of air in the mining area, and would have significant consequences on related economic activity ("Sulfur Oxide Control: A Grim Future," 1970, p. 187).

The second proposal is that of using tall smokestacks. Under any meteorological condition, a tall stack located in open, uncomplicated terrain will produce a dramatic reduction in the local ground-level concentrations of sulfur oxides. This reduction is accomplished simply by giving natural atmospheric turbulence an opportunity to dilute the pollutant before it reaches ground level. The tall stacks are even more valuable during temperature inversions, when the mixing

process is extremely slow and ineffective, particularly with respect to vertical movement of plumes. A plume emitted at any reasonable height above ground (500 feet or more) will remain aloft indefinitely, producing no ground-level concentrations (Smith, 1966, p. 151).[17]

Both of these proposals would significantly reduce the level of pollution in urban areas. Whereas the tall stacks allow the pollutants to disperse, moving power plants simply moves the pollution to another area. But both are strictly short-run solutions. They only reduce the local concentration of sulfur oxides in urban areas. They do nothing to eliminate the overall burden of pollution borne by the atmosphere.

The second approach is that of simply reducing the use of coal. Proposals follow two lines: use low-sulfur coal, oil, or gas to power steam-generating electric plants; or substitute other types of plants for the conventional steam plants. Fuel oils contain much less sulfur than does coal, and gas contains very little sulfur at all. Unfortunately, the substitution of gas for coal and oil is limited. The supplies of gas are limited, and the demand for gas in other uses has set a market price on gas which generally precludes its use as a primary input in generating electricity. Most power-generating plants would find alternative means of abatement more economically feasible than the continued use of this relatively high-priced input.

Nuclear power plants are an alternative to coal and will likely increase their share of the electricity-generating market. However, pollutants other than sulfur oxides accompany this means of generating

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[17]Tall stacks solve other problems that result in ground-level pollution as well. See (Smith, 1966, p. 154).

electric power. Another potential advance in conversion technology which now appears feasible is the magnetohydrodynamic (MHD) conversion. The MHD generator makes use of high-velocity electrically conducting gases to produce electric power without the need for a turbogenerator (Seaborg, 1966, p. 136).

The primary problem with identifying one, or a few, sources of fuel is that no one source of fuel will be able to satisfy, or is currently capable of satisfying, the electrical power demands of the United States (Sporn, 1966, p. 145). The power demands of this country in 1980 are estimated at twice the present level; and by 2000, approximately six times the present level (Rohrman, 1965, p. 4). Even under projected technology, the United States will have to call on all of its principal sources of fuel for power generation in future time periods. At present, and in the future, no major source of fuel can be heavily restricted in use for the purpose of maintaining cleaner air without seriously handicapping the capability of society to achieve many other objectives at least as important as cleaner air.

The third approach for reducing power plant emissions is the removal of the sulfur that accompanies coal. Three alternatives are available: (1) remove the sulfur from the coal before burning; (2) remove the sulfur during combustion; or (3) recover sulfur oxides from the flue gas.

The sulfur in coal is present in varying amounts of pyritic and organic forms. Organic sulfur is not amenable to removal by nondestructive methods. Pyritic sulfur can often be separated by use of conventional coal-cleaning equipment because of differences between its specific gravity and that of coal. Unfortunately, pyrite is sometimes

present in such finely divided particles that such separations are difficult, if not impossible. Further, the tonnages of coal which would need to be processed to supply power plants are so great that routine operations like crushing and washing would add substantially to the cost of power generation (Zimmerman, 1966, p. 61).

Numerous studies are under way to determine the feasibility of removing sulfur during combustion. In 1966, Detroit Edison was cooperating with a steam generator manufacturer on a pilot operation at their largest power plant. An attempt was made to capture the sulfur oxides by injecting dolomite dust during the firing of pulverized coal. Although the process was chemically and technically feasible, practical problems plagued the operation. They did learn that the process increased the cost of generating electricity, however (Cisler, 1966, p. 121). At best, operational technologies for removal of sulfur during fuel consumption are three to eight years away from being operationally feasible according to the National Research Council, and may not be retrofitted to existing plants ("Sulfur Oxide Control: A Grim Future," 1970, p. 187).

Hundreds of processes for removing sulfur oxides from flue gases have been proposed. These various processes can, in general, be classified into the following:[18]

1. Scrubbing with aqueous salt solutions
2. Sorption by metal oxides
3. Catalytic oxidation of sulfur dioxide to sulfur trioxide
4. Sorption by inorganic solids other than oxides

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[18]See ("Sulfur Oxide Removal from Power Plant Stack Gas--Ammonia Scrubbing," 1970, p. 15).

5. Reduction of sulfur dioxide to sulfur
6. Sorption by inorganic liquids
7. Sorption by organic solids
8. Sorption by organic liquids
9. Separation of sulfur dioxide by physical methods

Of these, the first three have received major attention although a few of the other sorption processes have been developed. There is not sufficient evidence to conclude that any are economically feasible. Some of those processes that have been developed to operational stages are discussed in the following section. It is safe to conclude that few other processes will be developed to the extent of being used in the next decade.

Technical Processes for Recovering Sulfur Oxides from Smokestack Flue Gas

Many of the recovery processes have some useful form of sulfur as the by-product of controlling sulfur dioxide emissions from electric power-generating plants. However, the first two described result in a by-product that is not useable on an economic basis.

A dry limestone-injection process to control sulfur dioxide from flue gas was initiated in 1964 by the Process Control Engineering Program of the National Air Pollution Control Administration (NAPCA), and later studied by the Tennessee Valley Authority (TVA). In this process, limestone and/or dolomite is pulverized and fed into the high-temperature combustion zone of the furnace where it is calcined to the active oxide forms of CaO and MgO (Figure II-8). The reaction of the additive with SO_2 and oxygen at temperatures above 1200° F forms gypsum ($CaSO_4$). Sulfates, unreacted lime, and fly ash are removed by conventional particulate collection equipment (Harrington, 1968, pp. 152-158).

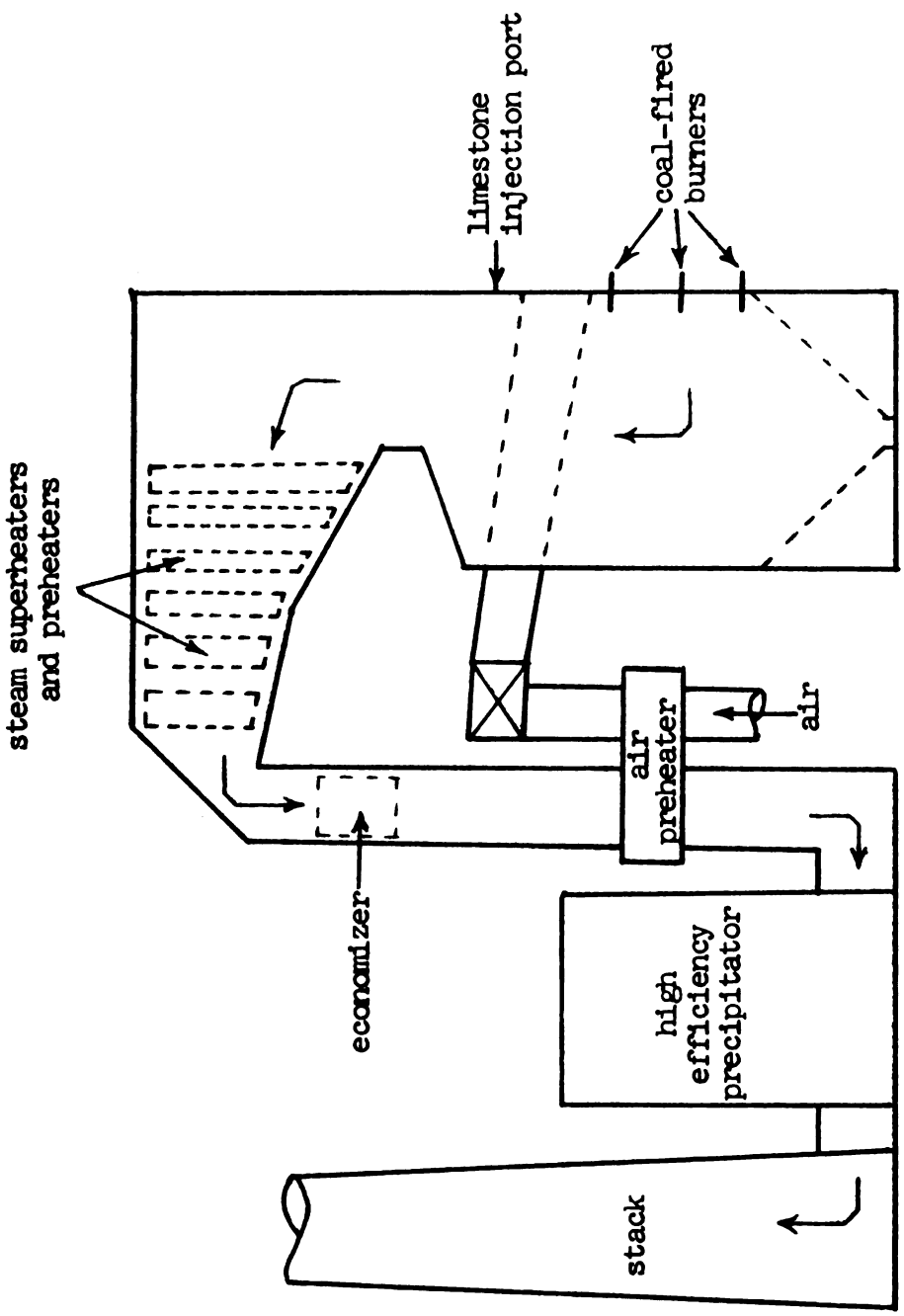

Figure II-8. Limestone injection-dry process for removing SO_2 from flue gas

The limestone-injection, wet-scrubbing process for recovering SO_2 is actually a combination of two individual processes, (1) dry limestone injection directly into the furnace where it is calcined to lime, and (2) scrubbing of the combustion flue gas by a lime slurry for removal of SO_2 (Figure II-9). In the second step of this process, lime and fly ash are collected by the scrubber, where the calcined limestone forms a slurry of reactive milk-of-lime, which reacts with the SO_2 in the flue gas to form sulfite and sulfate salts. The spent scrubber liquor and reaction products are allowed to settle. Ash and reacted lime are removed for disposal. Scrubber liquor is recycled to reduce water requirements and avoid water pollution (Control Techniques for Sulfur Oxide Air Pollutants, 1969, p. 53).

The Beckwell Process, developed by Wellman-Lord Company, is based on absorption of SO_2 in a potassium sulfite solution, crystallization of $K_2S_2O_5$ from this solution, and conversion of $K_2S_2O_5$ to $KHSO_3$ by dissolving the crystals in water. SO_2 is then stripped from this solution (Watt, 1970, p. 235).

The Westvaco SO_2 recovery process utilizes a specially tailored activated carbon in a small flue gas absorption unit. The sulfur dioxide in the cooled flue gas going to the stack is continuously absorbed on fluidized carbon and reacts with residual oxygen in the flue gas to form SO_3. This SO_3 reacts with water vapor in the carbon pores to form sulfuric acid which is retained at high levels within the carbon. The carbon is completely regenerated in a progressive reaction between sulfuric acid on the carbon and hydrogen with sulfur oxide or sulfur being released (Ball, 1970, p. 211).

The Stone and Webster-Ionics Process Utilizes a solution composed

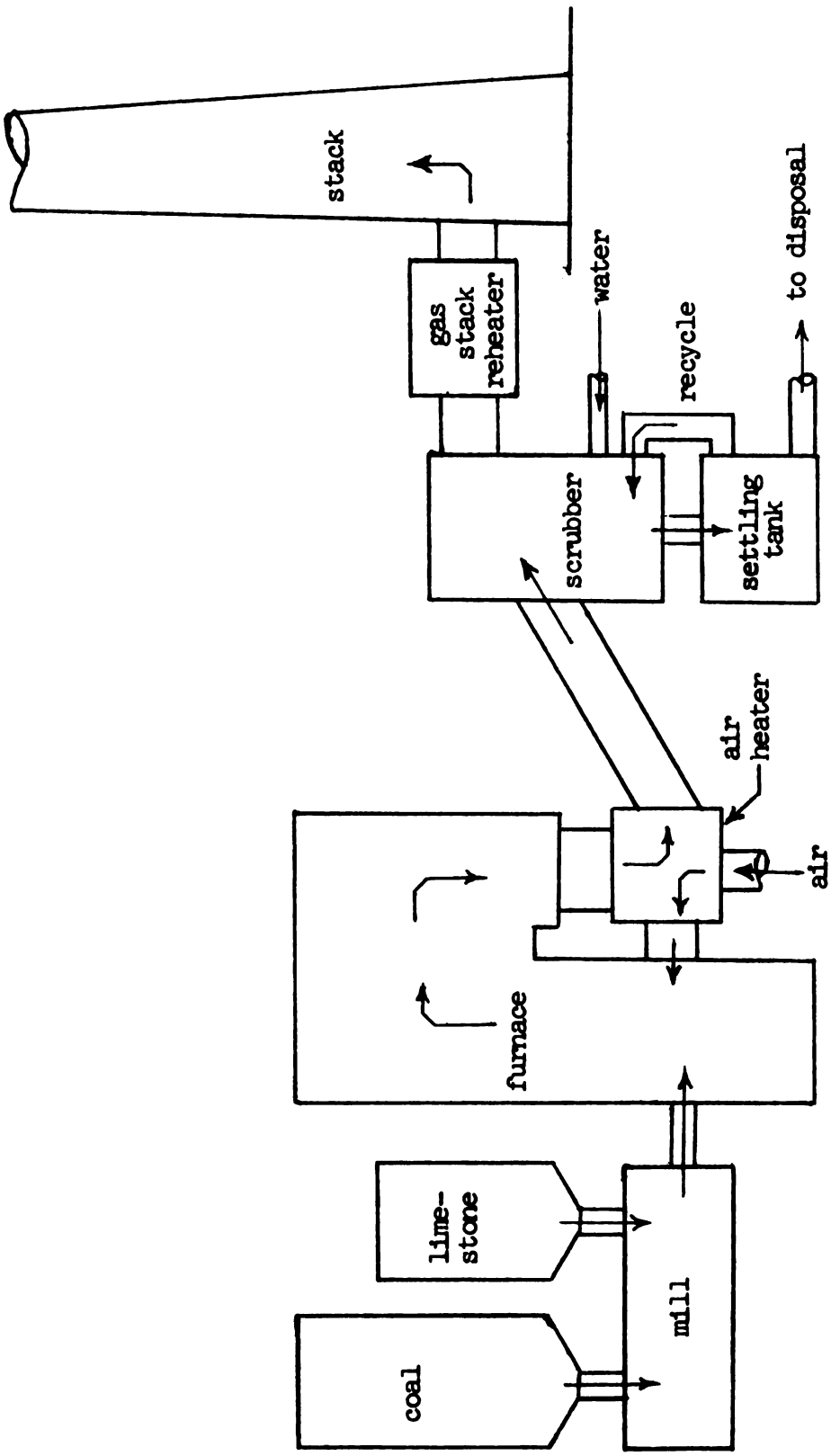

Figure II-9. Limestone injection-wet scrubbing process for removing SO_2 from flue gas

of sodium sulfate electrolyte which is fed into an electrochemical cell wherein a caustic stream is produced at the cathodes and an acidic stream at the anodes. The caustic stream is fed into the top of an absorption tower where it is contacted counter-currently with flue gas. A chemical reaction between the caustic and sulfur dioxide produces sodium acid sulfate which is fed to a heater tank where it is neutralized by the acidic stream from the electrochemical cell. The neutralization reaction results in the reformation of the sodium sulfate which is recycled to the electrochemical cells, and the evolution of pure sulfur dioxide ("Stone and Webster-Ionics Process for SO_2 Removal," 1970, p. 215).

The Alkalized Alumina Process is one of a number of flue gas-desulfurization schemes that use a dry metal oxide to contact and absorb the SO_2. The raw sorbent solid in the form of 1/16-inch spheres of dawsonite, $NaAl(CO_3)(OH_2)$, is activated at 1200° to form high-porosity, high-surface-area sodium aluminate, which reacts with SO_2 in the flue gas at 300° to 650° F to form sodium sulfate (Figure II-10). Regeneration of the sodium sulfate in the presence of a reducing gas at 1200° F produces a stream of SO_2 (Control Techniques for Sulfur Oxide Air Pollutants, 1969, p. 50).

The Air Pollution Control Department of Monsanto Enviro-Chem Systems, Inc. placed an emission control process on the market in 1968. Because of the proprietary nature of the process, details are not available. However, the process is a catalytic oxidation process, an adaption of the contact catalytic process used in the manufacture of sulfuric acid. A high-efficiency electrostatic precipitator is employed to remove particulate matter before the gas enters the catalyst

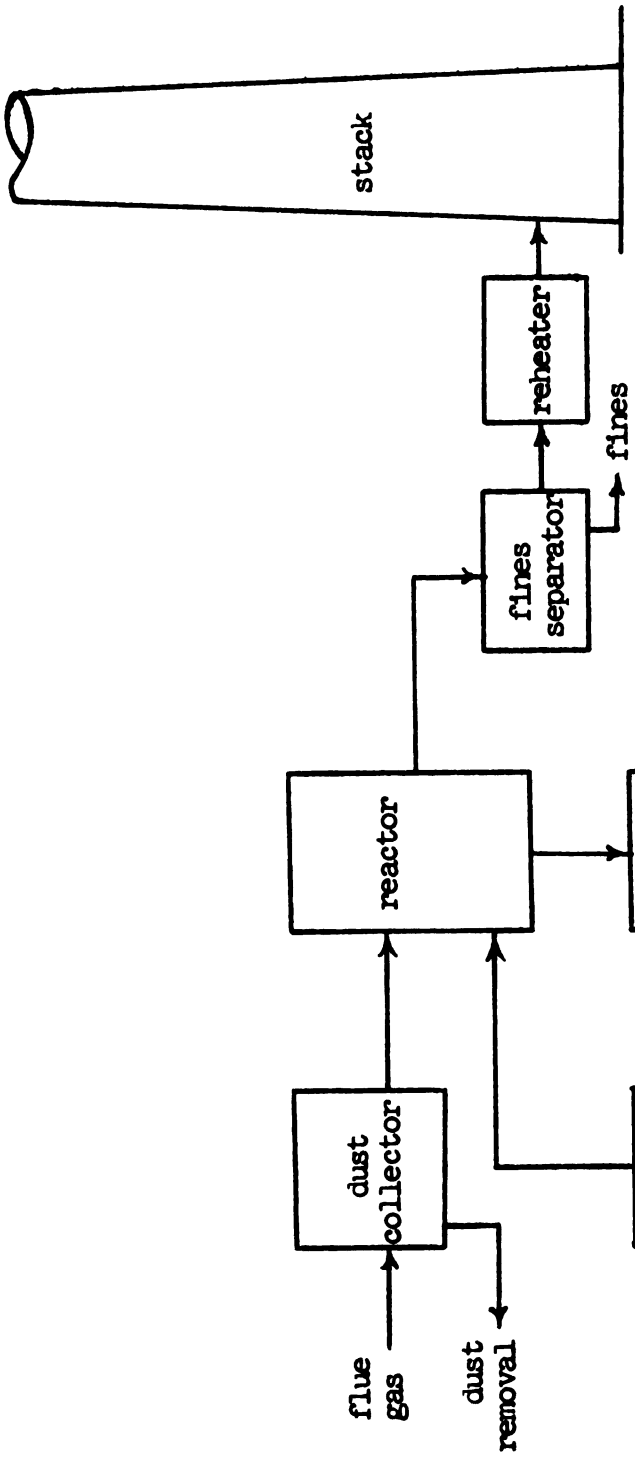

Figure II-10. Alkalized alumina process for recovering SO_2 from flue gas

bed at elevated temperatures of 800° to 850° F (Figure II-11). Sulfur trioxide formed in the catalyst bed reacts with water vapor in the flue gas to form sulfuric acid. Condensation occurs both in the acid condenser and mist eliminator sections (Stites, 1970, p. 222).

Recovery of sulfur oxides by ammonia scrubbing involves many possibilities. Several products can be made, and there are various ways of arriving at each product. Only the primary processes will be discussed.[19]

When ammonia is introduced into the scrubber system, three products result: ammonium sulfate, ammonium sulfite, and ammonium bisulfite. The relative amounts of each of these may vary, depending upon the control of the scrubbing operation. The amount of bisulfite increases as the pH of the solution is reduced. But at low pH, the sulfur dioxide is not removed effectively. In practice, the pH must be adjusted to give the best balance between sulfur dioxide leakage at low pH and ammonia loss at high pH. Best results can be obtained by stepwise scrubbing with relatively high pH in the early stages to capture most of the sulfur dioxide, and lower pH in the final stages to minimize ammonia loss.

The sulfite and bisulfite in the effluent solution are not useful products and must be converted to a more desirable product. Numerous methods for conversion and recovery have been proposed and some have been tested. The operational methods for treating the scrubber solution can be divided into three classes: stripping, acidification, and oxidation.

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[19]This part was based heavily on (Sulfur Oxide Removal from Power Plant Stack Gas, 1970, pp. 16-22).

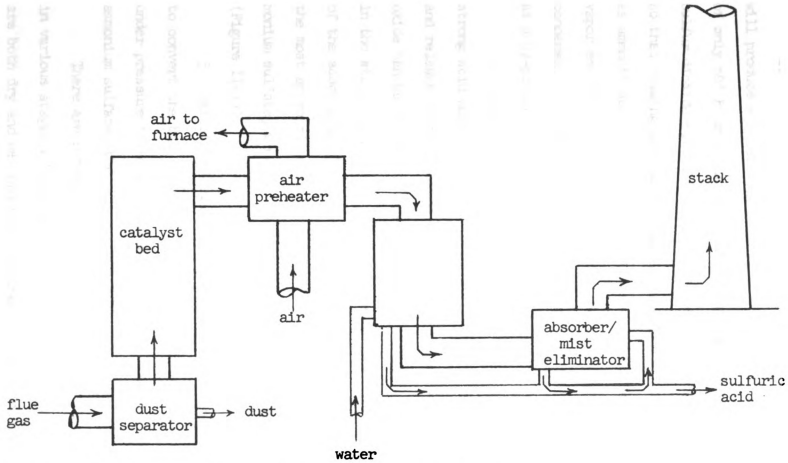

Figure II-11. Catalytic oxidation process for removing SO_2 from flue gas

1. Stripping--Ammonium bisulfite is an unstable compound and will produce a relatively high vapor pressure if heated even to a level of only 50° F or so above the scrubbing temperature. Moreover, the sulfur dioxide partial pressure is much higher than for the ammonia, so that passing the gas through a condenser to condense the ammonia as ammonia sulfite will produce a stream of sulfur dioxide and water vapor essentially free of ammonia. The stripping solution and the condensate are recycled to the scrubber, and sulfur dioxide remains as a by-product (Figure II-12).

2. Acidification--Since sulfurous acid is a weak acid, any strong acid added to the scrubber effluent will capture the ammonia and release sulfur dioxide from the sulfite and bisulfite. The sulfur oxide can be converted to either sulfuric acid or elemental sulfur as in the stripping process. The captured ammonia forms an ammonium salt of the added acid. Since sulfuric, nitric, and phosphoric acid are the most appropriate acids to use, the resulting salts would be ammonium sulfate, ammonium nitrate, and ammonium phosphate, respectively (Figure II-13).

3. Oxidation--Ammonia can be added to the scrubber liquor to convert the bisulfite to sulfite. Then the sulfite is oxidized under pressure by adding oxygen (ordinarily supplied as air) to form ammonium sulfate, the only product (Figure II-14).

There are between 60 and 70 other SO_2 removal systems that are in various stages of development. In inorganic sorption systems, there are both dry and wet processes proposed. The Reinluft Process is typical of the dry processes. Flue gas containing SO_2 is passed through a bed of activated char at temperatures of 200° to 300° F. During

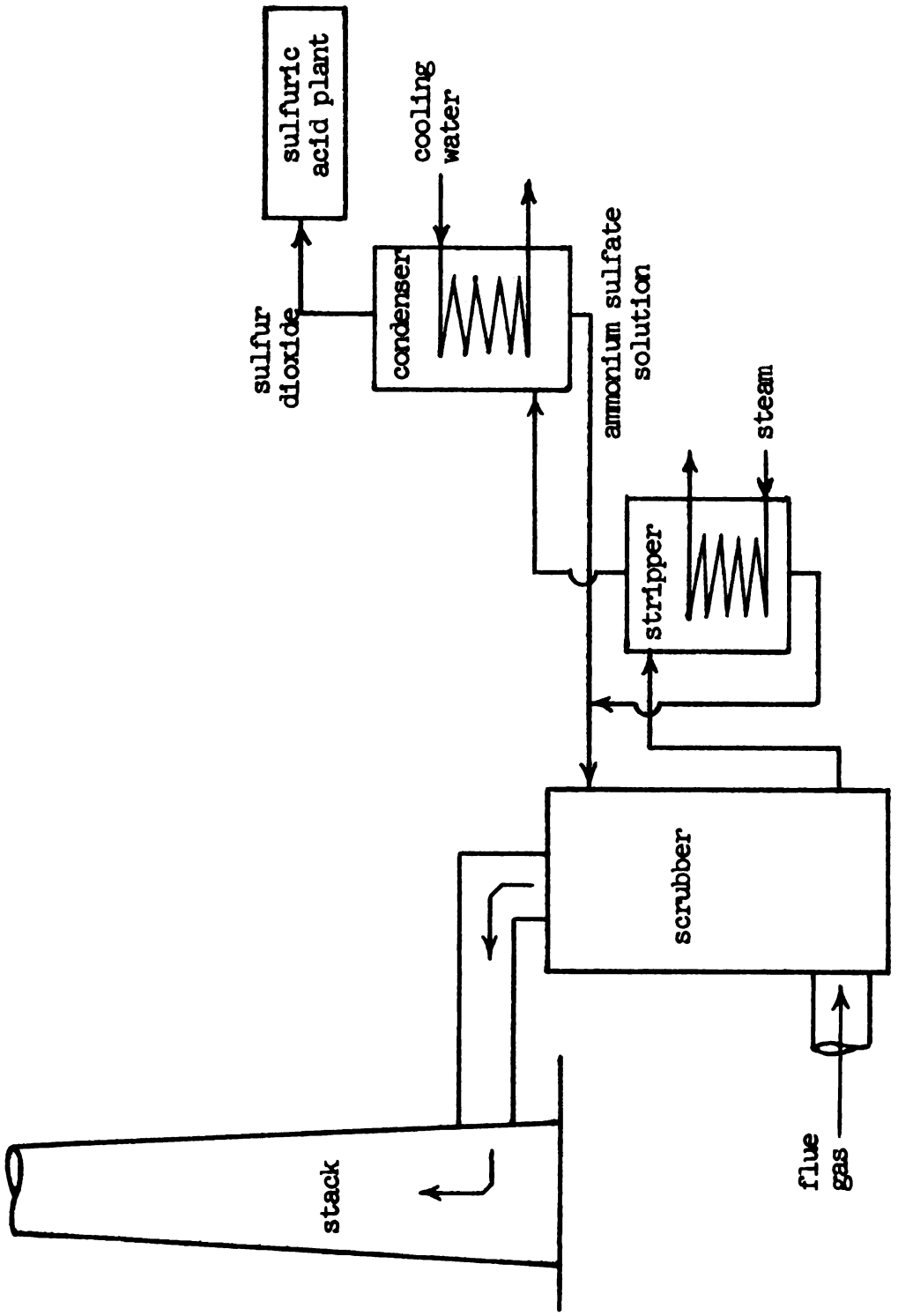

Figure II-12. Stripping process for removing sulfur oxides from flue gas

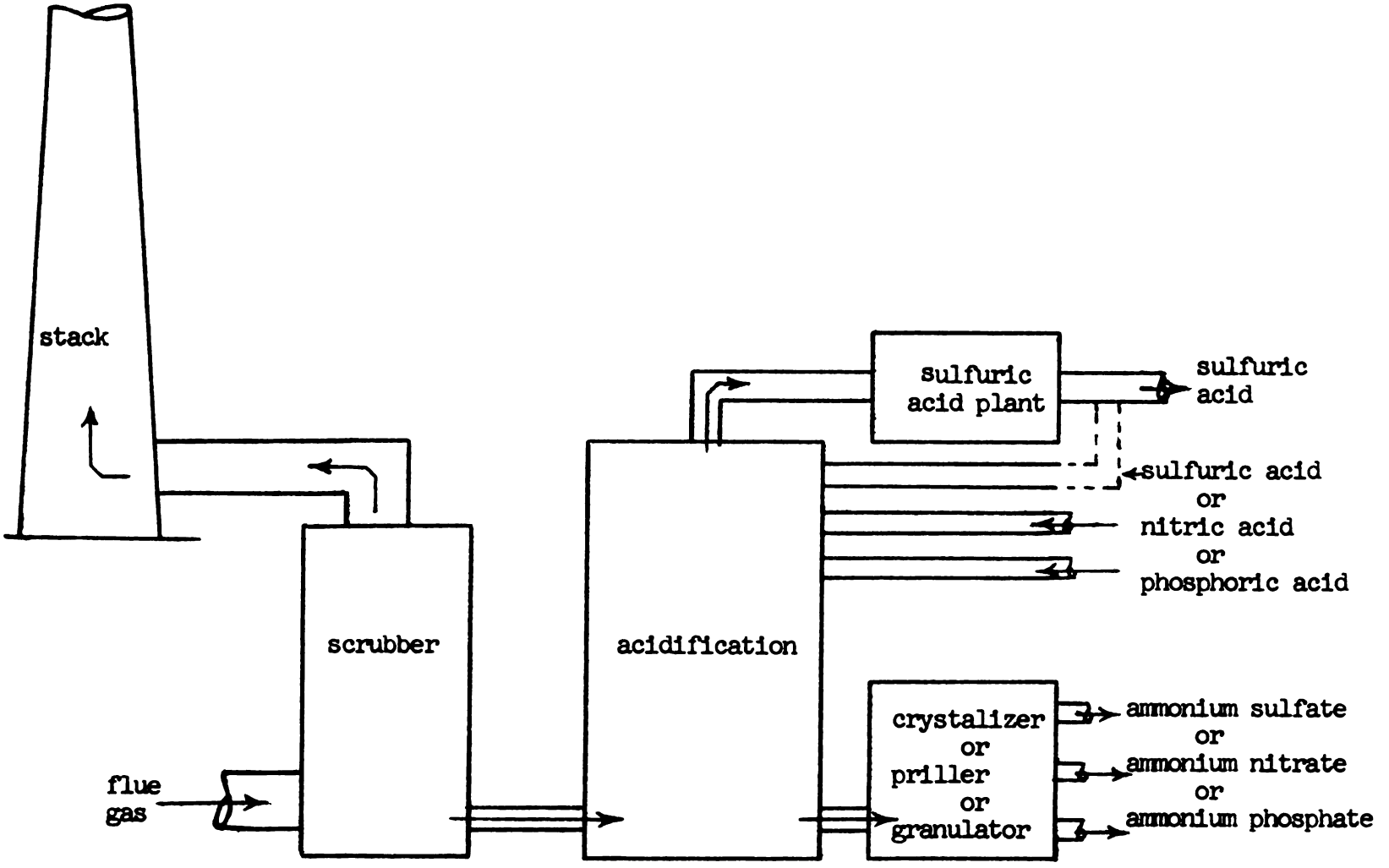

Figure II-13. Acidification process for removing sulfur oxides from flue gas

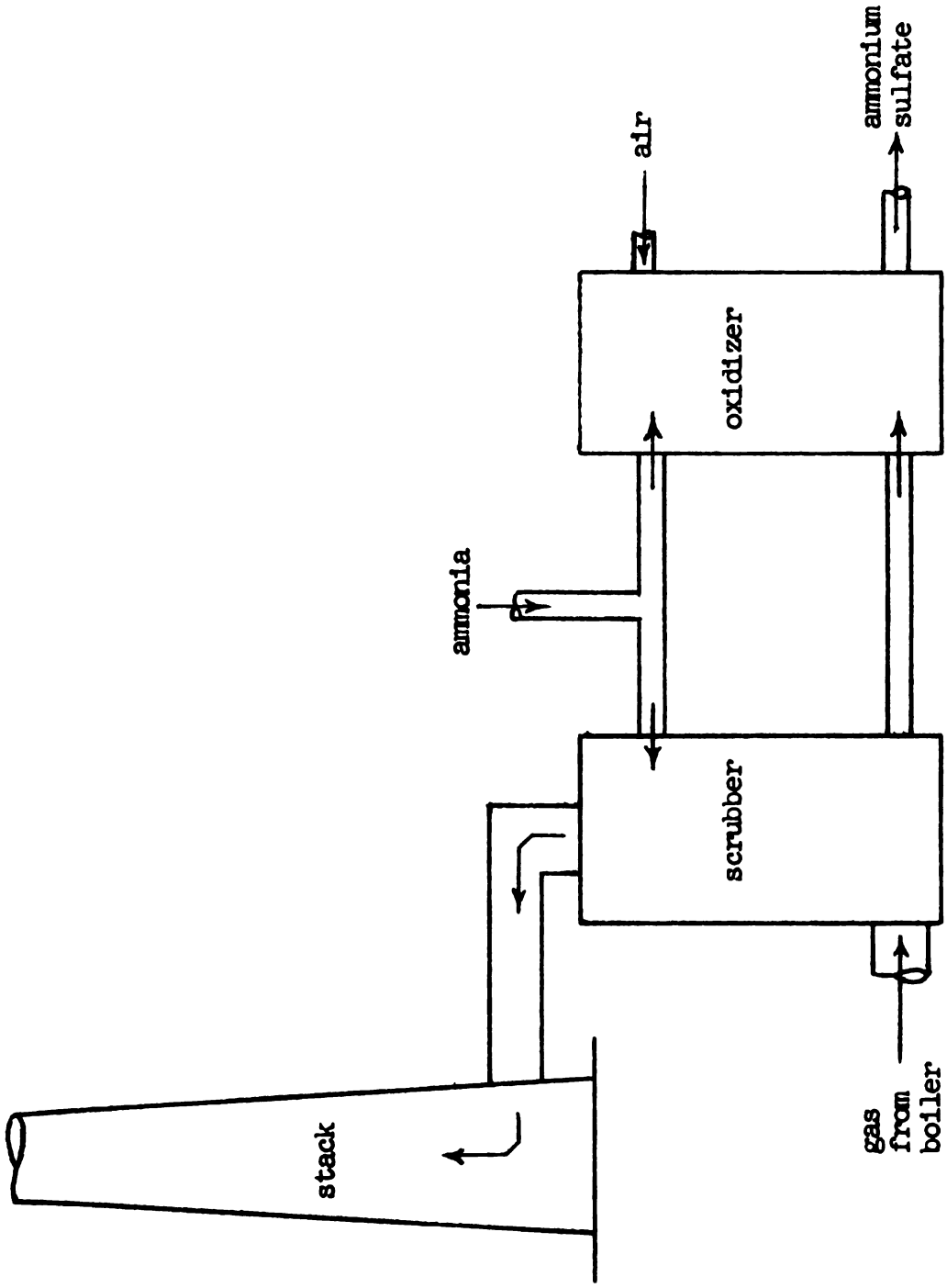

Figure II-14. Oxidation process for removing sulfur oxides from flue gas

adsorption, SO_2 is oxidized to SO_3, which reacts with flue gas moisture, yielding H_2SO_4. The char adsorbent is removed to a regenerator and heated to 750° F, liberating SO_2 and CO_2. A conventional acid plant converts SO_2 into concentrated acid (Control Techniques for Sulfur Oxide Air Pollutants, 1969, p. 56).

The Lurgi Process is a wet-char system that first cools the boiler gas by contact with a weak solution of sulfuric acid. After adsorption of converted SO_3 by the char, water is intermittently sprayed into the gas stream to remove acid (Slack, 1967, pp. 188-196).

Several metal-oxide sorption systems are also being investigated in addition to those already discussed. The Grillo Process uses a slurry of manganese and magnesium oxide as an absorbent. The gas is cooled by evaporation of the absorbent slurry. After absorption, the regeneration of the absorbent is carried out by heating a mixture of $MgSO_4$ and coke in a Herreshoff-type furnace. Concentrated SO_2 is evolved for sulfuric acid production. The ash and regenerated oxide are separated, the oxide suspended, and the slurry recycled (Control Techniques for Sulfur Oxide Air Pollutants, 1969, p. 57).

In the Carl Still Process, a brown coal (lignite) ash is reacted at 300° F after the SO_2-laden flue gas leaves the air preheater and before it reaches the control precipitator. The lime content of the lignite ash is 40 to 50 percent. After reaction with the flue gases, the spent absorbent can be discarded or the calcium sulfite can be heated to evolve a rich SO_2 stream for sulfuric acid production (Slack, 1967, pp. 188-196).

Few alternatives are currently available for controlling sulfur oxide concentrations in the atmosphere. But it is apparent that many

alternatives are in the development stage and a few may soon be operational. The next section projects development progress and identifies the pattern that can be expected as society attempts to improve the ambient air quality.

A Projection of Sulfur Oxide Control Technology

Were it not for three factors, society might enjoy air free of sulfur oxides: (1) the limited supply of natural gas; (2) the constraints on the construction of hydroelectric and nuclear power plants; and (3) the state of the technology for desulfurizing coal and oil, for new generating processes, and for removing sulfur oxides from flue gas. Although eliminating any one of these constraints could make possible the achievement of high-quality ambient air, researchers are in general agreement that progress in eliminating the latter two will weigh most heavily. This section projects the developments that can be expected in sulfur oxide control technology.

Two approaches will be used to minimize the impact of sulfur oxide emissions in the next two or three years; use of available supplies of low-sulfur fuels and tall smokestacks. By emitting the pollutants at higher levels (500-1,000 feet), the atmosphere is capable of mixing and dispersing the pollutants before they settle to earth. The dispersion prevents excessive concentration of sulfur oxides at ground level, and therefore improves the air quality.

The use of low-sulfur fuels will also be used to reduce sulfur oxide emissions in the near future. Some sources yield natural gas essentially free of sulfur, and the sulfur found in natural gas from other sources can be successfully removed. Although essentially all

oil contains sulfur, some of the sulfur can be removed. In addition, a small portion of the coal produced in the United States contains low levels of sulfur (less than one percent by weight). However, the limited supply and higher prices associated with fuels with lower sulfur content will discourage their widespread use.

Some air pollution control agencies are requiring the continual use of low-sulfur fuels. Although this is feasible on a small scale, the supply of these low-sulfur fuels is not sufficient to allow all or even a major portion of the country to use this approach. Therefore, most control agencies are allowing the consumption of high-sulfur fuels as long as the ambient air quality does not fall below the tolerable level. If it does, firms will be required to shift to low-sulfur fuel reserves for as long as the emergency exists.

Locating power plants away from major population and/or industrial centers when the opportunity affords itself will also serve to improve air quality. However, this approach will be used in few situations.

Atomic power will account for an increasing share of the energy source used for generating electricity. However, the rate at which its growth can proceed is physically limited. Although atomic power solves the problem of sulfur oxide emissions, some are concerned with emissions of radioactivity and heat. Although the heat problem must be reckoned with, the minute amount of radioactivity emitted "poses no health hazard whatsoever" (Seaborg, 1966, p. 131).

Although hydroelectric power plants are pollution free, they often require extensive amounts of valuable resources. Some segments of society are disenchanted with the use of the nation's resources

in this manner, and may be successful in limiting the construction of further hydroelectric power-generating capacity. Therefore, the construction of nuclear power plants and the location of the more conventional steam-generating plants in less populated areas will serve to reduce the levels of sulfur oxides in the atmosphere. Of these two approaches, the role of the atomic power plant will be by far the most important. Hydroelectric power facilities cannot be expected to play a major role.

Technological progress will be the key in attaining acceptable ambient air quality. Although novel power conversion schemes such as magnetohydrodynamics will not be available in the near future, they may be important in 20 or 30 years.

Of prime importance in the near future, however, is the removal of sulfur from either oil and coal or from their combustion gases. Technological advances in removing sulfur from oil can be expected in the next couple of years, and should play an increasingly important role in five years. The problems of desulfurization of coal for commercial purposes will not be so easily solved. If progress in the removal of sulfur from flue gas is good, desulfurization of coal will receive less attention and will not play a primary role.

There is much optimism in the potential of the recovery of sulfur in flue gas. Numerous processes are being studied and several will be developed. The wet limestone process that produced a throw-away by-product will likely be one of the first processes put to use, probably within five years. The alkalized alumina process, and the ammonia scrubbing process could be on the market by that time or shortly thereafter. The Monsanto process, which is already supposed

to be operational could also share in the early smokestack scrubbing duties. Three of the four processes could produce sulfur or sulfuric acid, and one of those three could produce ammonium sulfate.

The use of these processes in the next few years will be a function of the order of development and the reliability associated with each. Several factors lead to this conclusion. First, with the level of sulfur dioxide increasing in the ambient air as it is, it will be important to activate the technically feasible processes as they become available. In some population and industrial centers, where sulfur oxides are particularly concentrated, the returns to recovery of the pollutant may be so great that even relatively expensive processes can be used.

Second, the amount of risk associated with each process will be a primary consideration. A process that may be relatively expensive but has low risk associated with it may well be preferable. Currently, the risk associated with each process is high. Engineers at the TVA Development Center believe that such basic problems as corrosion and plugging have not been sufficiently solved. No power firm can be expected to risk the production of its plant on an unproven process. Rather, they would prefer a somewhat more expensive process where risk is at a minimum.

Third, in the early stages of use, the cost data associated with each process will not be sufficiently reliable to be a primary criteria for selection. For example, the traditional problem of cost allocation could result in an array of cost schedules for any facility. But equally important, the cost of operating a scrubbing plant varies with a number of different factors, such as size of the power plant,

age, level of operation, stack gas temperatures, sulfur content of the coal, ash content of the coal, degree of sulfur oxide and dust removal, and so on. Consequently, the cost of a process in one situation could be considerably different from that process in another situation. Therefore, in the early stages of use, cost considerations will not be primary.

After recovery processes have been in use for several years and the cost relationships are understood, cost information will become increasingly important in process selection. Firms will have several alternatives with low risk from which to choose, and the economics associated with each process will become an important consideration.

Finally, it should be kept in mind that public utilities are allowed a fair return on their investment. Therefore, by investing in high-cost equipment, they increase their rate base and are allowed a higher level of profit. Thus, there is an incentive to over-invest. There is little reason to believe that this will not happen. Although the Federal Power Commission is theoretically responsible for preventing such occurrances, their record is something less than admirable.

It is impossible to predict the cost that will be associated with each process. Engineers suspect that, on the basis of the physical process alone, the limestone process may be the cheapest. However, the situation could change when related factors are considered. For example, the purchase and transportation cost of limestone, and the problem of disposing of the waste by-product could add significantly to the cost. On the other hand, the alkalized alumina process uses a high-cost sorbent, but it can be regenerated with little loss (0.1 percent). Since ammonia is being produced at a rate of approximately

two-thirds the capacity of the industry, the ammonia scrubbing process may also be attractive. Both the alkalized alumina and the ammonia process produce by-products that have noteworthy value. Revenue generated from the sale of these products may more than offset their higher process cost.

In conclusion, tall smokestacks and consumption of the limited supply of low-sulfur fuels will serve as the primary solution to high-sulfur oxide concentrations in the atmosphere in the next five years. Mass desulfurization of oil will be an important source of low-sulfur fuel, but unless great technological advances are made in the desulfurization of coal, that process will not be commonly used. Use of smokestack scrubbers for removing sulfur oxides from flue gas will begin appearing within five years and will be widely used within ten years. Processes that produce throwaway products and that produce products useful to the fertilizer industry will be used. Continual construction of atomic power plants will allow for the production of electricity without producing sulfur oxides, and atomic energy will become a primary source of power. Finally, development of new conversion techniques will not be significant in terms of either generating electricity or controlling sulfur oxides in the next 20 or 30 years. There will be few power plants built in remote areas for the specific purpose of sulfur oxide control, and additions to hydroelectric generation capacity will be limited.

The significance of these activities to the sulfur industry and the fertilizer industry is clear. Large amounts of ammonium sulfate, sulfur, and sulfuric acid could be available as by-products from efforts to control sulfur oxide emissions. The next section examines

the use of these by-products in the fertilizer industry.

Sulfur, Sulfuric Acid, and Ammonium Sulfate as Fertilizers

The acidification and oxidation processes discussed earlier produce ammonium sulfate as either the sole by-product or a co-by-product with sulfuric acid. The ammonium sulfate by-product may be used as a primary input in manufacturing other fertilizer products. First, it can be used to make a nitric phosphate fertilizer. A slurry of phosphate rock and nitric acid can be treated with the ammonium sulfate, which reacts with the calcium nitrate in the slurry to form soluble ammonium nitrate and insoluble calcium sulfate. The precipitated calcium sulfate can be discarded and the remaining solution of ammonium nitrate and phosphoric acid can be reacted to give an ammonium phosphate-nitrate fertilizer.

The by-product, ammonium sulfate, can also be heated to about 700° F to convert it to ammonium bisulfate. Since ammonium bisulfate is acidic, it can replace sulfuric acid for dissolving phosphate rock. The resulting slurry would be filtered to remove calcium sulfate and then ammoniated to give an ammonium phosphate-sulfate fertilizer. Ammonia freed in the kiln can be recycled to the scrubber, or used in the ammoniation process (Figure II-15).

Ammonium sulfate can also be used to make sulfuric acid or sulfur. By reacting it with zinc oxide at high temperatures, ammonia and zinc sulfate result. The zinc sulfate can be further heated to regenerate the zinc oxide and give a rich stream of sulfur trioxide that can be absorbed directly to form sulfuric acid.

Sulfuric acid can also be produced from ammonium sulfate via

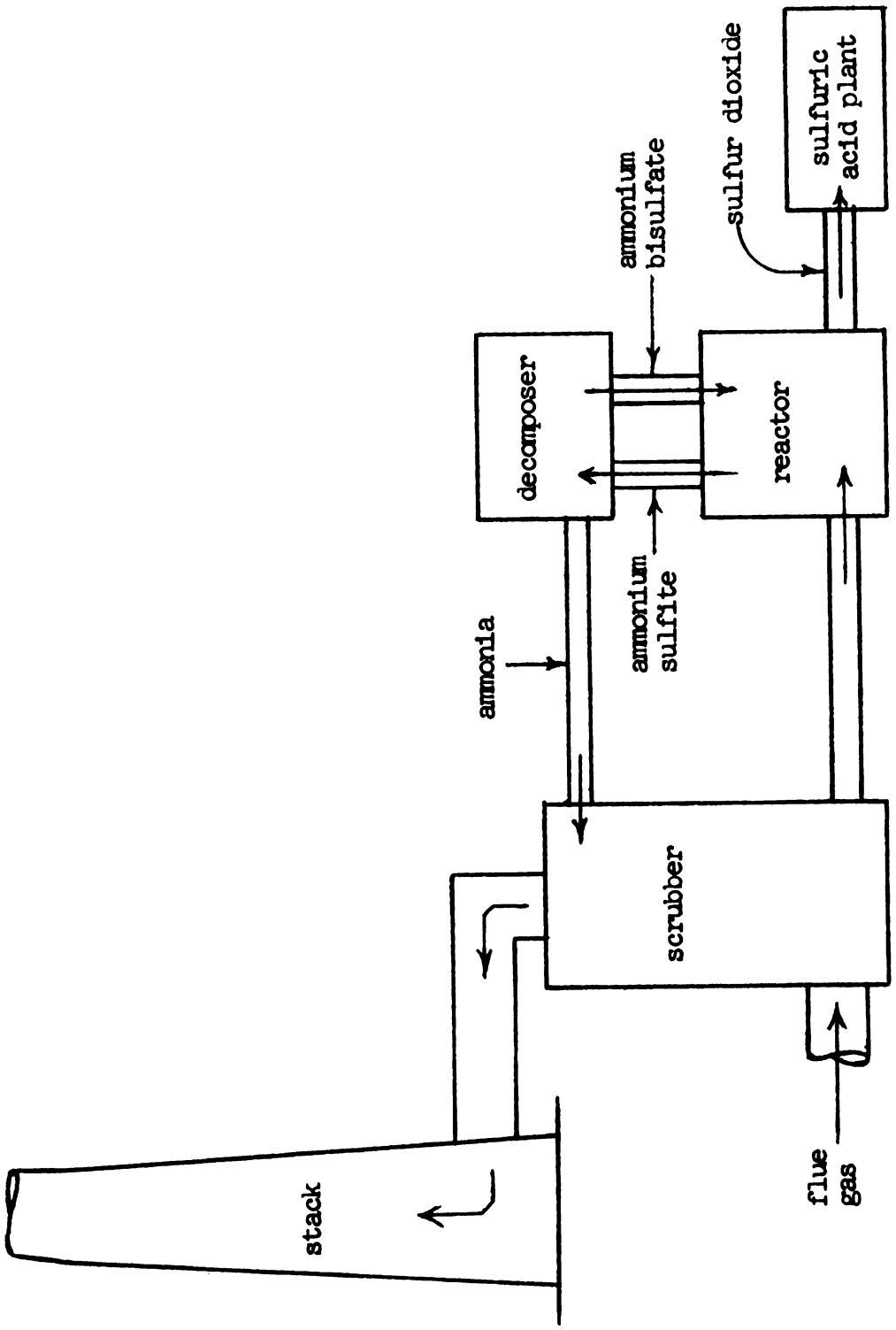

Figure II-15. Acidification process using ammonium bisulfite

a scrubber process. Since ammonium bisulfate made by heating ammonium sulfate is acidic, it can be used in the acidification method discussed earlier for processing the scrubber effluent solution. In that process, a strong acid was used to capture the ammonia and release sulfur dioxide, leaving an ammonium salt of the added acid. By substituting the bisulfate for the strong acid, the amount of ammonium sulfate ending up as final product is minimized. Only the sulfate resulting from oxidation before and in the scrubber results as final product, whereas if sulfuric acid is the acidification agent as in the method described earlier, all the ammonium sulfite is converted to sulfate as well (Figure II-16).

While the acidification and oxidation processes can result in ammonium sulfate, all other processes produce sulfur dioxide, sulfur, or sulfuric acid. In addition, the ammonium sulfate can be converted to sulfuric acid. Likewise, sulfur dioxide can be converted to sulfuric acid. Both sulfuric acid and sulfur are used in the production of phosphate fertilizers.

The Fertilizer Industry--A Consumer of Pollutants

In some respects, traditional waste disposal practices have real advantages. By-products that had no economic value were often discharged into the atmosphere or dumped into rivers, lakes, or streams. The atmosphere and water are excellent medias for disposing of waste as long as it is discharged in moderation. Both medias disperse and often chemically or biotically convert the waste to harmless material that does not disrupt the ecology. That is, it disposes of the waste at essentially zero cost. But as the discharge of waste increases,

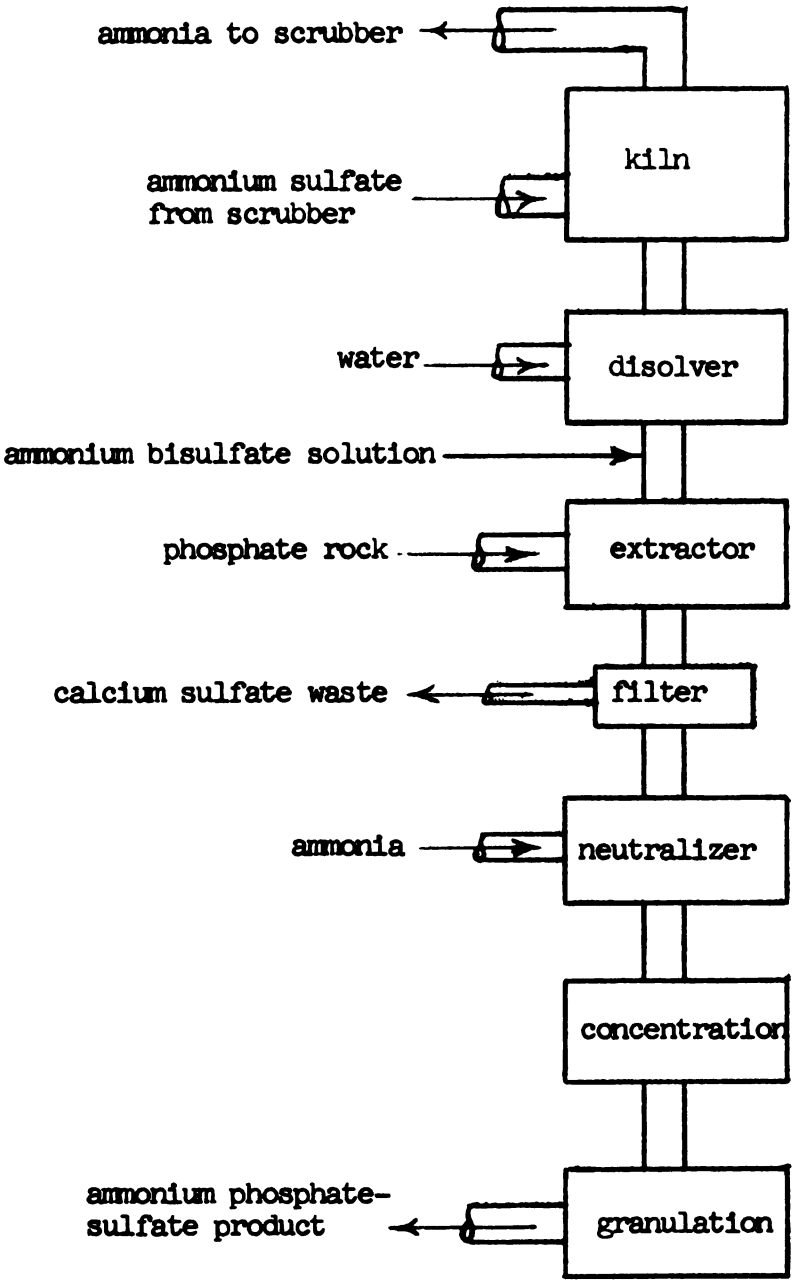

Figure II-16. Ammonium phosphate-sulfate process

damages from the materials are incurred and, consequently, additional costs are incurred.

While disposing of wastes by spreading them over soil requires distribution activities not needed with disposal via air or water, the soil has a great potential for absorbing wastes without ill effects. The chemical and biological activity in the soil is many times that of either air or water. And when the waste can be utilized by plant life, further benefits are realized.

When processes for removing sulfur oxides are installed in electric power-generating plants, and the effluents converted to products useable as fertilizer, the industry could become essentially a secondary industry utilizing by-product inputs. Indeed, the fertilizer industry might become a primary user of certain industrial waste. This would certainly require extensive readjustment within the fertilizer industry, an industry which has previously undergone considerable change.

Since 1940, the fertilizer industry has grown at a phenomenal rate. By 1948, consumption of all three nutrients had doubled their respective 1940 levels (Figure II-17 and Table II-3). This 100-percent increase in an eight-year period can be contrasted to the 20-year period before 1940 when N, P_2O_5 and K_2O (the three basic fertilizer nutrients) increased 84 percent, 38 percent, and 69 percent, respectively. The rate of increase then slackened for phosphates, without a tripling of the 1940 level until 1962.[20] In that same year, consumption of N was eight times the 1940 consumption level, and

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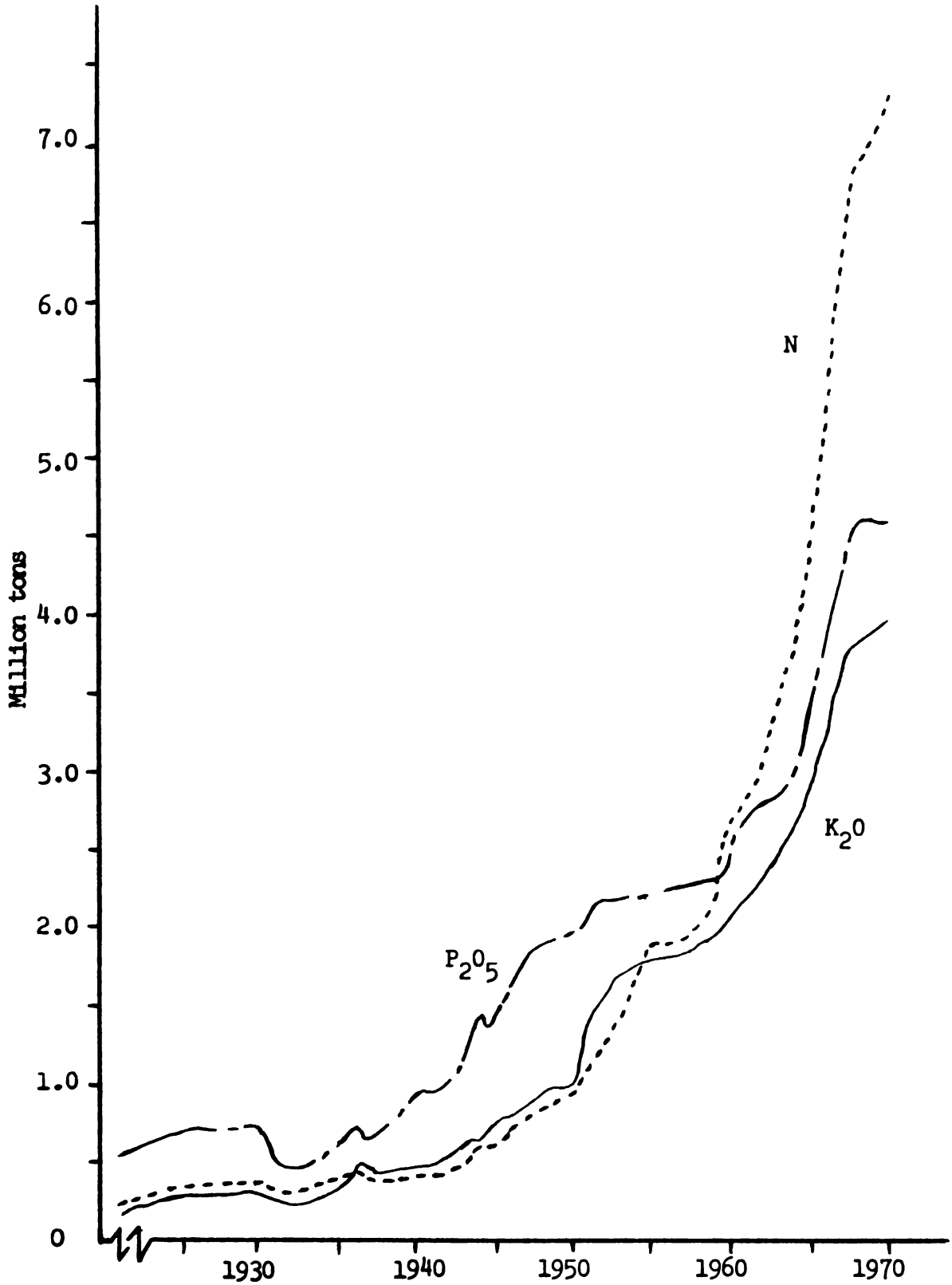
[20]Note that the consumption of P_2O_5 in the base year was more than double that of either N or K_2O.



Source: (Harre, 1969, p. 12) and (Fertilizer Situation, 1952, p. 8).

Figure II-17. Plant food consumption in the United States and possessions

Table II-3. Index of plant food consumption in the United States and Puerto Rico

Year	N	P_2O_5	K_2O
1940[a]	100	100	100
1941	109	109	107
1942	98	124	126
1943	121	136	148
1944	153	154	149
1945	150	148	168
1946	167	170	186
1947	187	190	197
1948	205	203	212
1949	220	213	247
1950	240	214	254
1951	295	231	317
1952	339	241	363
1953	391	249	400
1954	441	245	417
1955	468	250	431
1956	461	246	431
1957	510	252	445
1958	545	251	445
1959	637	280	504
1960	653	282	495
1961	723	290	498
1962	804	308	522
1963	938	337	575
1964	1039	370	627
1965	1107	385	651
1966	1271	427	740
1967	1438	472	837
1968	1597	488	872

Source: (Harre, 1969, p. 12) and (Fertilizer Situation, 1952, p. 8).

Base year: 1940.

[a]Production in the base year was: N - 419,000 tons; P_2O_5 - 912,000 tons; and K_2O - 435,000 tons.

consumption of K_2O was 5.2 times the 1940 consumption level (Fertilizer Situation, 1952) and (Harre, 1969).

More drastic increases occurred during the 60's. Consumption of N increased from 2,738,047 tons in 1960 to 6,693,790 tons in 1968, while consumption of P_2O_5 increased from 2,572,348 tons in 1960 to a 1968 level of 4,451,980 tons. Consumption of K_2O increased from 2,153,319 tons in 1960 to 3,792,013 tons in 1966.

The dramatic increase in the level of consumption of N, P_2O_5 and K_2O was not unique, it was paralleled by an increase in the number of firms supplying the nutrients. In 1940, only seven firms manufactured synthetic ammonia, the basic nitrogen product. The largest firm had 51 percent of the industry capacity and the two largest 87 percent. In 1966, there were 65 firms, with the largest having eight percent of industry capacity and the four largest 26 percent (Gale, 1968, p. 28).

Phosphate was produced by four firms in 1940. This number increased to 16 by 1966. In that year, the largest firm had 19 percent of industry capacity and the top four had 51 percent. Potash was produced by five firms in 1940 and, in spite of a 323-percent increase in industry capacity, by only ten firms in 1965 (Gale, 1968, p. 31).

It is apparent that the fertilizer industry can be characterized as an industry of great change. But what lies ahead? Chapter III examines the industry as it would appear if it were optimally organized in the long run and discusses the route it should take to obtain that organization. Chapter IV discusses the impact of large amounts of by-product ammonium sulfate on the long-run optimal organization, while Chapter V examines the sulfur industry and its relationship to the fertilizer industry.

CHAPTER III

THE LONG-RUN OPTIMAL ORGANIZATION OF THE FERTILIZER INDUSTRY

As noted in Chapter I, three basic situations were examined with the fertilizer model. First, the actual conditions that prevailed in the Michigan industry in 1970 were duplicated, as closely as possible, with the model. Such items as product mix, product flow, facilities used and so forth, were programmed into the model. This provides a benchmark from which analysis of special situations may be compared. This benchmark, the simulation of the industry as it was in 1970, is referred to as "1970 Actual" and its details are provided in Appendix A.

The second analysis involves the determination of the short-run optimal organization of the industry. This analysis determined the least-cost method of supplying the amount of N, P_2O_5 and K_2O Michigan farmers consumed in 1970. Being consistent with the economic concept of "short-run," the model was allowed to make any adjustment that lowered the total cost of fertilizer except to make investment in new facilities. Existing facilities only could be used. Although the short-run optimal organization of the fertilizer industry, called "Constrained Optimum," is not discussed here, its details are provided in Appendix A.

The third analysis involves the determination of the long-run optimal organization of the fertilizer industry. In this analysis, the

model was allowed to make any adjustment, within the constraints of the model, that lowered the total cost of fertilizer, including investment in new facilities. This organization, called "Optimum," will be discussed in this chapter. The details of Optimum are provided in Appendix A and can be compared with both Constrained Optimum and 1970 Actual.

The analysis of the impact of by-product ammonium sulfate and sulfuric acid, which is presented in Chapters IV and V, is based on the long-run optimal organization of the fertilizer industry and, therefore, frequent comparisons with Optimum will be made. Since Optimum is considerably different than the current organization of the industry, 1970 Actual, the most efficient manner of reaching Optimum starting at the organization of 1970 Actual is also explored in this chapter.

The Optimal Organization of the Fertilizer Industry

The optimal organization of the industry is quite simple, centering around three high-analysis products: anhydrous ammonia, monoammonium phosphate and granular potassium chloride (Figure III-1). Approximately 130,000 tons of anhydrous ammonia would be produced in a centrifugal plant in Michigan and trucked to farms for direct application. The Gulf Coast facilities would also manufacture 42,874 tons and barge it to monoammonium phosphate producers in Florida. Ammonia used for direct application would be produced in Michigan because it is cheaper to produce it in Michigan, near the market, than to produce it in the Gulf Coast area where natural gas is much cheaper,[1] and transport it to Michigan. Of course, when ammonia is needed in Florida, the Gulf Coast

[1]Natural gas is the primary input in the production of anhydrous ammonia.

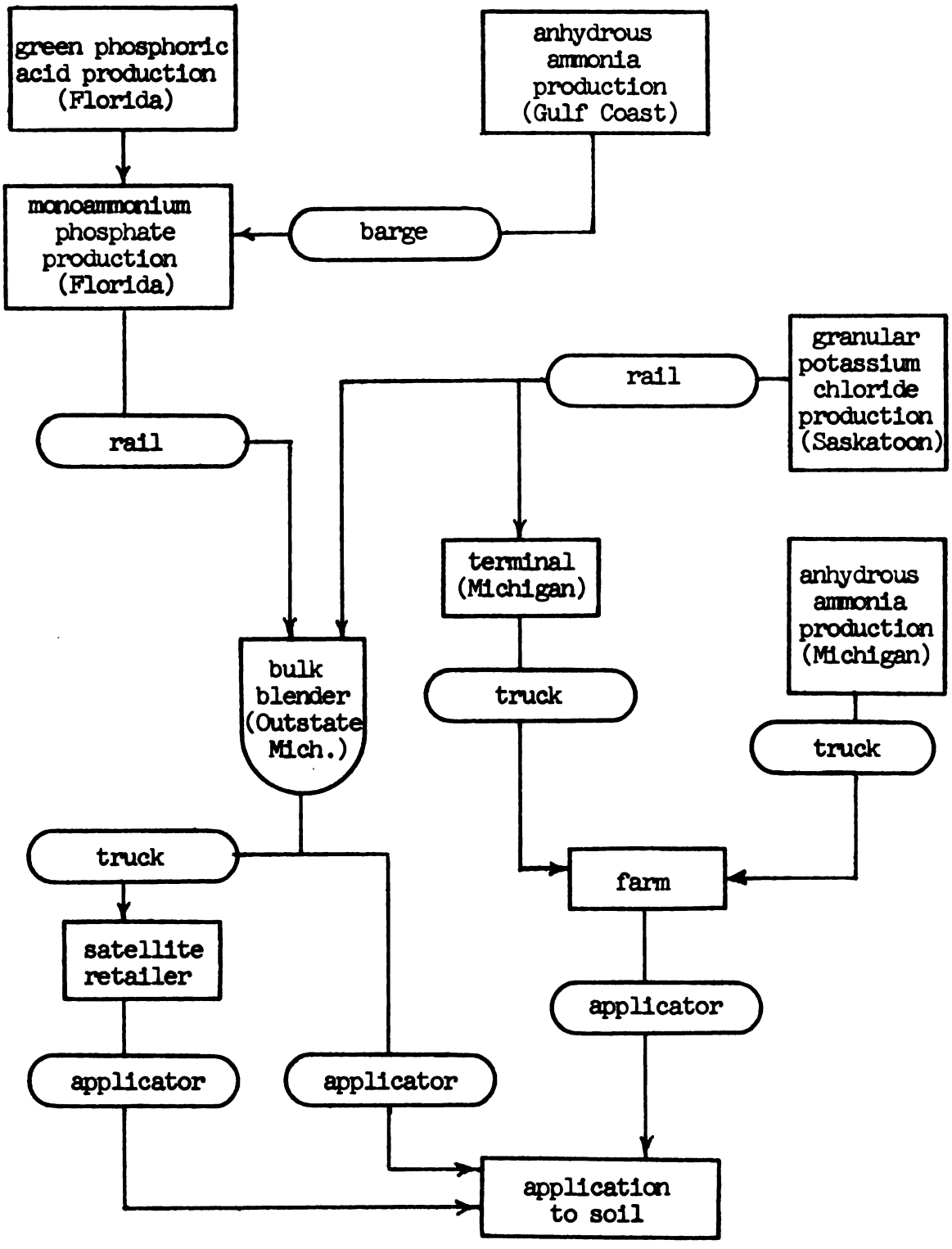


Figure III-1. Optimal organization of the fertilizer industry for supplying the amount of N, P_2O_5 and K_2O consumed in Michigan in 1970

is the logical source.

The ammonia received in Florida would be combined with green phosphoric acid in the production of 270,576 tons of monoammonium phosphate (13-52-0). Although the alternative of producing elemental phosphorus and converting it to phosphoric acid was available, acidulation of phosphate ore with sulfuric acid, the process for producing green phosphoric acid, was selected by the model as more economical.[2] All of the monoammonium phospahte would then be transported by rail to outstate blenders where it would be mixed with 172,713 tons of granular potassium chloride in two formulations: 7-28-28, a 1-4-4 ratio; and custom blend 10.6-42.55-10.85, approximately a 1-4-1 ratio. Because 75 percent of all materials going to blenders must be stored somewhere to reconcile nonseasonal production of those inputs with seasonal blending operations,[3] 202,932 tons of the monoammonium phosphate would be stored at the manufacturers in Florida, while 129,535 tons of the granular potassium chloride would be stored at the manufacturers in Saskatoon.

The remaining 86,319 tons of granular potassium chloride would

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[2]Sulfuric acid used to produce green phosphoric acid is a competitor of electricity which is used to produce elemental phosphorus in the electric arc furnace which, in turn, is used to produce white phosphoric acid. Consequently, their prices are critical. In this situation, the price of electricity was 4 mills per kilowatt hour, while the price of sulfuric acid was $12.32 per ton at the Florida production location (the elemental phosphorus route is discussed in greater detail on p. 138).

[3]The blending season is short, with most of the materials being blended in a two-month period in the spring, although a little is blended in each spring month, and some in the fall. Since the intermediate products (products that serve as inputs to blending) are produced year-round, 75 percent of each of them must be stored until the blending season. Seasonal production of the intermediate products is not economically feasible under current economic relationships and, in many situations, is not technically feasible.

be shipped to the Michigan terminal where it would be transferred to the truck and hauled to farms for direct application. It may seem unusual that some of the granular potassium chloride travels direct while the remainder is used in bulk blending. However, this is easily explained.

The bulk blend storage requirement combines with a nutrient storage requirement to cause this phenomenon. The nutrient storage requirement specifies that 50 percent of each nutrient supplied to Michigan farms must be stored.[4] For example, since 155,422 tons of K_2O are supplied, 77,721 tons must be stored. If granular potassium chloride is the only product being produced, as is the case in Optimum, this storage requirement can be satisfied by storing 129,535 tons of it. If several products are providing a nutrient, any amount of any product may be stored to satisfy the storage requirement. Of course, since the objective is to minimize cost, the product that can be stored the cheapest per nutrient content will be stored.

Returning to the granular potassium chloride phenomenon, line OD (Figure III-2) corresponds to the 75-percent blending storage requirement (the line is a locus of points where the amount being stored is 75 percent of the amount being blended). OE is the minimal amount of granular potassium chloride that can be stored in satisfying the 50-percent nutrient storage requirement, and is independent of the amount being blended. Point B (the point of intersection of lines OD and EB)

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[4]Fertilizer consumption is seasonal while production of fertilizers is not. Since seasonal production of fertilizer products (except for mixed products) is not economically feasible under current economic relationships and, in many situations, is not technically feasible, it was concluded that 50 percent of all production in each nutrient group must be stored.

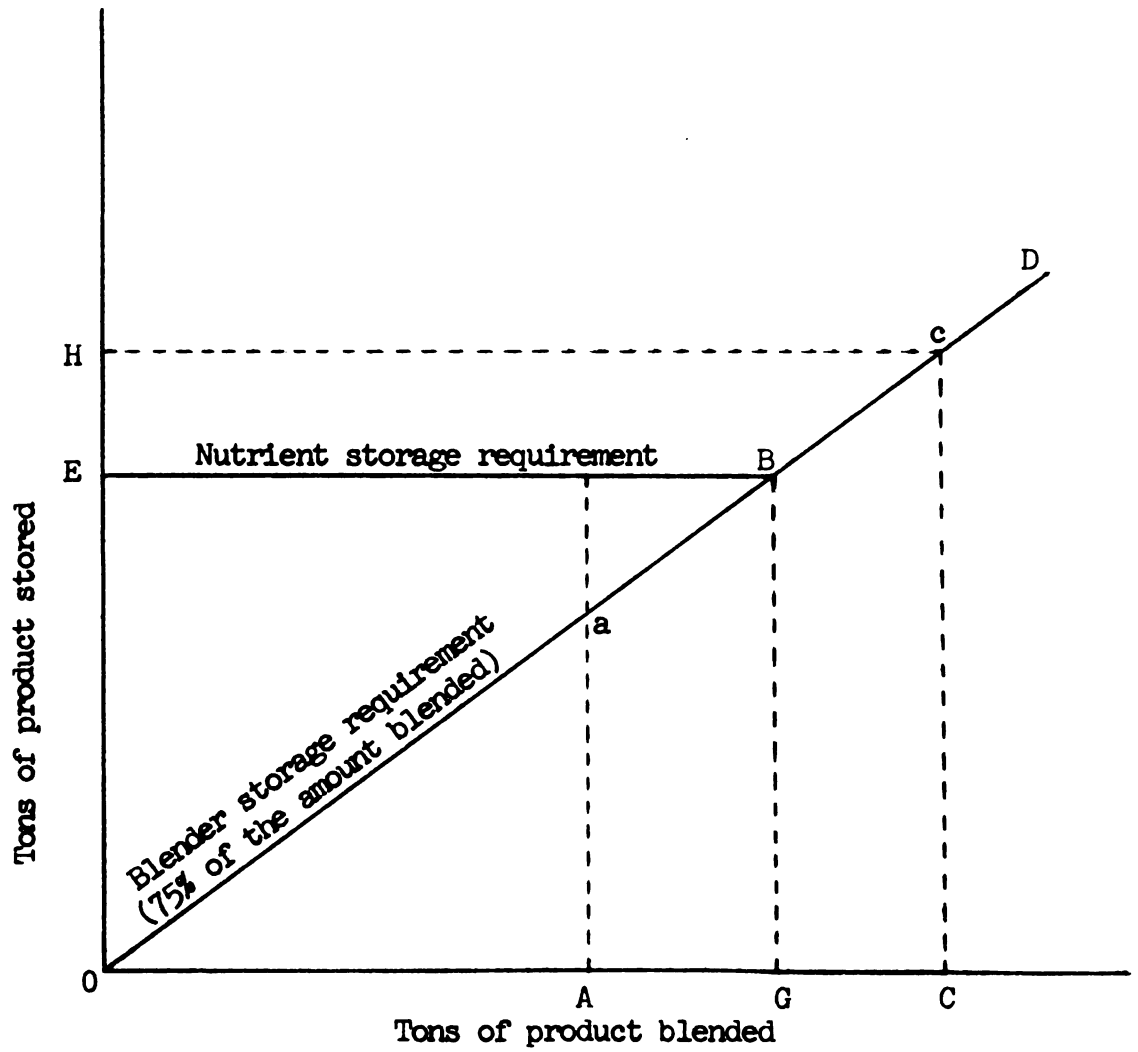

Figure III-2. Granular potassium chloride nutrient and bulk blend storage requirements

is the point where 75 percent of the amount being blended OG corresponds to the minimal nutrient storage requirement OE. Its significance lies in the fact that at levels of blending below OG (for example, OA), additional levels of product can be blended without affecting the minimal amount of product that must be stored since, at that amount, the minimal storage level, as specified by the 50-percent nutrient requirement, is well above Aa. But at levels of blending above OG (for example, OC), the minimal amount of product that must be stored is equal to 75 percent of the amount being blended, and is well above the 50-percent nutrient storage control. Therefore, the minimal storage requirement is line EBD in Figure III-2. If no more than OG is blended, the minimal storage requirement is OE. The BD portion of line OD is relevant only if blending exceeds OG. For example, if OC is being blended, the minimal storage requirement is OH.

In terms of the marginal cost of blending, no storage costs result from the blending activities up to level OG, which corresponds to 172,713 tons of granular potassium chloride. But at levels above OG, the additional storage requirements result entirely from increased levels of blending and consequently raise the marginal cost of blending.

Therefore, it can be concluded that it is cheaper to blend the granular potassium chloride with the monoammonium phosphate as long as there are no storage costs that result specifically from the blending operation. The 129,535 tons of potassium chloride had to be stored, whether it was being blended or not, to satisfy the 50-percent nutrient storage requirement. But if more than 172,713 tons of granular potassium chloride is being blended, the blending operation must bear the marginal cost of storage in addition to its own marginal cost. Since the marginal

cost of the direct application channel was less then the marginal cost of the blending channel above 172,713 tons, the remainder of the granular potassium chloride went direct. Figure III-3 illustrates this relationship. Line ABCD is the marginal cost of blending.[5] It is discontinuous at Point B since it incurs the additional marginal cost of storage. Up to 172,713 tons of product the marginal cost of blending is less than the marginal cost of direct application. But at that point, the marginal cost of blending raises above the marginal cost of the direct application channel. Therefore, all of the granular potassium chloride above 172,713 tons travels to the farm via the direct application channel.

One might now pose the question, "Why did not the same phenomenon occur with monoammonium phosphate?" The fact that all of the monoammonium phosphate went into the blending operation reflects the fact that the marginal cost of blending, even with the marginal cost of storage added in, is less than the marginal cost of direct application (Figure III-4). Therefore, at any level, the bulk blend channel is preferred to the direct application channel.

The contrasting patterns followed by monoammonium phosphate and granular potassium chloride in Optimum give rise to an interesting situation. Adding $2.33 (the marginal cost of storing .75 tons of granular potassium chloride) to the marginal cost of blending one ton of potassium chloride causes it to follow the direct application channel. But adding a larger amount, $2.42 (the marginal cost of storing .75 tons of monoammonium phosphate to the marginal cost of blending one ton

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[5]Only the relevant portion of the marginal cost curves are flat, or nearly flat, as represented in Figure III-3.

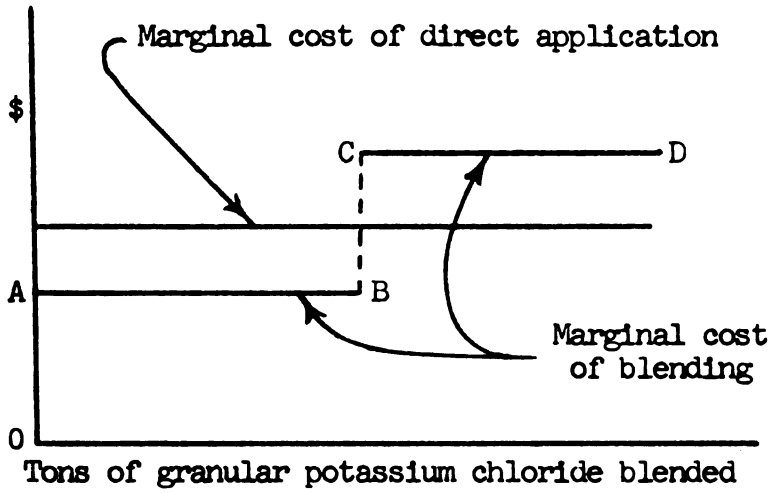

Figure III-3. Marginal costs of blending versus direct application for granular potassium chloride

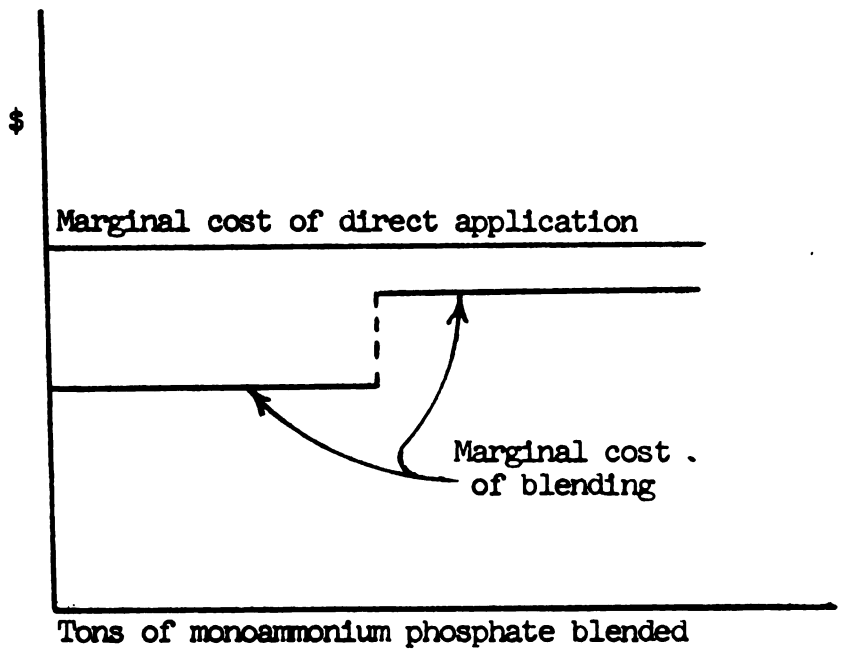

Figure III-4. Marginal costs of blending versus direct application for monoammonium phosphate

of monoammonium phosphate), does not cause it to use the direct application channel. The explanation is straightforward. To make comparisons across products, nutrient content must be taken into consideration. If the marginal costs discussed above are placed on a common denominator (nutrient content), we find that the additions were $3.88 per nutrient ton for potassium chloride and $3.72 per nutrient ton for monoammonium phosphate. It becomes apparent that, as long as the differential between the bulk blend route and the direct application channel lies between $3.72 and $3.88 per nutrient ton, only potassium chloride would utilize the direct application channel.

Although the product mix is the most striking characteristic of Optimum, a few other observations are of interest. Both anhydrous ammonia and granular potassium chloride bypass the retailers; the centrally located firms would perform the retailing functions. The two products would be transported directly from the central location to the farm. In terms of their functions, retailers appear to be relatively high in cost and low in benefits. This results primarily from their high investments and low thruput.

Thruput is an important factor in blending as well. Nine-thousand-ton blenders are identified as more economical than 2,500- or 1000-ton blenders. The economies of scale more than offset the diseconomies of increased distribution cost from the blender. However, a satellite distribution outlet would be utilized to assist in moving the fertilizer to the farm. Applicators would be used to move the product to the farm. By using applicators, the additional investment of trucks or tenders is avoided, as are handling costs that would be incurred in transferring the fertilizer to the applicator at the farm.

The effect of this organization on the total cost of supplying fertilizer to Michigan farmers is phenomenal. Whereas the cost of fertilizer under 1970 Actual is $71,445,667, the same amount of N, P_2O_5 and K_2O can be provided under Optimum at $48,297,963, a saving of 32.4 percent.

In view of the substantial cost reduction, it behooves farmers and firms in the fertilizer industry to take the necessary measures to improve performance within the industry. The best approach for going from the organization of 1970 Actual to Optimum is examined in the next section.

The Transition from 1970 Actual to Optimum[6]

The optimal approach for reorganizing the fertilizer industry in an attempt to go from the organization of 1970 Actual to the organization of Optimum is highly dependent upon the assumptions made. The transition discussed here is based on several assumptions.

1. The model was not allowed to invest in new facilities that do not appear in the organization of Optimum. The objective here was to optimize year by year, given the goal of attaining Optimum as rapidly as possible. Without this restriction, the model may have selected facilities that would have lowered cost in the specific year, but would have detained or prevented the achievement of Optimum. This latter approach would have been consistent with the objective of optimizing year by year without heading for any specific point.

Obviously, there is a trade off between the two objectives. With the objective of optimizing year by year without heading for a specific

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[6]For a thorough discussion of this transition, see (Perkins, 1972).

point, annual total cost may be lower in the first few years, but higher thereafter. With the objective selected, annual total cost may be higher in the first few years, but lower thereafter. Certainly, one of these approaches would result in a cost lower than the other over a span of a number of years. If the model had been recursive, the best route of transition in conjunction with an efficient long-run organization would have achieved lowest total cost for that time span. The outcome of that analysis could well have been different from the outcome under either of the two approaches that could have been taken with the current model. However, given the model available, the objective of optimizing year by year, given the goal of attaining Optimum as rapidly as possible was selected.

2. It is assumed that the capacity of existing facilities in the industry declines at a rate of 20 percent annually. This decline in capacity results from two factors. First, some plants become totally depreciated every year and cease to operate. Second those plants that continue to produce lose some of their productive capability due to usual deterioration and loss of efficiency.

3. The salvage value on all facilities is assumed to be zero. This seems to be very consistent with actual conditions. Fertilizer facilities have essentially no other use, and the cost of scrapping them is approximately matched by the revenue generated by the sale of the recoverable components and scrap.

4. Return on investment of existing facilities and those at least one year old is assumed to be zero. Only two factors will cause a plant to cease operating. The first is its total depreciation (physical rather than accounting). The second is learned from the

classical economists and is based on fixed asset theory. Interpreting this situation, a new facility will not replace an existing facility unless its total cost of production is less than the variable cost of production in the old facility. If an existing plant is just covering its variable cost of production, it is earning a return on the investment of zero. Therefore, by setting the return on investment at zero, while having a return on investment equal to that level required to induce firms to build the facility, a new plant will not replace the old plant unless its total cost is less than the variable cost of existing plants.

5. It is also assumed that farmers will purchase the products that are produced in each phase of the transition. This would involve some rather extensive and abrupt shifts in the consumption of fertilizers, and past observations tend to indicate that farmers do not change that rapidly. (But never before have the incentives been so great, i.e., a 32.4 percent reduction in the cost of fertilizer.) In any case, it is assumed that they will be willing to accept the products produced in each phase.

6. Finally, it is assumed that the level of consumption of N, P_2O_5 and K_2O does not change. Although a 32.4 percent reduction in the cost of fertilizer would certainly cause an increase in the quantity demanded, comparisons between the organizations and costs associated with 1970 Actual, Optimum and the transition periods are much more appropriate if the levels of the three nutrients are not allowed to change. The issue of the change in quantity demanded is discussed at the end of this chapter.

It is important to keep these assumptions in mind because the transition about to be discussed is optimum only for those assumptions.

If the assumptions were changed, the transition route would probably change also.

In making the transition from 1970 Actual to Optimum, the short-run optimum can be achieved instantaneously; no additional investment is needed. Therefore, the achievement of the short-run optimum takes place in year zero. In year one, the mechanics of the transition are initiated. The capacity of existing facilities decreases by 20 percent and investment is allowed. The short-run optimum (year zero) used in the transition is different than Constrained Optimum, however. This variation originates from the differences in the return on investment; as you recall, return on investment for the transition analysis is set at zero for existing facilities, while in Constrained Optimum a 7.5 percent return was allowed on facilities.

As expected, components that make up the organization of Optimum, those products that have high nutrient content-cost ratios, would begin placing inefficient products immediately. By year five, the optimal organization, for the most part, would be achieved (Table III-1).

Since anhydrous ammonia is the only source of nitrogen for all other fertilizer products, its level in year zero, year five, and each intermediate year is essentially the same. A slight variation results from the differing amounts of product loss in the various uses of ammonia. Although its general level would remain stable, there would be important changes in its production and distribution.

Production and storage of ammonia in the Gulf Coast would decline significantly. Whereas ammonia storage would drop to zero, production would fall no lower than 42,873 tons. This amount would be barged to Florida for use in the production of monoammonium phosphate. Both

Table III-1. Product use summary for the transition years (in tons)

Product	Year 0	Year 1	Year 2	Year 3	Year 4	Year 5
Anhydrous ammonia	171,974	172,327	172,473	172,619	172,763	172,763
Nitric acid	9,930	5,147	3,432	1,716	-0-	-0-
Ammonium nitrate	12,980	6,729	4,486	2,243	-0-	-0-
Nitrogen manufacturing solution	18,596	9,640	6,427	3,213	-0-	-0-
Elemental phosphorus	3,977	1,591	795	-0-	-0-	-0-
White phosphoric acid	16,866	6,746	3,373	-0-	-0-	-0-
Green phosphoric acid	220,645	242,603	249,688	256,774	260,487	260,487
Run-of-pile triple superphosphate	115,303	53,687	35,687	17,894	-0-	-0-
Granular triple superphosphate	8,352	-0-	-0-	-0-	-0-	-0-
Diammonium phosphate	111,857	59,586	42,709	25,833	-0-	-0-
Monoammonium phosphate	72,737	170,321	201,070	231,823	270,495	270,495
Run-of-mine potassium chloride	114,440	59,323	39,551	19,772	-0-	-0-
Granular potassium chloride	144,629	179,704	209,469	239,241	259,006	259,006
Coarse potassium chloride	-0-	20,000	10,000	-0-	-0-	-0-
Granulated mixed fertilizers	286,099	148,308	98,887	49,431	-0-	-0-
Bulk blended fertilizers	272,000	245,699	288,543	331,400	374,243	374,243
N supplied	141,932	141,932	141,932	141,932	141,932	141,932
P_2O_5 supplied	140,650	140,650	140,650	140,650	140,650	140,650
K_2O supplied	155,441	155,441	155,441	155,441	155,441	155,441

production and storage of anhydrous ammonia in the Midwest would fall to zero by year five. This loss of product and storage capacity in the Gulf Coast and Midwest would be made up by investments in those facilities in Michigan. By the end of the five years, ammonia production in Michigan would climb to 129,890 tons while storage would rise to 62,429 tons. All of the ammonia produced in Michigan in year five would be used for direct application.

One of the major changes that would occur in the transition would be the decline in granulation of mixed fertilizers. Whereas in year zero the granulator would produce 286,099 tons of mixed fertilizers, production would drop to 148,308 tons in year one, 98,887 tons in year two and 49,431 tons in year three. No mixed products would be granulated after year three.

Associated with this decline in granulation is a corresponding decline in all those products that serve as inputs into granulation, either directly or indirectly. They include nitrogen manufacturing solution, ammonium nitrate, nitric acid, run-of-pile triple superphosphate, diammonium phosphate, white phosphoric acid, elemental phosphorus and run-of-mine potassium chloride.

Although bulk blending would decline somewhat in year one, it would climb steadily thereafter, reaching 374,243 tons in year five. Only two intermediate products would be used in blending in year one, and thereafter: monoammonium phosphate and granular potassium chloride. By year five, 201,530 tons of monoammonium phosphate and 172,713 tons of granular potassium chloride would be blended, and another 68,965 tons and 86,293 tons of those products respectively would pass through the Central Michigan terminal enroute to the farm for direct application.

Finally, production of wet process-green phosphoric acid would increase somewhat, from 240,133 tons to 260,487 tons. This increase would substitute for an equal decrease in the production of white phosphoric acid.

Although the cost of supplying the fertilizer would continually decrease, the shift from 1970 Actual to the short-run optimal organization would account for most of the savings. In each of the succeeding years, additional savings would be realized as the efficient products replace the less efficient sources of N, P_2O_5 and K_2O. Interestingly, the savings generated in any one year would be more than sufficient to cover the new investment needed to continue improving the organization of the industry in the succeeding year, even if these savings were shared with farmers (Perkins, 1972, p. 116). This should be an important encouragement for an industry which is very likely exceedingly cautious about further investments.

Although holding the level of N, P_2O_5 and K_2O constant throughout the analysis was useful for comparative purposes, it is not consistent with economic concepts to expect their levels to remain unchanged in the presence of such remarkable price drops.

Several studies have been undertaken to determine the price elasticity of demand for fertilizer (Table III-2). In these studies, the elasticities varied widely, from positive, to inelastic, to quite elastic. It would be difficult to base any change in consumption on these elasticity estimates. Reiling estimated consumption of N, P_2O_5 and K_2O to be 187,000 tons, 172,000 tons and 167,000 tons respectively in Michigan in 1980 (Reiling, 1966, p. 139). Using this projection, or some other projections, consumption could be steadily increased

Table III-2. Estimated price elasticities of demand for fertilizer nutrients and total fertilizers (short run)

Study	Fertilizer nutrients N	P	K	Total
Griliches (1958)				-.50
Griliches (1959) (East North Central)				-.43
Yeh and Heary (1959) (U.S.) (Corn Belt)	-.499	-.488	-.403	-.49
Heady and Tweeten (U.S.)	-1.24 to -2.11	-1.34 to -1.90	-1.43 to -2.14	-1.40 to -1.52
Heady and Tweeten (Corn Belt)	-2.99	-3.90	-4.07	-3.67
Brake (1960) (East North Central)				-1.79 to -5.37
Daniel (1970)				-.66 and -.47
Reiling (1966) (Michigan)	-2.17	.783	.112	

Source: (Daniel, 1970, p. V-29).
(Reiling, 1966, p. 104).

throughout the transition.

In summary, the fertilizer industry could improve efficiency considerably without investing in additional facilities. By improving the use of existing facilities, the cost of supplying the amount of the three nutrients consumed in Michigan in 1970 can be reduced by more than 25 percent. However, by making modest investments, a reduction in the cost of fertilizer of 32.4 percent can be achieved.

A primary characteristic of Optimum is the use of only three basic and intermediate products; one product to supply each of the

nutrients. Granular potassium chloride provides all of the required K_2O, while monoammonium phosphate provides all of the P_2O_5. Although the monoammonium phosphate also provides some nitrogen, 75 percent of the nitrogen is provided by anhydrous ammonia.

The phosphoric acid used to produce the monoammonium phosphate would be produced as green phosphoric acid; i.e., it would be produced by the wet process. Since the wet process uses sulfuric acid as a primary input, the potential for by-product sulfur or sulfuric acid recovered from the smokestacks of electric generating plants is clear.

On the other hand, all nitrogen would be provided by anhydrous ammonia. Ammonium sulfate is not optimal. However, the by-product ammonium sulfate has a distinctive difference from synthetic ammonium sulfate, a difference that may well establish it a role in the fertilizer product mix. This difference will be discussed in the next chapter which examines "the use of by-product ammonium sulfate in the fertilizer industry."

CHAPTER IV.

THE USE OF BY-PRODUCT AMMONIUM SULFATE IN THE FERTILIZER INDUSTRY

More ammonium sulfate was consumed in the world than any other solid nitrogen fertilizer until 1959, when it was surpassed by ammonium nitrate. In 1966, consumption of ammonium sulfate and ammonium nitrate represented 18 and 28 percent of the world fertilizer consumption, respectively. Consumption of ammonium sulfate is equivalent to three million metric tons of nitrogen per year.

Ammonium sulfate is of lesser importance in the United States than it is on the world level. Although it was the major nitrogen fertilizer from 1923 to 1947, anhydrous ammonia, ammonium nitrate and urea have moved ahead. In 1970, 771,655 tons of ammonium sulfate were applied directly. Ammonia and ammonium nitrate supplied 3,491,603 and 2,847,334 tons of material for direct application, respectively (Hargett, 1971, p. 6). Only 2,366 tons of ammonium sulfate were consumed in Michigan in 1970, which accounts for only .26 percent of the total material sold (Tonnage of Fertilizer Sold in Michigan From January 1 Through December 31, 1970).

The decline in ammonium sulfate is not without reason. Because of its low nitrogen content (about 21%), the cost of handling, storing, transportation and application relative to its nutrient content is high. For example, if urea (45% N) and ammonium sulfate are transported at equal cost per ton of material, the cost per nutrient content would be 2.14 times as great for ammonium sulfate as it would be for urea

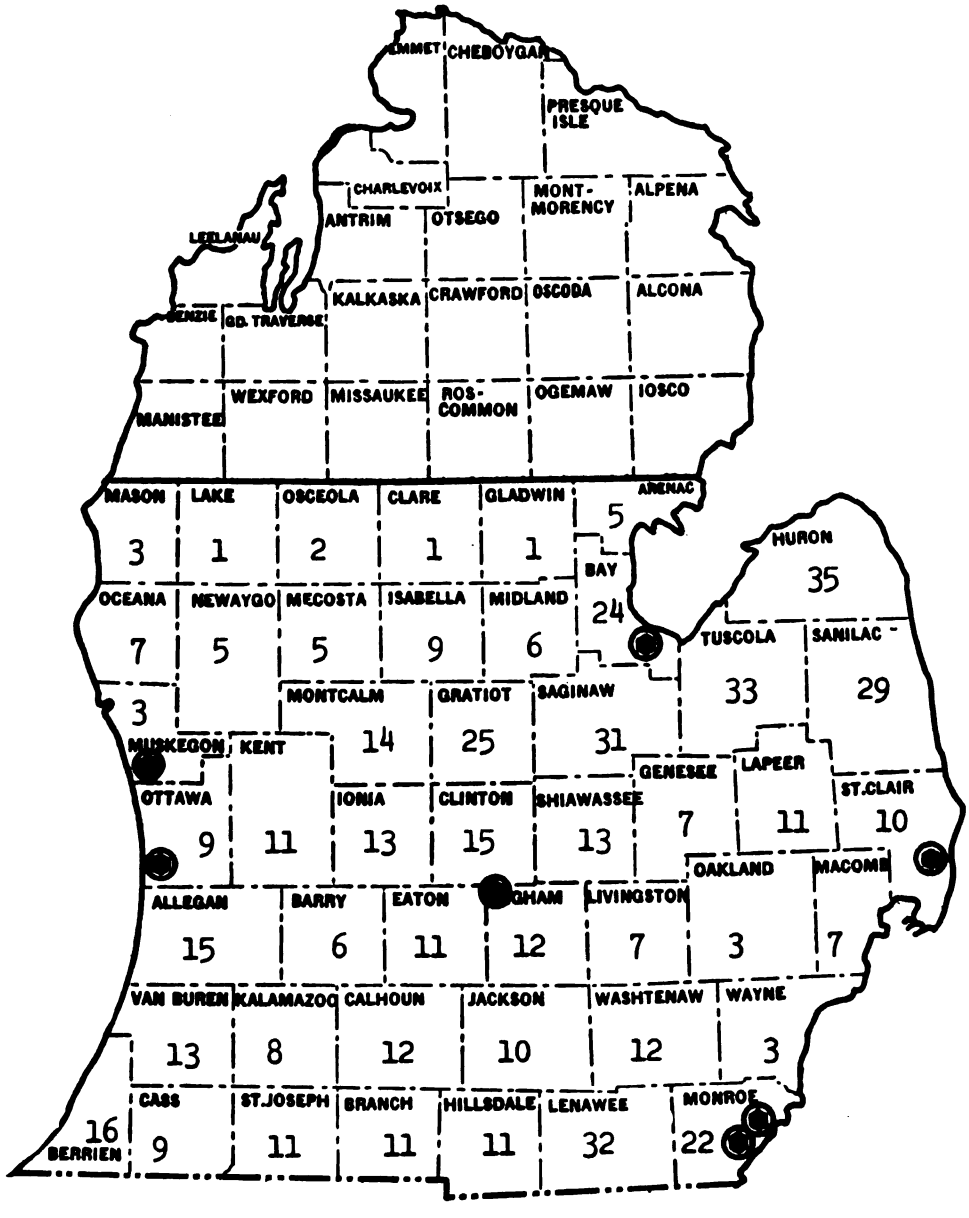
simply because urea can spread the transportation cost over more nitrogen content.

However, if the cost of manufacturing ammonium sulfate were sufficiently low, the premium that would be needed to handle, store, transport and apply ammonium sulfate might be offset, particularly if these operations were minimal. Indeed, the transportation differential should not be great since the potential source of by-product ammonium sulfate, the electric power-generating plants, are in proximity to the fertilizer consumer (Figure IV-1). How low must the manufacturing cost go to make ammonium sulfate competitive with the source of nitrogen in the long-run optimal organization?

Ammonium Sulfate for Direct Application

The option of utilizing by-product ammonium sulfate for direct application was introduced into the model. Although the technology relating to the use of the by-product powdered ammonium sulfate is not well-developed, it is assumed that it can be handled, stored, transported and applied at the same cost as can granular ammonium sulfate. To initiate the analysis, the price at which powdered ammonium sulfate was transferred from the smokestack scrubbing operation to the fertilizer enterprise was lowered until it became competitive with established sources of nitrogen.

An analysis indicates that at prices above two dollars per material ton, ammonium sulfate is not competitive with the products in Optimum. But at two dollars, 296,321 tons would enter the solution by replacing 75,703 tons of anhydrous ammonia being used for direct application in Optimum. By lowering the price to that level, the premium paid for handling, transportation and application is offset.



Source: 1969 Census of Agriculture.

Figure IV-1. Seven major coal-fired electric power-generating stations in Michigan and consumption of fertilizer by county (in 1,000 tons)

This relationship can be presented algebraicly:

$$\frac{P_{as} + H_{as} + T_{as} + A_{as}}{N_{as}} \leq \frac{M_a + H_a + T_a + A_a}{N_a} \qquad 1$$

where P = price, M = manufacturing cost, H = handling cost, T = transportation cost, A = application cost, N = nutrient content (i.e., 21 percent for ammonium sulfate) and the subscript "as" means "of ammonium sulfate" while "a" means "of ammonia."

As noted previously, ammonium sulfate's share of the market diminished because the handling, transportation and application costs per nutrient were high relative to other products. That is,

$$\frac{H_{as} + T_{as} + A_{as}}{N_{as}} > \frac{H_x + T_x + A_x}{N_x} \qquad 2$$

where "x" represents another product. But as ammonium sulfate's price per nutrient ton falls below the manufacturing cost per nutrient ton for other products, i.e., $\frac{P_{as}}{N_{as}} < \frac{M_x}{N_x}$

it diminishes the disparity in the total of the four operations until equation 1 holds true.

The ammonium sulfate would not replace all of the anhydrous ammonia going direct, however; 54,239 tons would remain. That amount of ammonia would be stored in order to meet the previously discussed storage requirements of the model. Since ammonia has a favorable storage cost per nutrient content relationship, and ammonium sulfate an unfavorable one, adding those two components into equaltion 1 swings the advantage back to ammonia. That is,

$$\frac{P_{as} + H_{as} + S_{as} + T_{as} + A_{as}}{N_{as}} \geq \frac{M_a + H_a + S_a + T_a + A_a}{N_a} \qquad 3$$

where "S" is the cost of storage. With ammonium sulfate priced at $2.00 per ton, its low price per nutrient content would be able to counterbalance the high nutrient cost of handling, transporting and applying, but would not be able to counterbalance storage in addition to those three. Consequently, ammonium sulfate would be able to replace only that amount of ammonia not being stored.[1]

This relationship can be illustrated in terms of marginal costs (Figure IV-2a). Line BCDE is the marginal cost per nutrient ton for providing ammonium sulfate. Portion BD corresponds to its marginal cost when it is not being stored. Portion DE is its marginal cost when it is being stored. The marginal cost of anhydrous ammonia, FGHI, is similar. When the marginal cost of ammonium sulfate fell to OB, which is below the marginal cost of ammonia (OF), it became desirable to supply N in the form of ammonium sulfate, rather than anhydrous ammonia, up to level OA. At that level, ammonium sulfate would need to be stored to satisfy the nitrogen nutrient storage requirement. But the marginal cost of storing ammonium sulfate was much greater than the marginal cost of storing anhydrous ammonia. So when the marginal costs of storage are considered in addition to the marginal cost of production (or purchase) and distribution, anhydrous ammonia is clearly preferable.

However, when the price of ammonium sulfate falls to one dollar per ton, the storage cost disparity is offset, the inequality in

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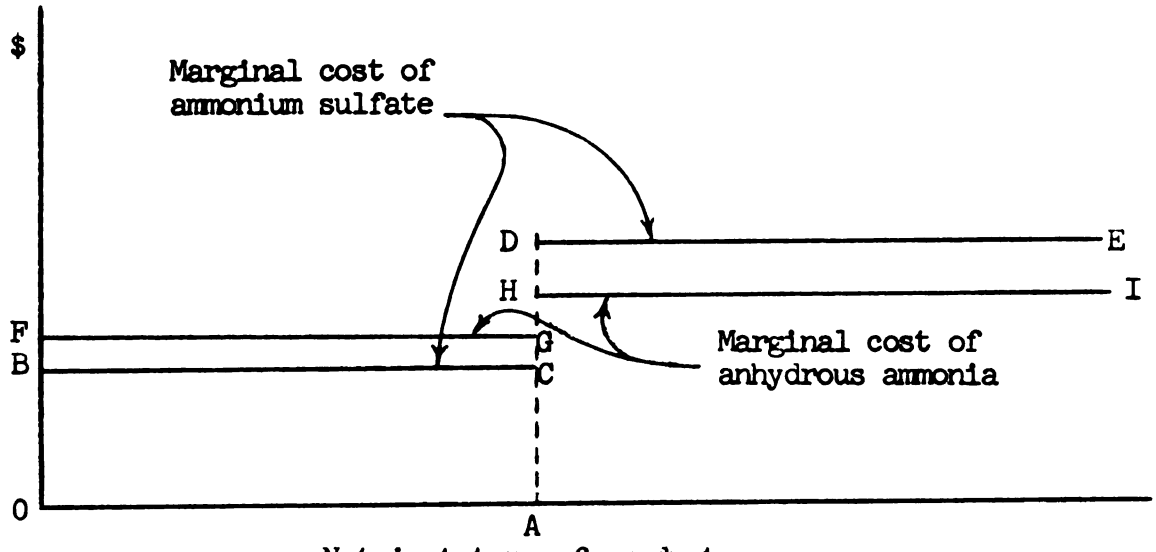
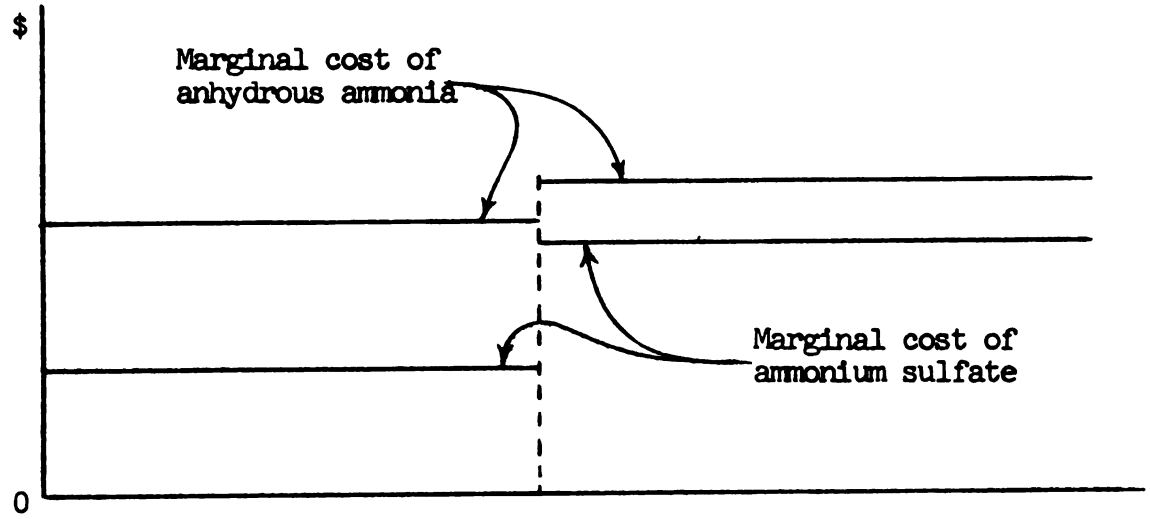
[1]Actually, the disparity between the per-nutrient storage costs of ammonium sulfate and ammonia does not specifically have to be neutralized if there are alternative products that can satisfy the storage requirement. For example, if urea were also going direct in the solution, it would have been stored rather than ammonium sulfate because its storage cost per nutrient content is less. In that case, the price per nutrient content of ammonium sulfate would need to offset the disparity between nutrient storage costs of ammonia and urea only.



(a) Price of ammonium sulfate at $2.00/ton



(b) Price of ammonium sulfate at $1.00/ton

Figure IV-2. Marginal costs of ammonium sulfate and anhydrous ammonia per nutrient ton

equation 3 reverses, and ammonium sulfate becomes the preferred product. At that point, all the 129,942 tons of ammonia going direct would be replaced by 508,629 tons of ammonium sulfate.

In terms of marginal costs, the purchase price of ammonium sulfate would be low enough that when the marginal cost of storage is added, it is preferred to anhydrous ammonia (Figure IV-2b).

Although there would still be some ammonia in the solution, the ammonium sulfate would not be able to replace it--even when its price dropped to zero. The remaining ammonia would be manufactured at the Gulf Coast and barged to Florida to be used in the production of monoammonium phosphate. The monoammonium phosphate would, in turn, be shipped to Michigan for use in blending. If the ammonium sulfate were to replace that ammonia, it would also have to offset the additional nutrient cost of producing and distributing phosphate products that are less efficient than monoammonium phosphate. The ammonium sulfate is not able to do that at positive price levels.

The entry of the by-product ammonium sulfate would reduce the total cost of fertilizer to Michigan farmers somewhat. When it replaces the nonstored ammonia, the cost would fall from $48,297,763 to $48,278,751, a meager savings of $19,012. When the cost fell to $1 and ammonium sulfate replaces all direct application ammonia, the total fertilizer bill would drop to $47,963,336, a savings of $315,415 or a .65 percent reduction in the cost of fertilizer.

If the price of ammonium sulfate continued to drop, the cost of supplying fertilizer would go down proportionately. As the price falls from $1 to zero, the total cost for fertilizer would be $47,454,707, an additional savings of $508,629, resulting in a 1.7 percent reduction in

the cost of supplying fertilizer to Michigan farmers.

All other production and distribution facilities would be unaffected by the substitution of ammonium sulfate for anhydrous ammonia used for direct application. Appendix B provides the detail of the organization of the industry at the three levels of ammonium sulfate usage (0, 296,321 and 508,629 tons). Table IV-1 summarizes the changes that would occur, while Figure IV-3 illustrates the organization when the price of ammonium sulfate is at one dollar per ton.

Table IV-1. Summary of powdered ammonium sulfate used for direct application (in tons)

	Price of ammonium sulfate			
	>2.00	2.00	1.00	0.00
Anhydrous ammonia:				
Production	172,828	97,125	42,886	42,886
Direct application	129,942	54,239	-0-	-0-
Storage	54,239	54,239	-0-	-0-
Ammonium sulfate:				
Production	-0-	296,321	508,629	508,629
Direct application	-0-	296,321	508,629	508,629
Storage	-0-	-0-	212,309	212,309

Ammonium Sulfate for Granulation

Powdered ammonium sulfate can also be used as an input in the granulation of an ammonium phosphate-sulfate (20-20-0) product by combining the by-product powdered ammonium sulfate with phosphoric acid. This results in a product with considerably higher nutrient content than has ammonium sulfate and, therefore, might be more competitive than the direct application of ammonium sulfate. However, the cost of

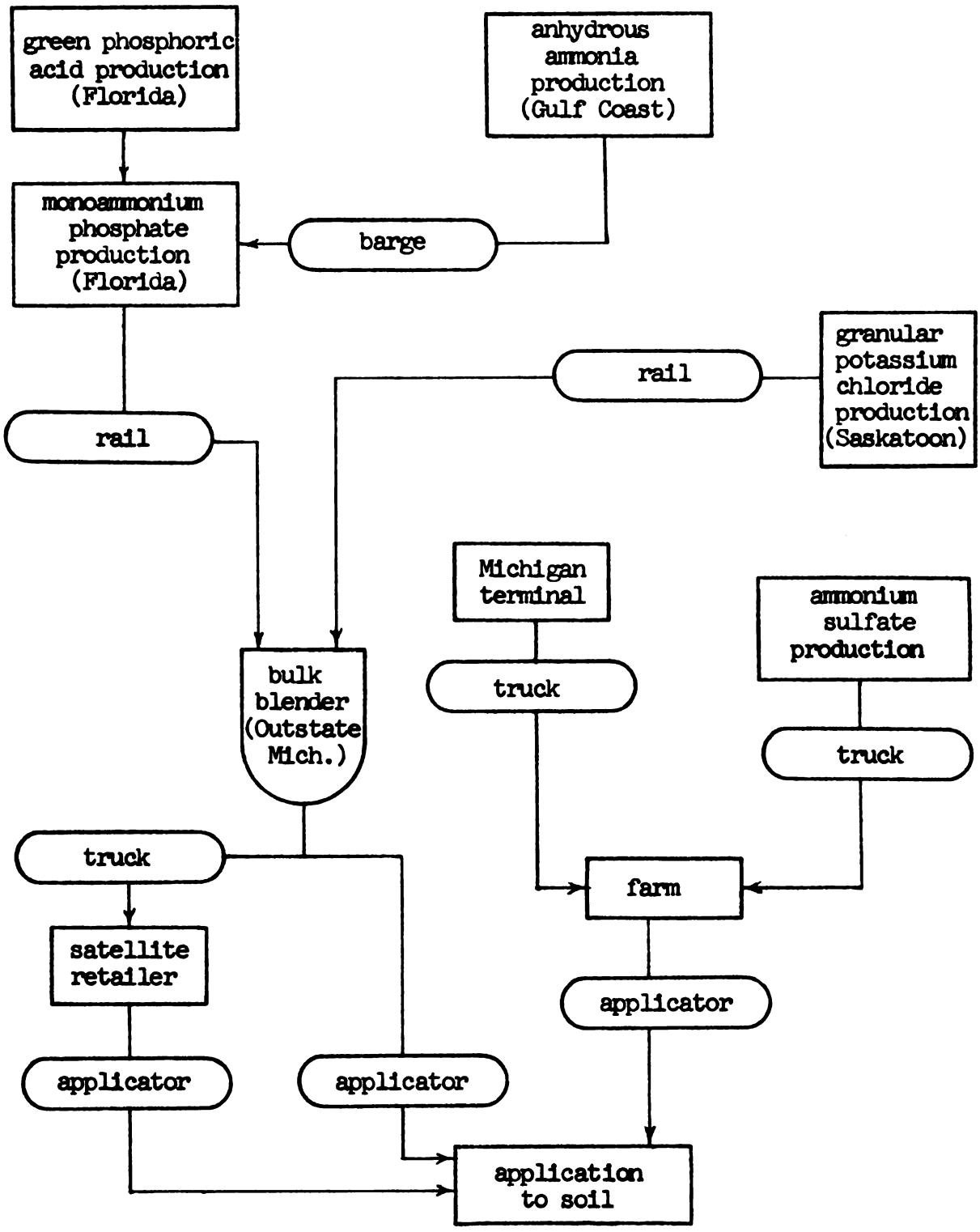


Figure IV-3. Summary of the industry organization when ammonium sulfate is used for direct application (with ammonium sulfate priced at $1.00/ton)

granulation must be covered, whereas there were no such costs for the ammonium sulfate applied directly, and granulation operations are not as efficient as many other processes. In addition, phosphoric acid will have to be shipped to granulation facilities in Michigan. From the discussion of Optimum, it was discovered that it is cheaper to ship phosphate in the form of monoammonium phosphate than it is to ship phosphoric acid. There are obviously factors that will facilitate, and others that will hinder, the potential of the ammonium phosphate-sulfate product.

Not until the price of ammonium sulfate drops to $1.40 per ton would the ammonium phosphate-sulfate product become competitive. At that price, the cost per nutrient content would be low enough to replace certain products in Optimum. The granulation of 179,309 tons of ammonium phosphate-sulfate would enter the solution replacing 113,600 tons of a custom-blended product with an analysis of 10.6-42.55-10.85. The amount of the other blended product, 7-28-28, would increase form 329,689 tons to 374,243. In addition, the amount of direct application of anhydrous ammonia would drop from 129,942 tons to 97,169, while the direct application of granular potassium chloride would decline slightly (Table IV-2 and Figure IV-4).

Two changes in the combination of intermediate products would occur as well. They would be primarily a result of the changes in the mixing operations. In the long-run optimal product mix, phosphoric acid would be produced in Florida and used as an input in producing monoammonium phosphate--all of which would be used in the bulk blending operation. But when granulation entered the solution, it would replace some of the phosphate that was provided in the blends. Consequently,

Table IV-2. Summary of powdered ammonium sulfate used for granulation (in tons)

Product	Price of ammonium sulfate in dollars/ton			
	$P > 1.40$	$1.40 \geq P > 0.70$	$0.70 \geq P > 0.30$	$P \leq 0.30$
Anhydrous ammonia production	172,828	129,112	82,060	76,265
Anhydrous ammonia direct application	129,942	97,169	57,627	57,557
Urea production	-0-	-0-	7,489	-0-
Ammonium sulfate production	-0-	190,068	396,300	420,168
Elemental phosphorus production	-0-	16,490	34,382	36,452
White phosphoric acid production	-0-	69,931	145,809	154,590
Green phosphoric acid production	260,565	149,073	122,061	113,666
Monoammonium phosphate production	270,576	201,530	126,751	118,033
Granular potassium chloride production	259,032	259,006	259,117	259,032
Granular potassium chloride direct application	86,319	86,243	86,404	157,876
Granulated mixed fertilizer (20-20-0)	-0-	179,309	373,868	396,385
Bulk blend	443,290	374,243	306,953	219,189
Bulk blend 7-28-28	329,689	374,243	107,246	219,189
Custom blend 10.6-42.55-10.85	113,601	-0-	-0-	-0-
Custom blend 6.15-17.95-37.0	-0-	-0-	199.707	-0-
Total cost (in dollars)	48,297,763	48,297,875[a]	48,151,800[b]	47,991,378[c]

[a] @ $P = 1.40.

[b] @ $P = 0.70.

[c] @ $P = 0.30.

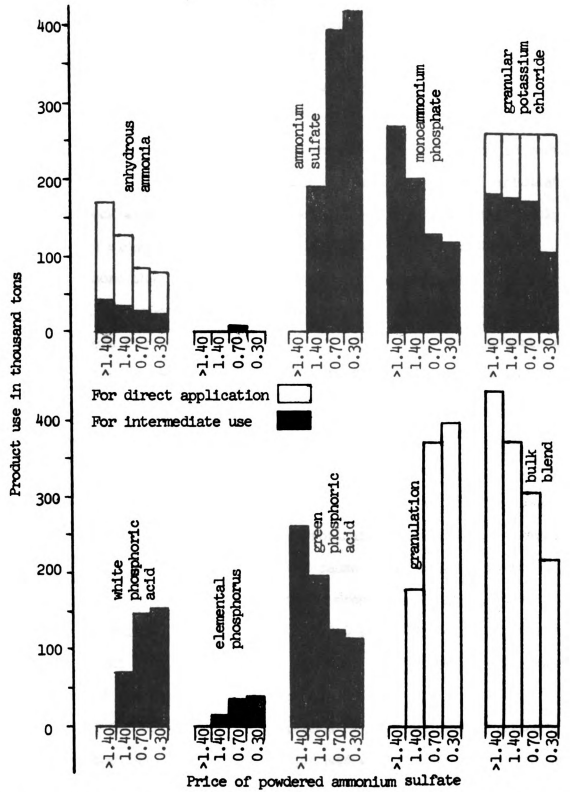


Figure IV-4. Summary of powdered ammonium sulfate used for granulation

blenders would need less monoammonium phosphate, and it would fall from 270,576 tons to 201,530 tons. But in turn the granulator would need phosphoric acid. Rather than produce green phosphoric acid in Florida, ship it to Michigan, and convert it to white phosphoric acid. Although the processes for producing elemental phosphorus and converting it to phosphoric acid are more expensive than the process of acidulating phosphate rock with sulfuric acid, the savings of shipping the highly concentrated elemental phosphorus (229% P_2O_5) over phosphoric acid (54% P_2O_5) more than offset the difference. Consequently, 16,490 tons of elemental phosphorus would be produced in Florida and shipped to Michigan where they would be converted to 69,931 tons of phosphoric acid. The production of green phosphoric acid in Florida would drop to 194,073 tons, which is the amount needed to manufacture the monoammonium phosphate.

As the price of ammonium sulfate continues to decrease, no organizational shifts would occur until it reached $0.70 per ton. At that price, 373,868 tons of ammonium phosphate-sulfate would be granulated. This product would replace approximately 40,000 tons of ammonia used for direct application, and would cause a shift in the products being blended. Bulk blend 7-28-28 would drop from 374,243 tons to 107,246 tons while 6.15-17.95-37.0, a 1-3-6 ratio blend, would come into the solution at a level of 199,707 tons. No other significant changes would occur in direct application products.

The 1-3-6 blend requires 75 pounds of urea per ton of product. Therefore, the 199,707 tons of that product would cause 7,489 tons of urea to be produced at the central Michigan location. Less monoammonium phosphate would be used in blends, and its production would fall to 126,751 tons. The increased need for phosphoric acid at the granulator

would prompt the production of more elemental phosphorus, which in turn would be shipped to the white phosphoric acid plant in Michigan. The production of green phosphoric acid would fall further to 122,601 tons. The total cost would drop $145,075 to $48,151,800. As the price continued to decrease, the solution would again change at $0.30 per ton. The changes for most of the products would be merely a continuation of the established trend. The formulation of blends would reverse, however; whereas the 1-3-6 ratio would come in at the price of $0.70 for ammonium sulfate, it would go back out at $0.30 so that all of the 219,189 tons of blended material would be of the formulation 7-28-28. The direct application of potassium chloride would jump from 86,404 to 175,876 tons. The total cost would ease lower to $47,991,378. If the price of ammonium sulfate drops to zero, no further organizational changes would occur. The only effect would be a reduction in total cost to $47,978,773, a meager reduction of .66 percent from Optimum.

Although the causes of each of these shifts cannot be positively identified, the grade of the granulated product and the grades of the blended products appear to be important. When granulated ammonium phosphate-sulfate enters the solution at 179,309 tons, the product would supply large amounts of N and P_2O_5, but no K_2O. Consequently, the shift in blending counters by providing a product high in potash relative to N and P_2O_5. Since 7-28-28 is the only product that uses monoammonium phosphate and granular potassium chloride and is relatively high in potash, it would be utilized. A custom blend product provides a 1-3-6 nutrient ratio; but it uses urea, a relatively expensive source of nitrogen. However, as the price of ammonium sulfate falls, the savings realized by using ammonium sulfate as a cheap source of N would

offset the increased cost of using urea in the 1-3-6 ratio custom blend, and the 20-20-0 product would combine with the custom blend (6.15-17.95-37.0) to provide the proper balance of nutrients. If additional amounts of the 20-20-0 product were to be produced, the potash would have to be provided by direct application, since no blend product is that concentrated with K_2O. This would happen only when the price of ammonium sulfate falls to $0.30 per ton.

The primary effects of routing the powdered ammonium sulfate into the production of ammonium phosphate-sulfate would be a reduction of production and application of anhydrous ammonia and bulk blends, a reduction in the use of monoammonium phosphate and green phosphoric acid, an increase (from zero) in the production of elemental phosphorus and furnace phosphoric acid, and an increase in the direct application of granular potassium chloride (Figure IV-5 shows the organization, with the price of ammonium sulfate at $0.70 per ton).

Granular Ammonium Sulfate for Bulk Blending

The optimal organization of the industry demonstrates the relative efficiency of bulk blending. Unfortunately, the powdered ammonium sulfate cannot be blended with other fertilizer products because of its physical characteristics. To blend two or more products, the particles of each product must be similar in size. Otherwise, they are difficult to blend evenly and, when they are loaded into applicators or into bins and make a conical pile, segregation occurs. In addition, they segregate when they are transported. Since the by-product ammonium sulfate is a very fine powder, it is not feasible to blend it with other popular blending materials.

The technology for recovering the ammonium sulfate in granular

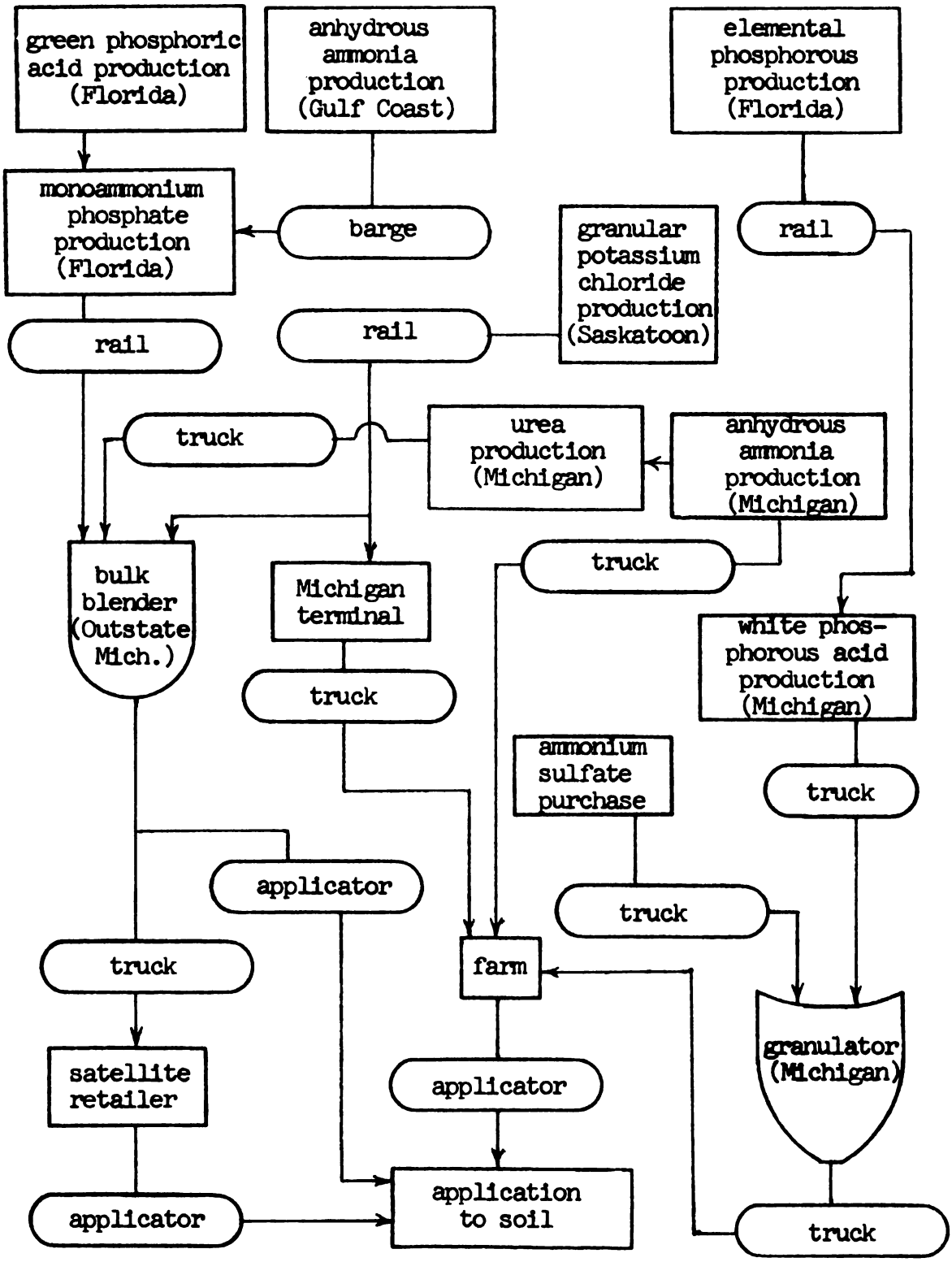


Figure IV-5. Summary of the industry organization when ammonium sulfate is used in the production of an ammonium phosphate-sulfate (with ammonium sulfate priced at $0.70/ton)

form, or for converting it from the powdered to the granular form, does not currently exist. However, it is relevant to query whether or not efforts should be directed toward developing such a technology. If indeed the product can be produced in granular form, new opportunities would result. It could become important in blending operations since a large number of fertilizer grades can be blended with ammonium sulfate as a source of nitrogen.

By assuming that the ammonium sulfate is in a form that can be blended, its value as an input into blending operations can be determined within the framework of the model. This information would be useful to decision makers in determining whether or not funds should be allocated toward the development of such a technique.[2] This assumption was made, and the price of granular ammonium sulfate lowered, to initiate analysis.

Granular ammonium sulfate would enter into the product mix when its price lowers to $12.50 per ton. At this price, 13,054 tons of it would feed into the blending operations to be combined with monoammonium phosphate and granular potassium chloride. The only other change in the system would be a reduction in the direct application of anhydrous ammonia from 129,942 tons to 124,242 tons, and a very slight rise in direct application of granular potassium chloride. Two formulations would be used to mix the 270,823 tons of monoammonium phosphate, 172,713 tons of granular potassium chloride, and the ammonium sulfate: custom blends 6.65-17.9-35.7 and 10.6-42.55-10.85 (Table IV-3).

When the price falls another dollar, to $11.50, the use of

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[2]This application of the model can be used to determine the value of new products, or potential products as well. By identifying some basic characteristics of the product, it can be compared with established product or with the optimal products within the model, and its value can be determined.

Table IV-3. Granular ammonium sulfate for bulk blending (in tons)

Product	Optimum	Price of ammonium sulfate in dollars/ton P=12.50	P=11.50	P=1.50	P=1.00
Anhydrous ammonia production	172,828	167,167	162,743	118,785	97,141
Anhydrous ammonia direct application	129,942	124,242	119,805	75,849	54,194
Granular ammonium sulfate production	-0-	13,054	23,042	193,116	279,448
Green phosphoric acid production	260,565	260,802	260,876	260,870	260,936
Monoammonium phosphate production	270,576	270,823	270,900	270,893	270,961
Granular potassium chloride production	259,032	359,108	259,096	259,068	259,117
Granular potassium chloride direct application	86,319	86,395	-0-	-0-	-0-
Bulk blends	443,290	456,590	553,039	723,078	809,527
Bulk blend 7-28-28	329,639	-0-	-0-	-0-	-0-
Custom blend 6.65-17.9-35.7	-0-	217,562	384,049	435,409	401,074
Custom blend 10.6-42.55-10.85	113,600	239,028	168,900	-0-	-0-
Custom blend 17.6-21.8-0	-0-	-0-	-0-	287,669	261,654
Custom blend 16.8-8.05-8.35	-0-	-0-	-0-	-0-	146,799
Total cost	48,297,763	48,296,046	48,279,035	48,004,973	47,900,488

ammonium sulfate would increase to 23,042 tons. The direct application of anhydrous ammonia would fall a little more to 119,805 tons, but direct application of granular potassium chloride would fall to zero. The same two formulations would be used again; but custom blend 6.65-17.9-35.7 would increase from 217,562 to 384,049 tons while custom blend 10.6-42.55-10.85 would fall from 239,028 to 168,990 tons. This amount of the two custom blends balance so that all of the ammonium sulfate, monoammonium phosphate and granular potassium chloride would be used in blending.

Other changes would not occur until the price of ammonium sulfate reached $1.50 per ton. The changes that would occur at that price, and the changes that would occur at $1.00 per ton, would be essentially a continuation of the trend already established. Anhydrous ammonia used for direct application would continue to drop, although much more than before, and ammonium sulfate would increase. Consumption of anhydrous ammonia would fall to 75,849 tons at the $1.50 level, and to 54,194 tons at the $1.00 level. The loss of N from ammonia would be replaced by the use of 193,116 tons and 279,448 tons of ammonium sulfate, respectively. Again, all of the ammonium sulfate, monoammonium phosphate and granular potassium chloride would be used in blending. However, there would be a shift in formulations. At the $1.50 level, custom blend 6.65-17.95-35.7 would increase from 384,049 tons to 435,409 tons. But custom blend 10.6-42.55-10.85 would drop out in favor of custom blend 17.6-21.8-0, of which 287,669 tons would be blended. At the $1.00 level, 6.65-17.9-35.7 would increase further to 401,014 tons, 17.6-21.8-0 would drop a little to 261,654, and 146,799 tons of 16.8-8.05-8.35 would also be blended.

The total cost of supplying fertilizer would change little. If the price of ammonium sulfate falls to zero, the total cost would be $47,621,040, compared to $48,297,763, the cost of Optimum. Although granular ammonium sulfate would come in at a much higher price than would powdered ammonium sulfate, $12.50 versus $2.00 for direct application and $1.40 for use in granulation, a very small amount would be involved. Consumption would increase little until the price drops to $1.50, which is in the range of activity for powdered ammonium sulfate (Figure IV-6).

Optimizing the Use of By-product Ammonium Sulfate

Summarizing, the analysis indicates the by-product powdered ammonium sulfate used for direct application had to be priced very low before it was competitive with alternative sources of nitrogen. However, it must be remembered that it is competing with products in Optimum; products that are highly efficient at supplying N, P_2O_5 and K_2O. This is considerably different from competing with products that constitute the current product mix. At the price of two dollars per ton, ammonium sulfate replaced 58 percent of the anhydrous ammonia that was going direct, and at one dollar per ton, ammonium sulfate replaced all of the anhydrous ammonia going direct.

When ammonium sulfate was priced at one dollar per ton, 508,629 tons were consumed. While this lowered the cost of fertilizer to the farmers in Michigan by $315,415, it returned $508,629 to the power plants. However, when ammonium sulfate was priced at $2.00 per ton and 296,321 tons were consumed, farmers realized a savings of only $19,012, whereas the returns to the power plant were higher at $592,642.

Nor did the use of ammonium sulfate in the granulation of an

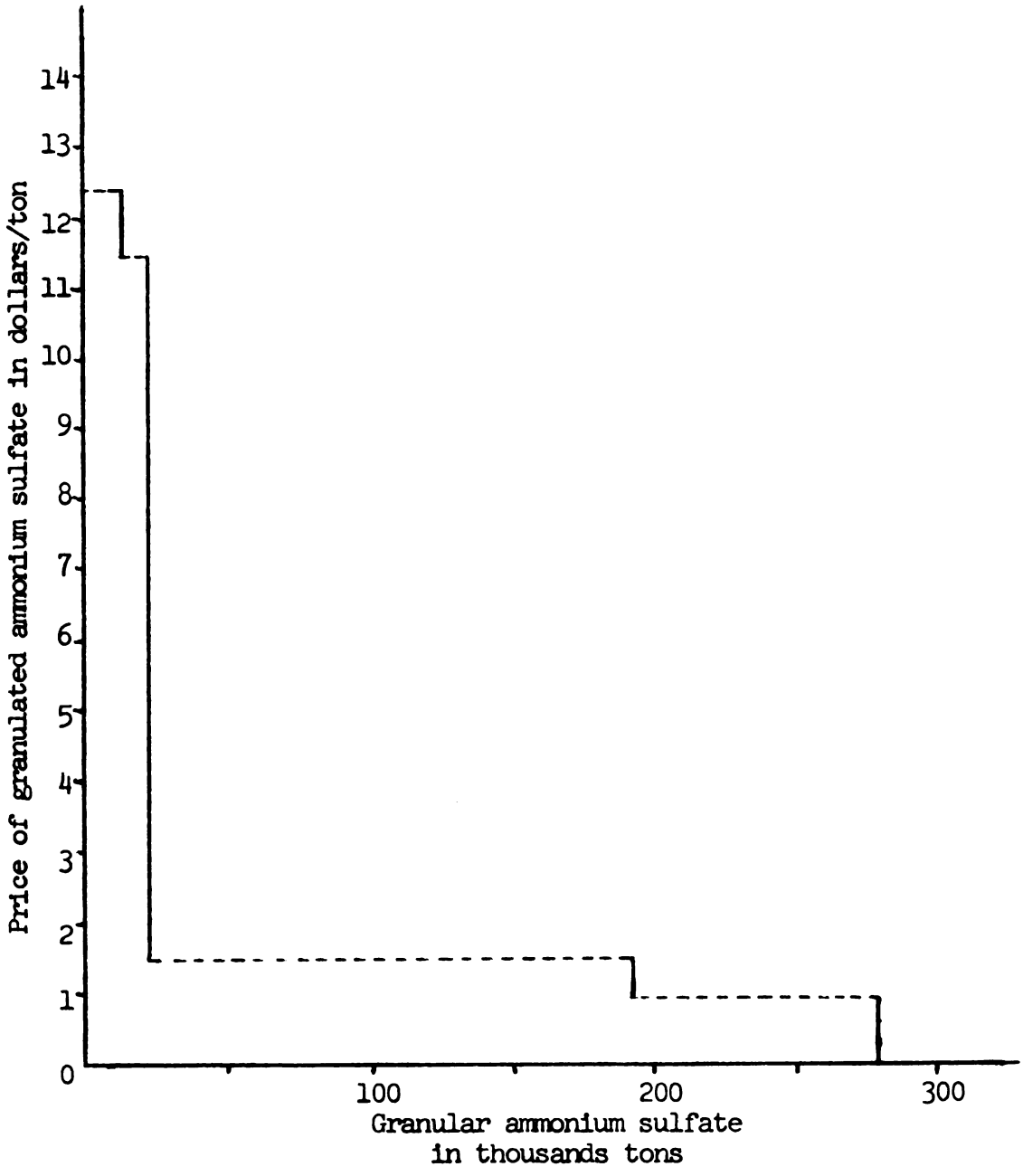

Figure IV-6. Granular ammonium sulfate price-consumption map

ammonium phosphate-sulfate (20-20-0) compete well with the products in Optimum. Although a large amount of the product was produced, it was not produced until the price of ammonium sulfate had dropped very low ($\leq$ \$1.40 per ton). With ammonium sulfate priced at \$0.30 per ton, the 396,385 tons of 20-20-0 caused a number of changes. The application of anhydrous ammonia fell 56 percent, while bulk blending dropped off 51 percent. Since bulk blending dropped off, the monoammonium phosphate which was used as an input in blending dropped off also, as did the green phosphoric acid used in the production of the monoammonium phosphate. The production of the 20-20-0 required phosphoric acid as an input. The acid was provided by producing highly concentrated (229 percent P_2O_5) elemental phosphorus in Florida, railing it to Michigan and converting it to white phosphoric acid. Finally, the amount of granular potassium chloride applied directly increased by 103 percent.

In spite of these organizational shifts, the revenues and savings were small. With ammonium sulfate priced at \$0.30 per ton, farmers' fertilizer bills fell by only \$301,385, which is less than was realized when ammonium sulfate was priced at one dollar per ton and used for direct application. Power companies would generate the most revenue by pricing ammonium sulfate at \$0.70 per ton. But even then the revenue would be only \$287,410, which compares unfavorably with the \$592,642 generated when the ammonium sulfate used for direct application was priced at \$2.00.

The use of ammonium sulfate in bulk blending was also considered. Although it was first used at a much higher price (\$12.50) than when used as a direct application product or as an input into the 20-20-0 granulated product, it entered in small amounts (13,054 tons). Before

large amounts were utilized, the price had to fall quite low ($1.50 per ton).

There were few organizational shifts associated with the use of ammonium sulfate in blending operations. As the amount of N supplied by ammonium sulfate increased, the amount of anhydrous ammonia used as a direct application source of N decreased. The increased amount of blending also pulled all of granular potassium chloride, that previously was going direct, into the blending operation.

With ammonium sulfate priced at $1.00 per ton, farmers realize a savings of $397,275 on the cost of obtaining fertilizer under the long-run optimal organization. This is a larger amount than was realized under either of the two previously discussed uses of ammonium sulfate, but still reduces their cost of fertilizer by only .82 percent. However, by pricing ammonium sulfate to generate the greatest return, power plants could still earn only $289,674, which is about half of what they could earn by using the ammonium sulfate for direct application.

In the previous discussion, the effect of lowering the price of ammonium sulfate to $0.00 was not considered since the power plant would not generate returns at that price. Needless to say, farmers would realize greatest savings if ammonium sulfate was priced at zero. Figure IV-7 shows the relationship between the revenues generated by the power plants marketing the by-product ammonium sulfate and the reduction in farmers' expenditures on fertilizer for each of the three uses of ammonium sulfate. Each linear portion in Figure IV-7 corresponds to a level of ammonium sulfate used for the purpose represented by the line. The letters correspond to the letters in Table IV-4 which identifies that level and the corresponding price range.

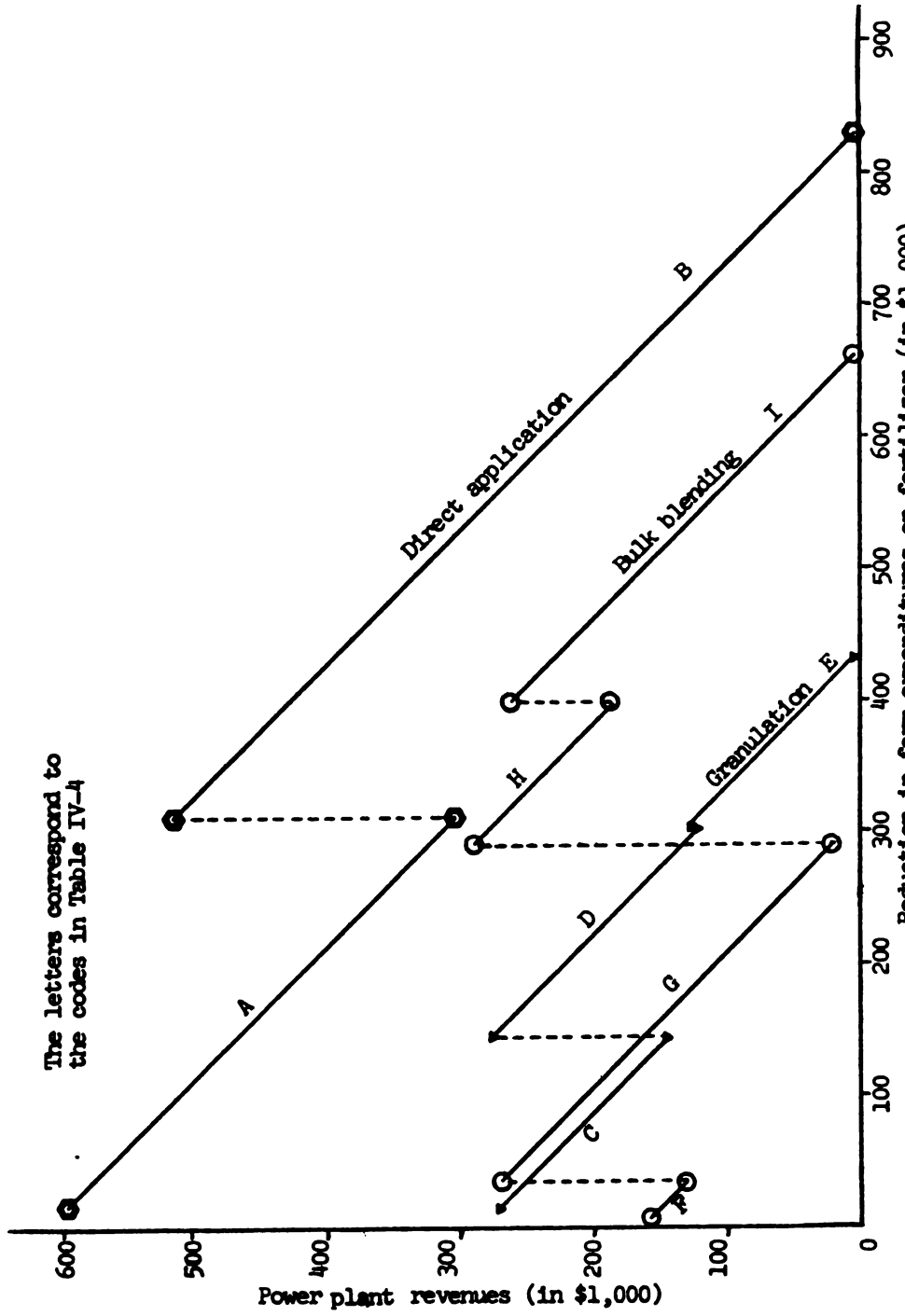

Figure IV-7. The impact of alternative uses of by-product ammonium sulfate on revenues of electric power-generating plants and farm expenditures on fertilizer

Table IV-4. Level and price range of ammonium sulfate used for three purposes

Code	Use	Ammonium sulfate used (in tons)	Price range
A	Direct application	296,321	$2.00-1.00
B	Direct application	508,629	1.00-0.00
C	Granulation	190,068	1.40-0.70
D	Granulation	396,300	0.70-0.30
E	Granulation	420,168	0.30-0.00
F	Bulk blending	13,054	12.50-11.50
G	Bulk blending	23,042	11.50-1.50
H	Bulk blending	193,116	1.50-1.00
I	Bulk blending	279,448	1.00-0.00

It can be seen that using ammonium sulfate in bulk blending is, for the most part, preferable to using it in granulating the 20-20-0 product, and that using it for direct application is preferable to using it in bulk blending. For example, section B on Figure IV-7 indicates the savings that can be generated by applying 508,629 tons of ammonium sulfate directly. The distribution of savings depends on the price placed on the by-product. If it is priced at $1.00 per ton, power plants would realize a savings of over $500,000 and farmers would realize a savings of over $300,000. As the price is lowered, increasing amounts of revenue are transferred from the power firm to the farmers. At a price of $0.00, the farmers enjoy all the benefits. If the utility regulators assume the responsibility of distributing the revenues, they need only pick a point on B, or A in Figure IV-7. This point would

specify the price of the by-product ammonium sulfate, the quantity that would be utilized at that price, and the corresponding fertilizer industry organization.

Exploration of Relevant Issues

As pointed out earlier, public utility regulators have encouraged power plants to invest in pollution control equipment by allowing investments and operating expenses for pollution control as justified expense in producing electricity. Thus, power firms are allowed to pass the cost of abating emissions on to the customers of electricity in the form of higher electrical rates. However, power firms have been reluctant to make those investments. Two factors probably cause this: the impact that increased prices for electricity may have on the quantity demanded from the power firm, and risk. Although power firms would not face the problems relevant to interregional competition for their product (their geographic markets seem to be well-defined), it would face competition from alternative sources of power, and would realize some secondary effects from interregional competition.

If electrical rates increased, consumers would tend to substitute alternative sources of power for electricity. Depending on the pollution control regulations, this may or may not be serious. If there were no sulfur oxide emission restrictions on firms that consume electricity, they could switch to high-sulfur coal or oil and avoid the cost associated with sulfur oxide control. This would result in a significant decrease in the quantity of electricity demanded and an increase in the quantity of coal and oil demanded. (If this occurred, air pollution control commissions would soon have a problem on their hands, for the sulfur content of ambient air would return to high levels.)

If, on the other hand, all firms were restricted by emission controls, there would be little reason for consumers of electricity to shift to other sources of fuel since the cost of abatement must be borne one way or another.[3] However, the higher price for electricity would increase the cost of producing those products that use electricity as an input, and those firms would be at a disadvantage in interregional markets if other regions did not also have pollution controls. Therefore, the derived effect of interregional competition could have important implications for the power firm and cannot be ignored.

There is also considerable risk associated with investments in scrubbing equipment. No process has yet been proven on full scale, and some engineers believe significant problems remain in those processes currently available. To risk the production of a plant on a process as yet unproven is not practical.

Although one can only speculate on the amount of return that is necessary to induce power plants to produce and market by-product powdered ammonium sulfate, or the savings necessary to convert farm consumption to a new product, it is not likely that the $592,642 return nor the $315,415 savings associated with using ammonium sulfate for direct application is sufficient. The return to the power plant would represent approximately a 2.19 percent increase in net income, or a .11 percent return on investment. The savings of $315.415 farmers could realize would represent a .65 percent reduction in their fertilizer bill.

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[3]The establishment of pollution controls may serve to shift the demand curve for electricity from power utilities to the right if, by virtue of their size, power plants can control their emissions at a lower unit cost than can firms that have their own power units.

A review of recent developments in the ammonium sulfate market also casts doubts. In 1970, 1,889,000 tons of synthetic ammonium sulfate were produced for fertilizer while 595,000 tons were produced as by-product from the metal industry. Consumption was somewhat less, and significant portions were reported to have been dumped at sea or burned.

From the analysis in this chapter, it is known that ammonium sulfate can compete with the optimal organization of the industry (although at low prices), and it can be inferred that ammonium sulfate would be able to compete with the products currently being used in the industry at considerably higher prices (the cost of the current product mix is 48 percent higher than the cost of the product mix in Optimum). But this conclusion does not appear consistent with the observation that by-product ammonium sulfate was destroyed last year. Two factors may explain the deliberate destruction of the product. First, some metal producers also produce synthetic anhydrous ammonia and other nitrogen products. They may have determined that marketing by-product ammonium sulfate at low prices would reduce the market for their other nitrogen products to the extent that they would realize in total a net loss from marketing ammonium sulfate. On the other hand, the metal producers may have determined that the cost of marketing ammonium sulfate was great enough that attempts to market the product could not be justified.

In the first four months of 1971, synthetic ammonium sulfate production was down 16 percent from one year ago while by-product ammonium sulfate production was up five percent from a year ago. Through much of 1971 the price of ammonium sulfate vacillated around the lower

side of $12 per ton, going as low as $7. It was even reported that one firm was offering the product free if the consumer would take delivery of the product at the plant (Harre, 1971).

The implication that ammonium sulfate does not sell even at low prices raises an interesting possibility. For years researchers, extension specialists and industry personnel have been informing the farmer that high-analysis fertilizers have the potential for lowest cost per nutrient content. If their efforts have been moderately successful, biases against low-analysis fertilizers may have resulted. Consequently, in those situations where low-analysis fertilizers such as ammonium sulfate are a cheap source of nitrogen, marketing efforts will have to include an effective information system. Such a bias could prove to be an important barrier to power plants that plan to market their by-product ammonium sulfate.

On the other hand, in analyzing the competitive position of ammonium sulfate, it was assumed that the sulfur had no fertilizer value. However, agronomists are rapidly becoming convinced that it is an important nutrient, and responses to sulfur-containing fertilizers have been recorded in Michigan (Beaton, 1971). If sulfur is an important nutrient, the fertilizer component of ammonium sulfate would rise to 45 percent from the 21 percent (21 percent N plus 24 percent S), and its value in the analysis would have been significantly understated.

The alternative uses for by-product ammonium sulfate from power plants are few. Because of its low analysis, it cannot be shipped far before it loses its competitive advantage. On the other hand, because of consumption constraints, it will have to travel moderate distances so that a market area large enough to consume all of the by-product

from a power plant can be obtained.

For example, assume (1) the Board of Water and Light in Lansing recovers 90 percent of the sulfur it normally emits to the atmosphere and produces ammonium sulfate, (2) the consumption of nitrogen per square mile in the area around Lansing is equivalent to the average consumption in the lower two-thirds of the Lower Peninsula, and (3) the Board of Water and Light can capture 15 percent of the nitrogen market in its geographic market area. The market area required to absorb the amount of ammonium sulfate recovered would have a radius of 90 miles. The Board of Water and Light could not expect to transport the ammonium sulfate farther and receive a positive price for the product. On the other hand, if it could increase its share of the market, it may be able to increase its product price. For example, if it had 50 percent of the nitrogen market, it would need a market area with a radius of only 50 miles to absorb the product. In this situation, the Board could expect to receive a little more for its product, possibly as much as $4 or $5 per ton.

If power firms market by-product ammonium sulfate, the effects on the various components of the fertilizer industry would be surprisingly few. Although the ammonium sulfate would replace anhydrous ammonia for direct application, the ammonia producers may benefit. The production of by-product ammonium sulfate requires the use of anhydrous ammonia as the scrubbing agent in the abatement process. Since some ammonia escapes in the process, more ammonia would be needed to produce enough ammonium sulfate to equal the amount of N that was being used for direct application. Consequently, the ammonia producers would realize a small increase in demand. Whereas previously the ammonia was going directly

to the farm for application, now it moves to the power plant, and from there to the farm in the form of ammonium sulfate. A shift in investment from ammonia applicators to dry spreaders would be required by this change.

No other component of the industry would be affected. Bulk blending of monoammonium phosphate and granular potassium chloride would be unaffected as would the remainder of the phosphate and potash industries.

It is doubtful that many power firms will produce ammonium sulfate as a by-product if they must compete against the long-run Optimum organization of the fertilizer industry. If, however, the fertilizer industry does not improve its performance, ammonium sulfate may be very competitive, and could be a profitable enterprise for the power firm. The ability of ammonium sulfate to compete effectively with the various products currently being used by Michigan farmers should be examined. Until then, the potential revenue that could be generated by a power firm's marketing ammonium sulfate can only be conjectured.

CHAPTER V

THE USE OF BY-PRODUCT SULFURIC ACID IN THE FERTILIZER INDUSTRY

While only those abatement processes that utilize ammonia as an input product ammonium sulfate as a by-product, nearly all processes, including those that use ammonia, can produce sulfur or sulfuric acid as a by-product.[1] Therefore, it is considerably more probable that electric power-generating plants will produce sulfur, or sulfuric acid, than ammonium sulfate.

Electric power firms need not be concerned, as was the case in by-product ammonium sulfate, whether or not its by-product sulfur has a market. Sulfur plays a major role in the economy of the United States, being one of the most important industrial raw materials (Hazleton, 1970, p. 1). The fertilizer industry accounts for nearly half of the annual sulfur consumption in the United States. Sulfur is converted to sulfuric acid and is used to acidulate phosphate rock in the production of phosphoric acid. Although other acids may substitute for sulfuric acid in the acidulation process, sulfur's primary competitor in the production of phosphoric acid is, ironically, electricity. Electricity is used to produce elemental phosphorus, which can easily be converted to phosphoric acid.

The sulfur industry is examined in this chapter. Attention is directed to demand, supply and prospective developments. Its role

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[1] A few of the processes produce nonuseable materials such as calcium sulfate.

in the fertilizer industry is examined as are other relevant issues.

Sulfur Consumption

United States sulfur consumption in 1970 was 9,132,000 long tons (Table V-1). Of this amount, over 85 percent was burned to form sulfur dioxide for conversion to sulfuric acid. Since all of the sulfuric acid is used in processing and manufacturing industries (Tables V-2 and V-3), the demand for sulfur is largely a derived demand dependent upon the demand for the end products of the industries that use sulfur either directly or indirectly as sulfuric acid.

A simple method of projecting aggregate sulfur demand is to assume that the demand for sulfur will continue to grow at about the same rate as industrial production. A long-run annual growth rate of 6.5 percent in industrial production--the rate actually experienced over the period from 1960 to 1969--would imply a rise in annual sulfur consumption in the United States from 9,132,000 long tons in 1970 to 12,100,000 long tons in 1975 and 15,100,000 long tons in 1980. However, such projections assume that the pattern of sulfur consumption will not change.

There exists clear evidence that the demand for sulfur could shift. For example, sulfuric acid can successfully be replaced by hydrochloric acid in iron and steel pickling; currently, six percent of domestic sulfur consumption is used in the manufacture of inorganic pigments; and DuPont has introduced a process whereby chlorine can be substituted for sulfuric acid in pigment manufacture. The use of sulfuric acid in the chemical industry is so widespread that the substitution of another input for sulfuric acid in the manufacture of

Table V-1. United States sulfur consumption, 1970

Source	Sulfur content (in 1,000 long tons)	Total
Frasch sales:		
Native	6,419	
Import	539	
	6,956	6,958
Recovered sulfur sales:		
Native	1,463	
Import	998	
	2,461	2,461
Other sulfur:		
Pyrites	130	
By-product sulfuric acid	535	
Other by-product sulfides	481	
	1,146	1,146
		10,565
Exports of Frasch:		
Crude	1,429	
Refined	4	
	1,433	-1,433
Total sulfur consumption		9,132

Source: (Merwin, 1971).

Table V-2. Industries and products in which sulfur is used

Acids	Inorganic or organic acids
Alcohols	Insecticides
Alum	Leather
Ammonium sulfate	Livestock food
Aniline	Lubricants
Bleaching agent	Magnesium
Bromine	Matches
Carbon dioxide	Medicine
Carbon disulphide	Metallurgy
Carbon tetrachloride	Paints and pigments
Casein	Paper pulp
Cellophane	Petroleum products
Celluloid	Pharmaceuticals
Cellulose esters	Phenol
Cements	Photography
Chlorine	Plastics
Coke	Plate glass
Copper	Rayon
Dehydrating agent	Refrigerants
Detergents	Resins
Dyes	Road-surfacing materials
Ebonite	Rubber goods
Electroplating	Soap
Explosives	Soda
Fertilizers	Solvents
Fire extinguishers	Steel pickling and galvanizing
Fireproofing agents	Storage batteries
Fireworks	Sugar
Food preservatives	Sulfonated oils
Fumigants	Synthetic fibers
Fungicides	Synthetic rubber
Glue	Textiles
Glycerin	Tires, rubber
Impregnant	Water purification

Source: (Mineral Facts and Problems, 1965, p. 908).

Table V-3. Distribution of domestic sulfur consumption, 1966

Consuming sector	Percent of total sulfur consumption
Acid uses:	
Fertilizers	48
Chemicals	18
TiO_2 and other inorganic pigments	6
Iron and steel	3
Rayon and film	3
Petroleum	2
Others	7
Total acid uses	87
Nonacid uses:	
Pulp and paper	5
Carbon bisulfide	3
Ground and refined	2
Other	3
Total nonacid uses	13

Source: (Hazleton, 1970, p. 53).

any one product would likely go unnoticed, but the accumulative effect of each substitution would lower the demand.

On the other hand, a decision to use sulfur or sulfuric acid usually coincides with a decision to use a particular production process. Changing from elemental sulfur to a technical substitute generally will involve a change of processes, requiring both changes in input proportions of other variable inputs and changes in plant and equipment. Since price stability reduces the element of risk in purchase and investment decisions, industrial decision makers may prefer the reliable source of sulfur to the uncertainty associated with substitute variable inputs. Even if they do shift to alternative inputs, they will likely delay such a change until their current sulfur-oriented fixed productive assets become technically obsolete and/or until the capital outlays have been recaptured through depreciation.

The use of sulfur in the fertilizer industry has increased sharply. Since sulfuric acid is used in the production of high-analysis fertilizers, the continuing trend to these products should further increase the demand for sulfur. In addition, the increasing attention being directed toward the use of sulfur as a fertilizer nutrient itself may further strengthen the role of sulfur in the fertilizer industry.

Sulfur Production

In 1970, 9,549,000 long tons of sulfur were produced in the United States (Table V-4). Of this amount, 7,082,000 long tons were produced as Frasch sulfur. Frasch sulfur is simply elemental sulfur mined via the Frasch process and is not different from elemental sulfur obtained in other ways. Although sulfur is abundant in the

Table V-4. United States sulfur production, all forms, 1970

Source	Sulfur content (in 1,000 long tons)
Elemental sulfur:	
Frasch	7,082
Recovered	1,449
Nonelemental sulfur:	
By-product sulfuric acid	535
Other by-product	483
Total	9,549

Source: (Merwin, 1971).

earth's crust, only highly concentrated deposits, or domes, located along the Gulf Coast are mined commercially in the United States.

Significant quantities of sulfur are also recovered from sour natural or refinery gases. The gases contain hydrogen sulfide which is separated from the other gases and converted to sulfur dioxide which can readily be converted to elemental sulfur (Estep, 1962, p. 329). In addition to these two sources, lesser amounts of sulfur are produced as by-product sulfuric acid and other sulfur compounds from numerous industries in the United States.

Production of Frasch sulfur in the United States is concentrated in only four firms, with the Texas Gulf Sulfur Company and the Freeport Sulfur Company producing 90 percent of the output.

The average total cost of producing Frasch sulfur varies considerably with the scale of plant and the quality of the mine.

Investment outlays per unit of capacity decline significantly with increases in the scale of plant. However, variable costs account for 75 percent of total production costs and the critical variable cost is water. The water ratio, i.e., the number of gallons of hot water required to produce a ton of sulfur, varies with the quality of the sulfur deposits and may range from 1,000 gallons to 12,000 gallons. Plants having identical water ratios experience decreasing average total costs with increases in plant scale over the range of plant sizes currently found in the industry. Similarly, average total costs of plants of identical size vary directly with the water ratio. The water ratio is more important than plant size in determining the level of average total costs, and the water ratio varies directly with the quality of the deposit (Hazleton, 1970, p. 146). Consequently, ownership of the higher quality deposits by those established in the industry serves as an effective barrier to entry.

Although entry into the production of Frasch sulfur is effectively barred in the United States, those four firms currently in the industry do not enjoy an oligopolistic market. The producers of recovered sulfur and by-product sulfuric acid have combined with importers to increase considerably the number of suppliers and supply of sulfur. By-product sulfuric acid is certain to increase considerably when smelters are required to recover the sulfur they currently emit as sulfur dioxide. Metal sulfides, such as iron-bearing pyrites and various nonferrous ore that are smelted or refined for their copper, lead and zinc content could be an important source of sulfur (Table V-5). Reserves of sulfur in these ores in the United States are estimated at 100 to 150 million tons (Ambrose, 1965, p. 909).

Table V-5. Estimated sulfur reserved in Canada, Mexico, and the United States

Type and sources	Million long tons
Elemental-Frasch:	
United States	200
Mexico	50
Recovered:	
United States—gas and petroleum	55
Canada—gas	350
Oil shale, tar sands, etc.:	
United States	50
Canada	780
Metal sulfides:	
United States	125
Coal:	
United States	15,000
Total reserves:	16,610

Source: (Hazleton, 1970, p. 137).

Large amounts of sulfur can also be extracted from natural gas and crude petroleum. The sulfur content of United States natural gas averages about 0.05 percent by weight. The sulfur occurs as hydrogen sulfide in concentrations from zero to 70 percent. Crude oils in the United States contain an average sulfur content of 0.6 percent, and oil shale 0.75 percent. Reserves of sulfur in these three sources are estimated to be 105 million tons (Mineral Trade Notes, 1965, pp. 29-30). In addition to this recoverable sulfur, huge amounts may also exist in the natural gas and petroleum located on the north slope of Alaska. However, the greatest source of sulfur in the United States lies in coal deposits. Sulfur accounts for 2.6 percent of the weight of coal. The sulfur content of recoverable United States coal reserves alone, taken at a conservative 220 billion tons, would come to five billion tons or more (Ambrose, 1965, p. 909).

The domestic market for sulfur is sensitive to international trade. Large amounts of sulfur are produced in Canada and Mexico, and this sulfur can flow freely to the United States market (the current surcharge on imports has no effect since there is no tariff on sulfur). Whereas Mexico has several high-quality deposits, up to 95 percent sulfur, most of Canada's sulfur is currently being recovered from natural gas. Alberta's natural gas contains from one to 38 percent hydrogen sulfide and reserves of sulfur in this source are estimated at 350 million tons. Further amounts of sulfur are being recovered from tar sands in Alberta, and the potential reserves of sulfur in this source have been calculated at 780 million tons (Mineral Trade Notes, 1965, pp. 29-30).

The increases in domestic production of sulfur and the shift

from a net exporter to a net importer resulted in severe declines in the price of sulfur. In the past two years, the price of sulfur has fallen to nearly 20 percent of its high. The current price of $7 per long ton compares with the 1969 high of $35 per long ton.

The future holds little promise for higher prices in competitive markets. The potential supply of sulfur will continue to exceed consumption by considerable margins, particularly when production of recovered and by-product sulfur increases rapidly with the establishment of sulfur oxide emission controls. Whether or not recovery of sulfur oxides from flue gas proves economical, the potential supply of by-product sulfur will continue to increase because removal of the sulfur from fuels is essential, and if it cannot be accomplished by scrubbing flue gas, it will be achieved by fuel desulfurization or some other process. The relevant question is whether or not the sulfur will be recovered in a useful form. This question is not so easily answered but, as explored earlier, there is sound reason to believe that much of it will.

Conversion of Sulfur to Sulfuric Acid

Although some sulfuric acid is produced and marketed, most fertilizer producers usually purchase sulfur and convert it to sulfuric acid. However, decisions to purchase sulfur rather than sulfuric acid must be based on their prices and the cost of conversion. Table V-6 shows typical cost of converting sulfur to sulfuric acid. The total cost, excluding the cost of sulfur, is $6.01 per ton of sulfuric acid. Figure V-1 shows the price indifference curve for sulfuric acid and sulfur. Simply stated, if the price of sulfuric

Table V-6. Cost of converting sulfur to sulfuric acid

	Dollar cost/production
Labor (0.10 man hours/ton @ $4.00)	0.40
Miscellaneous	3.56
Depreciation	0.79
Interest on nvestement ($11.90/ton @ 0.075)	0.89
Interest on working capital ($.33/ton @ 0.085)	0.37
	6.01
Plus 0.35 tons of sulfur	

Source: (Henderson, 1971, p. 34).

acid is more than $6.01 per ton over the cost of .35 tons of sulfur at the phosphate plant, the sulfur will be purchased. If the sulfuric acid is less than $6.01 per ton over the price of .35 tons of sulfur, it will be purchased.

Sulfuric Acid Versus Off-peak Electricity

Although sulfur is one of the most plentiful of the elements, twice within the postwar era it has been in short supply within the United States and abroad (Hazleton, 1970, p. 1). In these periods when prices of sulfur are high, phosphate producers are highly affected. Production of each ton of phosphoric acid requires 1.47 tons of sulfuric acid (Henderson, 1971, p. 32). Consequently, they have been highly motivated to develop substitutes for sulfuric acid.

Although there has been experimental use of such acids as nitric and phosphoric, the primary development was the electric arc

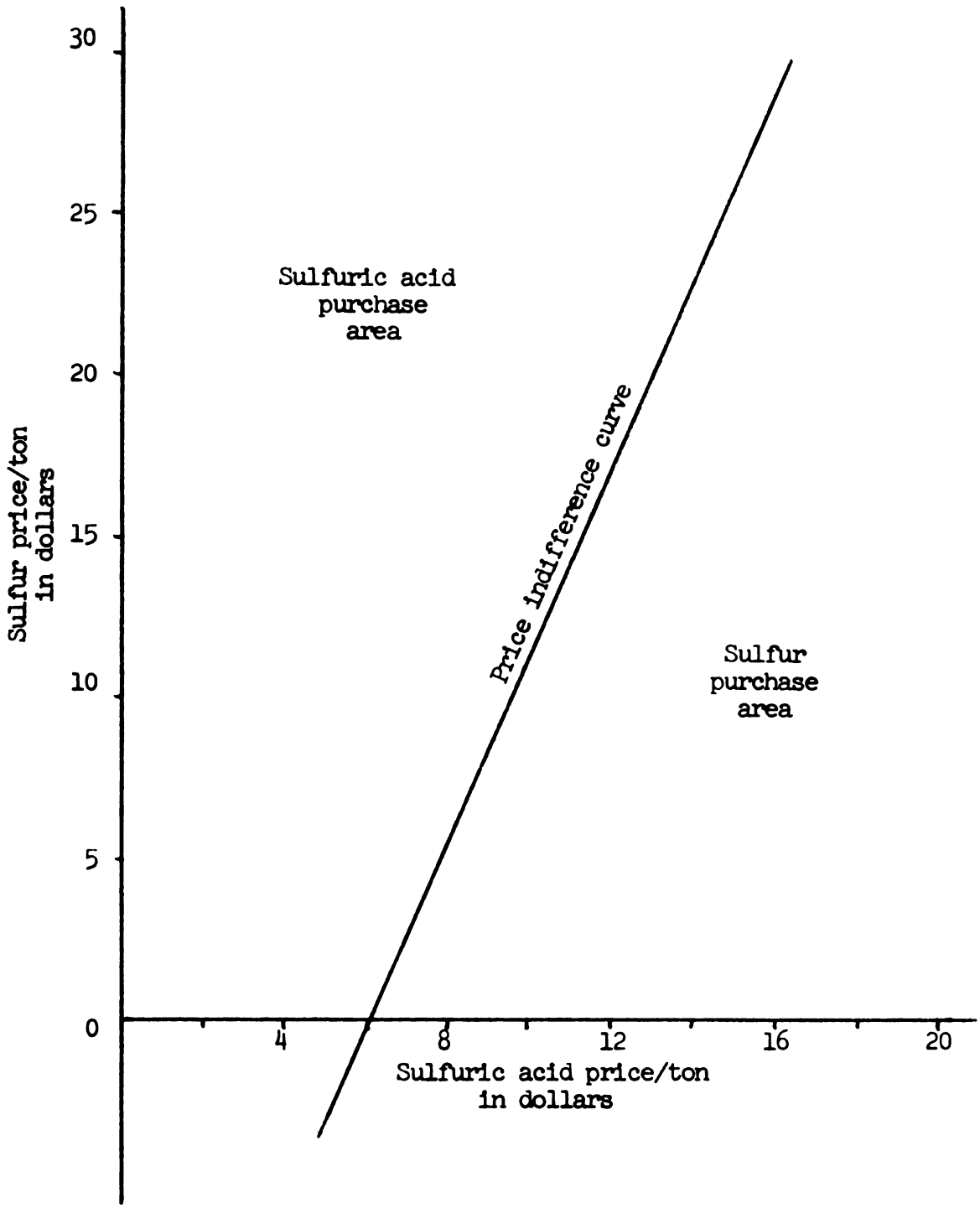

Figure V-1. Sulfur-sulfuric acid price indifference curve

furnace for producing elemental phosphorous. The process consists of two phases. In the first phase, rock phosphate and coke are mixed together and fed into an electric reduction furnace. The electric current enters through carbon electrodes and fuses the rock and silica, while the carbon in the coke reduces the phosphate. Phosphorus vapors are withdrawn from the furnace and condensed to form elemental phosphorus, an active material that contains 229 percent P_2O_5. In the second phase, the elemental phosphorus is then converted to white phosphoric acid by burning it and absorbing the resulting oxide in water (Bell, 1971, p. 39).

Tremendous amounts of electricity are required to fuse the rock phosphate-coke mixture. Each ton of elemental phosphorus requires 12,223 KWH. In addition, the electric reduction plant is a high-investment plant. A facility that can produce 131,000 tons per year requires an original investment of $45 million (Henderson, 1971, p. 31). However, one primary advantage of the elemental phosphorus route is that the second phase need not be carried out at the same location as the first phase. Therefore, the first phase can be located near the source of the rock phosphate while the second phase can be located near the fertilizer market area, making it possible to reduce transportation costs by shipping the highly concentrated (229 percent P_2O_5) elemental phosphorus.

Identifying the impact of by-product sulfuric acid on the fertilizer industry will involve some variations from the procedure used for by-product ammonium sulfate. Unlike the case of ammonium sulfate, the value of sulfuric acid to the fertilizer industry is known. At current prices, it is the established input for producing phosphoric

acid. Therefore, the problem is not to find a price at which it will become competitive, as was the case with ammonium sulfate. Rather, the approach will be to determine at what price electricity will become competitive with sulfuric acid.

To initiate the analysis, the price of sulfuric acid was set at $12 per ton at the phosphate-producing area, and the price of electricity was lowered from 4 mills. Not until the price reaches 1.2545 mills will the elemental phosphorus process become competitive. At that price, 15,660 tons of elemental phosphorus would be produced, shipped to the furnace acid plant in Michigan, and converted to 66,413 tons of phosphoric acid, the pattern that was expected. The phosphoric acid would then be used to produce 69,000 tons of monoammonium phosphate, which would be trucked to farms for direct application (Table V-7).

The production of phosphoric acid in Florida would fall by an amount equivalent to the amount produced in Michigan. It would be used to produce monoammonium phosphate, which would be railed to the bulk blenders and combined with 173,000 tons of granular potassium chloride to produce 374,000 tons of 7-28-28.

The storage controls on bulk blending and the K_2O nutrient storage control appear to combine to determine the levels of production of phosphoric acid and monoammonium phosphate in Michigan. As discussed earlier when 172,713 tons of granular potassium chloride are flowing to the bulk blender, 75 percent of that amount (the bulk blender storage requirement) is equivalent to 50 percent of total K_2O (that amount required for storage). Up to this level, blending is preferred to direct application; while above this level, direct application is preferred.

This relationship would cause 172,713 tons of granular potassium

Table V-7. The substitution of white phosphoric acid for green phosphoric acid with sulfuric acid priced at $12 per ton (in tons)

Product	Price of electricity in mills/KWH					
	P=4.00	P=1.2545	P=0.6131	P=0.3700	P=0.2686	P=0.2259
Total cost	48,175,194	48,154,522	48,056,229	47,995,388	47,957,330	47,927,586
Anhydrous ammonia production	172,828	172,764	172,852	172,852	172,852	172,763
Anhydrous ammonia application	129,942	129,890	128,744	128,744	128,744	129,890
Urea production	-0-	-0-	2,124	2,124	2,124	-0-
Elemental phosphorous production	-0-	15,660	20,480	30,716	56,982	61,422
White phosphoric acid production	-0-	66,413	86,852	130,264	241,655	260,485
Green phosphoric acid production	260,565	194,073	173,649	130,236	18,846	-0-
Monoammonium phosphate production	270,576	270,495	270,510	270,509	270,510	270,494
Monoammonium phosphate application	-0-	68,965	90,189	90,189	90,189	90,173
Granular potassium chloride production	259,032	259,006	259,037	259,037	259,037	259,012
Granular potassium chloride application	86,319	86,292	86,324	86,324	86,324	104,476
Bulk blend	443,290	374,243	355,158	355,158	355,158	334,857
Formulation 7-28-28	329,689	374,243	298,515	298,515	298,515	334,857
Formulation 6.15-17.95-37.0	-0-	-0-	56,643	56,643	56,643	-0-
Formulation 10.6-42.55-10.85	113,600	-0-	-0-	-0-	-0-	-0-
Sulfuric acid	383,031	285,288	255,264	191,488	27,704	-0-
Electricity (in 1000 KWH)	-0-	191,421	250,330	375,456	696,512	750,786

chloride to go to the blender. However, since it would be economical to produce elemental phosphorus, it would also be cheaper to produce monoammonium phosphate in Michigan, although not cheap enough to truck monoammonium phosphate to the blenders from the Michigan plant. Consequently, enough monoammonium phosphate would be produced in Florida to supply the Michigan blender. The trade off between direct application and blending would be such that 7-28-28 is the optimal mix. Since 172,713 tons of granular potassium chloride would move to the blenders, enough monoammonium phosphate, 201,530 tons, must also flow to formulate 7-28-28. The remainder of the granular potassium chloride, and the monoammonium phosphate produced in Michigan would be applied directly.

Production of the elemental phosphorous requires 191 million KWH of electricity. The sulfuric acid consumption drops by nearly 100,000 tons, however, since the elemental phosphorus would be used in the production of phosphoric acid. The total cost would fall by $20,000 because of this shift.

When the price of electricity falls to 0.6130 mills, the organization would again change. And again storage controls prove to be the critical determinant of the organization. However, this time the P_2O_5 storage control would combine with the 75-percent blending storage control on monoammonium phosphate to determine the organization in conjunction with the two storage controls on potassium chloride. To satisfy the P_2O_5 nutrient storage requirement, 135,240 tons of monoammonium phosphate would have to be stored (assuming it is the only carrier of P_2O_5). Since 135,240 is 75 percent of 180,321, this latter amount could be blended without additional storage costs. Consequently, 180,321 tons of monoammonium phosphate would be produced in Florida and,

although it all will eventually be transported to the blenders, 135,240 tons would be stored first. All of this monoammonium phosphate would be blended with 172,713 tons of granular potassium chloride, the same amount of the potash product that was in the previous product mix. The amount of 7-28-28 blended would decrease to 298,515 tons while 56,643 tons of custom blend 6.15-17.95-37.0, nearly a 1-3-6 ratio, would enter the product mix.

The remainder of the changes would center around this basis. Since less monoammonium phosphate would be used in bulk blending, less would be produced in Florida. And, correspondingly, less phosphoric acid would be produced there as well. The decrease in monoammonium phosphate production in Florida would be equalled by an increase in production in Michigan. And, likewise, phosphoric acid production would increase by the same amount that Florida production decreases. Again, all Michigan-produced phosphoric acid would utilize elemental phosphorus as the intermediate product.

All of Michigan-produced monoammonium phosphate would be trucked to the farm for direct application. Since the 6.15-17.95-37.0 formulation requires small amounts of urea, 2,124 tons of it would be produced in the Michigan plant and shipped to the outstate blenders. Electricity use would increase further to 250,330,000 KWH while sulfuric acid consumption would decrease to 255,264 tons. The total cost decreases to $48,056,229, a savings of approximately $250,000 over Optimum.

As the price of electricity falls to 0.370 mills, only a slight shift in the organization would occur. Whereas in the previous organization, 180,321 tons of monoammonium phosphate were produced in

Florida, of which 135,240 tons were stored, only 135,240 tons would be produced and stored at Florida in this organization. The remaining 45,080 tons would be produced in Michigan and blended at the central Michigan blender. Outside of this change, and the corresponding changes in the production of phosphoric acid and elemental phosphorus, and the transportation of granular potassium chloride to the central Michigan blender, no other changes would occur. However, the total cost would drop another $60,000.

As the price of electricity continues to fall, two more shifts would occur: at 0.268 mills and 0.225 mills. In both shifts, the trend of blending more at the central blender and less at the outstate blender would continue, as would the shifts necessary to accomodate this change. All phosphoric acid would be produced in Michigan from elemental phosphorus. The production of this elemental phosphorus in Florida would consume 751 million KWH, while the consumption of sulfuric acid would fall to zero (these changes are summarized in Table V-7 and are provided in detail in Appendix E).

A total cost savings of $226,936 could be realized by making these changes. Of more importance, however, are the implications on the organization of the industry, which changes radically from Optimum. The more important changes are the shift of bulk blending from outstate locations to a central Michigan location, the production of elemental phosphorus in Michigan, the substitution of furnace phosphoric acid produced in Michigan for phosphoric acid produced in Florida with sulfuric acid, and the production of monoammonium phosphate in Michigan rather than Florida (Figure V-2 illustrates the resulting industry organization).

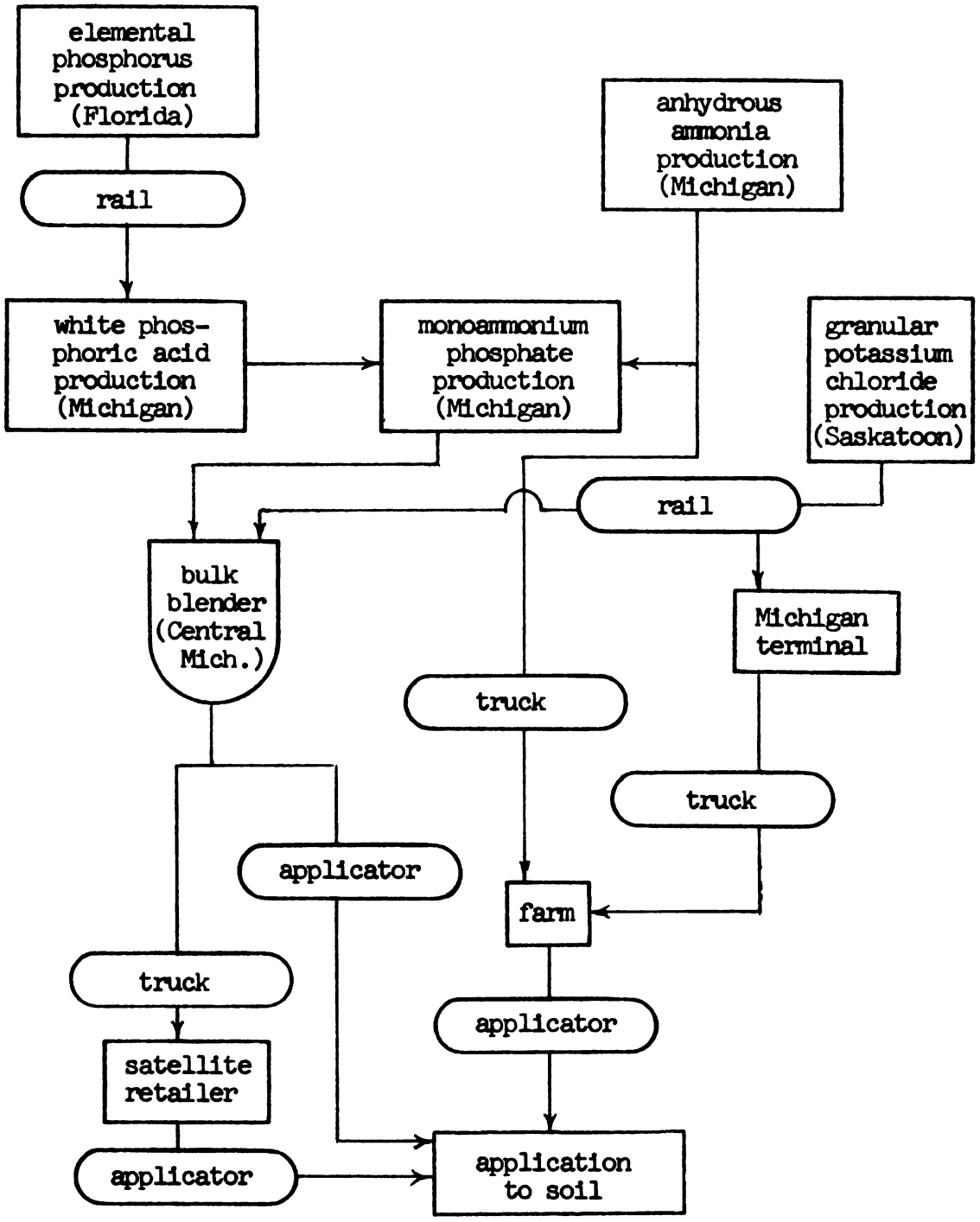

Figure V-2. Summary of the industry organization with green phosphoric acid replaced by white phosphoric acid

Although the analysis is revealing, it is not relevant for current price relationships because the price of electricity is not likely to fall to levels as low as are needed to induce the change. Consequently, the problem was reanalyzed using $16 per ton as the price of sulfuric acid rather than $12.

With sulfuric acid priced at $16, electricity would first start replacing it when priced at 3.2970 mills per KWH, and completely replace it when the price had lowered to 2.2677 mills. The transition would be identical, in terms of the intermediate organizations, to the transition with sulfuric acid at $12 per ton. For example, in the first transition organization, 15,660 tons of elemental phosphorus would be produced, just as was produced in the first organization when sulfuric acid was priced at $12 per ton. Table V-8 provides summary data for the transition from sulfuric acid to electricity in the production of phosphoric acid. Data are provided in greater detail in Appendix E. Since the solutions are identical, there is no reason to duplicate the discussion.

These two sets of data provide insight into what could be expected to occur if sulfuric acid were priced somewhere between $12 and $16 per ton, and the price of electricity lowered. By referring to Figure V-3, the situation could easily be analyzed. Each line refers to the loci where the industry organization would shift. Therefore, by selecting any price for sulfuric acid in that range, and a price for electricity, the resulting organization can be identified. The letters representing the organizational mix correspond to the organizational code which appears in Table V-8.

Table V-8. The substitution of white phosphoric acid for green phosphoric acid with sulfuric acid priced at $16 per ton (in tons)

Product	Price of electricity in mills/KWH					
	P=4.00	P=3.2970	P=2.5756	P=2.4101	P=2.3087	P=2.2677
Total cost	49,707,317	49,627,351	49,568,574	49,527,133	49,489,075	49,460,496
Anhydrous ammonia production	172,828	172,764	172,852	172,852	172,852	172,763
Anhydrous ammonia application	129,942	129,890	128,744	128,744	128,744	129,890
Urea production	-0-	-0-	2,124	2,124	2,124	-0-
Elemental phosphorus production	-0-	15,660	20,480	30,716	56,982	61,422
White phosphoric acid production	-0-	66,413	86,852	130,264	241,655	260,485
Green phosphoric acid production	260,565	194,073	173,649	130,236	18,846	-0-
Monoammonium phosphate production	270,576	270,495	270,510	270,509	270,510	270,494
Monoammonium phosphate application	-0-	68,965	90,189	90,189	90,189	90,173
Granular potassium chloride production	259,032	259,006	259,037	259,037	259,037	259,012
Granular potassium chloride application	86,319	86,292	86,324	86,324	86,324	104,470
Bulk blend	443,290	374,243	355,158	355,158	355,158	334,857
Formulation 7-28-28	329,689	374,243	298,515	298,515	298,515	334,857
Formulation 6.15-17.95-37.0	-0-	-0-	56,643	56,643	56,643	-0-
Formulation 10.6-42.55-10.85	113,600	-0-	-0-	-0-	-0-	-0-
Sulfuric acid	383,031	285,288	255,264	191,488	27,704	-0-
Electricity (in 1,000 KWH)	-0-	191,421	250,330	375,456	696,512	750,786
Organization code[a]	A	B	C	D	E	F

[a]Used in conjunction with Figure V-3.

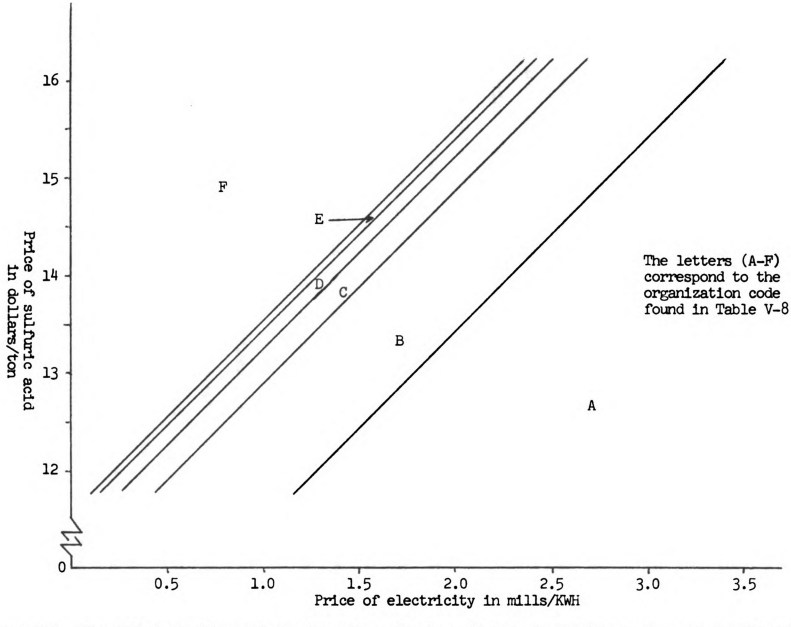

Figure V-3. The effect of alternative prices for sulfuric acid and electricity on the organization of the fertilizer industry

Exploration of Relevant Issues

It can be concluded from the foregoing discussion that at current prices ($12 per ton for sulfuric acid and four mills per KWH) the elemental phosphorus-phosphoric acid route cannot compete with the sulfuric acid-phosphoric acid route. However, facilities exist for producing elemental phosphorus and white phosphoric acid and, as long as they returned some amount on their investment (above and beyond operating costs), it would be irrational to close them down. Consequently, the return on investment was set at zero to determine if the plants would then become competitive with sulfuric acid. With the price of sulfuric acid at $12.32, and electricity at four mills, the sulfuric acid-green phosphoric acid route was cheaper, and no elemental phosphorus was produced. Therefore, on the basis of efficiency, the elemental phosphorus plants should be shut down, even in the short run. The variable cost of producing P_2O_5 and getting it to the soil via the elemental phosphorus-white phosphoric acid route is greater than the total cost of providing it via the green phosphoric acid route.

Even though such products as diammonium and monoammonium phosphate and ammonium polyphosphates are not optimally produced in the Michigan area, if they are produced, phosphoric acid needed for their production is best provided via the elemental phosphorus route. Even though the wet process is preferred over the elemental phosphorus route under optimal conditions, the elemental phosphorus to white phosphoric acid technique places phosphoric acid in Michigan cheaper than does the wet process technique.

In the ammonium sulfate analysis, it was assumed that the

by-product was produced at power plants around the state of Michigan. However, in the sulfuric acid analysis, the prices used were those at the phosphate plant in Florida. While this is satisfactory for analysis of the substitution between sulfuric acid and electricity, it cannot be inferred that by-product sulfuric acid from scrubbing power plants in Michigan has the same opportunity as does sulfuric acid in Florida. Consequently, use of by-product sulfuric acid for acidulating rock phosphate in Michigan was examined. If the proper cost relationship existed, rock phosphate could be railed to Michigan and converted to green phosphoric acid with the sulfuric acid in a wet process plant.

This situation was simulated in the model, with the price of the by-product sulfuric acid being allowed to fluctuate. Even if the price of the by-product sulfuric acid fell to zero, it was not cheaper to produce green phosphoric acid in Michigan than to produce it in Florida (with the price of sulfuric acid at $12.32 per ton), where it in turn was used to produce monoammonium phosphate which was railed to Michigan.

Since it is not economical to use by-product sulfuric acid for the production of green phosphoric acid in Michigan, the alternative of railing by-product sulfur or sulfuric acid to Florida was examined.

Sulfuric acid can be railed to Florida for $29.40 per ton, while sulfur can be railed for $26.40 per ton. Sulfuric acid is much less concentrated than sulfur, so it would obviously be logical to produce by-product sulfur rather than sulfuric acid. Given the conversion of sulfur to sulfuric acid cost $6.01 per ton of sulfuric acid, and a price of $12.32 per ton of sulfur at Florida, the value of 6.31 can be imputed to the .35 tons of sulfur. This is equivalent to $18.03

per ton. Since the value of the sulfur in Florida is only $18.03 per ton, it would not be feasible to rail it from Michigan to Florida at a cost of $26.40 per ton.

In conclusion, it does not appear economical to use Michigan's by-product sulfur in the fertilizer industry. However, as noted earlier, approximately half of the nation's sulfur is consumed in the fertilizer industry, and the other half in a great variety of manufacturing industries (Table V-2). Many of these indistries have producers in Michigan. For example, in Michigan in 1967 there were 36 firms producing textiles, 214 producing paper products, 431 producing chemicals, 296 producing rubber and plastic, 32 producing leather and leather products, and 556 producing metal products (Lukomski, 1970, p. 252). All of these product groups use sulfuric acid. The concentration of industry in the North and sulfur supplies primarily in the South results in a superb opportunity for Michigan power plants that choose to produce sulfuric acid. The price of sulfuric acid in Michigan reflects the cost of transporting sulfur to Michigan and is, therefore, priced considerably higher than it is in the Gulf Coast area. The price of sulfuric acid on September 29, 1971 was $31.60 per ton FOB Detroit. If the Board of Water and Light in Lansing recovered 90 percent of its sulfur as sulfuric acid and sold it at that price, it would return to the publicly owned electric power-generating plant $2,072,581 annually. This compares to their net income of $5,228,664 in 1968. If the power plant marketed the sulfuric acid, it would likely cause a decline in prices. Nevertheless, substantial returns could be generated.

In conclusion, there is a steadily increasing demand for sulfur in the United States. But the potential supply of sulfur is by far

greater. The price of sulfur will remain at relatively low levels for some time to come. These low prices will encourage its use in the production of phosphoric acid, and the role of electricity and elemental phosphorus will depend on the suboptimal use of phosphoric acid in the Midwest and Northern areas as well as on nonfertilizer uses. Although by-product sulfuric acid produced in Michigan is not particularly useful in producing fertilizer, it has numerous other uses in the manufacturing industry, many of which are located in Michigan, and can generate considerable revenue at current prices.

CHAPTER VI

THE ESSENCE

Summary

1. A massive linear programming model based on the prominent characteristics of the fertilizer industry as it relates to the Michigan market was developed, with a comprehensive set of controls, to examine problems of special interest to participants in the fertilizer industry and to those who consume its products. The objective of this study was to examine potential situations that may cause coal-powered electric power-generating plants to recover sulfur oxides from their flue gas, to project the consequences the possible by-products from this activity may have on the long-run optimal organization of the fertilizer industry, and to explore other issues relevant to the situation.

2. Society is becoming increasingly sensitive to damages caused by air pollution. The sulfur oxides, which are exceedingly damaging to most materials and to plant and animal life, are receiving much of the attention. Although legislation designed to solicit control of sulfur oxide emissions has already been enacted, more persuasive controls are sure to follow. These controls, which will originate from the Environmental Protection Agency, will take the form of direct regulation, although the payments approach and effluent fee approach will be used in a few cases. Public utilities will recapture their

expenditures on pollution control efforts by increasing their rate base accordingly and generating the revenues through higher electrical rates.

3. Numerous processes designed to recover sulfur oxides from the flue gas of coal-burning electric power-generating plants, the primary emission source, are in varying stages of development. Many of those processes produce by-product sulfuric acid, while a few produce ammonium sulfate and a few produce throwaway products. Both sulfuric acid and ammonium sulfate have value to the fertilizer industry. The amounts of these two by-products that could be recovered from the major electric power-generating plants in the United States far exceed the amount that can be absorbed by the fertilizer industry, even under the most favorable conditions.

4. The long-run optimal organization of the fertilizer industry is based on three high-analysis products: anhydrous ammonia, monoammonium phosphate and granular potassium chloride. Most of the latter two are used in a bulk blend product. By using only these products and by using a minimum number of facilities, the cost of supplying the amount of N, P_2O_5 and K_2O consumed in Michigan in 1970 can be reduced by 32.4 percent from the amount farmers actually paid.

5. Three uses of by-product ammonium sulfate were examined: for direct application, in granulating a mixed fertilizer and for bulk blending. Although the use of ammonium sulfate for direct application was superior to the two alternative uses, it competed with the optimal product mix at very low prices only ($\leq$\$2.00 per ton).

6. Increasing amounts of sulfur are consumed in the United States annually, primarily in fertilizer production and manufacturing. However, the potential supply of sulfur is so great that sulfur prices

can be expected to be relatively low for some time to come.

7. At the currently low price for sulfuric acid (approximately $12.50 per ton) at the Gulf Coast area, the elemental phosphorus-white phosphoric acid route cannot compete with the wet process-green phosphoric acid route, even in the short run.

8. Although by-product sulfuric acid produced in Michigan cannot be used efficiently in the fertilizer industry, the high concentration of manufacturing in the North combines with remoteness from sulfur sources (located in the South) to provide a good market price for sulfuric acid. When processes for recovering sulfur oxides become reliable, some power plants will be producing sulfuric acid.

Implications

The findings of this study can be valuable to the electric power industry, the sulfur industry and to the fertilizer industry in making short- and long-run adjustments.

1. Coal-burning power plants will have little reason not to invest in sulfur oxide recovery equipment once processes are satisfactorily developed. The most important problem is determining what type of process to invest in.

This study indicates that a power firm in the Michigan area can expect to generate considerably more revenue from the production of sulfuric acid than from the production of ammonium sulfate. At the current price of $31.60 per ton for sulfuric acid, returns to the power firm can be substantial. Although ammonium sulfate competes poorly with other sources of N in the long-run optimal organization of the fertilizer industry, its position is improved if a value is imputed for its sulfur content and if it competes against current prices for nitrogen

products. However, a power firm must evaluate the effect its production will have on the by-product's supply and price. For example, while sulfuric acid is currently priced at $31.60 per ton, the production that could result from sulfur oxide abatement could reduce the market price substantially, thereby reducing the potential revenue.

The location of the power firm in relation to the by-product market area is an important consideration. Since ammonium sulfate is a low-analysis product, it cannot be transported far without loss of its competitive advantage. Therefore, a power firm in an agricultural area will have a locational advantage over other power firms in marketing ammonium sulfate. On the other hand, power firms located in industrial areas will have a locational edge on other power firms in the production of sulfuric acid since it is used as an input in manufacturing.

If a power plant chooses to produce a saleable product, it must be prepared to develop a marketing program. Marketing sulfuric acid or ammonium sulfate could be a significant problem for the power firm since the characteristics of those markets are considerably different from the market for electricity. In addition, the high-analysis bias farmers may have could be a formidable barrier in marketing the low-analysis ammonium sulfate.

It appears that some balance between the processes that produce ammonium sulfate, sulfuric acid and a waste product will evolve. The markets for both ammonium sulfate and sulfuric acid are such that they could not absorb all of the potential by-products without substantial price changes. Firms must determine what processes are technically feasible for their plant, and evaluate the opportunities. Few firms will find the processes that result in ammonium sulfate desirable;

more will prefer those that result in sulfuric acid. If the quantity of these by-products marketed is sufficient to drive price down considerably, the remaining firms may prefer to use the processes that produce a waste product.

2. The sulfur industry will be greatly affected by developments in the power industry. It is apparent that by-product sulfur-sulfuric acid will account for an increasing share of the industry, and that low prices will prevail. Even though two firms control 90 percent of Frasch sulfur production, they will encounter keen competition from by-product sulfur. By working those mines where costs are at a minimum and by directing their marketing efforts to the nearby phosphate producers, their economic position will be enhanced. Because of overcapacity and the market situation, they will not improve their situation by investing in new facilities.

Northern industrial firms that are heavy users of sulfuric acid have an incentive to push for sulfur oxide abatement since the price of sulfuric acid in the North could be expected to fall. Of course, if they emit sulfur oxides themselves, the incentive may not be great.

3. Nitrogen producers and distributors will be greatly affected by the shift to the optimal organization of the industry. Whereas there are currently about 20 products that carry nitrogen, the optimal organization includes only anhydrous ammonia and monoammonium phosphate, of which the latter is used in blending a mixed product.

Although there is a trend to increased use of anhydrous ammonia, an acceleration would seem in order. In 1970, anhydrous ammonia satisfied only 36 percent of Michigan's N requirements. Analysis indicates that costs would have been minimized if ammonia would have

supplied 75 percent of the N.

On the other hand, the location of ammonia production facilities is following a pattern inconsistent with the analysis in this study. While the analysis indicates that ammonia firms could minimize production and distribution costs by locating near the consuming area, the trend has been to locate the plants near the source of natural gas, the primary input. A reversal of this trend would improve efficiency in the production and distribution of ammonia.

Production of other products that supply N is suboptimal, except for monoammonium phosphate, a high-analysis product that also supplies the P_2O_5 in the optimal organization. Production capacity for some of these nitrogen products has been steadily increasing. However, if firms discontinue development of those facilities and allow increasing amounts of anhydrous ammonia to flow to farms for direct application, performance would be improved.

Although the shift from the current organization to the optimal organization involves important shifts in nitrogen production and distribution, the shift from the optimal organization to the use of by-product ammonium sulfate involves essentially only one shift. Instead of ammonia moving from the producers to farms, it first moves to the power plant where it is converted to ammonium sulfate. The ammonium sulfate is then transported to farms.

The ammonia producer could gain from this shift. First, its demand for ammonia may increase slightly since some ammonia escapes in the scrubbing process. In addition, the demand for ammonia at the power plant would be much less seasonal than the demand for ammonia at the farm. Consequently, the ammonia producer would need considerably

less storage, and the problems of coordination would be reduced.

4. Phosphorus producers are currently improving performance in the industry by increasing production of high-analysis products and by moving production of phosphate fertilizers to the mines in Florida. This is consistent with the findings of this study. However, they would lower the cost of phosphates further if they limited production to monoammonium phosphate.

In recent years, high sulfur prices caused firms in the fertilizer industry to invest in electric arc furnaces, as well as search for other substitutes for sulfuric acid. But the low sulfur prices that will prevail for some time to come make the competitive products uneconomical. Consequently, investments in electric arc furnaces and in the development of other processes does not appear to be economically desirable.

5. Potash producers will not be greatly affected by a shift to the optimal organization nor to the possible substitution of ammonium sulfate for ammonia. The optimal organization indicates that granular potassium chloride should be used in bulk blends. Granular potassium chloride is currently produced with three other potash products, run-of-mine, standard and coarse. Granular, standard and coarse are derived simply by screening run-of-mine potassium chloride. Since granular is best suited for blending, potash producers will improve their economic position by adjusting their processes so that the production of standard and coarse is minimized.

6. The implication of the findings for the mixing sector are substantial. Costs are minimized by blending monoammonium phosphate and granular potassium chloride in large bulk blenders. Consequently, the number of blenders in the state can be expected to decrease while

the capacity of those remaining plants increases. Since all P_2O_5 and K_2O is blended in fewer blenders, those firms will have to transport the product farther. To do this they will find improved coordination of delivery necessary.

Granulators and hot and cold liquid mixers are less than optimal and costs would be minimized if they are eased out of production. These mixers, and the small-scale blenders can expect to find competing with large-scale blenders increasingly difficult.

7. Retailers will be adversely affected by a shift to the optimal organization. Analysis indicates that low-volume, high-cost retailers are inefficient. Instead, the retailing functions will be performed by blenders and by centrally located firms. For example, anhydrous ammonia will flow directly from the central Michigan producer to the farm. Retailers can expect to be bypassed as farmers seek lower cost fertilizer. On the other hand, the centrally located firm must be prepared to perform the distributive and retail functions, a task that is sure to require improved coordination. If power firms produce ammonium sulfate, they must perform those functions. This could be a significant problem for power firms since it would be a totally new activity in a strange environment.

8. Farmers can minimize their expenditures on fertilizer by making adjustments primarily in their buying behavior. They can buy fertilizer cheaper if they bypass the local retailer and purchase from blenders and central producers or distributors. For example, they could realize lower costs if they purchased their blended products from a plant located possibly as far as 35 miles. The cheapest source of ammonia may be a plant as far as 100 miles. If ammonium sulfate is

used, it may come from a power plant as far as 70 miles. If farmers choose to take advantage of the opportunities, they must be prepared to use products that may be strange to them, and they must invest in the equipment needed for application of those products. Whereas thousands of products are currently used, they will find it to their long-run economic advantage to use a blend product and anhydrous ammonia. If ammonium sulfate is substituted for anhydrous ammonia, only a dry spreader will be required for application. Otherwise, an ammonia applicator would also be required.

Research Needs

Although this study has provided considerable insight into relatively new problems, it leaves some pertinent questions unanswered:

1. The optimal organization of the fertilizer industry, and the variation from this optimum, were very sensitive to the assumptions of the length of the fertilizer season, and consequently to the storage requirements. For example, in Optimum, much of the granular potassium chloride was blended with monoammonium phosphate while the remainder went to the farm for direct application. This occurred because, given the storage requirements, it was preferable to blend those two products only as long as the blending operation did not have to bear the marginal cost of storage. Changing the storage requirements would change the solution. I believe that if the length of the blending season was the same as the direct application season, the optimal organization would show N, P_2O_5 and K_2O requirements being met by blending all monoammonium phosphate with all granular potassium chloride, and using anhydrous ammonia for direct application. Further analysis could eliminate the uncertainty of this belief.

2. The analysis evaluated the competitive capabilities of the two by-products against Optimum. This optimal organization provided the nutrients consumed in Michigan in 1970 at a cost of $48,297,763, which was 32.4 percent less than Michigan farmers actually paid. While the two by-products can compete against the optimum organization at very low prices only, there is every reason to believe that they could compete very favorably at significantly higher prices against the products actually consumed in 1970. Should the two by-products be produced in the near future (say, in the next five years), they would probably have to compete against a product mix closer to the actual product mix in 1970 than against the optimal product mix. Consequently, it seems useful to evaluate their competitive capabilities against a suboptimal product mix: preferably against a product mix most probably in 1975.

3. The analysis assumed a specific level of demand for the three nutrients, and this level did not change as the price of the fertilizer products changed. One would expect consumption to be related to the price. Although studies tend to bear this out, they are not at all certain of the extent of this relationship; the studies have varied considerably. It would be ideal to establish long-run price elasticities for the three nutrients in Michigan, combine them with a time trend, and vary the consumption in each time period so that it responds appropriately.

4. The optimal organization of the industry, and the variation from the optimum, indicate that high-volume facilities were preferable to the low-volume facilities that are currently characteristic of certain components of the fertilizer industry in Michigan. For example, although most bulk blenders in Michigan fall in the 1,000-2,500 tons-per-year

range, 9,000 tons-per-year blenders are most economical. The trend to high-volume facilities has implications to market structure; that is, to the number and size of firms, and their share of the market. Increasing the size of firms to realize economies of scale could result in firms that have monopolistic powers. If this occurred, there is no assurance that farmers would realize any of the benefits of producing and distributing fertilizer at lower cost. An investigation of the potential growth of market power that could result from the findings of this study is desirable.

5. Finally, the transition from the current organization of the industry to the long-run optimal organization is sensitive to a number of assumptions. The impact of various assumptions should be examined.

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APPENDICES

APPENDIX A

1970 Actual, Constrained Optimum, and Optimum: Data

Table A-1. Product use summary for 1970 actual, constrained optimum, and optimum (in tons)

Product	1970 actual	Constrained optimum	Optimum
Total cost (in dollars)	71,445,667	52,555,247	48,297,763
Anhydrous ammonia	164,309	171,894	172,828
Aqueous ammonia	3,897	-0-	-0-
Nitric acid	59,832	10,539	-0-
Ammonium nitrate	78,210	13,777	-0-
Nonpressure nitrogen solution	40,912	-0-	-0-
Low pressure nitrogen solution	28,171	-0-	-0-
Nitrogen manufacturing solution	16,067	19,737	-0-
Urea	52,006	-0-	-0-
Granular ammonium sulfate	35,628	-0-	-0-
Elemental phosphorous	4,004	-0-	-0-
White phosphoric acid	16,866	-0-	-0-
Green phosphoric acid	195,455	236,748	260,565
Superphosphoric acid	207	-0-	-0-
Ammonium polyphosphate liquid (10-34-0)	4,832	-0-	-0-
Ammonium polyphosphate liquid (11-37-0)	402	-0-	-0-
Normal superphosphate	53,791	-0-	-0-
Run-of-pile triple superphosphate	138,945	115,303	-0-
Granular triple superphosphate	26,598	5,274	-0-
Diammonium phosphate	105,205	77,810	-0-
Monoammonium phosphate	26,244	99,910	270,576
Rock phosphate	277	-0-	-0-
Run-of-mine potassium chloride	111,166	121,462	-0-
Standard potassium chloride	1,877	-0-	-0-
Granular potassium chloride	95,919	137,590	259,032
Coarse potassium chloride	50,000	-0-	-0-
Granulated mixed fertilizers	388,555	303,655	-0-
Bulk blended fertilizers	203,213	185,535	329,689
Custom blended fertilizers	27,785	86,465	113,600
Hot process clear mixed liquids	11,450	-0-	-0-
Cold process clear mixed liquids	7,633	-0-	-0-
Suspension liquids	-0-	-0-	-0-
N supplied	141,932	141,932	141,932
P_2O_5 supplied	140,650	140,650	140,650
K_2O supplied	155,441	155,441	155,441

Table A-2. Anhydrous ammonia product flow

Originating location	Activity	Type	Terminating location	Product tons per year		
				1970 actual	Constrained optimum	Optimum
Gulf Coast	Production	Centrifugal	—	73,033	80,308	42,886
Gulf Coast	Production	Piston	—	10,363	-0-	-0-
Midwest	Production	Centrifugal	—	46,913	45,175	-0-
Central Michigan	Production	Centrifugal	—	-0-	-0-	129,942
Central Michigan	Production	Piston	—	34,000	46,411	-0-
Gulf Coast	Mfr's. storage	Cyrogenic	—	13,189	45,540	-0-
Midwest	Mfr's. storage	Cyrogenic	—	-0-	7,647	-0-
Central Michigan	Mfr's. storage	Cyrogenic	—	-0-	-0-	54,239
Gulf Coast	Product transfer	On-site	Gulf Coast producers[1]	50,763	7,448	-0-
Gulf Coast	Transportation	Barge	Florida producers[2]	19,012	27,320	42,886
Gulf Coast	Transportation	Rail	Outstate retailers	13,622	45,540	-0-
Midwest	Product transfer	On-site	Midwest producers[3]	25,946	8,788	-0-

Table A-2. (cont'd.)

Originating location	Activity	Type	Terminating location	Product tons per year: 1970 actual	Constrained optimum	Optimum
Midwest	Transportation	Rail	Outstate processors[4]	2,157	-0-	-0-
Midwest	Transportation	Rail	Outstate retailers	18,810	-0-	-0-
Midwest	Transportation	Truck	Farms	-0-	36,387	-0-
Central Michigan	Product transfer	On-site	Michigan producers[5]	4,350	-0-	-0-
Central Michigan	Transportation	Truck	Outstate retailers	29,642	-0-	-0-
Central Michigan	Transportation	Truck	Farms	8	46,411	129,942
Outstate Michigan	Retailing	---	---	62,074	45,540	-0-
Outstate retailers	Transportation	Applicator	Farms	62,074	45,540	-0-
Farms	Application	---	---	62,082	128,338	129,942

[1]Nitric acid, ammonium nitrate, nitrogen manufacturing solutions, and urea producers.

[2]Diammonium phosphate and monoammonium phosphate producers.

Table A-2. (cont'd.)

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[3]Nitric acid, ammonium nitrate, nonpressure and low pressure nitrogen solutions, nitrogen manufacturing solutions, urea, ammoniated polyphosphates, diammonium phosphate, and monoammonium phosphate producers.

[4]Aqueous ammonia, granular mixed and liquid mixed fertilizer producers.

[5]Diammonium phosphate and granular mixed fertilizer producers.

Table A-3. Aqueous ammonia product flow

Originating location	Activity	Type	Terminating location	Product tons per year		
				1970 actual	Constrained optimum	Optimum
Outstate Michigan	Production	Ammonia converter	---	3,897	-0-	-0-
Outstate Michigan	Transportation	Rail	Outstate retailer	3,897	-0-	-0-
Outstate Michigan	Retailing	---	---	3,897	-0-	-0-
Outstate retailers	Transportation	Applicator	Farms	3,897	-0-	-0-
Farms	Application	---	---	3,897	-0-	-0-

Table A-4. Nitric acid product flow

Originating location	Activity	Type	Terminating location	Product tons per year		
				1970 actual	Constrained optimum	Optimum
Gulf Coast	Production	Medium pressure	---	41,882	7,377	-0-
Midwest	Production	Medium pressure	---	17,950	3,162	-0-
Gulf Coast	Product transfer	On-site	Gulf Coast producers[1]	41,882	7,377	-0-
Midwest	Product transfer	On-site	Midwest producers[1]	17,950	3,162	-0-

[1]Ammonium nitrate producers.

Table A-5. Ammonium nitrate product flow

Originating location	Activity	Type	Terminating location	Product tons per year: 1970 actual	Constrained optimum	Optimum
Gulf Coast	Production	Neutralization-evaporation	---	54,747	9,644	-0-
Midwest	Production	Neutralization-evaporation	---	23,463	4,133	-0-
Gulf Coast	Mfr's. storage	Bulk	---	4,879	-0-	-0-
Gulf Coast	Product transfer	On-site	Gulf Coast producers[1]	-0-	9,644	-0-
Gulf Coast	Transportation	Barge	Midwest producers[2]	20,105	-0-	-0-
Gulf Coast	Transportation	Rail	Michigan producers[3]	1,027	-0-	-0-
Gulf Coast	Transportation	Rail	Outstate processors[3]	5,912	-0-	-0-
Gulf Coast	Transportation	Rail	Outstate retailers	27,704	-0-	-0-
Midwest	Product transfer	On-site	Midwest producers[2]	23,463	4,133	-0-
Outstate Michigan	Retailing	---	---	27,704	-0-	-0-
Outstate retailers	Transportation	Applicators	Farms	27,704	-0-	-0-

Table A-5. (cont'd.)

Originating location	Activity	Type	Terminating	Product tons per year		
				1970 actual	Constrained optimum	Optimum
Farms	Application	---	---	27,704	-0-	-0-

[1]Nitrogen manufacturing solutions producers.

[2]Nonpressure and low pressure nitrogen solutions and nitrogen manufacturing solutions producers.

[3]Granulated mixed and dry blended fertilizer producers.

Table A-6. Nonpressure nitrogen solutions product flow

Originating location	Activity	Type	Terminating	Product tons per year		
				1970 actual	Constrained optimum	Optimum
Midwest	Production	Blending	—	40,912	-0-	-0-
Midwest	Mfr's. storage	Tank	—	40,635	-0-	-0-
Midwest	Transportation	Rail	Outstate processors[1]	1,109	-0-	-0-
Midwest	Transportation	Rail	Outstate retailers	39,803	-0-	-0-
Outstate Michigan	Retailing	—	—	39,803	-0-	-0-
Outstate retailers	Transportation	Applicators	Farms	39,803	-0-	-0-
Farms	Application	—	—	39,803	-0-	-0-

[1]Cold process liquid mixed fertilizer producers.

Table A-7. Low pressure nitrogen solutions product flow

Originating location	Activity	Type	Terminating location	Product tons per year		
				1970 actual	Constrained optimum	Optimum
Midwest	Production	Blending	---	28,171	-0-	-0-
Midwest	Mfr's. storage	Tank	---	9,472	-0-	-0-
Midwest	Transportation	Rail	Michigan producers[1]	16,260	-0-	-0-
Midwest	Transportation	Rail	Outstate processors[1]	9,756	-0-	-0-
Midwest	Transportation	Rail	Outstate retailers	2,155	-0-	-0-
Outstate Michigan	Retailing	---	---	2,155	-0-	-0-
Outstate retailers	Transportation	Applicators	Farms	2,155	-0-	-0-
Farms	Application	---	---	2,155	-0-	-0-

[1]Granulated mixed fertilizer producers.

Table A-8. Nitrogen manufacturing solutions product flow

Originating location	Activity	Type	Terminating location	Product tons per year		
				1970 actual	Constrained optimum	Optimum
Gulf Coast	Production	Blending	---	-0-	13,816	-0-
Midwest	Production	Blending	---	16,067	5,921	-0-
Gulf Coast	Mfr's. storage	Tank	---	-0-	2,616	-0-
Midwest	Mfr's. storage	Tank	---	4,519	-0-	-0-
Gulf Coast	Transportation	Rail	Michigan producers[1]	-0-	10,329	-0-
Gulf Coast	Transportation	Rail	Outstate processors[1]	-0-	3,488	-0-
Midwest	Transportation	Rail	Michigan producers[1]	10,042	5,921	-0-
Midwest	Transportation	Rail	Outstate processors[1]	6,025	-0-	-0-

[1]Granulated mixed fertilizer producers.

Table A-9. Urea product flow

Originating location	Activity	Type	Terminating location	Product tons per year		
				1970 actual	Constrained optimum	Optimum
Gulf Coast	Production	Gas separation	---	29,470	-0-	-0-
Gulf Coast	Production	Ammonium carbamate slurry	---	6,934	-0-	-0-
Gulf Coast	Production	Water absorption	---	10,401	-0-	-0-
Midwest	Production	Gas separation	---	5,201	-0-	-0-
Gulf Coast	Mfr's. storage	Bulk	---	33,878	-0-	-0-
Gulf Coast	Transportation	Barge	Midwest producers[1]	9,651	-0-	-0-
Gulf Coast	Transportation	Rail	Michigan processors[2]	1,247	-0-	-0-
Gulf Coast	Transportation	Rail	Outstate processors[2]	11,861	-0-	-0-
Gulf Coast	Transportation	Rail	Outstate retailers	24,047	-0-	-0-
Midwest	Product transfer	On-site	Midwest producers[1]	5,201	-0-	-0-
Outstate Michigan	Retailing	---	---	24,047	-0-	-0-

Table A-9

Table A-9. (cont'd.)

Originating location	Activity	Type	Terminating location	Product tons per year		
				1970 actual	Constrained optimum	Optimum
Outstate retailers	Transportation	Applicators	Farms	24,047	-0-	-0-
Farms	Application	---	---	24,047	-0-	-0-

[1]Nonpressure nitrogen solutions producers.

[2]Granulated mixed and dry blended fertilizer producers.

Table A-10. Ammonium sulfate product flow

Originating location	Activity	Type	Terminating location	Product tons per year		
				1970 actual	Constrained optimum	Optimum
Central Michigan	Purchase	---	---	11,174	-0-	-0-
Outstate processors	Purchase	---	---	21,984	-0-	-0-
Outstate retailers	Purchase	---	---	2,470	-0-	-0-
Outstate Michigan	Retailing	---	---	2,470	-0-	-0-
Outstate retailers	Transportation	Applicators	Farms	2,470	-0-	-0-
Farms	Application	---	---	2,470	-0-	-0-

Table A-11. Elemental phosphorus product flow

Originating location	Activity	Type	Terminating location	Product tons per year		
				1970 actual	Constrained optimum	Optimum
Florida	Production	Electric furnace	---	4,004	-0-	-0-
Florida	Transportation	Barge	Midwest producers[1]	27	-0-	-0-
Florida	Transportation	Rail	Michigan producers[1]	3,977	-0-	-0-

[1]White phosphoric and superphosphoric acid producers.

Table A-12. White phosphoric acid product flow

Originating location	Activity	Type	Terminating location	Product tons per year		
				1970 actual	Constrained optimum	Optimum
Central Michigan	Production	Furnace process	—	16,866	-0-	-0-
Central Michigan	Product transfer	On-site	Michigan producer[1]	16,866	-0-	-0-

[1]Diammonium phosphate producer.

Table A-13. Green phosphoric acid product flow

Originating location	Activity	Type	Terminating location	Product tons per year		
				1970 actual	Constrained optimum	Optimum
Florida	Production	Wet process	---	134,864	163,356	260,565
Midwest	Production	Wet process	---	60,591	73,392	-0-
Florida	Mfr's. storage	Rubber-lined	---	3,561	-0-	-0-
Florida	Product transfer	On-site	Florida producers[1]	134,864	163,356	260,565
Midwest	Product transfer	On-site	Midwest producers[1]	55,843	73,392	-0-
Midwest	Transportation	Rail	Outstate processors[2]	4,748	-0-	-0-

[1]Ammoniated polyphosphates, triple superphosphate, diammonium phosphate and monoammonium phosphate producers.

[2]Hot process clear mixed liquid fertilizer producers.

Table A-14. Superphosphoric acid product flow

Originating location	Activity	Type	Terminating location	Product tons per year		
				1970 actual	Constrained optimum	Optimum
Midwest	Production	Thermal	---	207	-0-	-0-
Midwest	Product transfer	On-site	Midwest producers[1]	207	-0-	-0-

[1]Ammoniated polyphosphates producers.

Table A-15. Ammoniated polyphosphate (10-34-0) product flow

Table A-15. Ammoniated polyphosphate (10-34-0) product flow

Originating location	Activity	Type	Terminating location	Product tons per year		
				1970 actual	Constrained optimum	Optimum
Midwest	Production	Ammoniation	—	4,832	-0-	-0-
Midwest	Mfr's. storage	Tank	—	3,624	-0-	-0-
Midwest	Transportation	Rail	Outstate processors[1]	4,832	-0-	-0-

[1]Cold process clear mixed liquid fertilizer producers.

Table A-16. Ammoniated polyphosphate (11-37-0) product flow

Table A-16. Ammoniated polyphosphate (11-37-0) product flow

Originating location	Activity	Type	Terminating location	Product tons per year		
				1970 actual	Constrained optimum	Optimum
Midwest	Production	Ammoniation	---	402	-0-	-0-
Midwest	Mfr's. storage	Tank	---	302	-0-	-0-
Midwest	Transportation	Rail	Outstate processors[1]	402	-0-	-0-

[1]Cold process clear mixed liquid fertilizer producers.

Table A-17. Normal superphosphate product flow

Originating location	Activity	Type	Terminating location	Product tons per year		
				1970 actual	Constrained optimum	Optimum
Florida	Production	Cone mixer	---	21,791	-0-	-0-
Central Michigan	Production	Cone mixer	---	32,000	-0-	-0-
Florida	Mfr's. storage	Bulk	---	16,660	-0-	-0-
Florida	Transportation	Rail	Outstate processors[1]	21,791	-0-	-0-
Central Michigan	Product transfer	On-site	Michigan producers[1]	31,540	-0-	-0-
Central Michigan	Transportation	Rail	Outstate processors[1]	89	-0-	-0-
Central Michigan	Transportation	Rail	Outstate retailers	371	-0-	-0-
Outstate Michigan	Retailing	---	---	371	-0-	-0-
Outstate retailers	Transportation	Applicators	Farms	371	-0-	-0-
Farms	Application	---	---	371	-0-	-0-

[1]Granulated mixed and dry blended fertilizer producers.

Table A-18. Run-of-pile triple superphosphate product flow

Originating location	Activity	Type	Terminating location	Product tons per year		
				1970 actual	Constrained optimum	Optimum
Florida	Production	Cone mixer	---	83,085	44,234	-0-
Midwest	Production	Cone mixer	---	55,860	71,069	-0-
Florida	Mfr's. storage	Bulk	---	55,907	25,897	-0-
Florida	Product transfer	On-site	Florida producers[1]	27,130	5,380	-0-
Florida	Transportation	Rail	Michigan producers[2]	14,024	38,854	-0-
Florida	Transportation	Rail	Outstate processors[2]	41,930	-0-	-0-
Midwest	Transportation	Rail	Michigan producers[2]	55,860	51,646	-0-
Midwest	Transportation	Rail	Outstate processors[2]	-0-	19,423	-0-

[1]Granulated triple superphosphate producers

[2]Granulated mixed fertilizers producers.

Table A-19. Granular triple superphosphate product flow

Originating location	Activity	Type	Terminating location	Product tons per year		
				1970 actual	Constrained optimum	Optimum
Florida	Production	Rotary drum granulator	---	26,598	5,274	-0-
Florida	Mfr's. storage	Bulk	---	17,242	3,956	-0-
Florida	Transportation	Rail	Michigan processors[1]	1,831	-0-	-0-
Florida	Transportation	Rail	Outstate processors[1]	21,159	5,274	-0-
Florida	Transportation	Rail	Outstate retailers	3,608	-0-	-0-
Outstate Michigan	Retailing	---	---	3,608	-0-	-0-
Outstate retailers	Transportation	Applicators	Farms	3,608	-0-	-0-
Farms	Application	---	---	3,608	-0-	-0-

[1]Dry blended fertilizer producers.

Table A-20. Diammonium phosphate product flow

Originating location	Activity	Type	Terminating location	Product tons per year		
				1970 actual	Constrained optimum	Optimum
Florida	Production	Slurry ammoniation	---	70,886	64,582	-0-
Midwest	Production	Slurry ammoniation	---	14,519	13,228	-0-
Central Michigan	Production	Slurry ammoniation	---	19,800	-0-	-0-
Florida	Mfr's. storage	Bulk	---	51,194	28,358	-0-
Florida	Trasnportation	Rail	Michigan producers[1]	-0-	26,772	-0-
Florida	Transportation	Rail	Outstate processors[1]	64,048	37,810	-0-
Florida	Transportation	Rail	Outstate retailers	6,838	-0-	-0-
Midwest	Transportation	Rail	Michigan producers[1]	14,478	13,228	-0-
Midwest	Transportation	Rail	Outstate processors[1]	40	-0-	-0-
Central Michigan	Product transfer	On-site	Michigan producers[1]	19,800	-0-	-0-
Outstate Michigan	Retailing	---	---	6,838	-0-	-0-

Table A-20. (cont'd.)

Originating location	Activity	Type	Terminating location	Product tons per year		
				1970 actual	Constrained optimum	Optimum
Outstate retailers	Transportation	Applicators	Farms	6,838	-0-	-0-
Farms	Application	---	---	6,838	-0-	-0-

[1]Granulated mixed and dry blended fertilizer producers.

Table A-21. Monoammonium phosphate product flow

Originating location	Activity	Type	Terminating location	Product tons per year		
				1970 actual	Constrained optimum	Optimum
Florida	Production	Slurry ammoniation	---	21,783	82,926	270,576
Midwest	Production	Slurry ammoniation	---	4,461	16,985	-0-
Florida	Mfr's. storage	Bulk	---	17,231	74,933	202,932
Florida	Transportation	Rail	Outstate processors[1]	18,514	72,156	270,576
Florida	Transportation	Rail	Outstate retailers	3,269	-0-	-0-
Florida	Transportation	Rail	Michigan processors[1]	-0-	10,770	-0-
Midwest	Transportation	Rail	Michigan processors[1]	2,180	-0-	-0-
Midwest	Transportation	Rail	Outstate processors[1]	2,281	16,985	-0-
Outstate Michigan	Retailing	---	---	3,269	-0-	-0-
Outstate retailers	Transportation	Applicators	Farms	3,269	-0-	-0-
Farms	Application	---	---	3,269	-0-	-0-

[1]Dry blended fertilizer producers.

Table A-22. Rock phosphate product flow

Originating location	Activity	Type	Terminating location	Product tons per year		
				1970 actual	Constrained optimum	Optimum
Florida	Production	Grinding	---	277	-0-	-0-
Florida	Transportation	Rail	Outstate retailers	277	-0-	-0-
Outstate Michigan	Retailing	---	---	277	-0-	-0-
Outstate retailers	Transportation	Applicators	Farms	277	-0-	-0-
Farms	Application	---	---	277	-0-	-0-

Table A-23. Run-of-mine potassium chloride product flow

Originating location	Activity	Type	Terminating location	Product tons per year		
				1970 actual	Constrained optimum	Optimum
Saskatoon	Production	Flotation	---	111,116	121,462	-0-
Saskatoon	Mfr's. storage	Bulk	---	31,265	16,096	-0-
Saskatoon	Transportation	Rail	Michigan producers[1]	69,479	100,000	-0-
Saskatoon	Transportation	Rail	Outstate processors[1]	41,687	21,462	-0-

[1]Granulated mixed fertilizer producers.

Table A-24. Standard potassium chloride product flow

Originating location	Activity	Type	Terminating location	Product tons per year		
				1970 actual	Constrained optimum	Optimum
Saskatoon	Production	Flotation	—	1,877	-0-	-0-
Saskatoon	Mfr's. storage	Bulk	—	1,407	-0-	-0-
Saskatoon	Transportation	Rail	Outstate processors[1]	1,877	-0-	-0-

[1]Hot and cold process clear mixed liquid fertilizer producers.

Table A-25. Granular potassium chloride product flow

Originating location	Activity	Type	Terminating location	Product tons per year: 1970 actual	Constrained optimum	Optimum
Saskatoon	Production	Flotation	---	95,919	137,590	259,032
Saskatoon	Mfr's. storage	Bulk	---	62,943	103,192	129,535
Saskatoon	Transportation	Rail	Michigan terminal	-0-	-0-	86,319
Saskatoon	Transportation	Rail	Michigan processors[1]	6,321	9,230	-0-
Saskatoon	Transportation	Rail	Outstate processors[1]	77,602	128,360	172,713
Saskatoon	Transportation	Rail	Outstate retailers	11,996	-0-	-0-
Michigan terminal	Transportation	Truck	Farms	-0-	-0-	86,319
Outstate Michigan	Retailing	---	---	11,996	-0-	-0-
Outstate retailers	Transportation	Applicators	Farms	11,996	-0-	-0-
Farms	Application	---	---	11,996	-0-	86,319

[1]Dry blended fertilizer producers.

Table A-26. Coarse potassium chloride product flow

Originating location	Activity	Type	Terminating location	Product tons per year		
				1970 actual	Constrained optimum	Optimum
Saskatoon	Production	Flotation	---	50,000	-0-	-0-
Saskatoon	Transportation	Rail	Outstate retailers	50,000	-0-	-0-
Outstate Michigan	Retailing	---	---	50,000	-0-	-0-
Outstate retailers	Transportation	Applicators	Farms	50,000	-0-	-0-
Farms	Application	---	---	50,000	-0-	-0-

Table A-27. Bagged granulated mixed fertilizers product flow

Originating location	Activity	Type	Terminating location	Product tons per year		
				1970 actual	Constrained optimum	Optimum
Central Michigan	Production	TVA continuous	—	97,139	-0-	-0-
Outstate Michigan	Production	TVA (30,000TPY)	—	58,283	-0-	-0-
Central Michigan	Mfr's. storage	Bagged	—	36,427	-0-	-0-
Central Michigan	Transportation	Truck	Outstate retailers	97,117	-0-	-0-
Central Michigan	Transportation	Truck	Farms	22	-0-	-0-
Outstate producer	Transportation	Truck	Outstate retailers	58,283	-0-	-0-
Outstate Michigan	Retailing	—	—	155,400	-0-	-0-
Outstate retailers	Transportation	Wagons	Farms	155,400	-0-	-0-
Farms	Application	—	—	155,400	-0-	-0-

Table A-28. Bulk granulated mixed fertilizer product flow

Originating location	Activity	Type	Terminating location	Product tons per year		
				1970 actual	Constrained optimum	Optimum
Central Michigan	Production	TVA continuous	—	145,708	250,000	-0-
Outstate Michigan	Production	TVA continuous	—	87,425	53,655	-0-
Central Michigan	Mfr's. storage	Bulk	—	-0-	187,500	-0-
Central Michigan	Transportation	Rail	Outstate retailers	145,708	-0-	-0-
Central Michigan	Transportation	Truck	Farms	-0-	250,000	-0-
Outstate producer	Transportation	Truck	Outstate retailers	87,425	-0-	-0-
Outstate producer	Transportation	Truck	Farms	-0-	53,655	-0-
Outstate Michigan	Retailing	—	—	233,133	-0-	-0-
Outstate retailers	Transportation	Applicators	Farms	233,133	-0-	-0-
Farms	Application	—	—	233.133	303,655	-0-

Table A-29. Bagged blended fertilizer product flow

Originating location	Activity	Type	Terminating location	Product tons per year		
				1970 actual	Constrained optimum	Optimum
Central Michigan	Production	Horizontal w/ rotary drum	---	16,444	-0-	-0-
Outstate Michigan	Production	Horizontal (1000TPY)	---	6,986	-0-	-0-
Outstate Michigan	Production	Horizontal (2500TPY)	---	29,787	-0-	-0-
Central Michigan	Transportation	Truck	Outstate retailer	16,444	-0-	-0-
Outstate processors	Transportation	Wagon	Farms	36,773	-0-	-0-
Outstate Michigan	Retailing	---	---	16,444	-0-	-0-
Outstate retailer	Transportation	Wagon	Farms	16,444	-0-	-0-
Farms	Application	---	---	53,217	-0-	-0-

Table A-30. Bulk blended fertilizers product flow

Originating location	Activity	Type	Terminating location	Product tons per year		
				1970 actual	Constrained optimum	Optimum
Central Michigan	Production	Horizontal w/ rotary drum	---	2,902	20,000	-0-
Outstate Michigan	Production	Horizontal (9000TPY)	---	-0-	252,000	-0-
Outstate Michigan	Production	Vertical (9000TPY)	---	-0-	-0-	443,290
Outstate Michigan	Production	Horizontal (2500TPY)	---	141,653	-0-	-0-
Outstate Michigan	Production	Horizontal (1000TPY)	---	33,226	-0-	-0-
Central Michigan	Transportation	Rail	Outstate retailers	2,902	-0-	-0-
Central Michigan	Transportation	Truck	Farms	-0-	20,000	-0-
Outstate processors	Transportation	Truck	Satellite outlets	-0-	126,000	221,645
Outstate processors	Transportation	Applicators	Farms	174,879	126,000	221,645
Outstate Michigan	Retailing	---	---	2,902	-0-	-0-

Table A-30. (cont'd.)

Originating location	Activity	Type	Terminating location	Product tons per year		
				1970 actual	Constrained optimum	Optimum
Outstate retailers	Transportation	Applicators	Farms	2,902	-0-	-0-
Satellite outlets	Product handling	---	---	-0-	126,000	221,645
Satellite outlets	Transportation	Applicators	Farms	-0-	126,000	221,645
Farms	Application	---	---	177,781	272,000	443,290

Table A-31. Clear mixed liquid fertilizer product flow

Originating location	Activity	Type	Terminating location	Product tons per year		
				1970 actual	Constrained optimum	Optimum
Outstate Michigan	Production	Hot process (3000TPY)	---	11,450	-0-	-0-
Outstate Michigan	Production	Cold blend (1000TPY)	---	7,633	-0-	-0-
Outstate processors	Transportation	Applicators	Farms	19,083	-0-	-0-
Farms	Application	---	---	19,083	-0-	-0-

APPENDIX B

Powdered Ammonium Sulfate for Direct Application: Data

Table B-1. Powdered ammonium sulfate for direct application: product use summary (in tons)

Product	Optimum	P_{AS}=\$2.00	P_{AS}=\$1.00
Total cost (in dollars)	48,297,763	48,278,751	47,963,336
Anhydrous ammonia	172,828	97,125	42,886
Aqueous ammonia	-0-	-0-	-0-
Nitric acid	-0-	-0-	-0-
Ammonium nitrate	-0-	-0-	-0-
Nonpressure nitrogen solution	-0-	-0-	-0-
Low pressure nitrogen solution	-0-	-0-	-0-
Nitrogen manufacturing solution	-0-	-0-	-0-
Urea	-0-	-0-	-0-
Powdered ammonium sulfate	-0-	296,321	508,629
Granular ammonium sulfate	-0-	-0-	-0-
Elemental phosphorous	-0-	-0-	-0-
White phosphoric acid	-0-	-0-	-0-
Green phosphoric acid	260,565	260,565	260,565
Superphosphoric acid	-0-	-0-	-0-
Ammonium polyphosphate liquid (10-34-0)	-0-	-0-	-0-
Ammonium polyphosphate liquid (11-37-0)	-0-	-0-	-0-
Normal superphosphate	-0-	-0-	-0-
Run-of-pile triple superphosphate	-0-	-0-	-0-
Granular triple superphosphate	-0-	-0-	-0-
Diammonium phosphate	-0-	-0-	-0-
Monoammonium phosphate	270,576	270,576	270,576
Rock phosphate	-0-	-0-	-0-
Run-of-mine potassium chloride	-0-	-0-	-0-
Standard potassium chloride	-0-	-0-	-0-
Granular potassium chloride	259,032	259,032	259,032
Coarse potassium chloride	-0-	-0-	-0-
Granulated mixed fertilizers	-0-	-0-	-0-
Bulk blended fertilizers	329,689	329,689	329,689
Custom blended fertilizers	113,600	113,600	113,600
Hot process clear mixed liquids	-0-	-0-	-0-
Cold process clear mixed liquids	-0-	-0-	-0-
Suspension liquids	-0-	-0-	-0-
N supplied	141,932	141,932	141,932
P_2O_5 supplied	140,650	140,650	140,650
K_2O supplied	155,441	155,441	155,441

Table B-2. Powdered ammonium sulfate for direct application: anhydrous ammonia product flow

Originating location	Activity	Type	Terminating location	Product tons per year		
				Optimum	P_{AS}=2.00	P_{AS}=1.00
Gulf Coast	Production	Centrifugal	---	42,886	42,886	42,886
Central Michigan	Production	Centrifugal	---	129,942	54,239	-0-
Central Michigan	Mfr's. storage	Cyrogenic	---	54,239	54,239	-0-
Gulf Coast	Transportation	Barge	Florida producers[1]	42,886	42,886	42,886
Central Michigan	Transportation	Truck	Farms	129,942	54,239	-0-
Farms	Application	---	---	129,942	54,239	-0-

[1]Monoammonium phosphate producers.

Table B-3. Powdered ammonium sulfate for direct application: ammonium sulfate product flow

Originating location	Activity	Type	Terminating location	Product tons per year		
				Optimum	P_{AS}=2.00	P_{AS}=1.00
Outstate retailers	Purchase	—	—	-0-	296,321	508,629
Outstate retailers	Retailing	Bulk	—	-0-	296,321	508,629
Outstate retailers	Storage	Bulk	—	-0-	-0-	212,309
Farms	Application	—	—	-0-	296,321	508,629

Table B-4. Powdered ammonium sulfate for direct application: green phosphoric acid product flow

Originating location	Activity	Type	Terminating location	Product tons per year		
				Optimum	P_{AS}=2.00	P_{AS}=1.00
Florida	Production	Wet process	---	260,565	260,565	260,565
Florida	Product transfer	On-site	Florida producers[1]	260,565	260,565	260,565

[1]Monoammonium phosphate producers.

Table B-5. Powdered ammonium sulfate for direct application: monoammonium phosphate product flow

Originating location	Activity	Type	Terminating location	Product tons per year		
				Optimum	P_{AS}=2.00	P_{AS}=1.00
Florida	Production	Slurry ammoniation	---	270,576	270,576	270,576
Florida	Mfr's. storage	Bulk	---	202,932	202,932	202,932
Florida	Transportation	Rail	Outstate processors[1]	270,576	270,576	270,576

[1]Dry blending fertilizer producers.

Table B-6. Powdered ammonium sulfate for direct application: granular potassium chloride product flow

Originating location	Activity	Type	Terminating location	Product tons per year		
				Optimum	P_{AS}=2.00	P_{AS}=1.00
Saskatoon	Production	Flotation	---	259,032	259,032	259,032
Saskatoon	Mfr's. storage	Bulk	---	129,535	129,535	129,535
Saskatoon	Transportation	Rail	Michigan terminal	86,319	86,319	86,319
Saskatoon	Transportation	Rail	Outstate processors[1]	172,713	172,713	172,713
Michigan terminal	Transportation	Truck	Farms	86,319	86,319	86,319
Farms	Application	---	---	86,319	86,319	86,319

[1]Dry blended fertilizer producers.

Table B-7. Powdered ammonium sulfate for direct application: bulk blended fertilizers product flow

Originating location	Activity	Type	Terminating location	Product tons per year		
				Optimum	P_{AS}=2.00	P_{AS}=1.00
Outstate Michigan	Production	Vertical (9000TPY)	---	443,290	443,290	443,290
Outstate processors	Transportation	Truck	Satellite outlets	221,645	221,645	221,645
Outstate processors	Transportation	Applicators	Farms	221,645	221,645	221,645
Satellite outlets	Product handling	---	---	221,645	221,645	221,645
Satellite outlets	Transportation	Applicators	Farms	221,645	221,645	221,645
Farms	Application	---	---	443,290	443,290	443,290
Bulk blend	Formulation	7-28-28	---	329,689	329,689	329,689
Custom blend	Formulation	10.6-42.55-10.85	---	113,600	113,600	113,600

APPENDIX C

Powdered Ammonium Sulfate for Granulation: Data

Table C-1. Powdered ammonium sulfate for granulation: product use summary (in tons)

Product	Optimum	P_{AS}=1.40	P_{AS}=0.70	P_{AS}=0.30
Total cost (in dollars)	48,297,763	48,296,875	48,151,800	47,991,378
Anhydrous ammonia	172,828	129,112	82,060	76,265
Aqueous ammonia	-0-	-0-	-0-	-0-
Nitric acid	-0-	-0-	-0-	-0-
Ammonium nitrate	-0-	-0-	-0-	-0-
Nonpressure nitrogen solution	-0-	-0-	-0-	-0-
Low pressure nitrogen solution	-0-	-0-	-0-	-0-
Nitrogen manufacturing solution	-0-	-0-	-0-	-0-
Urea	-0-	-0-	-0-	-0-
Powdered ammonium sulfate	-0-	190,068	396,300	420,168
Elemental phosphorous	-0-	16,490	34,382	36,452
White phosphoric acid	-0-	69,931	145,809	154,590
Green phosphoric acid	260,565	194,073	122,061	113,600
Superphosphoric acid	-0-	-0-	-0-	-0-
Ammonium polyphosphate liquid (10-34-0)	-0-	-0-	-0-	-0-
Ammonium polyphosphate liquid (11-37-0)	-0-	-0-	-0-	-0-
Normal superphosphate	-0-	-0-	-0-	-0-
Run-of-pile triple superphosphate	-0-	-0-	-0-	-0-
Granular triple superphosphate	-0-	-0-	-0-	-0-

Table C-1. (cont'd.)

Product	Optimum	P_{AS}=1.40	P_{AS}=0.70	P_{AS}=0.30
Diammonium phosphate	-0-	-0-	-0-	-0-
Monoammonium phosphate	270,576	201,530	126,751	118,033
Rock phosphate	-0-	-0-	-0-	-0-
Run-of-mine potassium chloride	-0-	-0-	-0-	-0-
Standard potassium chloride	-0-	-0-	-0-	-0-
Granular potassium chloride	259,032	259,006	259,117	259,032
Coarse potassium chloride	-0-	-0-	-0-	-0-
Granulated mixed fertilizers	-0-	179,309	373,868	396,385
Bulk blended fertilizers	329,689	374,243	107,246	219,189
Custom blended fertilizers	113,601	-0-	199,707	-0-
Hot process clear mixed liquids	-0-	-0-	-0-	-0-
Cold process clear mixed liquids	-0-	-0-	-0-	-0-
Suspension liquids	-0-	-0-	-0-	-0-
N supplied	141,932	141,932	141,932	141,932
P_2O_5 supplied	140,650	140,650	140,650	140,650
K_2O supplied	155,441	155,441	155,441	155,441

Table C-2. Powdered ammonium sulfate for granulation: anhydrous ammonia product flow

Originating location	Activity	Type	Terminating location	Product tons per year			
				Optimum	*P_{AS}=1.40	P_{AS}=0.70	P_{AS}=0.30
Gulf Coast	Production	Centrifugal	---	42,886	31,943	20,090	18,708
Central Michigan	Production	Centrifugal	---	129,942	97,169	61,970	57,557
Central Michigan	Mfr's. storage	Cyrogenic	---	54,239	29,709	-0-	-0-
Gulf Coast	Transportation	Barge	Florida producers[1]	42,886	31,943	20,090	18,708
Central Michigan	Product transfer	On-site	Michigan producers[1]	-0-	-0-	4,343	-0-
Central Michigan	Transportation	Truck	Farms	129,942	97,169	57,627	57,557
Farms	Application	---	---	129,942	97,169	57,627	57,557

[1]Monoammonium phosphate producers.

*P_{AS} = 'price of ammonium sulfate' in dollars per ton.

Table C-3. Powdered ammonium sulfate for granulation: urea product flow

Originating location	Activity	Type	Terminating location	Product tons per year			
				Optimum	*P_{AS}=1.40	P_{AS}=0.70	P_{AS}=0.30
Central Michigan	Production	Ammonium carbamate slurry	---	-0-	-0-	7,489	-0-
Central Michigan	Mfr's. storage	Bulk	---	-0-	-0-	5,617	-0-
Central Michigan	Transportation	Truck	Outstate processors[1]	-0-	-0-	7,489	-0-

[1]Dry blended fertilizer producers.

*P_{AS} = 'price of ammonium sulfate' in dollars per ton.

Table C-4. Powdered ammonium sulfate for granulation: ammonium sulfate product flow

Originating location	Activity	Type	Terminating location	Product tons per year			
				Optimum	*P_{AS}=1.40	P_{AS}=0.70	P_{AS}=0.30
Outstate processors	Purchase	Granulator	---	-0-	190,068	396,300	420,168

*P_{AS} = 'price of ammonium sulfate' in dollars per ton.

Table C-5. Powdered ammonium sulfate for granulation: elemental phosphorous product flow

Originating location	Activity	Type	Terminating location	Product tons per year			
				Optimum	*P_{AS}=1.40	P_{AS}=0.70	P_{AS}=0.30
Florida	Production	Electric furnace	---	-0-	16,490	34,382	36,452
Florida	Transportation	Rail	Michigan producers[1]	-0-	16,490	34,382	36,452

[1]White phosphoric acid producers.

*P_{AS} = 'price of ammonium sulfate' in dollars per ton.

Table C-6. Powdered ammonium sulfate for granulation: white phosphoric acid product flow

Originating location	Activity	Type	Terminating location	Product tons per year			
				Optimum	*P_{AS}=1.40	P_{AS}=0.70	P_{AS}=0.30
Central Michigan	Production	Furnace process	---	-0-	69,931	145,809	154,590
Central Michigan	Product transfer	On-site	Michigan producer[1]	-0-	69,931	145,809	154,590

[1]Monoammonium phosphate producer.

*P_{AS} = 'price of ammonium sulfate' in dollars per ton.

Table C-7. Powdered ammonium sulfate for granulation: green phosphoric acid product flow

Originating location	Activity	Type	Terminating location	Product tons per year			
				Optimum	*P_{AS}=1.40	P_{AS}=0.70	P_{AS}=0.30
Florida	Production	Wet process	—	260,565	194,073	122,061	113,666
Florida	Product transfer	On-site	Florida producers[1]	260,565	194,073	122,061	113,666

[1]Monoammonium phosphate producers.

*P_{AS} = 'price of ammonium sulfate' in dollars per ton.

Table C-8. Powdered ammonium sulfate for granulation: monoammonium phosphate product flow

Originating location	Activity	Type	Terminating location	Product tons per year			
				Optimum	*P_{AS}=1.40	P_{AS}=0.70	P_{AS}=0.30
Florida	Production	Slurry ammoniation	—	270,576	201,530	126,751	118,033
Florida	Mfr's. storage	Bulk	—	202,932	151,148	95,063	88,525
Florida	Transportation	Rail	Outstate processors[1]	270,576	201,530	126,751	118,033

[1]Dry blended fertilizer producers.

*P_{AS} = 'price of ammonium sulfate' in dollars per ton.

Table C-9. Powdered ammonium sulfate for granulation: granular potassium chloride product flow

Originating location	Activity	Type	Terminating location	Product tons per year			
				Optimum	*P_{AS}=1.40	P_{AS}=0.70	P_{AS}=0.30
Saskatoon	Production	Flotation	---	259,032	259,006	259,117	259,032
Saskatoon	Mfr's. storage	Bulk	---	129,535	129,535	129,535	129,535
Saskatoon	Transportation	Rail	Michigan terminal	86,319	86,293	86,404	157,876
Saskatoon	Transportation	Rail	Outstate processors[1]	172,713	172,713	172,713	101,156
Michigan terminal	Transportation	Truck	Farms	86,319	86,293	86,404	157,876
Farms	Application	---	---	86,319	86,293	86,404	157,876

[1]Dry blended fertilizer producers.

*P_{AS} = 'price of ammonium sulfate' in dollars per ton.

Table C-10. Powdered ammonium sulfate for granulation: granulated mixed fertilizer product flow

Originating location	Activity	Type	Terminating location	Product tons per year			
				Optimum	*P_{AS}=1.40	P_{AS}=0.70	P_{AS}=0.30
Central Michigan	Production	TVA continuous	---	-0-	179,309	373,868	396,385
Central Michigan	Mfr's. storage	Bulk	---	-0-	134,482	280,401	297,289
Central Michigan	Transportation	Truck	Farms	-0-	179,309	373,868	396,385
Farms	Application	---	---	-0-	179,309	373,868	396,385

*P_{AS} = 'price of ammonium sulfate' in dollars per ton.

Table C-11. Powdered ammonium sulfate for granulation: bulk blended fertilizers product flow

Originating location	Activity	Type	Terminating location	Product tons per year			
				Optimum	*P_{AS}=1.40	P_{AS}=0.70	P_{AS}=0.30
Outstate Michigan	Production	Vertical (9000TPY)	---	443,290	374,243	306,953	219,189
Outstate processors	Transportation	Truck	Satellite outlets	221,645	187,121	153,476	109,594
Outstate processors	Transportation	Applicators	Farms	221,645	187,122	153,477	109,595
Satellite outlets	Product handling	---	---	221,645	187,121	153,476	109,594
Satellite outlets	Transportation	Applicators	Farms	221,645	187,121	153,476	109,594
Farms	Application	---	---	443,290	374,243	306,953	219,189
Bulk blend	Formulation	7-28-28	---	329,689	374,243	107,246	219,189
Custom blend	Formulation	10.6-42.55-10.85	---	113,600	-0-	-0-	-0-
Custom blend	Formulation	6.15-17.95-37.0	---	-0-	-0-	199,707	-0-

*P_{AS} = 'price of ammonium sulfate' in dollars per ton.

APPENDIX D

Granular Ammonium Sulfate for Bulk Blending: Data

Table D-1. Granular ammonium sulfate for bulk blending

Product	Optimum	P_{AS}=12.50	P_{AS}=11.50	P_{AS}=1.50	P_{AS}=1.00
Total cost (in dollars	48,297,763	48,296,046	48,279,035	48,004,973	47,900,488
Anhydrous ammonia	172,828	167,167	162,743	118,785	97,141
Aqueous ammonia	-0-	-0-	-0-	-0-	-0-
Nitric acid	-0-	-0-	-0-	-0-	-0-
Ammonium nitrate	-0-	-0-	-0-	-0-	-0-
Nonpressure nitrogen solution	-0-	-0-	-0-	-0-	-0-
Low pressure nitrogen solution	-0-	-0-	-0-	-0-	-0-
Nitrogen manufacturing solution	-0-	-0-	-0-	-0-	-0-
Urea	-0-	-0-	-0-	-0-	-0-
Granular ammonium sulfate	-0-	13,054	23,042	193,116	279,448
Elemental phosphorous	-0-	-0-	-0-	-0-	-0-
White phosphoric acid	-0-	-0-	-0-	-0-	-0-
Green phosphoric acid	260,565	260,802	260,876	260,870	260,936
Superphosphoric acid	-0-	-0-	-0-	-0-	-0-
Ammonium polyphosphate liquid (10-34-0)	-0-	-0-	-0-	-0-	-0-
Ammonium polyphosphate liquid (11-37-0)	-0-	-0-	-0-	-0-	-0-
Normal superphosphate	-0-	-0-	-0-	-0-	-0-
Run-of-pile triple superphosphate	-0-	-0-	-0-	-0-	-0-
Granular triple superphosphate	-0-	-0-	-0-	-0-	-0-

Table D-1. (cont'd.)

Product	Optimum	P_{AS}=12.50	P_{AS}=11.50	P_{AS}=1.50	P_{AS}=1.00
Diammonium phosphate	-0-	-0-	-0-	-0-	-0-
Monoammonium phosphate	270,576	270,823	270,900	270,893	270,961
Rock phosphate	-0-	-0-	-0-	-0-	-0-
Run-of-mine potassium chloride	-0-	-0-	-0-	-0-	-0-
Standard potassium chloride	-0-	-0-	-0-	-0-	-0-
Granular potassium chloride	259,032	259,108	259,096	259,068	259,117
Coarse potassium chloride	-0-	-0-	-0-	-0-	-0-
Granulated mixed fertilizers	-0-	-0-	-0-	-0-	-0-
Bulk blended fertilizers	329,689	-0-	-0-	-0-	-0-
Bustom blended fertilizers	113,601	456,590	553,039	723,078	809,527
Hot process clear mixed liquids	-0-	-0-	-0-	-0-	-0-
Cold process clear mixed liquids	-0-	-0-	-0-	-0-	-0-
Suspension liquids	-0-	-0-	-0-	-0-	-0-
N supplied	141,932	141,932	141,932	141,932	141,932
P_2O_5 supplied	140,650	140,650	140,650	140,650	140,650
K_2O supplied	155,441	155,441	155,441	155,441	155,441

Table D-2. Granular ammonium sulfate for bulk blending: anhydrous ammonia product flow

Originating location	Activity	Type	Terminating location	Product tons per year				
				Optimum	*P_{AS}=12.50	P_{AS}=11.50	P_{AS}=1.50	P_{AS}=1.00
Gulf Coast	Production	Centrifugal	---	42,886	42,925	42,938	42,937	42,947
Central Michigan	Production	Centrifugal	---	129,942	124,242	119,805	75,849	54,194
Central Michigan	Mfr's. storage	Cyrogenic	---	54,239	54,210	54,201	54,202	54,194
Gulf Coast	Transportation	Barge	Florida producers[1]	42,886	42,925	42,938	42,937	42,947
Central Michigan	Transportation	Truck	Farms	129,942	124,242	119,805	75,849	54,194
Farms	Application	---	---	129,942	124,242	119,805	75,849	54,194

[1]Monoammonium phosphate producers.

*P_{AS} = 'price of ammonium sulfate' in dollars per ton.

Table D-3. Granular ammonium sulfate for bulk blending: ammonium sulfate product flow

Originating location	Activity	Type	Terminating location	Product tons per year				
				Optimum	*P_{AS}=12.50	P_{AS}=11.50	P_{AS}=1.50	P_{AS}=1.00
Outstate processors	Purchase	Bulk blenders	---	-0-	13,054	23,043	193,116	279,448

*P_{AS} = 'price of ammonium sulfate' in dollars per ton.

Table D-4. Granular ammonium sulfate for bulk blending: green phosphoric acid product flow

Originating location	Activity	Type	Terminating location	Product tons per year				
				Optimum	*P_{AS}=12.50	P_{AS}=11.50	P_{AS}=1.50	P_{AS}=1.00
Florida	Production	Wet process	---	260,565	260,802	260,876	260,870	260,936
Florida	Product transfer	On-site	Florida producers[1]	260,565	260,802	260,876	260,870	260,936

[1]Monoammonium phosphate producers.

*P_{AS} = 'price of ammonium sulfate' in dollars per ton.

Table D-5. Granular ammonium sulfate for bulk blending: monoammonium phosphate product flow

Originating location	Activity	Type	Terminating location	Product tons per year				
				Optimum	*P_{AS}=12.50	P_{AS}=11.50	P_{AS}=1.50	P_{AS}=1.00
Florida	Production	Slurry ammoniation	---	270,576	270,823	270,900	270,893	270,961
Florida	Mfr's. storage	Bulk	---	202,932	203,117	203,175	203,170	203,221
Florida	Transportation	Rail	Outstate processors[1]	270,576	270,823	270,900	270,893	270,961

[1]Dry blended fertilizer producers.

*P_{AS} = 'price of ammonium sulfate' in dollars per ton.

Table D-6. Granular ammonium sulfate for bulk blending: granular potassium chloride product flow

Originating location	Activity	Type	Terminating location	Product tons per year				
				Optimum	*P_{AS}=12.50	P_{AS}=11.50	P_{AS}=1.50	P_{AS}=1.00
Saskatoon	Production	Flotation	—	259,032	259,108	259,096	259,068	259,117
Saskatoon	Mfr's. storage	Bulk	—	129,535	129,535	194,322	194,301	194,338
Saskatoon	Transportation	Rail	Michigan terminal	86,319	86,395	-0-	-0-	-0-
Saskatoon	Transportation	Rail	Outstate processors[1]	172,713	172,713	259,096	259,068	259,117
Michigan terminal	Transportation	Truck	Farms	86,319	86,395	-0-	-0-	-0-
Farms	Application	—	—	86,319	86,395	-0-	-0-	-0-

[1]Dry blended fertilizer producers.

*P_{AS} = 'price of ammonium sulfate' in dollars per ton.

Table D-7. Granular ammonium sulfate for bulk blending: bulk blended fertilizers product flow

Originating location	Activity	Type	Terminating location	Product tons per year				
				Optimum	*P_{AS}=12.50	P_{AS}=11.50	P_{AS}=1.50	P_{AS}=1.00
Outstate Michigan	Production	Vertical (9000TPY)	---	443,290	456,590	553,039	723,078	809,527
Outstate processors	Transportation	Truck	Satellite outlets	221,645	228,295	276,519	361,539	404,763
Outstate processors	Transportation	Applicators	Farms	221,645	228,295	276,520	361,539	404,764
Satellite outlets	Product handling	---	---	221,645	228,295	276,519	361,539	404,763
Farms	Application	---	---	443,290	456,590	553,039	723,078	809,527
Bulk blend	Formulation	7-28-28	---	329,684	-0-	-0-	-0-	-0-
Custom blend	Formulation	6.65-17.9-35.7	---	-0-	217,562	384,049	435,409	401,074
Custom blend	Formulation	10.6-42.55-10.85	---	113,600	239,028	168,990	-0-	-0-
Custom blend	Formulation	17.6-21.8-0	---	-0-	-0-	-0-	287,669	261,654
Custom blend	Formulation	16.8-8.05-8.35	---	-0-	-0-	-0-	-0-	146,799

*P_{AS} = 'price of ammonium sulfate' in dollars per ton.

APPENDIX E

Substitution of White Phosphoric Acid for Green Phosphoric Acid: Data

Table E-1. Substitution of white phosphoric acid for green phosphoric acid: product summary (in tons)[1]

Product	*P_E=4.00 P_E=4.00	P_E=1.2545 P_E=3.2970	P_E=0.6131 P_E=2.5756	P_E=0.3700 P_E=2.4101	P_E=0.2686 P_E=2.3087	P_E=0.2259 P_E=2.2677
Total cost (sulfuric acid = $12/ton)	48,175,194	48,154,522	48,056,229	47,995,388	47,957,330	47,927,586
Total cost (sulfuric acid = $16/ton)	49,707,317	49,627,351	49,568,574	49,527,133	49,489,075	49,460,496
Anhydrous ammonia	172,828	172,764	172,852	172,852	172,852	172,763
Aqueous ammonia	-0-	-0-	-0-	-0-	-0-	-0-
Nitric acid	-0-	-0-	-0-	-0-	-0-	-0-
Ammonium nitrate	-0-	-0-	-0-	-0-	-0-	-0-
Nonpressure nitrogen solution	-0-	-0-	-0-	-0-	-0-	-0-
Low pressure nitrogen solution	-0-	-0-	-0-	-0-	-0-	-0-
Nitrogen manufacturing solution	-0-	-0-	-0-	-0-	-0-	-0-
Urea	-0-	-0-	2,124	2,124	2,124	-0-
Granular ammonium sulfate	-0-	-0-	-0-	-0-	-0-	-0-
Elemental phosphorous	-0-	15,660	20,480	30,716	56,982	61,422
White phosphoric acid	-0-	66,413	86,852	130,264	241,655	260,485
Green phosphoric acid	260,565	194,073	173,649	130,236	18,846	-0-
Superphosphoric acid	-0-	-0-	-0-	-0-	-0-	-0-
Ammonium polyphosphate liquid (10-34-0)	-0-	-0-	-0-	-0-	-0-	-0-

Table E-1. (cont'd.)

Product	*P_E=4.00 P_E=4.00	P_E=1.2545 P_E=3.2970	P_E=0.6131 P_E=2.5756	P_E=0.3700 P_E=2.4101	P_E=0.2686 P_E=2.3087	P_E=0.2259 P_E=2.2677
Ammonium polyphosphate liquid (11-37-0)	-0-	-0-	-0-	-0-	-0-	-0-
Normal superphosphate	-0-	-0-	-0-	-0-	-0-	-0-
Run-of-pile triple superphosphate	-0-	-0-	-0-	-0-	-0-	-0-
Granular triple superphosphate	-0-	-0-	-0-	-0-	-0-	-0-
Diammonium phosphate	-0-	-0-	-0-	-0-	-0-	-0-
Monoammonium phosphate	270,576	270,495	270,510	270,509	270,510	270,494
Run-of-mine potassium chloride	-0-	-0-	-0-	-0-	-0-	-0-
Run-of-mine potassium chloride	-0-	-0-	-0-	-0-	-0-	-0-
Standard potassium chloride	-0-	-0-	0-	-0-	-0-	-0-
Granular potassium chloride	259,032	259,006	259,037	259,037	259,037	259,012
Coarse potassium chloride	-0-	-0-	-0-	-0-	-0-	-0-
Granulated mixed fertilizers	-0-	-0-	-0-	0-0	-0-	-0-
Bulk blended fertilizers	329,689	374,243	298,515	298,515	298,515	334,857
Custom blended fertilizers	113,600	-0-	56,643	56,643	56,643	-0-
Hot process clear mixed liquids	-0-	-0-	-0-	-0-	-0-	-0-
Cold process clear mixed liquids	-0-	-0-	-0-	-0-	-0-	-0-
Suspension liquids	-0-	-0-	-0-	-0-	-0-	-0-

Table E-1. (cont'd.)

Product	*P_E=4.00 P_E=4.00	P_E=1.2545 P_E=3.2970	P_E=0.6131 P_E=2.5756	P_E=0.3700 P_E=2.4101	P_E=0.2686 P_E=2.3087	P_E=0.2259 P_E=2.2677
N supplied	141,932	141,932	141,932	141,932	141,932	141,932
P_2O_5 supplied	140,650	140,650	140,650	140,650	140,650	140,650
K_2O supplied	155,441	155,441	155,441	155,441	155,441	155,441
Sulfuric acid	383,031	285,288	255,264	191,488	27,704	-0-
Electricity (in 1000 KWH)	-0-	191,421	250,330	375,456	696,512	750,786

[1]The first row of electricity prices corresponds to sulfuric acid priced at $12 per ton, while the second row corresponds to sulfuric acid priced at $16 per ton. The data in the column applies to $12 sulfuric acid and the indicated electrical rate, as well as to $16 sulfuric acid and the higher electrical rate.

*P_E = 'price of electricity' in dollars per 1000 KWH.

Table E-2. Substitution of white phosphoric acid for green phosphoric acid: anhydrous ammonia product flow

Originating location	Activity	Type	Terminating location	Product tons per year[1] *P_E=4.00 P_E=4.00	P_E=1.2545 P_E=3.2970	P_E=0.6131 P_E=2.5756
Gulf Coast	Production	Centrifugal	---	42,886	31,943	28,581
Central Michigan	Production	Centrifugal	---	129,942	140,821	144,271
Central Michigan	Mfr's. storage	Cyrogenic	---	54,239	62,429	64,073
Gulf Coast	Transportation	Barge	Florida producers[2]	42,886	31,943	28,581
Central Michigan	Product transfer	On-site	Michigan producers[2]	-0-	10,931	15,527
Central Michigan	Transportation	Truck	Farms	29,942	129,890	128,744
Farms	Application	---	---	129,942	129,890	128,744

[1]The first row of electricity prices corresponds to sulfuric acid priced at $12 per ton, while the second row corresponds to sulfuric acid priced at $16 per ton. The data in the column applies to $12 sulfuric acid and the indicated electrical rate, as well as to $16 sulfuric acid and the higher electrical rate.

[2]Monoammonium phosphate producers.

*P_E = 'price of electricity' in dollars per 1000 KWH.

Table E-2. (cont'd.)

Originating location	Activity	Type	Terminating location	Product tons per year[1] *P_E=0.3700 P_E=2.4101	P_E=0.2686 P_E=2.3087	P_E=0.2259 P_E=2.2677
Gulf Coast	Production	Centrifugal	---	21,436	3,102	-0-
Central Michigan	Production	Centrifugal	---	151,416	169,750	172,763
Central Michigan	Mfr's. storage	Cyrogenic	---	64,073	64,073	64,945
Gulf Coast	Transportation	Barge	Florida producers[2]	21,436	3,102	-0-
Central Michigan	Product transfer	On-site	Michigan producers[2]	22,672	41,006	42,873
Central Michigan	Transportation	Truck	Farms	128,744	128,744	129,890
Farms	Application	---	---	128,744	128,744	129,890

[1]The first row of electricity prices corresponds to sulfuric acid priced at $12 per ton, while the second row corresponds to sulfuric acid priced at $16 per ton. The data in the column applies to $12 sulfuric acid and the indicated electrical rate, as well as to $16 sulfuric acid and the higher electrical rate.

[2]Monoammonium phosphate producers.

*P_E = 'price of electricity' in dollars per 1000 KWH.

Table E-3. Substitution of white phosphoric acid for green phosphoric acid: urea product flow

Originating location	Activity	Type	Terminating location	Product tons per year[1] *P_E=4.00 P_E=4.00	P_E=1.2545 P_E=3.2970	P_E=0.6131 P_E=2.5756
Central Michigan	Production	Ammonium carbamate slurry	---	-0-	-0-	2,124
Central Michigan	Storage	Bulk	---	-0-	-0-	1,593
Central Michigan	Transportation	Truck	Outstate processors[2]	-0-	-0-	2,124

[1]The first row of electricity prices corresponds to sulfuric acid priced at $12 per ton, while the second row corresponds to sulfuric acid priced at $16 per ton. The data in the column applies to $12 sulfuric acid and the indicated electrical rate, as well as to $16 sulfuric acid and the higher electrical rate.

[2]Dry blended fertilizer producers.

*P_E = 'price of electricity' in dollars per 1000 KWH.

Table E-3. (cont'd.)

Originating location	Activity	Type	Terminating location	Product tons per year[1] *P_E=0.3700 P_E=2.4101	P_E=0.2686 P_E=2.3087	P_E=0.2259 P_E=2.2677
Central Michigan	Production	Ammonium carbamate slurry	---	2,124	2,124	-0-
Central Michigan	Storage	Bulk	---	1,593	1,593	-0-
Central Michigan	Transportation	Truck	Outstate processors[1]	2,124	2,124	-0-

[1]The first row of electricity prices corresponds to sulfuric acid priced at $12 per ton, while the second row corresponds to sulfuric acid priced at $16 per ton. The data in the column applies to $12 sulfuric acid and the indicated electrical rate, as well as to $16 sulfuric acid and the higher electrical rate.

[2]Dry blended fertilizer producers.

*P_E = 'price of electricity' in dollars per 1000 KWH.

Table E-4. Substitution of white phosphoric acid for green phosphoric acid: elemental phosphorous product flow

Originating location	Activity	Type	Terminating location	Product tons per year[1]		
				*P_E=4.00 P_E=4.00	P_E=1.2545 P_E=3.2970	P_E=0.6131 P_E=2.5756
Florida	Production	Electric furnace	---	-0-	15,660	20,480
Florida	Transportation	Rail	Michigan producers[2]	-0-	15,660	20,480

[1]The first row of electricity prices corresponds to sulfuric acid priced at $12 per ton, while the second row corresponds to sulfuric acid priced at $16 per ton. The data in the column applies to $12 sulfuric acid and the indicated electrical rate, as well as to $16 sulfuric acid and the higher electrical rate.

[2]White phosphoric acid producers.

*P_E = 'price of electricity' in dollars per 1000 KWH.

Table E-4. (cont'd.)

Originating location	Activity	Type	Terminating location	Product tons per year[1] *P_E=0.3700 P_E=2.4101	P_E=0.2686 P_E=2.3087	P_E=0.2259 P_E=2.2677
Florida	Production	Electric furnace	---	30,716	56,982	61,422
Florida	Transportation	Rail	Michigan producers[2]	30,716	56,982	61,422

[1]The first row of electricity prices corresponds to sulfuric acid priced at $12 per ton, while the second row corresponds to sulfuric acid priced at $16 per ton. The data in the column applies to $12 sulfuric acid and the indicated electrical rate, as well as to $16 sulfuric acid and the higher electrical rate.

[2]White phosphoric acid producers.

*P_E = 'price of electricity' in dollars per 1000 KWH.

Table E-5. Substitution of white phosphoric acid for green phosphoric acid: white phosphoric acid product flow

Originating location	Activity	Type	Terminating location	Product tons per year[1]		
				*P_E=4.00 P_E=4.00	P_E=1.2545 P_E=3.2970	P_E=0.6131 P_E=2.5756
Central Michigan	Production	Furnace process	---	-0-	66,413	86,852
Central Michigan	Product transfer	On-site	Michigan producers[2]	-0-	66,413	86,852

[1]The first row of electricity prices corresponds to sulfuric acid priced at $12 per ton, while the second row corresponds to sulfuric acid priced at $16 per ton. The data in the column applies to $12 sulfuric acid and the indicated electrical rate, as well as to $16 sulfuric acid and the higher electrical rate.

[2]Monoammonium phosphate producers.

*P_E = 'price of electricity' in dollars per 1000 KWH.

Table E-5. (cont'd.)

Originating location	Activity	Type	Terminating location	Product tons per year[1] *P_E=0.3700 P_E=2.4101	P_E=0.2686 P_E=2.3087	P_E=0.2259 P_E=2.2677
Central Michigan	Production	Furnace process	---	130,264	241,655	260,485
Central Michigan	Product transfer	On-site	Michigan producers[2]	130,264	241,655	260,485

[1]The first row of electricity prices corresponds to sulfuric acid priced at $12 per ton, while the second row corresponds to sulfuric acid priced at $16 per ton. The data in the column applies to $12 sulfuric acid and the indicated electrical rate, as well as to $16 sulfuric acid and the higher electrical rate.

[2]Monoammonium phosphate producers.

*P_E = 'price of electricity' in dollars per 1000 KWH.

Table E-6. Substitution of white phosphoric acid for green phosphoric acid: green phosphoric acid product flow

Originating location	Activity	Type	Terminating location	Product tons per year[1]		
				*P_E=4.00 P_E=4.00	P_E=1.2545 P_E=3.2970	P_E=0.6131 P_E=2.5756
Florida	Production	Wet process	---	260,565	194,073	173,649
Florida	Product transfer	On-site	Florida producers[2]	260,565	194,073	173,649

[1]The first row of electricity prices corresponds to sulfuric acid priced at $12 per ton, while the second row corresponds to sulfuric acid priced at $16 per ton. The data in the column applies to $12 sulfuric acid and the indicated electrical rate, as well as to $16 sulfuric acid and the higher electrical rate.

[2]Monoammonium phosphate producers.

*P_E = 'price of electricity' in dollars per 1000 KWH.

Table E-6. (cont'd.)

Originating location	Activity	Type	Terminating location	Product tons per year[1]		
				*P_E=0.3700 P_E=2.4101	P_E=0.2686 P_E=2.3087	P_E=0.2259 P_E=2.2677
Florida	Production	Wet process	---	130,236	18,846	-0-
Florida	Product transfer	On-site	Florida producers[2]	130,236	18,846	-0-

[1]The first row of electricity prices corresponds to sulfuric acid priced at $12 per ton, while the second row corresponds to sulfuric acid priced at $16 per ton. The data in the column applies to $12 sulfuric acid and the indicated electrical rate, as well as to $16 sulfuric acid and the higher electrical rate.

[2]Monoammonium phosphate producers.

*P_E = 'price of electricity' in dollars per 1000 KWH.

Table E-7. Substitution of white phosphoric acid for green phosphoric acid: monoammonium phosphate product flow

Originating location	Activity	Type	Terminating location	Product tons per year[1] *P_E=4.00 P_E=4.00	P_E=1.2545 P_E=3.2970	P_E=0.6131 P_E=2.5756
Florida	Production	Slurry ammoniation	---	270,576	201,530	180,321
Central Michigan	Production	Slurry ammoniation	---	-0-	68,965	90,189
Florida	Mfr's. storage	Bulk	---	202,932	151,148	135,240
Central Michigan	Storage	Bulk	---	-0-	-0-	-0-
Florida	Transportation	Rail	Outstate processors[2]	270,576	201,530	180,321
Central Michigan	Product transfer	On-site	Michigan producers[2]	-0-	-0-	-0-

[1]The first row of electricity prices corresponds to sulfuric acid priced at $12 per ton, while the second row corresponds to sulfuric acid priced at $16 per ton. The data in the column applies to $12 sulfuric acid and the indicated electrical rate, as well as to $16 sulfuric acid and the higher electrical rate.

[2]Dry blended fertilizer producers.

*P_E = 'price of electricity' in dollars per 1000 KWH.

Table E-7. (cont'd.)

Originating location	Activity	Type	Terminating location	Product tons per year[1] *P_E=4.00 P_E=4.00	P_E=1.2545 P_E=3.2970	P_E=0.6131 P_E=2.5756
Central Michigan	Transportation	Truck	Farm	-0-	68,965	90,189
Farms	Application	---	---	-0-	68,965	90,189

[1]The first row of electricity prices corresponds to sulfuric acid priced at $12 per ton, while the second row corresponds to sulfuric acid priced at $16 per ton. The data in the column applies to $12 sulfuric acid and the indicated electrical rate, as well as to $16 sulfuric acid and the higher electrical rate.

*P_E = 'price of electricity' in dollars per 1000 KWH.

Table E-7. (cont'd.)

Originating location	Activity	Type	Terminating location	Product tons per year[1] *P_E=0.3700 P_E=2.4101	P_E=0.2686 P_E=2.3087	P_E=0.2259 P_E=2.2677
Florida	Production	Slurry ammoniation	---	135,240	19,570	-0-
Central Michigan	Production	Slurry ammoniation	---	135,269	250,940	270,494
Florida	Mfr's. storage	Bulk	---	135,240	19,570	-0-
Central Michigan	Storage	Bulk	---	-0-	115,670	135,240
Florida	Transportation	Rail	Outstate processors[2]	135,240	19,570	-0-
Central Michigan	Product transfer	On-site	Michigan producers[2]	45,080	160,750	180,321

[1]The first row of electricity prices corresponds to sulfuric acid priced at $12 per ton, while the second row corresponds to sulfuric acid priced at $16 per ton. The data in the column applies to $12 sulfuric acid and the indicated electrical rate, as well as to $16 sulfuric acid and the higher electrical rate.

[2]Dry blended fertilizer producers.

*P_E = 'price of electricity' in dollars per 1000 KWH.

Table E-7. (cont'd.)

Originating location	Activity	Type	Terminating location	Product tons per year[1] *P_E=0.3700 P_E=2.4101	P_E=0.2686 P_E=2.3087	P_E=0.2259 P_E=2.2677
Central Michigan	Transportation	Truck	Farm	90,189	90,189	90,173
Farms	Application	---	---	90,189	90,189	90,173

[1]The first row of electricity prices corresponds to sulfuric acid priced at $12 per ton, while the second row corresponds to sulfuric acid priced at $16 per ton. The data in the column applies to $12 sulfuric acid and the indicated electrical rate, as well as to $16 sulfuric acid and the higher electrical rate.

*P_E = 'price of electricity' in dollars per 1000 KWH.

Table E-8. Substitution of white phosphoric acid for green phosphoric acid: granular potassium chloride product flow

Originating location	Activity	Type	Terminating location	Product tons per year[1] *P_E=4.00 P_E=4.00	P_E=1.2545 P_E=3.2970	P_E=0.6131 P_E=2.5756
Saskatoon	Production	Flotation	---	259,032	259,006	259,037
Saskatoon	Mfr's. storage	Bulk	---	129,535	129,535	129,535
Saskatoon	Transportation	Rail	Michigan terminal	86,319	86,293	86,324
Saskatoon	Transportation	Rail	Michigan processors[2]	-0-	-0-	-0-
Saskatoon	Transportation	Rail	Outstate processors[2]	172,713	172,713	172,713
Central Michigan	Terminal storage	Bulk	---	-0-	-0-	-0-
Michigan terminal	Transportation	Truck	Farms	86,319	86,293	86,324
Farms	Application	---	---	86,319	86,293	86,324

[1]The first row of electricity prices corresponds to sulfuric acid priced at $12 per ton, while the second row corresponds to sulfuric acid priced at $16 per ton. The data in the column applies to $12 sulfuric acid and the indicated electrical rate, as well as to $16 sulfuric acid and the higher electrical rate.

[2]Dry blended fertilizer producers.

*P_E = 'price of electricity' in dollars per 1000 KWH.

Table E-8. (cont'd.)

Originating location	Activity	Type	Terminating location	Product tons per year[1] *P_E=0.3700 P_E=2.4101	P_E=0.2686 P_E=2.3087	P_E=0.2259 P_E=2.2677
Saskatoon	Production	Flotation	---	259,037	259,037	259,013
Saskatoon	Mfr's. storage	Bulk	---	129,535	129,535	115,902
Saskatoon	Transportation	Rail	Michigan terminal	86,324	86,324	104,476
Saskatoon	Transportation	Rail	Michigan processors[2]	38,634	137,765	154,537
Saskatoon	Transportation	Rail	Outstate processors[2]	134,079	34,949	-0-
Central Michigan	Terminal storage	Bulk	---	-0-	-0-	13,633
Michigan terminal	Transportation	Truck	Farms	86,324	86,324	104,476
Farms	Application	---	---	86,324	86,324	104,476

[1]The first row of electricity prices corresponds to sulfuric acid priced at $12 per ton, while the second row corresponds to sulfuric acid priced at $16 per ton. The data in the column applies to $12 sulfuric acid and the indicated electrical rate, as well as to $16 sulfuric acid and the higher electrical rate.

[2]Dry blended fertilizer producers.

*P_E = 'price of electricity' in dollars per 1000 KWH.

Table E-9. Substitution of white phosphoric acid for green phosphoric acid: bulk blended fertilizers product flow

Originating location	Activity	Type	Terminating location	Product tons per year[1] *P_E=4.00 P_E=4.00	P_E=1.2545 P_E=3.2970	P_E=0.6131 P_E=2.5756
Central Michigan	Production	Vertical	---	-0-	-0-	-0-
Outstate Michigan	Production	Vertical (9000TPY)	---	443,290	374,243	355,158
Central Michigan	Transportation	Truck	Farms	-0-	-0-	-0-
Outstate processors	Transportation	Truck	Satellite outlets	221,645	187,121	177,579
Outstate processors	Transportation	Applicators	Farms	221,645	187,122	177,579
Satellite outlets	Product handling	---	---	221,645	187,121	177,579
Satellite outlets	Transportation	Applicators	Farms	221,645	187,121	177,579

[1]The first row of electricity prices corresponds to sulfuric acid priced at $12 per ton, while the second row corresponds to sulfuric acid priced at $16 per ton. The data in the column applies to $12 sulfuric acid and the indicated electrical rate, as well as to $16 sulfuric acid and the higher electrical rate.

*P_E = 'price of electricity' in dollars per 1000 KWH.

Table E-9. (cont'd.)

Originating location	Activity	Type	Terminating location	Product tons per year[1] *P_E=0.3700 P_E=2.4101	P_E=0.2686 P_E=2.3087	P_E=0.2259 P_E=2.2677
Central Michigan	Production	Vertical	---	83,714	298,515	334,857
Outstate Michigan	Production	Vertical (9000TPY)	---	271,444	56,643	-0-
Central Michigan	Transportation	Truck	Farms	83,714	298,515	334,857
Outstate processors	Transportation	Truck	Satellite outlets	135,722	28,321	-0-
Outstate processors	Transportation	Applicators	Farms	135,722	28,322	-0-
Satellite outlets	Product handling	---	---	135,722	28,321	-0-
Satellite outlets	Transportation	Applicators	Farms	135,722	28,321	-0-

[1]The first row of electricity prices corresponds to sulfuric acid priced at $12 per ton, while the second row corresponds to sulfuric acid priced at $16 per ton. The data in the column applies to $12 sulfuric acid and the indicated electrical rate, as well as to $16 sulfuric acid and the higher electrical rate.

*P_E = 'price of electricity' in dollars per 1000 KWH.

Table E-9. (cont'd.)

Originating location	Activity	Type	Terminating location	Product tons per year[1]		
				*P_E=4.00 P_E=4.00	P_E=1.2545 P_E=3.2970	P_E=0.6131 P_E=2.5756
Farms	Application	---	---	443,290	374,243	355,158
Bulk blend	Formulation	7-28-28	---	329,689	374,243	298,515
Custom blend	Formulation	10.6-42.55-10.85	---	113,600	-0-	-0-
Custom blend	Formulation	6.15-17.95-37.0	---	-0-	-0-	56,643

[1]The first row of electricity prices corresponds to sulfuric acid priced at $12 per ton, while the second row corresponds to sulfuric acid priced at $16 per ton. The data in the column applies to $12 sulfuric acid and the indicated electrical rate, as well as to $16 sulfuric acid and the higher electrical rate.

*P_E = 'price of electricity' in dollars per 1000 KWH.

Table E-9. (cont'd.)

Originating location	Activity	Type	Terminating location	Product tons per year[1] *P_E=0.3700 P_E=2.4101	P_E=0.2686 P_E=2.3087	P_E=0.2259 P_E=2.2677
Farms	Application	---	---	355,158	355,158	334,857
Bulk blend	Formulation	7-28-28	---	298,515	298,515	334,857
Custom blend	Formulation	10.6-42.55-10.85	---	-0-	-0-	-0-
Custom blend	Formulation	6.15-17.95-37.0	---	56,643	56,643	-0-

[1]The first row of electricity prices corresponds to sulfuric acid priced at $12 per ton, while the second row corresponds to sulfuric acid priced at $16 per ton. The data in the column applies to $12 sulfuric acid and the indicated electrical rate, as well as to $16 sulfuric acid and the higher electrical rate.

*P_E = 'price of electricity' in dollars per 1000 KWH.

APPENDIX F

The Detrimental Effects of Sulfur Oxides

The Detrimental Effects of Sulfur Oxides

Society is becoming increasingly concerned with the detrimental effects of air pollution. Public opinion surveys indicate that dirty air is second only to poor public schools as a factor which drives young middle-income people from urban centers (Konheim, 1966, p. 552). Of all the pollutants, sulfur oxides are quite possibly the most costly. This appendix identifies many of the effects of the sulfur oxides.

Sulfur Oxides and Plants

Perhaps the most widespread effect of sulfur oxide pollution is the damage and destruction to vegetation. The most dramatic destruction of vegetation has taken place in the vicinity of smelters discharging large amounts of sulfur pollution. More than half a century ago, all of the major tree species were dead or dying in a five- to eight-mile radius from a smelter at Anaconda, Montana. In the vicinity of the Trail, British Columbia smelter, plant injury was observed as far as 52 miles from the smelter (The Effects of Air Pollution, 1966, p. 15).

Because most of the sulfur oxides are emitted in or near cities, the urban areas suffer more than do rural areas. More and more urban park superintendents are reporting that they are becoming increasingly limited in what they can grow. For example, in Central Park in New York, only one of the original 150 varieties of evergreens remains. Likewise, plant lovers and gardeners are realizing that they must limit

the types of plants they wish to cultivate (Konheim, 1966).

Generally, the plants most sensitive to sulfur pollution are those with succulent leaves having highly physiological activity, such as the grains, cotton, grapes, white pine, and apple. Plants with a heavy waxy leaf such as citrus and privet are more resistent to the sulfur oxides. High light intensity, high relative humidity, adequate moisture supply, and moderate temperature—ironically, all those things which cause a plant to thrive—predispose the plant to injury from the sulfur oxides.

The visible markings of sulfur pollution on vegetation frequently serve notice of damage. Acute exposure of broad-leafed plants to sulfur dioxide causes areas of the leaves to die, dry out, and usually bleach to a light tan or ivory color. Damage to grasses is similar except that the pattern is more a streaking along the blade, and frequently the tip is killed. In addition, a chronic type of injury may occur. The symptom of this injury, a yellowing of older leaves, is often described as early aging (The Effects of Air Pollution, 1966).

Sulfur Oxides and Materials

Sulfur oxides attack and destroy even the most durable materials. Steel corrodes two to four times faster in urban and industrial areas than in rural areas. When particulate matter is also present in the air, the corrosion rates multiply. For example, in the city of Pittsburgh during the period of 1926 to 1960, the corrosion of zinc went down by a factor of four as a direct result of a threefold reduction in sulfur pollution and a twofold reduction in dust. It has been estimated that one-third of the replacement cost of steel rails in England is attributable to sulfur pollution (The Effects of Air Pollution, 1966, p. 13).

Electrical equipment manufacturers are forced in some cases to use gold for electrical contacts because other materials corrode in sulfur atmospheres. At low levels, sulfur oxides can destroy paint pigments, and at slightly higher levels can attack fresh paint films to delay drying and to produce water sensitivity. In New York, marble ornamentation "crumbles between the fingers like a cube of sugar." Cleopatra's needle behind the Metropolitan Museum of Art has deteriorated more since its arrival in 1881 than it did during the more than three thousand years it spent in Egypt. In order to protect the ancient stone structures at The Cloisters, the Medieval Branch of the Metropolitan, wax coatings and other impregnations have been used for years.

Sulfur Oxides and Health

Sulfur oxides are equally destructive to human life. The most dramatic evidence lies in the disasters that have overtaken both large and small communities.

In December, 1930, a thick and stagnant smog enveloped a heavily industrialized section of the Meuse Valley, Belgium. By the third day many persons developed throat irritations, hoarseness, cough, and breathlessness. Some were nauseated; some died. The elderly and those already ill with respiratory disease or heart disease were most vulnerable.

In October, 1948, a similar fog blanketed the small industrial town of Donora, Pennsylvania (Schrenk, 1968). Before an afternoon rain cleared the smog away four days later, 6,000 persons of the town's 14,000 came down with one or more of an assortment of ills--cough, sore throat, chest constriction, headache, a burning sensation of the eyes, nasal discharge, and vomiting. Twenty persons died during a period

of the year when Donora could expect only two to die. Those present remarked on the heaviness of the fog and on the intensity of the familiar odor of sulfur dioxide whose source was largely in the industrial operations of the town.

At the beginning of December, 1952, the city of London went through a four-day period of still air during which pollution accumulated in a pea soup fog (The London Fog of 1952, 1954). Months later, a review of mortality statistics revealed that 4,000 excess deaths had occurred in the city during a seven-day period that began with the first day of fog. The illness rate during the period, especially the cardio-respiratory illness rate, increased to more than twice the normal rate for that time of year, and did not return to normal until two to three weeks later. In December, 1962, another episode of markedly increased levels of pollution in London accounted for 600 lives.

New York suffered from an episode in 1953 and again in 1966. On Thanksgiving Day, 1966, New Yorkers awoke finding their city shrouded in dirty yellow acrid smog, of such intensity to irritate eyes, nose, and throat. The city health department warned citizens with heart, lung, and upper respiratory ailments to stay indoors. That evening the air pollution index climbed to 60. Health officials believed that at 50, health is endangered if the level persists for 24 hours ("Pollution Alert," 1966, p. 66). The death rate rose to over 250 per day during a seven-day period, the first time that had happened in six years ("Air Pollution Can Kill," 1967, p. 85).[1]

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[1]The total number of deaths that were a direct result of the pollution is debated. While some argue that none were, others believe 150 is much more accurate.

The long-term effects of breathing sulfur oxides are even more alarming than the disasters. The most serious ills are the diseases that occur in the bronchial tree—from the common cold to lung cancer. Emphysema, the fastest growing cause of death in this country, is a progressive breakdown of air sacs in the lungs. Brought on by chronic infection or irritation of the bronchial tubes, it diminishes the ability of the lungs to transfer oxygen to the bloodstream and carbon dioxide from it.

Chronic bronchitis is defined as a chronic productive cough.[2] In Great Britain, nearly 10 percent of all deaths and more than 10 percent of all industrial absences because of illness are attributed to this disease. Using the British criteria, an investigation in this country found chronic bronchitis in 21 percent of men 40 to 59 years old. Sulfur dioxide may not be the only cause of this disease, however. Mortality varies with the pollution measures of population density, amount of fuel burned, settled dust, airborne dust and decreased visibility, as well as sulfur dioxide.

Deaths from lung cancer have been increasing rapidly in recent years. Although there are many causes of lung cancer, the disparity between rural and urban mortality rates points to air pollution. Even after full allowances for smoking habits, the death rate in large metropolitan areas is twice the rural rate.

In addition to these diseases, polluted air often aggravates bronchial asthma, increases the incidence of common colds, and in general weakens the respiratory system, making it vulnerable to other

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[2]The United States has not standardized the criteria for diagnosing chronic bronchitis. The above criteria is used in Great Britain.

diseases or viruses.

The danger of sulfur oxides is compounded if particulate matter accompanies it. Sulfur dioxide alone usually irritates only the upper respiratory tract. But if it is absorbed on particulates, it can be carried deep into the lung where it can easily injure delicate tissue. Sulfuric acid in the right particle size can also penetrate deep into the lung and damage tissue.

APPENDIX G

Environmental Protection Act of 1970

Environmental Protection Act of 1970

Public Act No. 127

House Bill No. 3055

An act to provide for actions for declaratory and equitable relief for protection of the air, water and other natural resources and the public trust therein; to prescribe the rights, duties and functions of the attorney general, any political subdivision of the state, any instrumentality or agency of the state or of a political subdivision thereof, any person, partnership, corporation, association, organization or other legal entity; and to provide for judicial proceedings relative thereto.

The People of the State of Michigan enact:

Sec. 1. This act, shall be known and may be cited as the "Thomas J. Anderson, Gordon Rockwell environmental protection act of 1970".

Sec. 2. (1) The attorney general, any political subdivision of the state, any instrumentality or agency of the state of a political subdivision thereof, any person, partnership, corporation, association, organization or other legal entity may maintain an action in the circuit court having jurisdiction where the alleged violation occurred or is likely to occur for declaratory and equitable relief against the state,

any political subdivision thereof, any instrumentality or agency of the state or of a political subdivision thereof, any person, partnership, corporation, association, organization or other legal entity for the protection of the air, water and other natural resources and the public trust therein from pollution, impairment or destruction.

(2) In granting relief provided by subsection (1) where there is involved a standard for pollution or for an anti-pollution device or procedure, fixed by rule or otherwise, by an instrumentality or agency of the state or a political subdivision thereof, the court may:

(a) Determine the validity, applicability and reasonableness of the standard.

(b) When a court finds a standard to be deficient, direct the adoption of a standard approved and specified by the court.

Sec. 2a. If the court has reasonable ground to doubt the solvency of the plaintiff or the plaintiff's ability to pay any cost or judgment which might be rendered against him in an action brought under this act the court may order the plaintiff to post a surety bond or cash not to exceed $500.00

Sec. 3. (1) When the plaintiff in the action has made a prima facie showing that the conduct of the defendant has, or is likely to pollute, impair or destroy the air, water or other natural resources or the public trust therein, the defendant may rebut the prima facie showing by the submission of evidence to the contrary. The defendant may also show, by way of an affirmative defense, that there is no feasible and prudent alternative to defendant's conduct and that such conduct is consistent with the promotion of the public

health, safety and welfare in light of the state's paramount concern for the protection of its natural resources from pollution, impairment or destruction. Except as to the affirmative defense, the principles of burden of proof and weight of the evidence generally applicable in civil actions in the circuit courts shall apply to actions brought under this act.

(2) The court may appoint a master or referee, who shall be a disinterested person and technically qualified, to take testimony and make a record and a report of his findings to the court in the action.

(3) Costs may be apportioned to the parties if the interests of justice require.

Sec. 4. (1) The court may grant temporary and permanent equitable relief, or may impose conditions on the defendant that are required to protect the air, water and other natural resources or the public trust therein from pollution, impairment or destruction.

(2) If administrative, licensing or other proceedings are required or available to determine the legality of the defendant's conduct, the court may remit the parties to such proceedings, which proceedings shall be conducted in accordance with and subject to the provisions of Act No. 306 of the Public Acts of 1969, being sections 24.201 to 24.313 of the Compiled Laws of 1948. In so remitting the court may grant temporary equitable relief where necessary for the protection of the air, water and other natural resources or the public trust therein from pollution, impairment or destruction. In so remitting the court shall retain jurisdiction of the action pending completion

thereof for the purpose of determining whether adequate protection from pollution, impairment or destruction has been afforded.

(3) Upon completion of such proceedings, the court shall adjudicate the impact of the defendant's conduct on the air, water or other natural resources and on the public trust therein in accordance with this act. In such adjudication the court may order that additional evidence be taken to the extent necessary to protect the rights recognized in this act.

(4) Where, as to any administrative, licensing or other proceeding, judicial review thereof is available, notwithstanding the provisions to the contrary of Act No. 306 of the Public Acts of 1969, pertaining to judicial review, the court originally taking jurisdiction shall maintain jurisdiction for purposes of judicial review.

Sec. 5. (1) Whenever administrative, licensing or other proceedings, and judicial review thereof are available by law, the agency or the court may permit the attorney general, any political subdivision of the state, any instrumentality or agency of the state or of a political subdivision thereof, any person, partnership, corporation, association, organization or other legal entity to intervene as a party on the filing of a pleading asserting that the proceeding or action for judicial review involves conduct which has, or which is likely to have, the effect of polluting, impairing or destroying the air, water or other natural resources or the public trust therein.

(2) In any such administrative, licensing or other proceedings, any in any judicial review thereof, any alleged pollution, impairment or destruction of the air, water or other natural resources or the public

trust therein, shall be determined, and no conduct shall be authorized or approved which does, or is likely to have such effect so long as there is a feasible and prudent alternative consistent with the reasonable requirements of the public health, safety and welfare.

(3) The doctrines of collateral estoppel and res judicata may be applied by the court to prevent multiplicity of suits.

Sec. 6. This act shall be supplementary to existing administrative and regulatory procedures provided by law.

Sec. 7. This act shall take effect October 1, 1970.

Ordered to take immediate effect.

Approved July 27, 1970.

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