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ENERGY USED FOR FERTILIZERS

by

Folke Dovring and Donald R. McDowell

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Department of Agricultural Economics  
University of Illinois at Urbana-Champaign  
305 Mumford Hall, Urbana, IL 61801



## Energy Used for Fertilizers

Folke Dovring and Donald R. McDowell

Abstract. { Energy used for fertilizers was estimated as the total of energy used directly in fertilizer factories and that used indirectly through the "backward linkages" in other industries, both those supplying fuels and electricity and those supplying other inputs to the fertilizer factories, and including energy use by and for the marketing of fertilizers. Direct energy data were borrowed from a 1978 survey by The Fertilizer Institute, and indirect energy figures were computed on the basis of an input-output study for 1967 from the University of Illinois Energy Research Group combined with other economic and energy statistics. } The results show average energy consumption for nitrogen fertilizers of 38,000 Btu per pound of N, for phosphate fertilizers of 12,500 Btu per pound of  $P_2O_5$ , and for potash fertilizers of 4,500 Btu per pound of  $K_2O$ . For nitrogen, the comprehensive estimate exceeds direct energy consumption per unit of nutrient by about one-third, while for phosphate and potash indirect energy consumption is larger than direct energy consumption. Because of the method of estimation, the estimates are likely to be on the low side and should remain usable

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Folke Dovring is professor of Land Economics and Donald R. McDowell is graduate research assistant, both in the Department of Agricultural Economics at the University of Illinois at Urbana-Champaign. The authors acknowledge helpful comments to an earlier draft of this paper by Mr. Charles H. Davis (Director of Chemical Development, Tennessee Valley Authority, Muscle Shoals, Alabama); Professor Maurice Green (Institute of Food and Agriculture, University of Florida, Gainesville); Professors Bruce Hannon and Robert Herendeen (both of the Energy Research Group, University of Illinois at Urbana-Champaign); Professor Robert G. Hoeft (Department of Agronomy and Cooperative Extension Service, University of Illinois at Urbana-Champaign), and Mr. William C. White (The Fertilizer Institute, Washington, D.C.). The study was made as part of Project Hatch 378 "Energy Analysis for Midwest Agriculture."



in the near future.

Purpose of the study is to estimate energy used for fertilizer production and marketing, both directly by fertilizer factories and indirectly by other industries supplying inputs (goods and services) to the making and delivery of fertilizers.

The reasons for this study are two: the need for comprehensive estimates as a basis for analysis of the relation between energy consumption and output in agriculture, and the lack of such comprehensive estimates to date.

Information is needed on the energy content of agriculture's various inputs, both because of the general energy problem of our time and because of the recently heightened interest in producing fuel from crops. This will require not only data on average energy consumption per unit of output (e.g., per bushel of corn) but also on energy consumption for additional output in the form of higher yield through higher fertilization rates -- the marginal rates of return to fertilizers. This is especially important in the case of nitrogen fertilizers, where high application rates may lead to rising rates of loss of nitrogen through leaching and denitrification,<sup>1/</sup> causing diminishing marginal returns to nitrogen.

Industry data on energy consumed in fertilizer factories usually relate to energy used directly, in producing, formulating, mixing and packaging of fertilizers and in mining of rock phosphate, potash, and sulfur. Indirectly used energy is in most cases not included in industry data on energy use. That is, industry data do not (or, not consistently) include the energy used indirectly at two levels: by the energy industries before they deliver fuel and electricity to fertilizer mining and



manufacturing, and by other industries for the non-energy goods they deliver to fertilizer mining and manufacturing. Results shown in this paper will illustrate the significance of these limitations on the industry data.

For information on indirect energy, we would either have to perform time consuming process analyses at several levels for each of the industries on which the fertilizer industries rely for supplies, or cite data from input-output studies. Input-output studies available to date relate to the fertilizer industry as a whole, without any distinction as to kind of fertilizer, and are also constrained by the industry classifications in the underlying statistics, as will be discussed below.

Procedure. Estimates will be based on a combination of industry data and input-output data. The former analysis combines data relating to several steps in the manufacturing processes, as described in some of the literature. The estimates of direct energy use obtained in this way are thereafter expanded by three sets of estimates obtained from the input-output statistics in the Energy Analysis Handbook (EAH): of indirect energy through the energy industries (in oil refineries, power plants, etc.), through other goods and services contributing to fertilizer production (investment goods, packaging, transportation, etc.), and through the marketing of fertilizers.<sup>2/</sup>

We now first pursue the indirect energy through the energy industries, separately for nitrogen, phosphate, and potash fertilizers. Coefficients of energy contents in the principal kinds of energy used are borrowed from a technical memorandum underlying the computations in the Energy Analysis

Handbook (EAH):<sup>3/</sup> as follows:

Distillate fuel oil, 5,825,000 Btu/barrel = 138,690 Btu/gallon

Natural gas, 1,035 Btu/cubic foot

Electricity, 3,413 Btu/kwh (= heat content of the current)

To include indirect energy used by the energy industries, the following energy-intensity coefficients (multipliers to obtain the sum of direct and indirect energy) are borrowed from the EAH (p. 48):<sup>2/</sup>

Petroleum refinery products, 1.2227

Utility gas, 1.1166

Electricity, 4.0683

The industry data also include quantities of imported steam, and small quantities of "other fuels," for which no indirect-energy coefficients were used in this analysis.<sup>4/</sup>

Nitrogen. By the procedures described, energy use was computed for the principal types of nitrogen fertilizers, as shown in Table 1.<sup>5/</sup> For ammonia production, the industry data include separate figures for fuel used as feedstock and for process energy. The feedstock is nearly all natural gas.





TABLE 1. Nitrogen fertilizers: Use of direct energy, and indirect energy through the energy industries. Btu per pound of N.

	1	2	3
Product	Direct	Indirect energy	Total, 1 + 2
Product	energy	through energy	Total, 1 + 2
		industries	
Ammonia <sup>a/</sup>	25,000	4,300	29,300
Urea, liquid <sup>b/</sup>	31,400	6,900	38,300
Urea, solid <sup>b/,c/</sup>	35,100	8,000	43,100
Ammonium nitrate, liquid <sup>b/</sup>	27,200	5,200	32,400
Ammonium nitrate, solid <sup>b/,c/</sup>	31,150	6,350	37,500

a/ Weighted average of ammonia from reciprocating plants and from centrifugal plants, using as weights the production quantities shown in the 1978 TFI survey.

b/ Includes energy used for ammonia consumed in production.

c/ Weighted average of prilled products and granulated products, using as weights the production data in the 1978 TFI survey.

Source: Computations based on data in the 1978 Energy Use Survey by The Fertilizer Institute, using EAH coefficients for computing indirect energy through the energy industries.

For comparison we may cite a British source,<sup>6/</sup> which has indirect energy in somewhat more restrictive definition than used in this study. It gives 24,300 Btu per pound of N in ammonia, 35,000 in ammonium nitrate, 38,000 in urea, and 38,000 - 41,000 Btu per pound of nitrogen in various compound fertilizers.

Phosphates. Data from The Fertilizer Institute survey of 1978 were complemented by detailed information on industrial processes from Davis and Blouin.<sup>7/</sup>



The energy requirement per pound of  $P_2O_5$  has varied a great deal and still does so if to a lesser extent than before. In the processing of rock phosphate, grinding versus wet beneficiating causes some variation. Sulfur from Frasch mining (now nearly the only sulfur mining technique used in the United States) requires about 7 million Btu per ton of sulfur,<sup>8/</sup> versus less than 1 million when sulfur is reclaimed from gases.<sup>9/</sup> The production of phosphoric acid by dry (electric-furnace) method (which is now virtually abandoned) took several times as much energy as the now prevailing wet method. Leaving out the latter difficulty as obsolete, we still have to note the proportions between mined and recovered sulfur which is continuously changing in the direction of recovered sulfur. The share of Frasch mining was about 75 percent in the late 1960s and has fallen since then, suggesting 50 percent as applicable at the end of the 1970s.<sup>10/</sup>

Results of the calculations are given in Table 2.

Table 2. Phosphate fertilizers: Use of direct energy, and indirect energy through the energy industries. Btu per pound of  $P_2O_5$

	1	2	3
		Indirect energy through energy industries	
Product	Direct energy		Total, 1 + 2
Concentrated superphosphate <sup>a/</sup>	2,900	2,800	5,700
Diammonium phosphate	4,100	3,700	7,800

<sup>a/</sup> Assuming 30 percent ground rock feed.

Sources: Computations based on data in the 1978 Energy Use Survey by The Fertilizer Institute and in Davis (1974) and Blouin and Davis (1975) as cited in Note 7, and using EAH coefficients for computing indirect energy through the energy industries.

The British data <sup>6/</sup> indicate 6,500 - 7,200 Btu per pound of  $P_2O_5$ , which includes some backward linkages (electricity is entered at 12,400 Btu per kWh).

Potash. Different mining techniques again cause large differences in energy requirement per unit of product. The newer technique appears as the more energy intensive (directly), but may have smaller backward linkages (in the cost of opening a mine), although quantitative data on the latter aspect are not available. <sup>11/</sup>

Data in The Fertilizer Institute's 1978 survey include a single set of figures for all potash products, leading to 920 Btu (direct) and 1650 Btu (direct plus indirect) per pound of  $K_2O$  (assuming 60 percent nutrient content). This is considerably lower than reported by TFI for 1972 <sup>12/</sup>.

The British data <sup>6/</sup> give 3,750-4150 Btu per pound of  $K_2O$ , averaging about 4,000.

Mixed fertilizers. The Census of Manufactures gives separate data on energy used directly in plants specializing on fertilizer mixing only (code 2872 in 1967, 2875 in 1972). The amounts given, with allowance for "other fuels" by their price, indicate 6.6 trillion Btu in 1967 and 6.3 trillion in 1972. With allowance for backward linkages in energy industries, we obtain close to 9.1 trillion Btu in both census years. This regards only those plants specializing in mixing only. Other plants (classified as "Fertilizers," code 2871 in 1967, and as "Phosphatic fertilizers," code 2874, in 1972, and "Nitrogenous Fertilizers," a new classification in 1972 with code 2873) also ship some mixed products, although the quantities appear minor. <sup>13/</sup> An estimate of 7 trillion Btu (direct) is given by Davis

and Blouin, based on TFI's 1972 data.<sup>14/</sup> Thus, mixing used about 1-1/2 percent of all energy (either direct or total) used by fertilizer production in 1967 and about 1 percent in 1972. The amount is applicable to only a fraction of the nitrogen fertilizers but to large parts of the phosphate and potash. The estimates given above would be raised by about 3 percent for phosphate and potash, 1 percent for nitrogen other than anhydrous ammonia, and none for the latter (including as a component, e.g., in ammonium phosphate, which is compound rather than mixed -- the formulation energy is charged to the phosphate).

Indirect energy through non-energy goods. The preceding has aimed at showing the contribution of the energy industries directly and indirectly (through their own backward linkages) to energy invested in fertilizers. It remains to gauge the scope of energy invested, directly and indirectly, in goods (capital goods and other goods) and services used by the fertilizer industries and their suppliers.

For this we rely on input-output data in the Energy Analysis Handbook (EAH) and some underlying statistics.<sup>2/</sup> The main difficulty here is that the EAH is based on input-output data from 1967 and thus uses the same industry classification as in the dollar-value input-output tables for that year.<sup>15/</sup> For fertilizer industry, there is a single classification (group 27.02). This classification allows of no distinction between nitrogen, phosphate, and potash fertilizers. Nor does it cover all fertilizers: as can easily be shown from the 1967 input-output tables and the 1967 Census of Manufactures, production of unblended nitrogen fertilizers then belonged





to the classification "chemicals not elsewhere classified" (group 27.01). The input-output tables' classification "Fertilizers" (group 27.02) corresponds to two classifications in the 1967 Census of Manufactures labeled "Fertilizers" (2871) and "Fertilizers, mixing only" (2872). The 1972 Census, as already mentioned, has added a separate classification for nitrogen fertilizers.

The input-output analysis in the EAH has produced two kinds of information not available directly in other statistics: coefficients of energy intensity in the main energy types themselves, and of energy intensity in the output of each specified industry group. The former, which we have used in the above analysis, have the form of multipliers by which the energy content of oil products, gas, electricity etc. can be raised to include the energy used (directly and indirectly) by the energy industries to supply these energy goods. Energy intensities for the output of industry groups have the form of a figure for heat units used (directly and indirectly) to produce a dollar's worth (in the prices of the table's reference year) of goods in the industry group. For the group "Fertilizers" (27.02) the energy intensity was found to be 187,051 Btu per dollar's worth in 1967 prices, which is more than twice that in the economy as a whole. For the group "Inorganic-organic chemical products" (27.01) which includes ammonia production, the coefficient is 303,231 Btu per dollar's worth. In these data, ammonia can not be separated from several other products, so we have to analyze backward linkages on the basis of the group 27.02, "Fertilizers."

Census details allow tentative estimates of energy used by the two census classifications which add up to 27.02, "Fertilizers," directly in fuel and electricity and indirectly through fertilizer materials purchased, from other industries such as ammonia factories (27.01), phosphate quarries and potash and sulfur mines. Some specifications are in dollars only. In these cases, physical quantities of fuel and materials had to be estimated from the dollar amounts and available price information. As a result we have obtained:

Table 3. Energy use by fertilizer industries, 1967.

Industry group	Energy use, incl. indirect through energy industries, and purchased fertilizer materials, trillion Btu	Value of shipments, \$ million	Btu per dollar
2871	185	1196.9	154,600
2872	95	731.1	129,900
Total, = 27.02	280	1928.0	145,200

Source: Based on 1967 Census of Manufactures

The last figure shown should be compared with the energy intensity coefficient given by the EAH for group 27.02, which is 187,051 per dollars worth of goods in 1967 prices. This indicates energy in backward linkages other than those of direct energy amounting to 42,000 Btu per 1967 dollar, or 22.4% of the EAH total.

This figure is not unlikely. An energy input-output tableau,<sup>16/</sup> which has fewer classifications than the EAH and does not yet include capital expenses among amounts allocated to industry groups, indicates that other indirect energy (than those in energy industries, mining, and imports)



amounts to about 12 percent of all allocated energy in the total for chemical industries. Another 10 percent for depreciation of capital appears well in line with other investment data from the fertilizer industries and related groups.

It does not follow that this estimate -- 42,000 Btu per dollars worth of goods in 1967 prices -- can be easily distributed among the three main categories of fertilizers. For one thing, there is some overlap between the two groups (2871 and 2872); both have some receipts for resales, and 2872 has acquired some fertilizer materials from 2871. If these overlaps could be eliminated, the energy quotient for the census entries would go down. We can not tell by how much, but an outer limit is given if we try the extreme assumption that 2872 took all its fertilizer materials from 2871. If both the energy and dollar amounts were subtracted from 2872, then the energy quotient for the total of the two groups would fall to 126,000 Btu per dollar's worth, and the backward-linkage estimate would rise to 61,000. This is too high, however. Looking at 2872's purchases of fertilizer materials, item by item, it is evident that most of these do not come from 2871 but from other industries (ammonia factories, potash mines, rock phosphate quarries). Therefore, the true quotient for the combined total of the two groups would be well over 135,000. The original estimate of 145,000 is therefore close to being accurate, and 42,000 for backward linkages (through non-energy goods) is acceptable for our purpose. It may be slightly too low.

Distributing this amount among the fertilizer groups can not be done very accurately. The best we can do is to use the price proportions. In





this case this means the prices of 1967, the year of the input-output data. In round figures, we can use 7 cents per pound of N in ammonia, 10 cents per pound of N in other fertilizers and per pound of  $P_2O_5$ , and 5 cents per pound of  $K_2O$ . Then, 42,000 Btu is the backward-linkage energy (for non-energy goods) for 14.3 pounds of N in ammonia, 10 pounds of N in other fertilizers, 10 pounds of  $P_2O_5$ , and 20 pounds of  $K_2O$ . This yields, in round numbers, 2900 Btu per pound of N in ammonia, 4200 Btu per pound of N in other fertilizers and per pound of  $P_2O_5$ , and 2100 Btu per pound of  $K_2O$ .

Marketing margins. Transport and distribution also entail use of energy, and this is additional to the EAH's coefficients of dollar's worth of merchandise (which refer to the factory gate). Since these marketing margins are proportionate to fertilizer quantity and not to acreage treated, they will be included here. (For the reverse reason, cost of application will be treated in a later analysis of on-farm energy use rather than here). Involved are fractions of sectors 65.01, 65.03, 69.01 and 69.02, which together account for 18 percent of the purchase price of fertilizers at the farm gate. With energy intensities lower than in the fertilizer industries, these activities add about 7.1 percent to the energy coefficient of the whole fertilizer group, or about 13,200 Btu per dollar's worth of fertilizer industry production in 1967 prices.<sup>17/</sup> This is 31 percent of the amount for factory-level backward linkages (through non-energy goods), and thus we can add another 900 Btu per pound of N in ammonia, 1300 per pound of N in other fertilizers and per pound of  $P_2O_5$ , and 650 per pound of  $K_2O$ .

Comprehensive estimates. Adding the figures for factory-level backward linkages (through non-energy goods) and for marketing margins to the figures in Tables 1 and 2 and in the paragraph about potash (with some upward



rounding to allow for mixing), we obtain the following comprehensive estimates of energy used (Btu per pound of pure nutrient):

Ammonia	33,100
Urea, liquid	44,200
Urea, solid	49,000
Ammonium nitrate, liquid	38,200
Ammonium nitrate, solid	43,400
Concentrated superphosphate	11,400
Diammonium phosphate	13,500
Potash	4,500

In all those cases where data relate only to  $N$ ,  $P_2O_5$  and  $K_2O$  without specifications as to variety of each fertilizer, we need a weighted average to represent the nitrogens and the phosphates. Based on annual statistics of fertilizer use in agriculture (which is the relevant aggregate for our purpose, rather than manufacturing totals),<sup>18/</sup> we arrived at averages of 38,000 Btu per pound of  $N$  and 12,500 per pound of  $P_2O_5$ . Using these, and the 4,500 per pound of  $K_2O$ , fertilizer use can be converted into aggregate energy consumption for fertilizers, as shown in Table 4.



Table 4. Use of Fertilizers in the United States Agriculture and Estimates of Energy Used in Their Production, Selected Years.

Years	Fertilizers (pure nutrient content), billion pounds			Energy Used for Fertilizer Production, trillion Btu <sup>a/</sup>			
	N	P <sub>2</sub> O <sub>5</sub>	K <sub>2</sub> O	N	P <sub>2</sub> O <sub>5</sub>	K <sub>2</sub> O	Total
1951-55	3.24	4.44	3.36	123	56	15	194
1961-65	7.71	6.17	5.00	293	77	23	393
1967	13.39	8.90	7.58	509	111	34	654
1972	16.18	10.78	9.24	615	135	42	792
1974 <sup>b/</sup>	16.85	11.12	8.27	640	139	37	816
1974	18.31	10.20	10.16	696	128	46	870
1976	20.73	10.46	10.41	788	131	47	966
1977	21.28	11.24	11.66	809	141	52	1002

a/ Assuming 38,000 Btu per pound of N, 12,500 Btu per pound of P<sub>2</sub>O<sub>5</sub> and 4,500 Btu per pound of K<sub>2</sub>O.

b/ The first line for 1974 represents the Census of Agriculture, as used in the USDA Data Base.

Source: Fertilizer data from Fertilizer Summary Data and other recurrent USDA statistics.

The numbers for 1974 based on the Census may be compared with those of the USDA Data Base, which report a total of 621 trillion Btu, which does not include any backward linkages as in this study.<sup>19/</sup>

These estimates are limited to the three main fertilizer categories. They do not include energy used in producing lime, micro-nutrients, fertilizers of organic origin, or non-fertilizer soil conditioners.





Recent Changes. The data used for estimating direct energy use in fertilizer production are from the 1978 survey by The Fertilizer Institute. According to an article using 1977 survey data, they represent a 12 percent reduction in energy use, compared to a similar survey from 1972.<sup>20/</sup> When indirect energy through the energy industries is included, the saving is somewhat less in heat units (reduction in the use of gas was accompanied by an increase in the use of fuel oil which has a larger backward linkage). Nonetheless, it is apparent that the 1978 level of direct energy use (even including indirect use through the energy industries) is lower than in earlier years included in Table 4.

Against this stands the likelihood that indirect energy has increased. Some of the gains in fuel efficiency in factories have been made at the expense of additional equipment, the energy cost of which is not included in any data available to us.<sup>21/</sup> The backward linkages of the energy industries are now also likely to be larger than at the time represented by the input-output data of 1967. Up-to-date information is not available, but it is evident that oil and gas drilling is now costlier because more dry holes are drilled (including some very expensive ones off-shore), drilling is pursued to greater depth with costs going up exponentially, and more "heavy oil" is produced from deep wells at additional costs for hot water or chemical solvent and with high refinery costs and lower refinery yields in high-value products. For all we know this may both offset and exceed gains made by chemical industry, and we therefore have no firm basis for saying that comprehensive energy costs of fertilizers have become smaller.

The combination of recent (1978) industry data on direct energy use,



which are lower than in previous years, with somewhat older (1967) input-output data on indirect energy which are likely to be lower than in subsequent years, means that all the estimates given in this paper should be regarded as being on the low side. The estimates should be useful for several years in the near-term future.

## NOTES

1. See Welch, L.F., Nitrogen use and behavior in crop production. Bulletin 761, Agricultural Experiment Station, College of Agriculture, University of Illinois at Urbana-Champaign, February 1979, pp. 43-52.
2. Bullard, Clark W., Peter S. Penner and David A. Pilati, Net energy analysis; Handbook for combining process and input-output analysis. Energy Research Group, Center for Advanced Computation, University of Illinois at Urbana-Champaign, October 1976 (CAC Document 214).
3. Simpson, David, and David Smith, Direct energy use in U.S. economy, 1967, Center for Advanced Computation, University of Illinois at Urbana-Champaign, January 1975 (CAC Technical Memo No. 39), citing a Battelle research report of 1972.
4. "Imported steam" is likely to be a by-product from other industry, hence its indirect energy requirements are likely to be charged to the main output of those industries. "Other fuels" in our industry data are small and may be coal, which in any event has only a small coefficient for indirect energy consumption.
5. Industry data from The Fertilizer Institute, Energy Use Survey, CY 1978, July 1979, pp. 5. See also White, William C., "Energy, food and fertilizers," in Fertilizer Progress, July/Aug 1978, Vol. 9, No. 4 pp. 14-18, 108. Parallel estimates, based on 1972 TFI Survey data, in Hoeft, R.D., and J. C. Siemens, "Energy consumption and return from adding nitrogen to corn," in Illinois Research, Winter 1975, pp. 10-11.
6. The energy input to a bag of fertilizer. Issued by Planning and Coordination Department, Imperial Chemical Industries, Limited, Agricultural Division, Billingham, Cleveland, England, p. 12.



(6 continued)

Cf. Green, Maurice B., "Energy in agriculture," in Chemistry in Industry, 7 August 1976, pp. 641-646, esp. table 3, p. 643, citing the above source.

7. Davis, Charles H., and Glenn M. Blouin, "How much energy does fertilizer consume?" in Farm Chemicals, June 1977, pp. 18-22. See also Davis, Charles H., Energy requirements for alternative methods for processing phosphate fertilizers, presented at Technical Conference of International Superphosphate and Compound Manufacturers Association, Limited, Prague, Czechoslovakia, September 23-27, 1974; Blouin, Glenn M. and Charles H. Davis, Energy requirements for the production and distribution of chemical fertilizers in the United States, paper presented at the Southern Regional Education Board Meeting in Atlanta, Georgia, Oct. 1-3, 1975, and Charles H. Davis and Glenn M. Blouin, "Energy consumption in the U.S. chemical fertilizer system from the ground to the ground," in Agriculture and Energy, ed. William Lockeretz, 1977, p. 315.
8. White, William C., "Energy - the name of the game," in Fertilizer Progress 4:6, 1973, pp. 12-18, 52; cf idem, "Fertilizer - food - energy relationships," in 1974 Illinois Fertilizer Conference Proceedings (Jan. 23-24, 1974), pp. 37-43, citing The Sulphur Institute for Frasch sulfur.
9. Cf Davis (1974), pp. 4-7
10. The Statistical Abstract of the United States shows mined sulfur declining slowly while total sulfur production goes up, with the percentage mined falling from near 75 percent in 1965 and 1970 to



(10 continued)

less than 60 percent in 1976 and 56 percent in 1977. Note the accounting problem: fertilizer should be charged its proportion of mined and recovered sulfur, not the incidental share it happened to secure by astute purchasing arrangements, which might entail manipulation at the expense of other industry.

11. Blouin and Davis (1975), p. 36.
12. White 1973 and 1978 (see note 8 above).
13. U.S. Bureau of the Census, Census of Manufactures, 1967, Washington, D.C., 1971. Vol. 2, Industry Statistics, Part 2, Major groups 25-33, Issued January 1971, and corresponding tables in the 1972 Census of Manufactures. Note that "mixed fertilizers" here refers to NPK mixtures; they do not include compound products such as ammonium phosphate.
14. Davis and Blouin, op cit (Farm Chemicals), p. 20.
15. Input-Output Structure of the U.S. Economy: 1967. Vol. 1-3. A Supplement of the Survey of Current Business. Washington, D.C., U.S. Department of Commerce, 1974.
16. Energy Flow Through the United States Economy. (Wall poster), University of Illinois Center for Advanced Computation, Energy Research Group, Clark Bullard, Bruce Hannon, Robert Herendeen, 1975. (Copies available from Office of Energy Programs, U.S. Department of Commerce Washington, D. C. 20230).
17. For details of computation, see John F. Yanagida, Productivity on a sample of Illinois grain farms 1972-76, Unpublished Ph.D. thesis, University of Illinois Department of Agricultural Economics 1978,

(17 continued)

p. 52 and Appendix 3-8.

18. The Fertilizer Supply USDA, Washington (annual), with data on domestic production, imports, and exports, separately for several kinds of nitrogen, phosphate, and potash fertilizers.
19. Energy and U.S. Agriculture: 1974 Data Base. (U.S. Department of Agriculture, Economic Research Service, FEA/D-76/459, Vol. 1, September 1976, p. 15.
20. White, William C., in Fertilizer Progress 1978 (see note 5).
21. Thus, Waggoner, Donald R., Effect of energy optimization on design and operation of ammonia plants, presented at FAI annual seminar 1978, Improving Productivity in Fertilizer Industry, Nov. 30 to Dec. 2, New Delhi, India (mimeo, pp. 31, from Tennessee Valley Authority, Division of Chemical Development, Muscle Shoals, Alabama), discussing the Selectoxo process which will better economize with materials and heat but also requires some additional equipment.