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ENERGY CONSUMPTION IN NORTH AMERICAN FERTILIZER PLANTS AND POTENTIAL SAVINGS.

TA/82/3

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SUMMARY

Energy consumption in North American fertilizer plants in 1979 was estimated for the principal products. Nitrogen fertilizers are energy intensive. Manufacture of ammonia requires an average of 57 GJ/mt of N.[1] Solid N fertilizer energy use ranges from 80 to 60 GJ/mt of N for prilled urea and ammonium sulfate, respectively.

Energy use for the most popular phosphate fertilizers including phosphate rock production ranged from 8 to 10 GJ/mt of P_2O_5, and potash production averaged 2.6 GJ/mt of K_2O. Diammonium phosphate (DAP) (18-46-0) was the most energy efficient NP product.

Maximum energy savings using current proven technology were estimated to be 25% for ammonia and 32% for prilled urea. Phosphate fertilizer manufacture could become nearly self-sufficient in energy in plants with captive sulfuric acid units based on elemental sulfur.

Energy for transportation of raw materials and products and for packaging and application of products was estimated for the world as a whole for each nutrient. World total energy use for the fertilizer sector was about 5,150 PJ for production and distribution of 113 million mt of NPK in 1978/79.

INTRODUCTION

The world fertilizer sector consumes only about 1.5% of the total world use of commercial energy. Although fertilizer energy use is relatively small, it is a crucial factor in the price and supply of fertilizers which in turn affect the price and supply of food. This is particularly true of nitrogen fertilizers which are by far the most energy intensive and are used in the largest amounts. Energy prices are likely to continue to rise with the result that fertilizer prices will continue to rise and nitrogen fertilizers will become relatively more expensive than other less energy-intensive fertilizers.

The need for more intensive agriculture is illustrated by the decline in arable land per person from about 0.41 ha/caput in 1962 to 0.31 in 1979 and 0.22 for the year 2000 for the world as a whole. Data for 1979 show an average of 0.56 ha of arable land per person for developed countries, 0.21 for all developing countries, 0.22 for Western Europe, and 0.06 for centrally planned Asian developing countries (mainly China). The prospect is for steady decline in arable land per person in the world as a whole and in developing countries in particular. So the need for more intensive agriculture is evident--higher yields

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[1] 1 GJ (gigajoule) = 0.948 million Btu.

per crop and more crops per year where practical. More intensive and efficient fertilizer use is the most important single factor in intensive agriculture.

The purpose of this paper is to discuss energy consumption in fertilizer manufacture and distribution and prospects for improving energy efficiency of these operations.

THE IFDC ENERGY-FERTILIZER STUDY

In 1980 IFDC undertook a study of energy-fertilizer relationships intended mainly for the guidance of developing countries. The study, completed in 1982, covers numerous aspects of the problem including estimates of present energy use in agriculture; prospects for improving energy efficiency of fertilizer manufacture, distribution, and use; and policy implications for developing countries (1).

For this IFDC study estimates of energy use in fertilizer manufacturing were based on a 1979 survey that was conducted on behalf of The Fertilizer Institute (TFI). Thirty-seven U.S. and Canadian companies participated in this survey (hereafter called "the TFI survey"). Although IFDC is interested mainly in developing countries, North American practice was selected as a reference point because the basic data were readily available. Because the TFI survey gives energy use by process step, extensive calculations and numerous assumptions were required to arrive at total energy use for any given product. In addition, supplemental data were taken from other sources, and where appropriate, estimates were adjusted to make them more relevant to world practice.

The TFI survey data relate only to mining and manufacturing operations. Therefore, data concerning energy use for transportation of raw materials and products and for packaging and application of fertilizers were drawn entirely from other sources. Estimates of energy used for these purposes were made for the world as a whole, with particular emphasis on developing countries. These nonmanufacturing costs are designated "PTA," for packaging, transportation, and application. In North America most of the manufacturing operations are located at or near the raw material sources, most of which are distant from the main agricultural areas. Thus, transportation of manufactured products is the main conponent of PTA energy use. In some other areas, however, transportation of raw materials may be a high percentage of PTA while transport of finished products may be much less important.

In the area of energy used in fertilizer manufacturing, the TFI survey is an especially valuable source of information because it relates to actual experience rather than contractor's estimates for plants operating near optimum conditions and because it covers total energy input rather than battery-limits energy use. The TFI survey includes a large number of plants, some of which may be old and inefficient. Thus, it gives a more accurate account of actual use. Moreover, actual energy consumption per unit output exceeds battery-limits consumption estimates, sometimes by a wide margin. The difference may be caused by a large variety of operating problems and by inclusion of energy consumption of facilities external to battery-limits facilities. Examples of these external factors are unloading, storing, and conveying of raw materials and products; disposal of effluents and solid wastes; and startups, shutdowns, delays and maintenance problems.

The original TFI survey is in short tons and British thermal units (Btu). However, all data have been converted to metric units such as joules (J) or multiples thereof and metric tons. The heating values for fuels are gross heating values, which include the heat of condensation of water vapor in combustion products. The energy equivalent for electricity (1 kWh = 10,000 Btu) implies an efficiency of about 34% in converting thermal to electrical energy.

ENERGY CONSUMPTION FOR NITROGEN FERTILIZERS

AMMONIA--Energy consumption for ammonia production as reported in the TFI survey was 46.9 GJ/mt for plants using centrifugal compressors and 49.0 GJ/mt for plants using reciprocating compressors. The weighted average was 47.3 GJ/mt.

The energy consumed was mainly in the form of natural gas. Centrifugal plants consumed an average of 45.4 GJ/mt of ammonia as natural gas energy of which 57.2% was feedstock, 37.2% was used for heating the reformer, and 5.6% was other process energy; reciprocating compressor plants used less natural gas and more electricity. In further calculations the energy use for ammonia is taken as 57.2 GJ/mt of N, equivalent to the average of plants using centrifugal compressors. The interquartile range for centrifugal plants was ± 5.5% of the average.

About 80% of the world's ammonia production is based on natural gas (2); consequently, the average energy use for North America may be fairly typical of world use if operating efficiencies are comparable.

UREA--Conversion of ammonia to urea solution requires an average of 5.53 GJ/mt of urea, and converting the urea solution to prilled or granulated product requires a further 4.07 or 2.53 GJ, respectively. Thus, the total energy input for urea including that used for ammonia production can be calculated as follows:

	Energy Use, GJ/mt of Urea (46% N)	
	Prilled	Granular
Ammonia manufacture	26.97	26.97
Urea synthesis	5.53	5.53
Prilling	4.07	-
Granulation	-	2.53
TOTAL	36.57	35.03
	GJ/mt of N	
TOTAL	79.50	76.15

The average energy use for conversion of ammonia to prilled urea is about 2.5 times the battery-limits value of 3.9 GJ/mt (3). This difference can be accounted for in part by inclusion of older, less energy-efficient plants in the average. However, it is likely that the main reason for higher energy use is compliance with stringent pollution control regulations. There is a wide range in reported energy use; the lowest value of the interquartile range is only 58% of the average. Granular urea requires less energy than prilled urea partially because the pollution control problems are less difficult with the granular product. The main forms of energy used in urea manufacture are steam and electricity, which can be generated by any fuel.

Participants in the TFI Survey reported 4.3 million mt of urea produced as solution of which 2.2 was granulated and 1.3 was prilled; the remaining 0.8 million mt presumably was used in liquid fertilizers.

AMMONIUM NITRATE--Production of ammonium nitrate involves three steps: production of nitric acid, neutralization of the acid with ammonia, and prilling or granulating the resulting product. The first two steps are exothermic and can produce steam for export. However, the average energy use reported is 1.74 GJ/mt for the two-step conversion of ammonia to ammonium nitrate solution. The interquartile range of 0.28-2.77 GJ/mt reflects the wide differences in the extent to which various plant operators utilize the heat of reaction to minimize net energy use. Here again, inclusion of older, less energy-efficient plants raises the average. The means used to comply with pollution control regulations (NO_x from nitric acid units and fume from neutralizer) can be energy-intensive also, but low-energy methods are available.

Prilling or granulating the product including evaporating the solution and controlling air and water pollution consumes a further 2.92 or 2.39 GJ/mt, respectively. The total energy input is tabulated below:

	Energy Use, GJ/mt of Ammonium Nitrate (34% N)	
	Prilled	Granulated
Ammonia manufacture	20.29	20.29
Ammonium nitrate solution	1.74	1.74
Prilling	2.92	-
Granulation	-	2.39
TOTAL	24.95	24.42
	GJ/mt of N	
TOTAL	73.38	71.82

As in the case of urea, the difference in energy use between granulation and prilling probably is related to the more difficult pollution control problems for prilling. Participants reported 4.6 million mt of ammonium nitrate produced as solution of which 2.4 was prilled, 0.5 was granulated, and 1.7 was presumably used as solution.

UREA-AMMONIUM NITRATE SOLUTION--Urea-ammonium nitrate (UAN) solution is a popular nitrogen fertilizer in the United States and in several other countries. It is produced by mixing urea and ammonium nitrate solutions and adding water to adjust to the desired grade, which ranges from 26% to 32% N. The energy input is calculated as follows:

	GJ/mt of UAN (30% N)
Ammonia manufacture	17.38
Urea, 0.327 mt (solution)	1.81
Ammonium nitrate, 0.422 mt (solution)	0.73
Mixing, cooling, storage, etc.	0.25
TOTAL	20.17
Total per mt of N	67.20

AMMONIUM SULFATE--Ammonium sulfate is produced directly from ammonia and sulfuric acid, or from a solution which is obtained as a byproduct from manufacture of caprolactam, from scrubbing coke oven gas, or from various other processes.

The direct process is exothermic, and little energy is required. Production from byproduct solution, however, requires a substantial amount of energy for evaporating the water from the solution, which usually contains about 40% ammonium sulfate. Estimated energy requirements are taken from the Fertilizer Manual (3). They do not include the energy involved in producing sulfuric acid, which may be positive or negative. Also, energy for granulation is not included; some direct processes make a crystalline product of suitable size without granulation.

In the case of byproduct material, energy for the manufacture of ammonia is not included. If synthetic ammonia is used, its energy component is charged to the process that produces the byproduct. Estimated energy use values follow:

	Energy Use, GJ/mt of Ammonium Sulfate (21% N)	
	Synthetic	Byproduct
Process energy	0.59	4.70
Ammonia manufacture	12.01	-
TOTAL	12.60	4.70
	GJ/mt of N	
TOTAL	60.00	22.40

AMMONIUM PHOSPHATES--Although ammonium phosphates usually are considered as phosphate fertilizers, the most popular grade (DAP) contains 18% N (18-46-0). For present purposes, the energy component of nitrogen in ammonium phosphates is taken to be equivalent to the ammonia used in its manufacture--57.2 GJ/mt of N. The logic of this assumption will be discussed later.

COMPARISON OF ENERGY USE FOR NITROGEN FERTILIZERS--For comparative purposes, the energy inputs for manufacture of various nitrogen fertilizers are tabulated below:

Product	% N	Energy Input, GJ/mt of N
Ammonia	82	57.2
Urea		
Prilled	46	79.5
Granular	46	76.1
Ammonium nitrate		
Prilled	34	73.4
Granular	34	71.8
UAN solution	30	67.2
Ammonium sulfate		
Synthetic	21	60.0
Byproduct	21	22.4
Ammonium phosphate	10-21	57.2

ENERGY CONSUMPTION FOR PHOSPHATE FERTILIZERS, RAW MATERIALS, AND INTERMEDIATES

PHOSPHATE ROCK--Phosphate rock is prepared for further processing by mining, beneficiation, drying, calcining, and grinding or some combination of these steps. Not all of these steps are required in all cases. For example, several plants use processes that accept rock with only mining and beneficiation; the wet concentrate is fed directly to phosphoric acid production. Several other plants accept wet rock for wet grinding. Calcining is not necessary for the majority of rocks; when it is necessary it usually replaces drying.

Participants in the TFI survey reported the following amounts of rock were dried, calcined, or used as wet rock feed to phosphoric acid plants:

Type	Million Mt	% of Total
Dried	31.8	75.2
Calcined	2.5	5.9
Wet feed	8.0	18.9
TOTAL	42.3	100.0

The energy use for the rock preparation steps that are reported in the TFI survey pertains to the United States, mainly Florida, and is not necessarily typical of world averages. The average grade of the ore mined in Florida is about 10% P_2O_5, the concentrate is about 30% P_2O_5, and the P_2O_5 recovery is about 60%. This means 5 mt of ore must be mined and beneficiated to get 1 mt of commercial phosphate rock. In addition, various amounts of overburden are removed and eventually replaced to reclaim the mined-out area.

In contrast, in most of the west and north African and the Middle East phosphate mines, the grades of the ore as mined are in the range of 25%-30% P_2O_5, and simple size separation (screening and/or washing) is used to beneficiate the ore. In a few cases beneficiation is not necessary.

In this study, the lower value of the interquartile range of energy use from the TFI survey is assumed to apply to the world average for mining and beneficiation. The survey does not show energy use for grinding as a separate step, so this value was calculated from other data sources. Average survey values will be accepted for the other steps. The accepted values are as follows:

Energy Use in Phosphate Rock Preparation

Step	Thousands of Btu/Short Ton	MJ/mt
Mining and reclamation	188	219
Beneficiation	210	244
Drying	402	467
Calcining	902	1,049
Grinding	270	314

About 8% of the world's phosphate fertilizer is supplied by direct application of ground phosphate rock to the soil (4). Rock sold for this purpose on the world market is mined, beneficiated, dried, and ground. The total energy use is 1.21 GJ/mt or 4.05 GJ/mt of P_2O_5 assuming an average grade of 30% P_2O_5. If domestic rock is used for direct application, as is the case particularly in the U.S.S.R. and China but also in some other countries, the total energy use is only 0.53 GJ/mt or 2.12 GJ/mt of P_2O_5 assuming an average grade of 25% P_2O_5. Most of this domestic rock is used with only mining and grinding, and hence is usually lower in grade.

Phosphate rock sold on the world market for further processing is mainly dried but not ground before shipment. It is usually considered uneconomical to ship wet rock (about 15% moisture) farther than about 500 miles (800 km). Thus, in this study, rock sold in world trade is assumed to be mined, beneficiated, and dried, with an energy input of 0.93 GJ/mt or 2.91 GJ/mt of P_2O_5 (the average grade is about 32% P_2O_5). Grinding, when required, is considered as part of further processing.

SULFUR AND SULFURIC ACID--Sulfuric acid is required for producing about 80% of the world's phosphate fertilizer. The world production of sulfurous materials by type is estimated as follows (5):

Type	1980 Estimated Production of Sulfur: Millions of mt of S	1980 Estimated Production of Sulfur: % of Total S
Frasch-mined elemental sulfur	13.6	24.4
Recovered elemental sulfur	22.6	40.6
Pyrite	9.5	17.1
Other, mainly byproduct smelter acid	10.0	17.9
TOTAL	55.7	100.0

Of these forms of sulfur, only Frasch-mined sulfur is energy intensive. The energy use is likely to vary from one mine to another; Huffman gives a range of 6.33-8.44 GJ/mt, with an average of 7.38 GJ/mt (6). Frasch-mined sulfur is expected to decrease as a percentage of the total in the future, whereas recovered sulfur is expected to increase. The energy component for recovered sulfur is assumed to be zero, since any energy involved is charged to the main product, i.e., gaseous or liquid fuels. In this paper we will consider only sulfur-burning sulfuric acid plants that are operated in conjunction with phosphoric acid plants. The average net energy recovery is 1.32 GJ/mt of H_2SO_4, assuming no energy charge for sulfur.

PHOSPHORIC ACID--About 60% of the world's phosphate fertilizer is made from phosphoric acid. The TFI survey data show four steps in production of phosphoric acid: preparation of phosphate rock, production of sulfuric acid, production of filter acid, and production of merchant or superphosphoric acid. Filter acid has a usual concentration of 28% P_2O_5; merchant acid, 54% P_2O_5; and superphosphoric acid, 70% P_2O_5. Another concentration, 42% P_2O_5, should be considered, since this concentration is sufficient to produce granular triple superphosphate (TSP), DAP, and monoammonium phosphate (MAP) by slurry processes. Plants that make these products often concentrate part of the acid to about 54% P_2O_5 and use a mixture of the concentrated and dilute acid equivalent to an average concentration of about 40% P_2O_5. Fertilizer companies participating in the TFI survey reported production of about 8 million short tons of P_2O_5 as filter acid of which 46% was concentrated to merchant-grade acid and 12% was further concentrated to superphosphoric acid.

One company in the United States uses a hemihydrate process which produces filter acid at a concentration of 42% P_2O_5. Since this process has an energy-saving potential, it will be considered separately. Several plants using hemihydrate processes have been built recently in European countries and in Japan; they produce filter acid ranging from 40% to 52% P_2O_5. The estimated energy use for the various grades of phosphoric acid and for various processes is shown in Table 1.

Hemihydrate processes in general have the advantage of producing a more concentrated filter acid, thereby saving the energy required to concentrate the acid to the required level. The steam savings for the OXY process are equivalent to 1.64 GJ/mt of P_2O_5 based on electricity generated from the steam (7). Some hemihydrate processes produce acid as concentrated as 52% P_2O_5 (using high-grade rock). Thus, further savings are possible when acid of this concentration is required. Because steam usually is available from an adjacent sulfuric acid plant, any steam saved must be utilized to recover energy. In the case of the OXY plant, the steam is used to generate electricity.

Table 1. Energy Use for Phosphoric Acid Production[a]

Process	Dihydrate, Dry Rock Feed	Dihydrate, Wet Rock Feed	Dihydrate, Wet, Unground Rock Feed	Hemihydrate, Wet, Unground Rock Feed
	(GJ/mt of P_2O_5)			
Rock preparation[b]	3.09	1.49	1.49	1.49
Sulfuric acid[c]	-3.67	-3.67	-3.67	-3.67
Filter acid[d]	4.18	3.65	2.61	2.61
Concentrated to 42% P_2O_5[e]	4.28	4.28	4.28	-
Total for 42% P_2O_5	7.88	5.75	4.71	0.43
Concentrated to 54% P_2O_5	1.92	1.92	1.92	1.92
Total for 54% P_2O_5	9.80	7.67	6.63	2.35
Concentrated to 70% P_2O_5	3.13	3.13	3.13	3.13
Total for 70% P_2O_5	12.93	10.80	9.76	5.48

a. Assumptions: 94% P_2O_5 recovery; 3.32 mt of phosphate rock and 2.78 mt of H_2SO_4/mt of P_2O_5 recovered.

b. Mining, beneficiation, and (when required) drying.

c. Based on use of elemental sulfur with zero energy charge.

d. Including grinding when required.

e. Based on TFI average of 6.2 GJ/mt P_2O_5 for production of merchant grade from filter grade. Filter grade assumed to be 28% P_2O_5 and merchant grade 54% P_2O_5. Energy use assumed to be proportional to water evaporation. For hemihydrate process 42% P_2O_5 acid is obtained directly from the filter.

Other energy saving features of some processes are the elimination of rock drying which saves 1.55 GJ/ton of P_2O_5 and the elimination of rock grinding which saves about 1.04 GJ/ton of P_2O_5. In some processes both drying and grinding are eliminated by using wet, unground rock feed directly to the extraction step. The TFI survey shows that 31% of the phosphoric acid was produced from wet rock feed which presumably includes both wet grinding and wet rock used without grinding. At least two dihydrate processes as well as most hemihydrate processes are adaptable to using wet, unground rock provided the maximum particle size is less than about 1 mm. Most commercial rock meets this criterion.

Production of phosphoric acid provides another source of energy through recovery of uranium. For those plants that use Florida phosphate rock, recovery of 1 lb of uranium oxide (U_3O_8) per short ton of P_2O_5 in phosphoric acid may be typical. This is equivalent to 0.5 kg of U_3O_8/mt of P_2O_5. With current technology this amount of uranium is capable of generating roughly 200 GJ of energy in nuclear reactors; this is 20 times the average energy use of manufacturing merchant-grade phosphoric acid.

TRIPLE SUPERPHOSPHATE--Granular TSP is made by one of two processes. In the two-step process, nongranular TSP is produced in the first, and granulated in a second step. The nongranular TSP, also called run-of-pile TSP, also is used to make granular mixed fertilizers. In the slurry process, ground phosphate rock reacts with phosphoric acid of about 40% concentration, and the resulting slurry is granulated and dried. In both processes, the rock must be dried and finely ground. The usual grade of the product is 46% P_2O_5. Energy requirements for the two processes, based on average process energy from the TFI survey and phosphoric acid energy requirements from Table 1, are shown in Table 2.

Table 2. Energy Use in Production of Granular TSP

	GJ/mt of TSP[a]	
Process	Dihydrate, Dry Rock Feed	Hemihydrate, Wet Rock Feed
A. Two-Step Process		
Rock for TSP	0.36	0.36
Acid P_2O_5 (as 54%)	3.39	0.81
Nongranular TSP[b]	0.41	0.41
Granulation	1.01	1.01
TOTAL	5.17	2.59
B. Slurry Process		
Rock for TSP	0.36	0.36
Acid P_2O_5 (as 42% P_2O_5)	2.73	0.15
Process energy[b]	1.74	1.74
TOTAL	4.83	2.25

a. 46% P_2O_5.
b. Process energy including rock grinding.

The two-step process is more energy intensive than the slurry process, mainly because it requires more concentrated phosphoric acid. However, the slurry process is not entirely satisfactory for use with some unreactive rocks. The data also show that the total energy use for TSP is strongly influenced by the type of process used for preparation of phosphoric acid.

AMMONIUM PHOSPHATES--The average process energy use for DAP is 0.942 GJ/mt and this is assumed to apply to MAP also. Nearly all of the DAP is produced as a standard grade (18-46-0), whereas numerous grades of MAP are marketed--11-48-0, 13-39-0, 11-55-0, 13-54-0, etc. Some of the grades contain ammonium sulfate. For the purpose of this study a grade of 11-54-0 will be assumed. The great majority of ammonium phosphate plants use a slurry process in which the phosphoric acid is used at an average concentration of about 40% P_2O_5. In this study an average concentration of 42% is assumed. Total energy use including that for phosphoric acid preparation by dihydrate and hemihydrate processes is shown in Table 3.

Table 3. Energy Use in Production of Granular DAP and MAP

	Phosphoric Acid Process	
Product	Dihydrate Process Dry Rock Feed	Hemihydrate Process Wet Rock Feed
	-(GJ/mt)-	
DAP (18-46-0)		
Acid P_2O_5 (as 42% P_2O_5)[a]	3.66	0.20
Process energy	0.94	0.94
Total, not including ammonia	4.60	1.14
Energy for ammonia[a]	10.40	10.40
Total, including ammonia	15.00	11.54
MAP (11-54-0)		
Acid P_2O_5[a]	4.29	0.23
Process energy	0.94	0.94
Total, not including ammonia	5.23	1.17
Energy for ammonia	6.36	6.36
Total, including ammonia	11.59	7.53

a. Assuming 99% recovery.

In comparing the three most popular phosphate fertilizers--TSP, DAP, and MAP--it seems logical to compare them on a P_2O_5 basis, omitting the energy input for ammonia. The comparison follows:

	GJ/mt of P_2O_5	
Product	Dihydrate	Hemihydrate
TSP	9.43	4.89
DAP	8.57	2.48
MAP	8.26	2.17

The comparison indicates that TSP is somewhat more energy intensive than DAP or MAP probably because the heat of reaction of ammonia with phosphoric acid is utilized to decrease energy use. However, the choice of the method used for preparing the phosphoric acid, dihydrate versus hemihydrate, gives the greatest opportunity for energy saving.

Calculations have been made to compare the energy requirement for DAP with that for equivalent amounts of N and P_2O_5 supplied as TSP and urea. The calculations show that DAP is by far the more energy-efficient alternative, particularly on a delivered basis.

SINGLE SUPERPHOSPHATE--The number of responses in the TFI survey was insufficient to provide usable data for energy use in single superphosphate; therefore, other sources were used to calculate the following values:

	GJ/mt of SSP	
	Nongranular	Granular[a]
Rock mining, beneficiation, and drying	0.58	0.58
Process energy including rock grinding	0.41	1.11
TOTAL	0.99	1.69

[a] Ex-den granulation process.

If sulfuric acid were manufactured onsite from elemental sulfur, an energy credit of 0.41 GJ/mt of SSP could be taken for excess energy from this source. However, many SSP manufacturers use purchased acid such as spent acid or byproduct acid from smelter operations.

COMPARISONS OF ENERGY USE FOR PHOSPHATE PRODUCTS--It is evident that energy use for phosphate fertilizers can vary widely depending on the phosphate rock preparation steps and on the phosphoric acid manufacturing process. However, the average energy use for phosphates is much lower than for nitrogen fertilizers. Triple superphosphate, the most popular straight phosphate fertilizer, requires less than 10 GJ/mt of P_2O_5 when made by the most popular combination of process steps, whereas urea, the most popular straight nitrogen fertilizer, requires about 80 GJ/mt of N. Average values for the use of energy for the more popular phosphate fertilizer intermediates and products are summarized in Table 4.

Table 4. Comparison of Energy Use for Phosphate Products[a]

Product	GJ/mt of Product	GJ/mt of P_2O_5
Phosphate rock for direct application		
Mined, beneficiated, dried, and ground, 30% P_2O_5	1.21	4.03
Same as above but granulated	2.06	6.87
Mined and ground only, 25% P_2O_5	0.53	2.12
Phosphoric acid, merchant-grade, 54% P_2O_5		
Hemihydrate process	1.27	2.35
Dihydrate process	5.29	9.80
TSP, nongranular, 46% P_2O_5		
Hemihydrate process	1.58	2.93
Dihydrate process	4.16	9.02
TSP, granular, slurry process, 46% P_2O_5		
Hemihydrate process	2.25	4.89
Dihydrate process	4.83	10.50
DAP granular, 18-46-0		
Hemihydrate process	1.14	2.48
Dihydrate process	4.60	10.00
MAP granular, 11-54-0		
Hemihydrate process	1.17	2.17
Dihydrate process	5.23	9.69
SSP, 20% P_2O_5[b]		
Nongranular	0.99	4.95
Granular	1.69	8.45

a. Does not include energy for transportation of raw materials or products. Use of recovered sulfur assumed; no energy charge.
b. No credit for energy from sulfuric acid production.

POTASH FERTILIZERS

The TFI survey gives an average energy use of 2.55 GJ/mt of product for production of muriate of potash by shaft mining and beneficiation. Since this applies to 8.2 million mt of product, it is presumably typical of energy use by the North American potash industry, but not necessarily applicable to other areas. The average includes all size grades: standard, coarse, and granular. In 1977, about 79% of the potash sold in North America was coarse and granular, but most of that exported was the standard (nongranular) grade.

Energy use in mining per ton of product increases as the depth of the mine increases and as the grade of the ore decreases. The grade of the ore determines the number of metric tons of ore that must be mined per metric ton of product. The ore:product ratio is typically 2.3 in Canada, but in New Mexico and in some European mines the ratio may be 4, 5, or even 6.

In beneficiating the ore, a physical separation such as crushing followed by flotation is the least energy intensive and is widely used. However, not all ores are suitable for this process. The main alternative is dissolution and selective crystallization for separation of soluble impurities; insoluble impurities are separated by sedimentation and washing. This method requires a substantial amount of energy (as steam) for evaporation and thermal cycling of solutions. Many producers use a combination of methods, recovering as much as possible of the potash by physical separation and an additional amount by evaporation and crystallization.

By using data from various sources, energy requirements for granular and nongranular potash in North America were estimated. Estimates for European production are also included (8) as follows:

Energy Requirements for KCl (60% K_2O)

	GJ/mt of Product	GJ/mt of K_2O
North America		
Granular[a]	2.9	4.8
Nongranular	2.3	3.8
Average	2.6	4.2
Europe, average	4.6	7.7

a. Including "coarse" grades.

MIXED FERTILIZERS

The TFI survey gives the average energy use for granular mixed fertilizers as 1.048 GJ/mt, for bulk blends as 0.179 GJ/mt, and for fluid mixtures as 0.629 GJ/mt. These data include energy for unloading raw materials and conveying them to storage, reclaiming raw materials from storage, conveying the product to storage, and reclaiming it and loading for shipment.

Although the process of granulation in itself is more energy intensive than bulk blending, the raw materials are likely to require less energy. All materials for bulk blending must be granular when received, and extra energy is required for that purpose. In other words, it is not necessarily cheaper or less energy intensive to granulate two, three, or more materials separately than to granulate them together. Therefore, in general, energy for producing mixed (compound) fertilizers replaces the energy that would be used in making the N, NP, P, and K products that have already been considered.

ENERGY SAVINGS IN FERTILIZER MANUFACTURING

For these estimates current (1979) North American practice was used as a reference point since data for other areas were not available. However, there is reason to believe that fertilizer plants in most developing countries are less energy efficient than North American plants and that potential energy savings may be greater. The following assumptions were made in calculating potential energy savings over average North American consumption.

AMMONIA--The most energy efficient proven design for new natural gas based plants would be used. The value selected was a compromise based on data from several sources. Some of the energy-saving innovations may not be economical in locations where natural gas is inexpensive and would be flared if not used.

UREA AND AMMONIUM NITRATE--Energy use would be reduced to the lower value of the interquartile range reported in the TFI survey.

PHOSPHORIC ACID--Energy savings were based on plants using elemental sulfur with increased energy recovery from sulfuric acid manufacture and on use of a hemihydrate process to eliminate the need for concentrating phosphoric acid. Wet rock feed was assumed, and grinding would be eliminated or reduced to crushing oversize. Process energy would be reduced to the lower value of the interquartile range. Not all of these savings would be possible at all locations. For example, use of wet rock will not save energy when the rock is shipped to points distant from the mine.

TSP, DAP, AND MAP--Process energy would be reduced to the lowest value of the interquartile range. Maximum use would be made of ammonium phosphates, and especially of DAP, because it is the most energy-efficient combination of equivalent amounts on N and P, particularly at the farm level.

POTASH FERTILIZERS--No estimates were made for energy savings in mining and refining potash fertilizers. Energy use is now relatively small, and any energy saving may be offset by future use of leaner ores.

COMPOUND FERTILIZERS--Modern processes for making compound fertilizers are no more energy intensive than processes for making the separate products considered above and may be less so. The main energy savings for compounds will come from savings for the intermediates used.

POSSIBLE ENERGY SAVINGS--Estimated savings in energy use for selected N, NP, and P fertilizers are reported in Table 5. Energy savings for ammonia, urea, and ammonium nitrate amount to 25%, 32%, and 31% of present use, respectively, for new plants. Not all of these savings are economical. Important factors in the economics of energy saving are energy source, energy supply, and capital costs.

Table 5. Probable Maximum Savings in Energy Use for New Fertilizer Plants Using Available Technology for Selected Fertilizers

Process/Product	Energy Use Present	Energy Use Future	Energy Saving
	(GJ/mt of nutrient)		(%)
Nitrogen fertilizers (N)			
Ammonia	57.2	42.9	25
Urea	79.6	54.2	32
Ammonium nitrate	73.4	50.7	31
Phosphate fertilizers (P_2O_5)			
Phosphoric acid (42% P_2O_5)	7.9	-2.1	127
DAP[a]	10.0	-0.2	102
MAP[a]	9.7	-0.4	104
TSP	10.5	0.9	91

a. Not including energy for N input.

Possible energy savings for phosphate fertilizers range from 118% for phosphoric acid to 72% for TSP. Although on a percentage basis the savings are greater for phosphate fertilizers than for nitrogen fertilizers, in absolute terms the savings are greater for nitrogen products because they are more energy intensive. Some of the savings can be realized in existing plants and some only in new or extensively modified plants.

ENERGY USE AND SAVINGS IN FERTILIZER DISTRIBUTION

Energy use for transportation of raw materials and distribution of fertilizers was estimated for the world as a whole rather than for North America, and with particular emphasis on developing countries. The estimates were based on a mix of fertilizer products and transportation methods approximating current use. All fertilizer products were assumed to be bagged before reaching the farmer. The following tabulation summarizes the results of the IFDC study and compares energy use for manufacturing with that for packaging and transportation of raw materials and products and application of products (PTA).

	GJ/mt of Nutrients[a]		
Activity	N	P_2O_5	K_2O
Manufacturing	69.5	7.7	6.4
PTA	8.6	9.8	7.3
TOTAL	78.1	17.5	13.7

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[a] The energy requirements for manufacture of individual nutrients are based on (1) weighted world average of all nutrient supply sources, (2) energy use survey for North America during 1979 and other appropriate sources, (3) high heating value estimates, and (4) total rather than battery-limits estimates.

This tabulation shows that for phosphate and potash fertilizers PTA energy use exceeds manufacturing use, whereas for nitrogen, manufacturing energy use predominates. Of the total PTA energy use, packaging accounts for 30%, 27%, and 24% for N, P_2O_5, and K_2O, respectively; transportation accounts for 52%, 58% and 63%; and application accounts for 18%, 15%, and 13%. Only minor energy savings in PTA energy use can be foreseen in the near future unless achieved at the expense of delivering the fertilizer to the farmers on time and in good condition.

ENERGY SAVING IN FERTILIZER USE

Probably the greatest saving in fertilizer energy, particularly in developing countries, could be realized through more efficient fertilizer use, especially more efficient nitrogen use and more energy-efficient proportions of N, P, and K. This subject is beyond the scope of the present paper, but is examined in detail in the IFDC study.

ENERGY USE IN THE WORLD FERTILIZER SECTOR

By using the world average energy use per ton of nutrient that was developed in the preceding table and the world production as reported by FAO for the 1978/79 fertilizer year, the total world energy use for the fertilizer sector was calculated. The results are tabulated below.

World Energy Use for Fertilizer Production, Packaging, Transportation, and Application in 1978/79

	N	P_2O_5	K_2O	NPK
Production, million mt	53.8	32.4	26.5	112.7
Manufacturing energy PJ	3,755.2	259.2	161.6	4,176.0
PTA energy PJ	462.7	317.5	193.5	973.7
Total energy PJ	4,217.9	576.7	354.1	5,148.7
% of NPK total	82	11	7	100

The total energy use is 5,148.7 PJ (petajoules = 10^{15} joules) or 4.881 "quads" (quadrillion Btu). The estimated energy use in North America for fertilizer production is about 1,208 PJ or about 23.5% of the world total, assuming that energy use per ton of nutrients is the same as the world average. The assumption is not entirely correct, of course. The PTA energy use is probably less for North America than for the world as a whole. For example, energy for packaging is small in North America because 87% of all fertilizers were sold in bulk (in 1979/80 in the United States).

SELECTED POLICY IMPLICATIONS

So far we have discussed energy consumption and potential energy savings in fertilizer manufacturing, distribution, and use. The policy implications in realizing these savings, especially for the developing countries, are numerous and have been discussed in detail in the IFDC study. Some of these policy implications, however, may be relevant in this context.

First, the empirical evidence points out that the average energy output/input ratios for fertilizer use are generally very high. Also the output energy is largely in the form of food which is necessary for human survival and well being. Consequently, every effort should be made to encourage expanded and efficient use of fertilizer, even in some countries where fertilizer use is already high. However, the nutrient balance can be improved, especially in favor of less energy-intensive fertilizers.

Second, governments in most developing countries either make or influence decisions related to the selection of fertilizers to be produced, manufacturing processes to be used, foreign exchange to be allocated, power allocation, imports of spare parts, and so forth. Energy efficiency, along with reliability and cost, should be given high priority in making such decisions.

Third, the international financial organizations can also play an important role in encouraging the development, transfer, and use of energy-efficient fertilizer manufacturing processes by using energy efficiency as one of the criteria in their feasibility studies for new fertilizer plants.

Fourth, energy saving must be viewed within the perspective of local conditions. For example, in countries where natural gas would be flared if not used there is little justification for saving energy at the expense of increased capital cost and more complicated facilities.

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TA/82/3 Energy consumption in North American fertilizer plants and potential savings, by T.P. HIGNETT, M.S. MUDAHAR, International Fertilizer Development Center, USA.

DISCUSSION : (Rapporteur : P. BECKER, COFAZ SA, France)

Q - Mr. J.D. CRERAR, Norsk Hydro Fertilizers Ltd, United Kingdom

I was pleased, but not surprised, to see the emphasis placed on the energy saving available from using the hemihydrate route for phosacid.

Experience outside USA has proved operation of hemihydrate plants to produce 50% P_2O_5 acid. This gives a further saving of 2.2. GJ/t P_2O_5.

Do the authors agree that the hemihydrate route will become increasingly accepted, as wet grinding has done.

A - Yes, we do expect that the hemihydrate route will be increasingly accepted. Some study may be needed to find the best compromise between product acid concentration and wet rock feed. We understand that the U.S. plant that uses a hemihydrate process uses wet rock containing about 15 percent moisture without grinding.