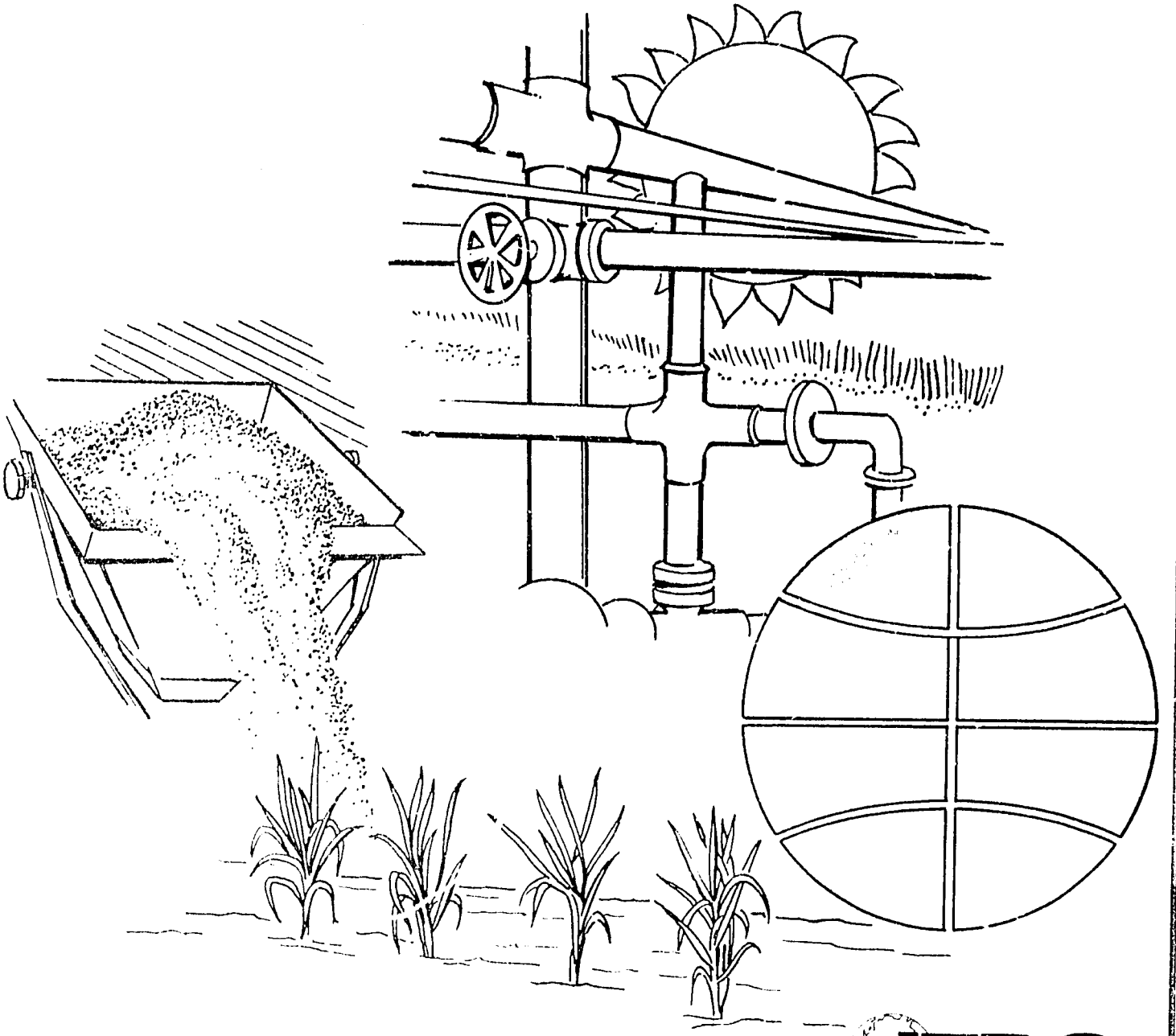
EXECUTIVE BRIEF

ENERGY AND FERTILIZER

POLICY IMPLICATIONS AND OPTIONS FOR DEVELOPING COUNTRIES



IFDC

Technical Bulletin IFDC - T-19
September 1981

ABSTRACT

The executive brief provides highlights of the study which deals with economic and technical analysis of the linkages among energy, fertilizer, and agricultural sectors. The main objectives of the study are to estimate energy requirements for fertilizer manufacturing, packaging, transportation, and application; to evaluate the policy implications of energy supply and prices on fertilizer production, distribution, and prices; and to evaluate policy options to reduce the adverse impact of energy supply and prices on fertilizer and agricultural sectors.

Even though the focus of the study is developing countries, policymakers, planners, and researchers dealing with different aspects of fertilizer sector planning around the world will find it useful. The major emphasis of the study is on nitrogen fertilizers which are not only highly energy intensive but are most popular among developing countries. However, the fertilizer sector accounts for only a small percentage of total energy use. Technical Bulletin No. 20 provides complete details of the study.

The most promising mean. for saving fertilizer energy is more efficient use of fertilizer at the farm level. In fertilizer manufacturing, the greatest energy saving is likely to come from operating existing plants more efficiently. Many energy-efficient innovations are available which together promise potentially large savings in fertilizer manufacture. The potential for energy saving in fertilizer distribution is likely to be small in the short run and should be approached with caution.

The national governments must take the lead in promoting energy-efficient manufacture, distribution, and use of fertilizer. The international organizations can play a crucial role in facilitating the formulation and successful implementation of such national programs.

Keywords: energy, fertilizer, agriculture, developing countries, policy

Prepared by

Mohinder S. Mudahar, Economist
and
Travis P. Hignett, Chemical Engineer
International Fertilizer Development Center

IFDC INTERNATIONAL FERTILIZER DEVELOPMENT CENTER . . . MUSCLE SHOALS, ALABAMA 35660
P.O. BOX 2040 . . . 205-381-6600
TWX-810-731-3970 IFDEC MCHL

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August 16, 1982

ENERGY AND FERTILIZER: POLICY IMPLICATIONS AND OPTIONS FOR DEVELOPING COUNTRIES

We are very pleased to announce our new publication, Technical Bulletin IFDC-T-20, entitled "Energy and Fertilizer: Policy Implications and Options for Developing Countries." The study is co-authored by Dr. Mohinder S. Mudahar and Mr. Travis P. Hignett. This is probably the first comprehensive treatment of this extremely important subject--energy as it relates to fertilizer and agricultural sectors.

The publication is based on a major research effort and provides a set of guidelines for government policymakers, fertilizer manufacturers, fertilizer distributors, and personnel engaged in agricultural research or extension in their efforts to save energy and improve energy efficiency in the fertilizer sector. The improved energy efficiency will in turn lower fertilizer prices and expand the contribution of fertilizer to food production.

Enclosed is the Abstract along with an abridged Table of Contents for the study, which provides some additional information. The study is now available at a nominal cost and the information related to obtaining the publication is also enclosed. The Executive Brief of the study, which was published earlier as Technical Bulletin IFDC-T-19, is also available.

IFDC is dedicated to developing and disseminating fertilizer technology and know-how that will improve fertilizer use efficiency, especially in the tropics. This technology will not only save energy but will also result in higher food production to feed the growing world population.

Sincerely yours,

Donald L. McCune

Donald L. McCune
Managing Director

Enclosure

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ABSTRACT

This study deals with economic and technical analysis of the linkages among energy, fertilizer, and agricultural sectors. The main objectives of the study are to estimate energy requirements for fertilizer manufacturing, packaging, transportation, and application; to evaluate the policy implications of energy supply and prices on fertilizer production, distribution, and prices; and to evaluate policy options to reduce the adverse impact of energy supply and prices on fertilizer and agricultural sectors.

Even though the focus of the study is developing countries, policymakers, planners, and researchers dealing with different aspects of fertilizer sector planning around the world will find it useful. The major emphasis of the study is on nitrogen fertilizers which are not only highly energy intensive but are the most popular among developing countries. However, the fertilizer sector accounts for only a small percentage of total energy use. Technical Bulletin No. 19, which was issued as the "Executive Brief," provides highlights of the study.

The most promising means for saving fertilizer energy is more efficient use of fertilizer at the farm level. In fertilizer manufacturing, the greatest energy saving is likely to come from operating existing plants more efficiently. Many energy-efficient innovations are available which together promise potentially large savings in fertilizer manufacture. The potential for energy saving in fertilizer distribution is likely to be small in the short run and should be approached with caution.

The national governments must take the lead in promoting energy-efficient manufacture, distribution, and use of fertilizer. The international organizations can play a crucial role in facilitating the formulation and successful implementation of such national programs.

Keywords: energy, fertilizer, agriculture, developing countries, public policy

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EXECUTIVE BRIEF

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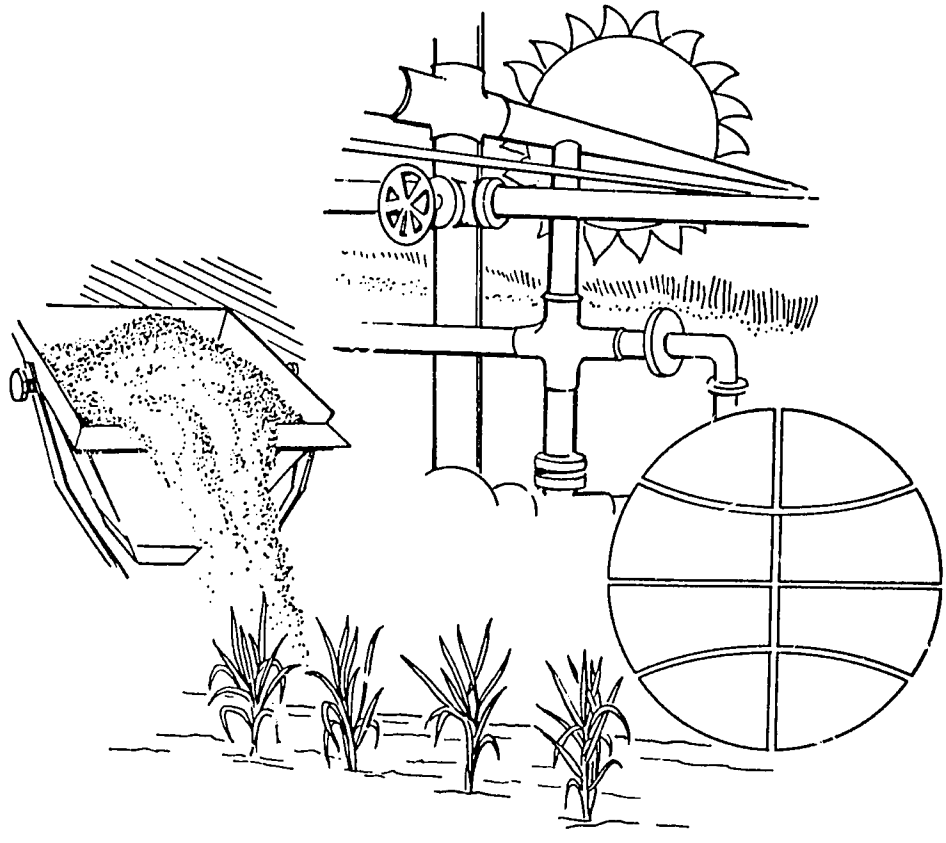

INTERNATIONAL FERTILIZER DEVELOPMENT CENTER

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FOREWORD

At the expected rates of increase, the world population is projected to reach 6.3 billion by the year 2000. Approximately 78% of this population will reside in developing countries. This increase in population represents an addition of about 2 billion people to this spaceship earth. The major challenge faced by all of us in the remainder of the 20th century is to find ways of expanding the production of food, feed, and fiber in order to provide the basic human needs for the rapidly expanding population. Fertilizer is a major factor in expanding the yields and production of food, feed, and fiber.

From 1950 to 1971, the world fertilizer prices declined steadily as advances in technology, economies of scale, and improvements in distribution more than offset rising labor and construction costs. Starting in 1971, skyrocketing energy prices, general inflation, and increases in construction costs have reversed the downward trend in fertilizer prices. In 1980 the world prices of some popular fertilizers such as urea were quadruple the 1971 low. Nitrogen fertilizers are energy intensive, hence, most severely affected; they are also the most popular among developing countries.

Higher fertilizer prices slowed the spread of the "green revolution" except where the adverse effect of higher fertilizer prices was cushioned through massive injection of fertilizer subsidies. The recent increase in energy prices and the resultant increase in fertilizer and food prices pose a renewed threat of economic disaster, especially to the low-income developing nations. Obviously, something needs to be done to avoid the catastrophic consequences on humanity of scarce energy supply and rising energy prices in many developing countries.

It is in this context that the International Fertilizer Development Center (IFDC) initiated a major study at the request of the U.S. Agency for International Development (USAID). Dr. Mudahar, Economist, and Mr. Hignett, Chemical Engineer, of IFDC undertook the study to provide a comprehensive analysis of the linkages between the energy and fertilizer sectors. Specifically, the study deals with assessing the implications of energy supply and prices on fertilizer production and prices, determining energy requirements for fertilizer production and distribution, and evaluating policy options and prospects for improving energy efficiency in the fertilizer sector.

Despite its significance, it is ironic that only about 3.5% of total commercial energy is used for agricultural production in the world. However, fertilizer accounts for about 45% of this energy use. Clearly there is a need not only to provide priority allocation of energy to these sectors but also to improve energy efficiency in all phases of fertilizer manufacture, distribution, and use. Approximately 81% of the total commercial energy consumed in the fertilizer sector is for fertilizer manufacture, and 90% of this is for nitrogen fertilizer alone. The average energy use for manufacture of nitrogen is about 9 times that of phosphate and 11 times that of potash.

The study analyzes ways to save energy and improve energy efficiency in fertilizer production, distribution, and use. The most promising way to save fertilizer energy is to use fertilizer more efficiently. This is especially true of nitrogen fertilizer use in developing countries where the use efficiency may be substantially lower than 40%. An improvement in fertilizer use efficiency will reduce the amount of fertilizer needed to increase food production, improve the economics of fertilizer use at the farm level, and increase agricultural production at the national level. The best way to improve energy efficiency in manufacturing, especially in developing countries, is through efficient utilization of fertilizer plants. For example, an improvement in the operating rate of fertilizer plants not only saves energy per unit of output but also reduces fertilizer production costs and increases fertilizer supply.

The initial results of the study were discussed at the National Academy of Sciences (NAS) workshop on "Energy and Food Production in Developing Countries." The study is published in two volumes. The highlights of the study are contained in this technical bulletin; whereas, the whole study is contained in Technical Bulletin No. 20. The study is expected to provide a useful guide to fertilizer manufacturers, distributors, extension agents, and policymakers in their efforts to improve energy efficiency in the fertilizer sector.

There is an all-out need to design and implement programs to improve energy efficiency in the fertilizer sector in order to ensure that more fertilizer will be available at reasonable prices in the decades to come. IFDC is dedicated to developing and disseminating fertilizer technology and know-how that will improve fertilizer use efficiency, especially in the tropics. This will not only save energy but also result in higher food production.

Donald L. McCune
Managing Director
International Fertilizer Development Center

PREFACE

The fertilizer sector provides an important link between the energy and agricultural sectors. Energy is used as feedstock and/or fuel to manufacture and distribute fertilizer, which, in turn, is a major factor in expanding agricultural production.

The population pressure, limited availability of new cultivable land, ever-increasing energy prices, and scarcity of energy supply further reinforce these linkages. The importance of fertilizer will increase further in order to provide food, feed, and fiber for the expanding population and to earn foreign exchange.

The purpose of this study is to analyze the implications of energy supply and prices on fertilizer production, distribution, and prices and evaluate policy options to reduce the unfavorable impact of energy supply and prices on fertilizer and agricultural sectors.

The summary, conclusions, and recommendations of the study are discussed in this particular technical bulletin, which is directed mainly at the policymakers and administrators in both developed and developing countries. However, the complete details of the study are available in the companion volume, as Technical Bulletin No. 20.

The study was initiated during 1980 in response to a request from USAID. However, in view of lack of a comprehensive study of this nature and its perceived usefulness to a wider audience, the scope of the study was expanded. The highlights of the study were discussed at a workshop sponsored by the NAS on "Energy and Food Production in Developing Countries," Washington, D.C., June 29-July 1, 1981.

The superb research assistance provided by C. David Edwards at different stages of this study is gratefully acknowledged. The authors also wish to thank Mr. Edwin M. Wheeler, President, and Dr. William C. White, Senior Vice-President, of The Fertilizer Institute (TFI) for permission to use their energy use survey for estimating energy requirements in fertilizer manufacture.

SYMBOLS, ACRONYMS, AND ABBREVIATIONS

Fertilizers

DAP . . . . . diammonium phosphate
KCl . . . . . potassium chloride
K_2O . . . . . potassium; expressed as potassium oxide
MAP . . . . . monoammonium phosphate
N . . . . . nitrogen
P_2O_5 . . . . . phosphate; expressed as phosphorus pentoxide
SSP . . . . . single superphosphate
TSP . . . . . triple superphosphate

Organizations and Countries

IFDC . . . . . International Fertilizer Development Center
NAS . . . . . National Academy of Sciences
TFI . . . . . The Fertilizer Institute
U.S. . . . . United States
USAID . . . . . U.S. Agency for International Development
U.S.S.R. . . . . Union of Soviet Socialist Republics

Measuring Units

bbl . . . . . barrel
Btu . . . . . British thermal unit
c.i.f. . . . . cost, insurance, and freight
ft^3 . . . . . cubic feet
f.o.b. . . . . free on board
gal . . . . . gallon
GJ . . . . . gigajoule
ha. . . . . hectare
kcal . . . . . kilocalorie
kg. . . . . kilogram
kWh . . . . . kilowatthour
mt . . . . . metric ton
scf . . . . . standard cubic feet

EQUIVALENT ENERGY UNITS

Gigajoule (GJ)

1 GJ = 10^9 joule
1 GJ = 10^6 x 0.948 Btu
1 GJ = 10^6 x 0.239 kcal

Crude Oil

1 U.S. gallon of crude oil = 0.1457 GJ
1 U.S. gallon of gasoline = 0.1329 GJ
1 U.S. gallon of diesel oil = 0.1498 GJ
1 U.S. gallon of No. 4 fuel oil = 0.1519 GJ

Naphtha

1 mt of naphtha = 47.3 GJ

Bituminous Coal

1 mt of coal = 26.5 GJ

Natural Gas

1,000 scf of natural gas = 1.08 GJ

Electricity

1 kWh = 0.01055 GJ (assuming 34% conversion efficiency)

Objectives of the Study

The purpose of this summary is to provide highlights of a study on energy and fertilizers. The main objectives of the study were (1) to examine the policy issues and linkages between the energy and fertilizer (with an emphasis on nitrogen) sectors; (2) to assess the implications of energy supply and prices on fertilizer production and prices; (3) to estimate energy requirements for fertilizer manufacturing, packaging, transportation, and application; and (4) to evaluate policy options and prospects for improving energy efficiency in order to reduce the unfavorable impact of energy supply and prices on the fertilizer and, hence, on the agricultural sectors. Even though the focus of this study is developing countries, it is expected to be useful for policy-makers, planners, and researchers dealing with different aspects of the fertilizer sector around the world.

Energy and Fertilizer: Policy Problem

Fertilizer is not only a major factor in expanding agricultural output, but its production is highly energy intensive. This is especially the case with respect to nitrogen fertilizers which are the most popular in developing countries. One 50-kg bag of urea, for example, requires as much energy as is contained in about 15 U.S. gal of gasoline.

The world population is expected to increase from 4.4 billion during 1980 to 6.3 billion by the year 2000. Furthermore, the share of developing countries in world population is expected to increase from 73% to 78%, respectively.

The demand for food is increasing rapidly in response to population growth, income growth, and various government efforts to reduce the incidence of hunger and malnutrition. The prevalence of malnourishment is widespread in most developing countries.

Efficient and equitable distribution of available food supplies and implementation of various food subsidy and nutritional programs, specially designed for the low-income comsumers, are extremely important to ameliorate the malnutrition problem. However, the total supply of food that is being distributed must be increased so that these programs can succeed.

Agricultural products other than food crops are also important to developing countries. Feed and fodder crops provide a major share of food for livestock. Export of agricultural products is the main source of foreign exchange in many countries. Fiber

crops are needed for clothing and other necessities, and agriculture often supplies much of the energy needs in rural areas.

Despite the need to earn foreign exchange and expand feed and fiber production, however, the expansion in food production remains the primary goal of most developing countries. Unless the developing countries make a concerted effort to raise their own food production potential, the projected large food deficits and malnutrition cannot be eliminated.

A large proportion of incremental food production must come from an increase in crop yields. The use of chemical fertilizers is an extremely important component of the "package of inputs" and "package of practices" required to achieve an increase in crop yields and, hence, food production.

The fertilizer use level in developing countries is still very low. High fertilizer cost and lack of its availability are major factors for low levels of fertilizer use. The fertilizer production (especially nitrogen) and distribution are not only highly energy intensive, but they depend primarily on nonrenewable energy resources. Consequently, fertilizer supply and price are closely tied with energy supply and price.

The modernization of the agricultural sector in most developing countries was severely hurt by the quadrupling of fertilizer prices during the 1974/75 energy crisis. The recent increase in energy prices and the resultant increase in fertilizer prices are again threatening to sap the vitality from the budding "green revolution" in many of these countries. High fertilizer prices would result in high food prices and thus could jeopardize the national programs to achieve food self-sufficiency and/or better standards of living.

It is therefore vital that fertilizer manufacture, marketing, and use be as energy- and cost-effective as possible, especially where the energy supply is scarce and expensive. This study was undertaken to better understand the relationships between the energy and fertilizer sectors The knowledge of these relationships would then serve as a basis for examining various policy options and designing strategies to improve energy efficiency in order to minimize the adverse impact of increases in energy prices and accelerate the contribution of fertilizer to agricultural growth in the developing countries.

Energy for Fertilizer Sector in Perspective

Food, not commercial energy, is the basis of human survival. However, energy is necessary to produce fertilizer that, in turn,

is necessary to produce food. Yet, ironically, the proportion of total commercial energy used in agricultural production is rather small. As reported in Table 1 for the world as a whole, fertilizer manufacture and distribution consume only about 1.5% of the total commercial energy, and approximately 3.5% is used in the entire agricultural production sector. This energy is used mainly in the form of fertilizers, pesticides, irrigation, and fuel. Of the total commercial energy used in world agricultural production, 45% is used in the form of fertilizers. However, 68% of the energy used in agricultural production in developing countries is in the form of fertilizers. Despite the strategic role of agriculture in economic growth in developing countries, it does not seem to receive priority for energy allocation that is commensurate to its contribution. Since a major component of energy used at the farm level is in the form of fertilizer, any increase in energy price will inevitably have a major impact on fertilizer price, fertilizer use, food production, and food prices.

Table 1. Share of Total Commercial Energy Used in the Fertilizer and Agricultural Sectors

Region	% of Energy Used in Fertilizer Sector	% of Energy Used in Agricultural Production	Fertilizer Sector as % of Energy Used in Agricultural Production
Developed countries	1.3	3.4	40
Developing countries	2.7	4.0	68
World	1.5	3.5	45

The primary plant nutrients are nitrogen (N), phosphate (P_2O_5), and potash (K_2O). Commercial energy is used for manufacturing, packaging, transportation, and application of chemical fertilizers. The average energy requirements for fertilizer nutrients are reported in Table 2. The manufacture of nitrogen fertilizers is highly energy intensive (approximately 9 times that of phosphates and 11 times that of potash). This is in part due to the fact that in manufacturing ammonia, the basic material for all nitrogen fertilizers, energy is used both as feedstock (about 55% of total) and as fuel (about 45% of total). The amount of energy required in fertilizer distribution is rather small. However, in the case of P_2O_5 and K_2O, more energy is used in their distribution than in their production. As reported in Table 3,

81% of the total commercial energy used in the world fertilizer sector during 1978/79 was used in the manufacture of N, P_2O_5, and K_2O and 19% for their distribution. As far as nutrients are concerned, nitrogen is by far the major energy consumer in the fertilizer sector. During 1978/79 the share of energy used in manufacturing and distribution of fertilizers was 82% for N, 11% for P_2O_5, and 7% for K_2O. Nitrogen accounted for 94% of the energy used in manufacturing all of the fertilizers consumed in developing countries.

Table 2. Average Energy Requirements for Fertilizer Nutrients[a] (U.S. Barrels of Oil Equivalents Per Metric Ton of Nutrients)

	Nutrients		
Activity	N	P_2O_5	K_2O
Manufacturing	11.4	1.3	1.0
PTA[b]	1.4	1.6	1.2
TOTAL	12.8	2.9	2.2

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.
b. Refers to packaging, transportation of raw materials and products, and application.

Table 3. Share of Energy Consumption in the World Fertilizer Sector by Activities and Nutrients (1978/79)

	Share (%)			
Activity	N	P_2O_5	K_2O	Total
Manufacturing	73	5	3	81
PTA[a]	9	6	4	19
TOTAL	82	11	7	100

a. Refers to packaging, transportation of raw materials and products, and application.

Changing Structure and Outlook for the Fertilizer Sector

Fertilizer use has been rapidly increasing over time, especially in developing countries. Despite this, the average fertilizer use in developing countries is rather low (approximately 39 kg/ha during 1978), amounting to 52% of the world average and 34% of average use in developed countries. Furthermore, as revealed by the $N:P_2O_5:K_2O$ ratio (5.0:2.2:1.0) during 1978, the fertilizer use in developing countries is dominated by nitrogen. This reflects a certain degree of imbalance in fertilizer use in developing countries, as compared with the nutrient needs of most crops. For comparison, the corresponding $N:P_2O_5:K_2O$ ratio in developed countries is about 1.6:1.1:1.0.

During 1978/79, 107 million mt of plant nutrients was supplied by chemical fertilizers. Of this amount, 27% was consumed in developing countries and the rest in developed countries. The share of world NPK consumption by developing countries is projected to increase to about 31% by 1984/85. The developing countries as a group meet at least one-third of their fertilizer requirements through imports. Countries with serious balance of payment and foreign exchange problems, especially those that import food and energy, are finding it exceedingly difficult to finance fertilizer imports. Some of these countries have chosen to expand domestic production of fertilizers even though this expansion cannot always be economically justified.

The world fertilizer industry, especially nitrogen fertilizer, is going through a process of realignment. This realignment is mainly a response to increases in energy prices. Nitrogen fertilizer production is gradually shifting away from traditional nitrogen fertilizer producers (e.g., Japan) and toward the energy-rich (mainly natural gas) countries. The major raw material for phosphate fertilizers is phosphate rock, which is relatively widely distributed around the world. Morocco and the United States will still continue to dominate the world market for phosphate rock, although many developing countries are planning to use indigenous resources. Since potash deposits are found only in a few countries, the world location and trade patterns are not expected to change very much in the near future. Canada and the U.S.S.R. will continue to be the major sources of fertilizer potash for the world market. Among developing countries Jordan and Brazil are reported to have definite plans for potash production.

Energy and Growth in the Nitrogen Fertilizer Sector

Nitrogen dominates the fertilizer scene at all levels, including fertilizer use at the farm level and aggregate fertilizer

production, consumption, and trade. The degree of dependence on nitrogen fertilizers is relatively greater in developing than in developed countries. It is this dependence on nitrogen fertilizers, much of which are imported, that makes the developing countries relatively more vulnerable to energy shortages and price hikes in the international market. The nitrogen fertilizer industry depends exclusively on ammonia as an intermediate to manufacture nitrogen fertilizers. However, among various nitrogen fertilizers, urea is by far the most commonly used form of solid nitrogen fertilizer (and ironically the most difficult to use efficiently). The proportionate share of urea in the nitrogen fertilizer production capacity in developing countries has increased from 34% in 1971 to 64% in 1979 and is projected to be 67% during 1985.

The world ammonia production capacity has increased from 50.7 million mt (in terms of N) in 1970 to 94.1 million mt in 1980. The share of total ammonia production capacity by developing countries has increased from 17% during 1970 to 27% during 1980. The market outlook for ammonia production seems bright. However, the location and trading patterns are shifting away from traditional supply sources. During 1970 the United States and the U.S.S.R. accounted for 25% and 14%, respectively, of world ammonia capacity. However, during 1985 these respective roles in ammonia production capacity are projected to reverse. Among the developing countries, China, India, Mexico, and Indonesia are emerging as major ammonia producers. It should be noted, however, that urea cannot be produced economically from imported ammonia because carbon dioxide is a necessary raw material that is available at no cost only at ammonia plants.

The sources of feedstock to provide hydrogen in ammonia synthesis include natural gas, naphtha, fuel oil, coke oven gas, refinery gas, coal, and electrolytic hydrogen. During 1980, 71% of world ammonia capacity was based on natural gas. This share is expected to increase still further. At the world level natural gas is clearly the dominant feedstock for ammonia production. However, the proportional share of feedstocks in ammonia capacity varies across world regions and countries. Natural gas, nevertheless, is the most preferred feedstock for ammonia production. This is because ammonia based on natural gas is relatively less energy intensive and capital intensive compared with that based on other feedstocks. Also, the price of natural gas is often lower than that of petroleum-based feedstocks. Considering the prevailing naphtha prices in the international market, it is cheaper to import ammonia and/or urea than to produce urea based on imported naphtha. Ammonia plants based on coal are not yet price competitive with plants based on natural gas.

As far as the availability of feedstocks is concerned, the outlook for ammonia production seems bright. There are large

known reserves of natural gas and other hydrocarbons, which if used for nitrogen production alone can last for centuries. However, the exploitation of these reserves and their allocation for fertilizer production depend on price of nitrogen fertilizers and the opportunity cost of gas. Nevertheless, at current market prices and with modern exploration techniques, the prospects of finding new reserves of natural gas seem rather good. Many "gas-rich" developing countries are already expanding their domestic capacity of nitrogen fertilizers. During 1980 the developing countries' share in estimated proved reserves of natural gas was 47%, and their share in estimated proved reserves of oil was 80%.

Impact of Energy Prices on Fertilizer Production Cost

Fertilizer price is one of the major determinants of fertilizer use at the farm level. Fertilizer prices in turn are heavily influenced by energy prices through an increase in fertilizer production costs. The declining trend in fertilizer prices reversed itself in 1971. Peak-level prices during 1974/75 were at least four times the price levels for 1971. This rapid increase was caused mainly by the energy crisis. However, other economic factors also played an important role in determining the behavior of the international fertilizer market. The prices dropped during 1975 but stayed above the pre-1972 prices. During early 1979 the oil prices started increasing again and led to an increase in fertilizer prices through an increase in fertilizer production costs and freight rates. During the last 15 years, a period of major growth in the fertilizer industry, fertilizer prices have generally been following oil price movements. A further increase in energy prices will result in even higher prices for fertilizer and food.

An increase in natural gas prices results in higher ammonia production costs and, hence, higher urea production costs. However, the actual proportional impact of an increase in natural gas prices on urea production costs depends on at least two other factors: (1) capital costs and (2) plant utilization rate. Higher capital costs and low utilization rates reduce the relative impact of energy price hikes at the expense of increasing total fertilizer manufacturing costs. The fertilizer plants in most developing countries generally have high capital costs and low utilization rates. The developing countries which are creating domestic nitrogen production capacity have their own natural gas reserves, which are available to the fertilizer sector at rather low prices.

At a given price of natural gas, e.g., \$3.50/thousand ft^3, the energy cost component in urea production costs is estimated

to be approximately 46%, 39%, and 34% in developed, developing, and remote sites, respectively. Since prevailing natural gas prices in some developing countries are much lower than those in developed countries, the energy cost component in urea production costs will be even lower (approximately 10%-20%). However, as long as the developed countries control the major share of the international market for nitrogen fertilizers, the f.o.b. and c.i.f. prices will be heavily influenced by the energy prices.

Energy Requirements for Fertilizer Manufacturing

Average energy requirements for manufacturing common nitrogen, phosphate, and potash fertilizers are summarized in Table 4. These estimates are based on an energy use survey in North America during 1979 and information from other sources. Consequently, these estimates are representative of actual energy use by fertilizer plants in operation. However, one must be careful in generalizing these estimates for the developing countries because of the differences in technology, processes, management, and efficiency. As a result, the energy requirements in manufacturing fertilizers may be underestimated for developing countries. Furthermore, the energy requirements are based on high heating value and total rather than battery-limits energy estimates.

There is a substantial variation in energy requirements across different fertilizers, ranging from 79.5 GJ/mt of nutrient content for prilled urea (highest) to 3.8 GJ/mt for nongranular potassium chloride (KCl) (among the lowest). Both phosphate and potash fertilizers use very little energy; most of it is in the form of fuel, electricity, and steam. Since steam and electricity can be generated from any commercial fuel, the manufacture of phosphate and potash fertilizers presents a fairly wide latitude in choice of basic energy sources. On the other hand, nitrogen fertilizers are highly energy intensive and require energy both as feedstock (source of hydrogen for ammonia) and fuel (including steam). Most of the direct and indirect energy uses in the existing fertilizer sector depend primarily on nonrenewable hydrocarbons.

The production of urea requires commercial energy which is over 8 times that of triple superphosphate (TSP) and 19 times that of KCl. This is precisely the reason why many countries that produce ammonia based on imported feedstocks find it difficult to continue operating the existing nitrogen fertilizer industry or plan to phase it out.

Table 4. Average Energy Use for Manufacturing Selected Nitrogen, Phosphate, and Potash Fertilizers

Product		% Nutrients	Average Energy Input, GJ: Per mt of Product	Average Energy Input, GJ: Per mt of Nutrient
Nitrogen fertilizers (N)				
Ammonia		82	46.9	57.2
Urea: prilled		46	36.6	79.5
granular		46	35.0	76.1
Ammonium nitrate:	prilled	34	24.9	73.4
	granular	34	24.4	71.8
Ammonium sulfate:	synthetic	21	12.6	60.0
	byproduct	21	4.7	22.4
Phosphate fertilizers (P_2O_5)				
Ground rock[a]		30	1.2	4.0
Phosphoric acid		54	5.3	9.8
TSP, granular		46	4.3	9.4
DAP, granular		46	14.3[b]	8.6
MAP, granular		54	10.8[c]	8.3
SSP, nongranular		20	1.0	5.0
SSP, granular		20	1.7	8.5
Potash fertilizers (K_2O)				
Muriate:[d]	granular	60	2.9	4.8
	nongranular	60	2.3	3.8
	average	60	2.6	4.2
Muriate:[e]	average	60	4.6	7.7

a. For direct application, dried and finely ground.
b. Contains 18% N. Energy use is 57.2 GJ/mt of N.
c. Contains 11% N. Energy use is 57.2 GJ/mt of N.
d. For North America.
e. For Europe.

Energy Requirements for Fertilizer Distribution

After the chemical fertilizer is manufactured, commercial energy is also required to pack it in bags, transport it to the farm level, and apply it to the crop. However, the total amount

of energy required for fertilizer distribution and application is rather small relative to its manufacture. The major share of energy required for distribution is used in transportation of fertilizer products and raw materials.

Average energy use for fertilizer packaging, transportation, and application is 8.6 GJ/mt of N, 9.8 GJ/mt of P_2O_5, and 7.3 GJ/mt of K_2O. Of this amount, transportation accounts for 52%, 58%, and 63%; whereas, packaging accounts for 30%, 27%, and 24% for N, P_2O_5, and K_2O, respectively. In the case of P_2O_5 and K_2O, since their manufacture is relatively less energy intensive, packaging and transportation account for approximately 46% of the total energy needs on a nutrient basis.

Even though it is difficult to make any generalizations, two other features for fertilizer transportation stand out. First, trucks are the most common mode of transporting fertilizer, especially at the secondary level. Second, truck transportation is highly energy intensive. On the average, trucks use four times more energy than rail and almost nine times more energy than waterways for transporting 1 mt of fertilizer for a distance of 1 mile.

Prospects for Saving Energy in Fertilizer Manufacturing

The probable maximum saving in energy use for new fertilizer plants using available technology is summarized in Table 5 for nitrogen and phosphate fertilizers. Even though, on a percentage basis, the potential energy saving for phosphate fertilizers is large as compared with that for nitrogen fertilizers, it is much smaller in an absolute sense. The saving shown in Table 5 is based on 1979 practice in North America as a reference point.

Scattered data indicate that some developing countries where operating efficiency is low could save a much larger percentage of current energy use by improving capacity utilization, particularly by avoiding frequent shutdowns of ammonia-urea plants. For example, operation of an ammonia plant at 60% capacity may use 25% more energy per ton of product than continuous operation at full capacity.

There do not seem to be any commercially feasible technological breakthroughs in nitrogen manufacturing that would result in major energy saving. Most of the energy saving innovations involving changes and modifications would result in a small percentage energy saving. However, the sum of numerous

savings amounts to a substantial total of 25.5 GJ/mt of urea N; in absolute terms this is the largest energy saving that can be foreseen in fertilizer manufacture. These marginal changes would involve large capital expenditures and can be easily incorporated in new fertilizer plants; some of them can be used in existing plants.

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

Process/Product	Energy Use, GJ/mt of Nutrient Present	Future	Energy Saving (%)
Nitrogen fertilizers (N)			
Ammonia	57.2	42.9	25
Urea: ammonia input	58.7	44.0	25
synthesis	12.0	6.7	44
finishing	8.9	3.5	61
urea total	79.6	54.1	32
Phosphate fertilizers (P_2O_5)			
Phosphate rock for phosphoric acid	3.1	1.5	52[a]
Phosphoric acid production	4.2	2.3	45[b]
Phosphoric acid concentration	2.9	0.0	100[c]
Sulfuric acid for phosphoric acid	-3.7	-5.0	35
Total for phosphoric acid[d]	6.5	-1.2	118
DAP production[e]	2.0	1.7	15
Total for DAP	8.5	0.5	94

a. Eliminate drying.
b. Less grinding.
c. Eliminate.
d. Net energy use from external sources.
e. Not including energy for N input.

Energy substitution innovations are limited but do exist for both feedstock and fuel. Some of these innovations are technically feasible but relatively more expensive. However, the situation may vary from one country to another depending upon the economics, raw material reserves, level of industrialization, and the size of the fertilizer market. Many countries with a domestic supply of raw material (coal for ammonia, for example) may find it a nationally attractive strategy from the security point of view to switch from imported to domestic feedstock, even if it does not save energy and is more expensive.

Similarly, many marginal changes can also result in an energy saving in manufacturing phosphate fertilizers. Some of these innovations include (1) use of undried (wet) rock; (2) wet grinding of rock or completely eliminating it; (3) the use of the hemihydrate process in phosphoric acid manufacture, as opposed to the commonly used dihydrate process, which eliminates the need for concentrating the acid; and (4) generation of electric power from waste heat.

However, before making any changes in existing or even in new fertilizer plants which are supposedly more efficient, it is extremely important to ask "How much energy is being saved and at what cost?" Saving a small amount of energy for the sake of saving it does not provide very strong economic justification to make large capital investments.

Energy Saving by Supplementing Chemical Nitrogen Sources

In rapidly modernizing and intensive agriculture it is not possible to completely replace nitrogen or other nutrients supplied by chemical fertilizers. However, there is a need to supplement nutrients supplied by chemical fertilizers with nutrients from organic and biological sources.

Some preliminary estimates indicate that two-thirds of the total nitrogen of the world is supplied by organic and biological sources; whereas, only one-sixth is supplied by chemical fertilizers. Clearly, these large magnitudes of nutrients supplied by nonchemical sources cannot be easily ignored.

The use of organic fertilizers not only adds crop nutrients to the soil but also has a positive effect on crop yields through the interaction effect, water effect, micro-organism effect, and soil structure effect. Furthermore, if properly handled, it can also solve waste disposal problems and be a source of energy through bioconversion. However, one should be aware of the fact that organic fertilizers are bulky, are expensive to transport, could be a health hazard, and do compete in some cases with alternative uses either as fuel or as feed. Even in countries like China where the use of organic wastes as a source of plant nutrients has received the highest priority, the need to supplement organic wastes with chemical fertilizer has been recognized, as witnessed by China's recent additions of several large ammonia/urea plants.

Biological fixation of nitrogen is another major source of nitrogen. Many organisms, including blue-green algae, fix atmospheric nitrogen either in symbiosis with other plants or

asymbiotically. However, the processes involved in fixing nitrogen biologically are not yet very well understood. Whatever is empirically known indicates that there is a large potential to fix substantial amounts of nitrogen biologically. Contrary to common belief, biological fixation of nitrogen is not always free and does not always save energy, particularly as related to cereal crop production. There may also be a trade-off between crop yields and biological fixation of nitrogen.

The available empirical evidence indicates that, under present fertilizer practices, there exists a negative correlation between nitrogen fixed biologically and the presence of nitrogen supplied by chemical fertilizers. The nitrogen fixed biologically can, however, be increased through more appropriate fertilizers and better fertilizer management practices.

Energy Saving Through Efficient Fertilizer Marketing

The fertilizer marketing systems in many developing countries are not very efficient. These systems need to be streamlined in order to reduce energy use, reduce marketing costs, and make the fertilizer available to farmers on time.

Fertilizer transportation is the major consumer of energy needed in fertilizer marketing. Since major transportation modes use hydrocarbons as fuels, the transportation costs are very sensitive to energy prices. The approximate share of freight costs in c.i.f. fertilizer prices in India during 1980 is reported, as an example, in Table 6. The contribution of freight costs to c.i.f. prices is estimated to be 19% for urea, 21% for DAP, and 36% for KCl. Furthermore, from 1978 to 1980 the freight costs have increased by 97% for urea, 102% for DAP, and 181% for KCl. Any increase in energy prices will be reflected in a major way in higher c.i.f. fertilizer prices. Since most developing countries import part or all of their fertilizer needs, any increase in energy prices would result in higher fertilizer prices. This situation would also be true for countries importing fertilizer raw materials and intermediates and for in-country transportation.

Some ways to reduce energy consumption in fertilizer transportation are: (1) to import fertilizer in large shiploads and use larger conveyances when they are practical, (2) to provide preferential berthing facilities at ports to ships carrying fertilizer, (3) to maximize load factor, especially backhaul, (4) to use slower speeds when economical, (5) to make great use of waterways and rail, (6) to move fertilizer in bulk, if practical, and (7) to use high-analysis fertilizers with due regard for secondary nutrients.

Table 6. Approximate Share of Freight Costs in c.i.f. Fertilizer Prices in India During 1980

Product	f.o.b. Price[a] $/mt	Freight Rate[b] $/mt	c.i.f. Price $/mt	% Share of Freight
Urea	208	49	257	19
DAP	225	61	286	21
KCl	107	60	167	36

a. The f.o.b. prices refer to bagged urea from Western Europe, DAP in bulk from the U.S. Gulf, and KCl in bulk from Canada.
b. The freight rates refer to those of Netherland-India for urea, U.S. Gulf-India for DAP, and Vancouver-India for KCl.

Energy Saving Through Efficient Fertilizer Use

An improvement in fertilizer use efficiency promises the greatest saving in energy use. The available empirical evidence indicates that not only nutrient recovery from applied fertilizers is low but also the productivity of recovered nutrients is low. For example, more than 60% of applied nitrogen is lost and may become a source of air and water pollution. Approximately 15%-20% of applied phosphate fertilizers is taken up by the crop, and the rest is fixed in the soil to become available to the succeeding crops in the next 10-20 years. The potash fertilizers appear to behave somewhere between nitrogen and phosphate after they are applied.

The efficiency of applied fertilizers can be improved through appropriate fertilizer technology and management. The appropriate fertilizers, especially in the case of nitrogen, include (1) controlled-release fertilizers, (2) fertilizers amenable to deep placement, (3) more efficient forms of N, and (4) compound fertilizers. On the other hand, appropriate fertilizer management includes (1) right nutrient dose, (2) proper nutrient balance, (3) right time of application, and (4) right method of application. For example, heavy applications of nitrogen alone are wasteful when other, less energy-intensive nutrients are limiting yields.

The potential economic benefits and saving in the form of energy are substantial enough to justify efforts to improve fertilizer use efficiency. The potential saving in nitrogen,

energy, or production of additional grain through improved nitrogen use efficiency is summarized in Table 7. Doubling the efficiency of nitrogen use in the world can annually result in a saving of 20.6 million mt of nitrogen worth $11.3 billion, a saving of energy equivalent to 262 million barrels of oil worth $7.8 billion, or production of 200-300 million mt of additional grain. Greenhouse and field plot experimental results indicate that it is technically possible to at least double nitrogen use efficiency. The target of doubling N use efficiency is a challenging and worthwhile goal for everyone involved in the fertilizer sector.

Table 7. Potential Economic Benefits of Doubling Nitrogen Use Efficiency During 1978/79

Region	Nitrogen Saving[a]		Equivalent Energy Saving[b]	
	Million mt	Billion $	Million bbl	Billion $
Developed countries	13.4	7.4	171.1	5.1
Developing countries	7.2	3.9	91.4	2.7
World	20.6	11.3	262.5	7.8

a. Assuming existing average nitrogen use efficiency of 40%.
b. Energy in the form of crude oil.

Energy and Fertilizer: Policy Recommendations

1. Fertilizer is a major factor in expanding food production to meet the needs of the growing population and rising expectations of developing countries. Appropriate fertilizer sector planning should receive a high priority. However, the plans should be designed and implemented carefully with as much emphasis on energy efficiency as is consistent with ensuring sufficient fertilizer supplies, increasing fertilizer productivity, reducing fertilizer prices, and other economic considerations.

2. The most promising means for saving fertilizer energy is more efficient use of nitrogen at the farm level. Increased

fertilizer use efficiency will not only save energy but also improve fertilizer productivity and economics at the farm level. High fertilizer use efficiency can be attained by (a) better timing and placement of nitrogen fertilizers, (b) use of more efficient forms of nitrogen fertilizers, (c) use of greater proportions of the less energy-intensive primary fertilizer elements (phosphorus and potassium) where soil contains limited supplies of those elements, and (d) identification and correction of deficiencies with respect to secondary and micronutrients.

3. Appropriate fertilizer timing, placement, and nutrient balance often are not widely practiced by farmers. This is due to several reasons, including lack of recommendations, inadequate farmer education, late fertilizer deliveries, unavailability of the right kind of fertilizers, or delay in approval of fertilizer loans. Appropriate fertilizer programs need to be designed and implemented to correct these deficiencies. For example, balanced nutrient use could be ensured by supply of NP or NPK compound fertilizers of appropriate ratio, which contain secondary or micronutrients that are known to be needed.

4. Research dealing with improvement of fertilizer use efficiency should receive high priority, especially in the context of cropping systems and integrated nutrient management. Increased emphasis needs to be placed on continued research to update fertilizer recommendations, to improve fertilizer management practices, and to develop products that are easier to use efficiently--compound fertilizers, granular urea, and controlled-release fertilizers. In many cases urea may not be the most cost-effective nitrogen fertilizer; other nitrogen sources should be considered. Modified fertilizers need to be evaluated on a large scale for different crops, under farmers' field conditions, under varied agroclimatic conditions, and under different socioeconomic conditions and resource endowments. Further research is needed to make better use of biologically fixed nitrogen and of crop residues or other organic materials.

5. As far as fertilizer manufacturing is concerned, the greatest energy saving is likely to come from operating existing plants more efficiently. For example, an operation of ammonia-urea plants at 60% capacity (frequent shutdowns) may use 25% more energy per ton of ammonia than continuous operation at full capacity. An improvement in operational efficiency of fertilizer plants also results in higher fertilizer production and lower per-unit production costs. Further study is needed to determine the implications of power interruptions on energy use, operating rates, and fertilizer production costs.

6. For manufacturing nitrogen fertilizers, no single major technical breakthrough is in view that will drastically reduce the energy requirements. However, many energy-efficient innovations are available that together promise potentially large energy savings in fertilizer manufacture. Some of these innovations can be added to existing plants, and most can be incorporated in new plants. However, these process modifications are not always economical and may adversely affect reliability. Careful consideration is needed to balance prospective energy savings against possible adverse effects. There is need to study economic costs and benefits of various energy-saving technologies for countries with different raw material supply scenarios. The techno-economic feasibility of small-scale fertilizer plants for landlocked developing countries with small market and potential for hydroelectric power generation or other natural resources deserves further evaluation.

7. The potential for saving energy in fertilizer transportation and distribution is likely to be small in the short run. Any efforts to save energy in fertilizer distribution should be approached with caution to ensure that they do not interfere with the primary objective of getting the right kind of fertilizer to the farmer on time and in good condition. In fact, more energy use in fertilizer distribution could be cost-effective in some cases if spent on better, stronger, smaller bags or more prompt delivery. In the long run, an energy saving could result from better planning, greater use of rail and waterways for transport, shipping in bulk when practical, importing few selected fertilizers in large shiploads, and using high-analysis and compound fertilizers.

8. Unless national security dictates it, no energy-saving innovation in the fertilizer sector will be adopted by individual decisionmakers if its use is not economic. If fertilizer prices continue to increase as a result of energy price hikes, the policymakers must ensure that economic returns to fertilizer use do not decline. In this context, there is need for research on the role, options, and implications of various economic incentive programs, including fertilizer subsidies. This should be done in the context of fertilizer-related national goals, including (a) improving the efficiency of fertilizer use, (b) achieving balanced fertilization, and (c) saving nonrenewable energy.

9. Appropriate information is prerequisite for designing and implementing effective government policies. Those policies that are based on sound information and economic analysis with respect to their costs and benefits would have a relatively higher degree of success than those that do not have any scientific base. Energy use estimates based on

country-specific energy surveys of fertilizer plants in operation provide a more realistic basis for energy use analysis, potential for energy saving, and energy-related costs. Modified fertilizer technology needs to be evaluated with respect to its impact on energy costs and requirements in all phases of fertilizer manufacture, distribution, and use.

10. The national fertilizer programs will not succeed unless there is a strong commitment and active support on the part of the government to implement them. The government must take the lead in promoting energy-efficient manufacture, distribution, and use of fertilizer. This could be accomplished through appropriate incentives, interventions, education, research, regulation, or some combination of these actions. The food-, fertilizer-, foreign exchange- and energy-deficit developing countries must give a high priority to designing and implementing fertilizer programs based on these recommendations if they are serious about raising the standards of living of their people The international research, technical assistance, and financial organizations can play a crucial role in facilitating the formulation and successful implementation of such national programs.

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INTERNATIONAL FERTILIZER DEVELOPMENT CENTER
P.O. Box 2040
Muscle Shoals, Alabama, U.S.A. 35660