Fertilizers

INDUSTRIAL CODES

NAICS: 32–5311 Nitrogenous Fertilizer Manufacturing, 32–5312 Phosphatic Fertilizer Manufacturing, 32–5314 Fertilizer (Mixing Only) Manufacturing

SIC: 2873 Nitrogenous Fertilizers, 2874 Phosphatic Fertilizers, 2875 Fertilizers, Mixing Only

NAICS-Based Product Codes: 32–53111, 32–53114, 32–53117, 32–51321, 32–51324, 32–51327, 32–531401, and 32–531402

PRODUCT OVERVIEW

The major fertilizers used are based on nitrogen, phosphorus, and potassium. Potassium is often referred to as *kalium* in Latin and is abbreviated *K*. Producers of fertilizers routinely put the *NPK* content of fertilizers on the packaging. Gardeners and farmers know just which combinations of these three vital ingredients they need at which time of the season.

Nitrogen. Nitrogen is 78 percent of the earth's atmosphere. The element, however, occurs in paired atoms tightly bonded to each other and thus are not reactive chemically. Very small amounts of nitrogen come down in rain, produced by lightning. Living things are built of proteins of amino acids. Every amino acid has an amino group in which nitrogen holds hydrogen atoms and an acid group made up of carbon bonded to oxygen atoms. Without nitrogen to help build it, no life can exist. Nitrogen-capture from the atmosphere, consequently, is a basic cycle in nature. It is efficiently accomplished by bacteria living in symbiotic relationship with legumes and other families of plants. In biology nitrogen is most commonly present as ammonia (NH_3) and as ammonium (NH_4) compounds. Bacteria producing these groups are rewarded by their hosts with payments of sugar. These are rhizobial bacteria, named after the word for *root* in Greek; they are most concentrated in root systems. When plants die some of the nitrogen remains present in the decaying vegetation and some is converted back into atmospheric nitrogen by other, so-called denitrifying, bacteria. These activities together constitute the nitrogen cycle.

Humanity has traditionally employed three methods of supplying nitrogen to the soil. One has been to plow back plant wastes that still hold ammonia. Another has been to use animal wastes as manures. Wastes are rich in nitrogen (ammonium hydroxide, a liquid, as decaying protein, and as urea, the last made in the liver and expelled in urine). Human wastes were also used to fertilize certain crops. The third approach used has been crop rotation. Planting crops like beans, peas, peanuts, lentils, and soybeans—or clover or alfalfa—renews soil fertility because these legumes (formally the *Fabaceae*) are most strongly associated with rhizobial bacteria that naturally fix nitrogen. Traditional approaches continue in use in parts of the world and even in industrialized countries by those engaged in organic gardening and agriculture. The dominant modern approach is to use manufactured nitrogen products, which require substantial amounts of energy to make.

The industrial method of nitrogen fixation was invented in the first decade of the twentieth century (1908–1910) and is known as the Haber-Bosch process. It is easy, conceptually, to grasp what happens. Methane is one atom of carbon surrounded by four atoms of hydrogen. Ammonia is one atom of nitrogen surrounded by three atoms of hydrogen. If we pluck the carbon out of methane and replace it with a nitrogen, the job is done. We will have one hydrogen left over or, if we react the product further, we can keep methane's fourth hydrogen as well to make ammonium compounds such as the common solid fertilizer ammonium nitrate. In actual fact the Haber process and its variants require multiple sequences in which methane is processed into a synthesis gas containing the right proportion of nitrogen and hydrogen. The actual synthesis of ammonia is the last of several stages. Each stage is facilitated by catalysts and heat. Temperatures ranging between 572 and 1022 degrees Fahrenheit are needed—as well as relatively high pressures which also require energy. Furthermore, and most relevantly, the raw material of nitrogen fertilizer is itself humanity's cleanest high-energy fuel, natural gas. The carbon taken out of methane is released as carbon dioxide.

Ammonia is a gas that liquefies under pressure or when cooled. It can be used in that form if injected below the soil grade to minimize its loss to the atmosphere. It dissolves in water readily to form ammonium hydroxide and can be sprayed on crops. It also comes in solid forms of nitrate fertilizers or is compounded with phosphate.

Phosphorus. Like nitrogen, phosphorus is a crucial element of proteins. A phosphate group is present in every component of deoxyribonucleic acid (DNA) and in ribonucleic acid (RNA), the genetic code and its messenger/transfer agent. Neither life nor its hereditary transmission is possible without the P in NPK. Phosphorus is a widely occurring element. It is very reactive and is not encountered in elemental form. It occurs as phosphate rock, made up of phosphate and calcium. The word phosphate is the collective designation of a family of compounds derived from phosphoric acid (H_3PO_4). Phosphorus-rich deposits have formed, and continue to form, at the bottom of oceans, the phosphorus thought to originate from once-living creatures. The largest deposits of phosphate rock in the United States (in Florida and North Carolina) were at one time at the bottom of oceans, revealed by marine fossils embedded in the rock. Other phosphorus -rich rock deposits, however, have no such tell-tale signs, with the consequence that geologists still continue to study the origins of phosphorus in nature.

Producers mine and crush phosphate rock to reduce it to fine size. Screening removes waste to the extent possible. The aim of processing is to concentrate the active element as phosphorus pentoxide (P_2O_5), achieved by processing the beneficiated rock with 93 percent sulfuric acid. Phosphate content is increased; gypsum (calcium sulfate) is a byproduct. Phosphorus comes to crops in the form of superphosphate, a dilute solution containing 20 percent phosphate, or as triple-superphosphate with 40 to 50 percent phosphate. It can be enriched by compounding the phosphorus with ammonia into ammonium phosphate; this fertilizer may be applied as a solid. All manner of combinations of phosphorus with other nutrients are common.

Potassium. This element is fundamentally involved in cellular regulation, cell structure modification, and in the operation of the nervous system. The concentration of potassium ions inside living cells continuously changes to maintain electrical equilibrium or to concentrate energy potential. Leaves of plants can orient themselves toward the sun and our muscles can tense or relax only because potassium mediates such actions. The element is present in all living entities.

Potassium is very active chemically and occurs in combination with chlorine, oxygen, sulfur, and magnesium. The name is derived from the English *potash*, a word literally derived from ash found at the bottom of a pot in which wood had been burned. This ash, dissolved in water, becomes rich in potassium carbonate (K_2CO_3). The word is somewhat loosely applied to various compounds of potassium, thus to potassium chloride, potassium oxide, potassium hydroxide, and potassium sulfate.

Two major ores of potash are sylvinite (potassium chloride) and langbeinite (potassium magnesium sulfate). The ores have formed by the gradual evaporation of ocean waters in which they had been dissolved long ago and are closely linked to ordinary salt deposits. Most domestic potassium is obtained from three mines in New Mexico (77% of U.S. production), the rest from three operations in Utah and one in Michigan.

Potash is either mined as rock and then processed to concentrate the potassium or is obtained as a brine by pumping water into inaccessible underground deposits. Whether as rock or as brine, the raw input has a high content of clay, insoluble minerals, and ordinary salt. Wet-processing by flotation and screening separate tailings (clay, salt, and fines) from potassium-rich fractions. The latter are dried and further processed into desirable grain sizes for distribution. Large areas of land are associated with potash processing whether for waste disposal or for solar drying of brines, which is also practiced.

Major product categories are muriate of potash (potassium chloride), a dry crystal, potassium sulfate, also dry, applied directly or sold for blending into mixed fertilizers, potassium nitrate used in blends, potassium hydroxide used in liquid fertilizers, and sulfate of potash magnesia, also called Sul-Po-Mag or K-Mag. This last product, a dry substance, is made from langbeinite ores that naturally occur with magnesium.

Minor Minerals. Also important for supporting plant life are minerals usually referred to as secondary fertilizers in the industry. They are more readily available in soil but are incorporated in the major nutrients as additional helpers. These are calcium, magnesium, and sulfur. Calcium is part of triple superphosphate, magnesium in K-Mag, and sulfur is introduced in ammonium sulfate and in potassium fertilizers.

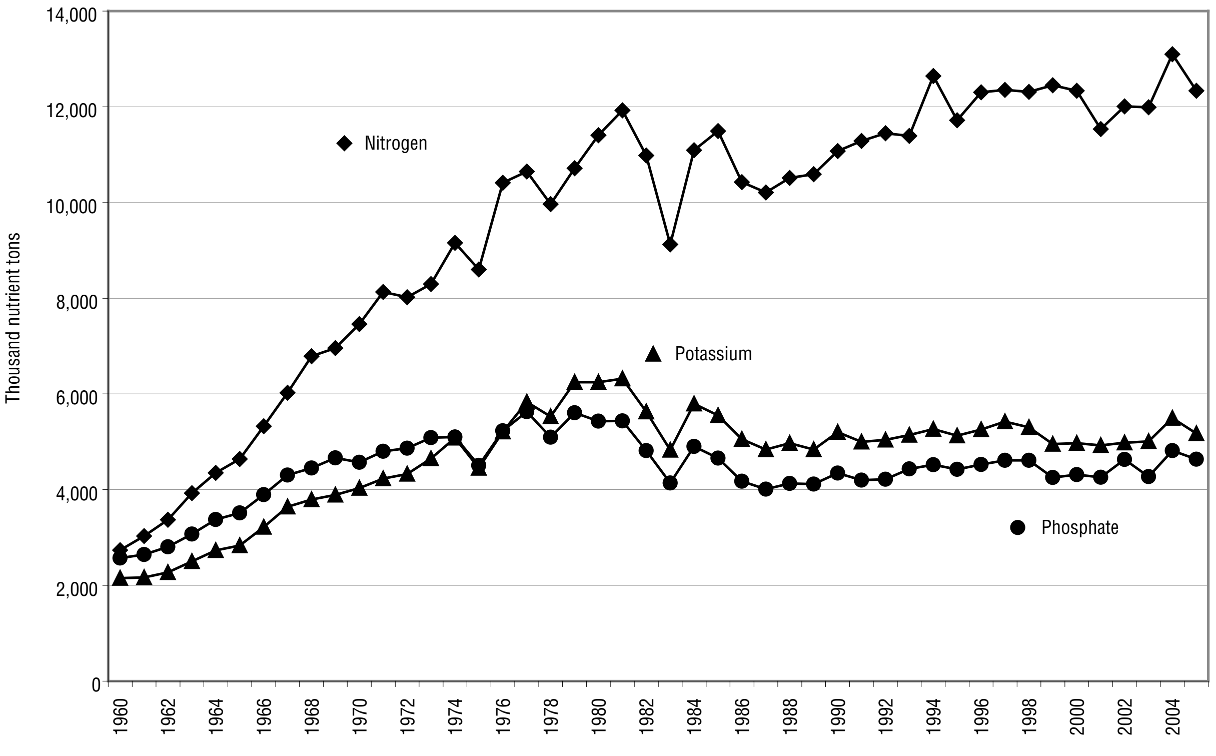
Natural and Manufactured Fertilizers. In looking at the history of modern fertilizer utilization, it is important to keep in mind that fertilizers in the modern sense almost always refer to manufactured products based either on natural gas or mined minerals that require substantial inputs of energy. Within the nitrogenous fertilizer category, for instance, only 1.5 percent of output in 2002 was fertilizer of organic origin, thus activated sewage sludge, processed tankage, and other organic wastes. The modern industry emerged early in the twentieth century. Fertilization by manuring, crop rotation, or letting the soil rest were extensions of natural processes. Intensive fertilization lifted crop yields dramatically. Nitrogen fixation ushered in the Green Revolution in underdeveloped parts of the world. Rapid population growth was one consequence. More food has been available to sustain more people. Life spans also lengthened. The negative consequences of such interventions, although known for a long time, began emerging into full view in the last decades of the century past. These include soil erosion, water pollution, and questions regarding the sustainability of such practices in the long run.

MARKET

The Market in Dollars. In 2005 the three major industries under which the Census Bureau classifies fertilizer production had shipments of $13.75 billion. Of this total nitrogenous fertilizers represented 35.4 percent, phosphatic fertilizers 37.8 percent, and the fertilizer mixing industry 26.9 percent, with shipments, respectively, of $4.86,

FIGURE 91

Fertilizer Consumption in the United States by Type, 1960–2005



SOURCE: Compiled by the staff with data from "U.S. Consumption of Plant Nutrients," U.S. Department of Agriculture, Economic Research Service. 2006.

$5.20, and $3.69 billion. In the Census Bureau classification potassium as a nutrient does not have a unique industrial categorization; potash derivates are present as inputs in the other three industries. Potassium is incorporated into nitrogenous and phosphatic products and is also used in the production of mixed fertilizers. Pricing and nutrient tonnage data provided by the Economic Research Service of the U.S. Department of Agriculture (USDA) indicate that potassium-based products represented approximately $1.27 billion of the $13.75 billion total market in 2005. Organic fertilizers represented an estimated volume of $73 million in 2005, thus barely visible.

In 1997 the market for fertilizers was $12.76 billion, indicating annual compounded growth of 0.9 percent from 1997 to 2005. The component industries, however, had quite divergent rates of growth. Nitrogenous fertilizers increased from a 1997 base of $3.96 to $4.86 billion, showing the most rapid growth, 2.6 percent per year. Phosphatic fertilizers declined from a 1997 level of $5.47 to $5.20 billion in 2005, eroding at the rate of 0.7 percent per year. The fertilizer mixing industry represented a middle ground, growing at 1.3 percent yearly from $3.32 to $3.69 billion.

The growth in the nitrogenous fertilizer sector during this period was due almost entirely to increasing prices rather than growing consumption. All nitrogen-based fertilizers had annual price increases above 3 percent, with the widely used anhydrous ammonia topping the list with a 4 percent annual price increase in that industry. Phosphate shipments declined despite much lower price increases of 1.9 percent per year for superphosphate and 1.4 percent for diammonium phosphate. This category, however, had a small quantitative increase in product shipments measured in weight. Potassium chloride had the highest level of price increases, 6.1 percent per year. It also declined in tonnage shipped between 1997 and 2005.

The Market in Tonnage. Figure 91 shows the dramatic increase in nitrogen-based fertilizer consumption going back to 1960. In that year 2.7 million tons of nitrogen nutrient were consumed by U.S. agriculture. By 2005 tonnage consumed had increased to 12.3 million tons, a 4.5-fold increase. In that same period, phosphate tonnage consumed increased from 2.57 to 4.64 million tons (a more modest 1.8-fold increase). Potassium tonnage grew from 2.15 to 5.17 million tons, a 2.4-fold increase.

Nitrogenous fertilizers have the most direct relationship to yield per acre, indirectly illustrated by the dramatic increase in nitrogen usage in agriculture as shown in the graphic. The largest single crop produced in the United States is corn (maize). Corn is typically grown in monoculture, the same acreage planted with corn year after year, a type of farming that tends to exhaust the soil so that fertilizer use is vital to maintain productivity. In recent decades, however, it has become clear that adding fractionally more fertilizer does not produce an equivalent, linear, increase in yields. Plants are unable to use all of the fertilizer and it runs off into rivers and pollutes groundwater sources. In the more recent period, for which Census Bureau data in dollars are available, nitrogen consumption has been largely flat. This is also visible in Figure 91. Consumption of nitrogen fertilizers actually decreased fractionally between 1997 and 2005, from 12.35 to 12.34 million tons between those years—although 2004 was a record year of consumption with 13.1 million tons reaching croplands across the country. Phosphates had a small increase in tonnage during this period (25,800 tons), potassium a significant tonnage loss (251,600 tons).

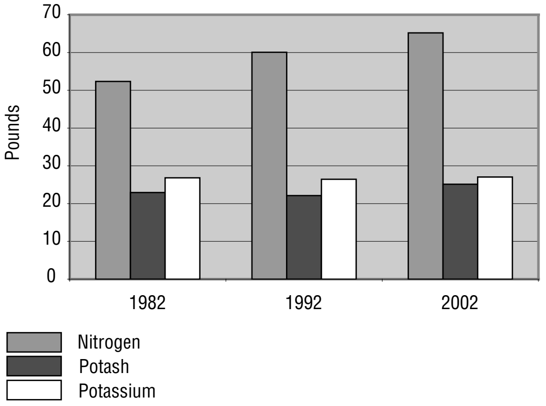
Another view of the market is provided by looking at apparent tonnage of fertilizers applied per acre of cropland. According to the National Resources Conservation Service (NRCS), an element of the USDA, cropland in the United States is decreasing. The decrease is largely attributable to use of land for development to accommodate a growing population and the services it needs. In 1982 NRCS classified 420 million acres as cropland, in 1992 381 million, and in 2002 368 million. Using these data as benchmarks, we can calculate the average weight of fertilizer applied per acre on average in these years. The results are shown in Figure 92.

It is worth noting that in these years nitrogen allocated to the acres of cropland increased from 52 to 60 to 65 pounds per acre. Thus, even in the period after 2002,

FIGURE 92

Pounds of Nutrient Used per Acre of Cropland, by Type

Data are for usage in the United States in the years 1982, 1992, and 2002.



SOURCE: Compiled by the staff with data from "U.S. Consumption of Plant Nutrients," U.S. Department of Agriculture, Economic Research Service. 2006.

when nitrogen fertilizer tonnage remained essentially flat, more nitrogen was still applied per acre if cropland continued to decrease at the rates indicated by the NRCS for earlier years. Application rates for phosphates (rendered as potash in the graphic) went up somewhat. In the potassium category, application rates were essentially unchanged. The application rates shown here are, to be sure, gross averages, derived by dividing total tonnage of nutrients by total acres of cropland. Actual rates of application are significantly higher and are noted in the Key Users section.

Factors Influencing the Market. Modern agriculture, much as everything that characterizes industrial civilization, is dependent on ample supplies of fossil energy for cultivation, for fertilizing the soil, and for killing off competing herbs or insects.

The extent of energy use may be illustrated by an analysis produced by David Pimentel of Cornell University published in *Natural Resources Research* in June 2003. Pimentel's analysis focused on corn production, the nation's largest grain crop, in the context of ethanol production. The growing of corn, Pimentel found, requires energy equivalent to 13.7 million British thermal units (Btus) per acre. The corn produced for this expenditure of energy (around 7,660 pounds per acre) has a caloric content equivalent to 50 million Btus. Thus, at the point of harvesting, the energy balance is favorable, a ratio of 1 unit yielding 3.65 units of energy. To be sure, the energy efficiency diminishes thereafter because the crop requires substantial additional processing and transportation before it appears as food on the table. One frequently encounters estimates stating that a single calorie delivered by the modern food industry requires ten calories of energy as input. In the field itself, however, the balance is positive.

In Pimentel's analysis, of energy consumed in growing corn the largest proportions are accounted for by fertilizers, 37.1 percent of the total. Other major categories are herbicides and pesticides (2.7%) and fuels used to generate electricity used, to move farm machinery, and to transport fuels, seeds, and chemicals to the parcel of land (20.7%). Energy consumption directly related to modern agriculture accounts for minimally 60 percent of all energy used, not counting energy required to manufacture the farm machinery itself or that used in irrigation. The single largest energy-consumptive component in agriculture is nitrogen fertilizer, accounting for 32 percent of all energy used.

Based on this analysis, which is representative of studies carried out by others, the fertilizer industry is tied to future trends in energy generally and to the availability of natural gas particularly. The tie-in—fuels and agriculture—has become even more obvious and complex since the Bush Administration's announcement in the president's 2007 State of the Union address, which set a goal of replacing 20 percent of the nation's fossil fuel use by 2017 by substituting ethanol for gasoline. Corn-production, highly dependent on fossil fuels, is thus viewed at the highest levels as a viable replacement for fossil fuels. Not everyone agrees. Richard Manning, a critic of modern agriculture, wrote an article for *Harper's* in 2004 titled "The Oil We Eat." Manning's chief point was that in modern agriculture humanity transforms oil into food. The new national policy thus suggests another kind of title for an as yet unwritten article, "The Food We Pump." Time and experience will resolve the evident contradictions inherent in this national initiative. In the short term, however, substantially higher rates of corn production will certainly require expanded uses of nitrogen and other fertilizers—either on abandoned acreage reclaimed for agriculture or taken from other crops to grow more corn.

In the absence of extraordinary departures, such as a major shift to ethanol as fuel represents, the fertilizer industry appears either to have reached or to be in the process of reaching natural limits to its growth. With the exception of phosphate fertilizers, which have shown a slight tonnage advance in the 1997 to 2005 period, the other major nutrients have exhibited flat growth as measured in tonnage of nutrients consumed. In large part such results are due to low marginal additions to yield by marginal additions of fertilizer, in part due to water pollution concerns, not least ground-water contamination with nitrogen, in part due to shrinking acreage.

Total acreage in croplands had been declining. At the same time, organic farm acreage, according to data provided by the USDA's Economic Research Service, has exhibited explosive rates of growth. Certified organic farm acreage increased from 638,500 acres in 1995 to 1.72 million acres in 2005, growing at an annual rate of 10.4 percent, representing a three-fold increase in this 10-year period. Total organic acreage, to be sure, remains less than 1 percent of total cropland, but the growth rate at least indirectly indicates response to consumer demand which, itself, is motivated by health concerns. Of the total organic acreage, 33 percent is devoted to gains, with wheat and corn representing the largest components in that order. Beans of all kinds represented 9 percent, and fruits and vegetables 6 percent each of total organic acreage in 2005.

KEY PRODUCERS/MANUFACTURERS

As reported by the Census Bureau, some 116 companies participated in nitrogenous fertilizer and 31 in phosphatic fertilizer manufacturing in 2002. In essence these companies, aside from a handful of potash mining companies reported under mining statistics, were the key producers in the industry. Those engaged in potash mining were also active in phosphate and nitrogen production. A much larger number of companies, 373, were involved in fertilizer mixing operations, taking their inputs from primary producers. Unlike other mature industries, especially in the chemicals sector, fertilizers are not dominated by three or four major companies with the rest of the participants a distant second. Instead, production capacity is widely distributed, especially in nitrogen. Geographically limited potash and phosphate mining have also limited participants. But these companies compete on a global scale with mining companies overseas exploiting indigenous deposits.

In 2001 most of the domestic nitrogen capacity was owned by 19 companies of which the leading producer, the Kansas City-based cooperative, Farmland Industries, had a 16 percent capacity share. Since that time the U.S. nitrogen sector experienced both consolidation and contraction. Natural gas prices moved up in response to demand and later as a consequence of supply curtailments caused by the 2005 hurricane season which ended with two storms, Katrina and Rita, devastating the U.S. Gulf Coast. Long before that time Farmland Industries were bankrupt due to cost squeezes (2002); its elements were sold. Koch Industries, Inc. purchased Farmland's nitrogen business and thus moved into the top ranks of nitrogen producers. Mississippi Chemical Company, a diversified fertilizer producer, filed for bankruptcy in 2003. Price pressures continued to affect the U.S. nitrogen sector well into the first decade of the 2000s so that, in 2006, according to data published by PotashCorp, approximately 30 percent of domestic capacity was largely unused and ammonia was brought in by producers from their overseas-based operations where gas prices were low.

Among the leaders in fertilizers are Terra Industries, Inc., Koch Industries, Inc., CF Industries, Inc., The Mosaic Company, Agrium Inc., and PotashCorp. The last two are Canadian corporations but with U.S.-based nitrogen facilities.

Terra Industries, headquartered in Sioux City, Iowa, is most likely the leading producer of nitrogen-based fertilizers in the United States, reporting production of 4.6 million tons of anhydrous ammonia, 4.3 million tons of urea ammonium nitrate, and 1.8 million tons of ammonium nitrate. The company had sales of $1.8 billion in 2006.

Koch Industries has its headquarters in Wichita, Kansas. After its acquisition of Farmland's nitrogen operations, it had in excess of 3.5 million tons of capacity. Koch is a highly diversified and privately held organization active in food product and fertilizer sales in 60 counties. Koch has 80,000 employees.

CF Industries (CFI) reported sales of $1.9 billion in 2006. The company, operating for many decades as a cooperative, went public in 2005. CFI is located in Deerfield, Illinois.

Agrium, based in Calgary, Alberta, reported sales of $4.2 billion in 2006. The company is a diversified fertilizer producer and also one of the leading retailers of agricultural products to farmers. The company is thus forward-deployed into distribution, the retail portion of its business dominating the production of fertilizers.

The Mosaic Company is what might be called an instant Fortune 500. The company came into being in 2004 when Cargill Corporation's Cargill Nutrition, active in nitrogen fertilizers, came to be combined with IMC Global to form a $5.3 billion (2006) fertilizer company. IMC Global has been a leader in phosphate mining since the 1940s, exploiting its New Mexico mineral holdings by operating its Carlsbad production plant. With IMC now a part of it, Mosaic is the nation's largest phosphate fertilizer producer.

PotashCorp is also known as Potash Corporation of Saskatchewan (PCS). The company had sales in 2006 of $3.7 billion in U.S. dollars. CFI, Agrium, and PCS are all significantly involved in phosphate and potash fertilizer production in addition to producing nitrogen. PCS, indeed, is the leading producer of potash in North America and holds a commanding market share in that product in the world as well. With headquarters in Saskatoon, Saskatchewan, the company owns the largest potash rock deposit in the world. PotashCorp's most profitable ammonia production is centered in Trinidad. Substantial natural gas deposits were discovered there but not exploited until the 1970s and 1980s. Low cost gas available in Trinidad has been one source of ammonia imported into the United States by PCS and others to displace domestic capacity.

Whereas the companies highlighted above are well known in the industry, the public at large is not likely to recognize many of the names, if any. The name most likely to spell fertilizer to the public is Scotts, formally The Scotts Company or The Scotts Miracle-Gro Company (after Scotts merged with Miracle-Gro). Scotts is the unquestioned leader, with fiscal year 2005 sales of $2.3 billion, in the consumer lawn and garden industry.

MATERIALS & SUPPLY CHAIN LOGISTICS

Potash is geographically concentrated in just a few locations across the world. The largest reserves are in Canada (4,400 million metric tons), in Russia (1,800 million), and in Belarus (750 million). U.S. reserves stand at approximately 90 million metric tons. The tonnages cited represent the weight of potassium carbonate (K_2O) in the rock deposits. Metric tons are 2,205 pounds. More than three-quarters of domestic potash production comes from

New Mexico. In 2006, however, more than 80 percent of domestic consumption was imported from Canada.

Phosphate rock is mined in 40 countries across the world. In 2005, 46.1 million metric tons of phosphorus pentoxide equivalent was mined across globe, the United States being the largest producer (10.5 million metric tons), China the second largest (9.1 million), and Morocco the third (8.3 million). Despite high production rates domestically, the United States is a major importer of phosphate rock; the country is a major exporter of potassium fertilizers.

As of 2005, total world reserves of natural gas stood at 6,359 trillion cubic feet (cf). U.S. reserves were 204 trillion cf or 0.3 percent of the world total. In 2004, the last year for which data were available at time of writing, world consumption of natural gas was 99.7 trillion cf. The United States represented 22.5 percent of that consumption (22.4 trillion cf). In the period from 1980 to 2004, the U.S. growth in consumption was a modest 0.5 percent per year, but world consumption rose at a much more rapid rate of 2.68 percent yearly. If we assume gas consumption worldwide at current rates without any growth at all, gas reserves will be exhausted in just under 64 years. If the 2.68 percent growth rate continues, gas runs out in 47 years. If growth accelerates, gas will run out sooner.

If the United States relies entirely on its own reserves (which it does not at present), gas will be mined out in nine years requiring either import of ammonia fertilizers or of natural gas. The movement of natural gas requires considerable energy because the gas must be shipped as liquefied natural gas, or LNG, in special tankers. The gas is held in liquid form at approximately -261 degrees Fahrenheit and under pressure (approximately 3.63 pounds per square inch). Providing the cryogenic temperatures, pressures, and expensive insulated shipping adds to the cost of the fuel/raw material. Rising natural gas prices in the 2000 to 2006 period had already caused cutbacks in domestic production and increases in ammonia imports.

Unless the rosiest expectations of techno- and natural-resources optimists turn out to be right—that large new fields of gas will be discovered as needed—the fertilizer industry is likely to undergo dramatic changes in the early third of the twenty-first century, principally because its most important raw material will be exhausted. Very expensive nitrogen fertilizers will affect, in the first instance, the nation's and the world's grain products. Yields will diminish as organic wastes or crop rotation will have to be substituted to return fertility to the soil.

DISTRIBUTION CHANNEL

Fertilizers reach their ultimate users—farmers—by means of some 7,400 merchant farm supply establishments that had approximately $50 billion in sales in 2007 based on data reported in *Manufacturing & Distribution USA* (*MDUSA*). These organizations also supply the lawn service industry. The relatively small fraction of total tonnage that reaches homeowners is sold in lawn and garden outlets, hardware stores, and by mass merchandisers. The dollar volume includes herbicides, insecticides, seed, and other supplies along with fertilizers.

Farmers' cooperatives play a very important role in distribution. Among 75 leading distributors listed in *MDUSA*, with total sales of $27.6 billion, 26 were cooperatives. Many cooperatives as well as profit-making wholesaler/retailers in this industry are also directly involved in manufacturing at least some of the products they sell in a pattern similar in other branches of what might be called the agricultural-industrial complex.

KEY USERS

When looking at key users of the products of this industry, it is important to distinguish between customers of finished fertilizer and customers who buy chemicals from fertilizer manufacturers. For instance, 78 percent of ammonia production is converted to fertilizers, but 22 percent is sold for industrial uses. Fertilizer manufacturers cultivate industrial sales; these are less affected by increases in price of the underlying natural gas. A portion of phosphate manufacturing is sold as animal feed supplements. Buyers of supplements are less influenced in their buying decisions by price because the supplements represent very small proportions of total feeds but deliver well-known benefits.

The principal users of fertilizers are farmers. Which fertilizers they use and how intensively will depend on the crop or crops they plant. Using four major crops as an example (corn, wheat, soybeans, and cotton) data from the USDA indicate that highest use of nitrogen is associated with corn, with 97 to 98 percent of acres treated. Wheat is second with 80 to 88 percent of acres treated. Cotton is third with 79 to 86 percent of acres receiving nitrogen. Soybean, a crop that by its very character is a natural nitrogen fixer, has the lowest rates of application, 13 to 18 percent of soybean acreage.

Corn farmers are the chief users of fertilizers. They applied the most nitrogen per acre (127–136 pounds), the most phosphate (56–59 pounds), and the most potash (80–84 pounds). Cotton farmers applied the second highest rates of nitrogen (84–100 pounds per acre), soybean farmers the second highest rates of phosphate (47–50 pounds) and of potash (76–88 pounds). Wheat farmers generally occupied a middle ground in these highly fertilized crop varieties.

The role of the ordinary household in fertilizer usage is somewhat difficult to determine because Census data do not provide product breakdowns detailed enough to discern the ultimate destination of major types of fertilizers. At the same time, commercial reporting tends to lump together all lawn and garden chemicals and uses retail pricing as its basis—difficult to relate back to production data. What little information is available indicates that the homeowner consumes somewhere between 13 and 14 percent of the industry's total production.

ADJACENT MARKETS

The modern fertilizer industry represents a major break with traditional farming. It deploys technology and fossil energy to lift soil fertility by artificial means. In effect markets adjacent to fertilizers lie in two directions—in the distant past and in a possible, if problematic, genetic future.

The distant past suggests a return to natural and organic ways of fertilizing soil without the use of nitrogen derived from hydrocarbon sources. Organic farming is expanding quite rapidly and in so doing is using ancient farming methods in new and modern ways. This approach has an enthusiastic but still small public following. It is more labor intensive and consequently produces food that costs more. The costs of modern fertilizers, however, are also rising and may rise dramatically in the future, thus leveling the playing field.

A futuristic solution to avoid fossil-rich fertilizers would lie in modifying plants genetically so that, for example, they attract and hold symbiotic nitrogen-fixing bacteria. Public reaction to genetically modified foods, however, has been mixed. The dangers of "messing with Mother Nature" are becoming more and more visible. Examples in the early 2000s were puzzling die-offs of pollinating bees, mad cow disease, and large dead zones in the waters of the Gulf of Mexico. European resistance to genetically modified foods was spreading to the United States where, for instance, resistance to the use of bovine growth hormone, produced by recombinant DNA modification, was voluntarily shunned by major elements of the dairy industry as a result of adverse public reactions.

Looming shortages of fossil fuels, already signaled by spiking gasoline and very high natural gas prices in the United States, combined with rapidly shrinking supplies of gas, strongly suggest that adjacent markets may become primary markets in the future for ensuring fertile soils and ample food. If all goes well the transition will be smooth and gradual. The fertilizer industry, however, is sure to be transformed in the process.

RESEARCH & DEVELOPMENT

Fertilizer usage is supported by an extraordinarily diverse research activity based on agricultural schools present in every state and in part supported by funds made available by the U.S. Department of Agriculture. USDA's research funding, for all categories, of which fertilizers are a small slice, was running around $1.7 billion annually in the first decade of the 2000s. Research is also supported by the Environmental Protection Agency in the context of ground water pollution. Most projects are focused on specific issues related to crops, or varieties within them. A significant number of the studies being done are aimed at discovering optimal application rates over time to curtail overuse of nutrients and their loss to runoff.

CURRENT TRENDS

As the first decade of the new century was drawing to a close, a handful of developments were pointing, if somewhat vaguely or contradictorily, to the future shape of the fertilizer industry. The most significant of these was rising costs of energy, more specifically of natural gas. In the 1960s, based on data from the Energy Information Agency, well-head prices for natural gas averaged 16 cents for 1,000 cubic feet. In the 1970s prices had risen to 50 cents, in the 1980s to $2.08, in the 1990s they averaged $1.92, and then, in the early 2000s, gas had risen to an average (2000–2006) of $4.96. The price in 2006 was $6.42 per 1000 cf. This run-up in the price of the raw material for ammonia was causing the shuttering of numerous U.S. ammonia plants and growing imports of nitrogen fertilizers from regions with lower gas prices. Total consumption was also flattening out.

Acreage devoted to organic farming was growing at a surprisingly strong rate in the 1995 to 2005 period, 10.4 percent per year overall, 14.9 percent in corn, 11.2 percent in wheat, and 13.4 percent per year in oats. The growth in organic farming might be seen as the early and barely visible greening of a new order, yet to emerge fully into view. Organic agriculture is the old order reborn in a new shape, likely to take a stronger hold as its unfavorable economics are made ever more viable by rising energy costs.

If rising energy prices portend the weakening of industrial agriculture and organic farming the nascent emergence of a response, the national emphasis on ethanol fuels is difficult to fit into the picture. Ethanol is made from corn, the most intensively fertilizer-dependent crop. It would appear that as nitrogen fertilizers grow ever more expensive because of diminishing fossil fuels, fuels based on corn can only be a temporary solution to the problem of transportation energy. Hence the policy promoting ethanol fuels is clearly a short-term fix rather than a sustainable strategy.

Emerging near-term problems in the nitrogen sector will not necessarily impact the entire fertilizer sector in a uniform manner. Rising ammonia costs will tend naturally to cause more farmers to rotate crops. Leguminous crops require proportionally more phosphorus and potassium fertilizers while leaving soil richer in residual nitrogen. Minerals-based fertilizers, therefore, will benefit from pressures created by shrinking natural gas supplies.

TARGET MARKETS & SEGMENTATION

Fertilizers are formulated for specific crops, seasons of application, and specific soil conditions. Product purchasing is closely tied to scientific essaying by farmers who buy their products based on soil analysis and their own experience. The industry routinely produces basic nutrient mixes with the most commonly employed proportions of NPK in the product. Segmentation is therefore largely dictated by the requirements of the targeted plant species, regions, and climates. At one extreme of targeting, refrigerated tanker trucks arrive at the field to dispense liquid ammonia by underground injection. At the other, the home gardener will uncap a tiny bottle of a rose nutrient solution and apply two or three drops to a single plant. Between these two extremes exist very large segments each served by specialized formulations.

RELATED ASSOCIATIONS & ORGANIZATIONS

The Fertilizer Institute, http://www.tfi.org/factsandstats/fertilizer.cfm

International Fertilizer Industry Association, http://www.fertilizer.org/ifa

Minerals Information Institute, http://www.mii.org

BIBLIOGRAPHY

"2006 Overview of PotashCorp and Its Industry." Corporate Brochure. Potash Corporation. Undated.

Darnay, Arsen J. and Joyce P. Simkin. *Manufacturing & Distribution USA,* 4th ed. Thomson Gale, 2006.

Helikson, Helen. "The Energy and Economics of Fertilizers." *Energy Efficiency & Environmental News.* September 1991.

Kirk, David. *Biology Today.* Random House, 1972.

Kostick, Dennis S. "Potash." *Mineral Commodity Summaries.* U.S. Department of the Interior, U.S. Geological Survey. January 2007.

Manning, Richard. "The Oil We Eat." *Harper's.* February 2004.

"Modern Agriculture Footprints." *Redefining Progress.* 2005. Available from <http://www.redefiningprogress.org/pdf_files/Modern_Agriculture_Footprints.pdf>.

"National Resources Inventory, 2002 Annual NRI." U.S. Department of Agriculture, Natural Resources Conservation Service. April 2004. Available from <http://www.nrcs.usda.gov/technical/land/nri02/landuse.pdf>.

"Nutrient Management." U.S. Department of Agriculture, Economic Research Service. Available from <http://www.ers.usda.gove/publications/arei/eib16/chapter4/4.4/>.

"Organic Production." U.S. Department of Agriculture, Economic Research Service. Available from <http://www.ers.usda.gov/Data/Organic/>.

"Phosphate Rock." *2005 Minerals Yearbook.* U.S. Department of the Interior, U.S. Geological Survey. August 2006.

Pimentel, David. "Ethanol Fuel: Energy Balance, Economics, and Environmental Impacts are Negative." *Natural Resources Research.* June 2003. Available from <http://www.ethanol-gec.org/netenergy/neypimentel.pdf>.

"Table 1.2.–11. Description of Fertilizer Materials." *Agronomy Guide 2007–2008.* Pennsylvania State University. Available from <http://agguide.agronomy.psu.edu/cm/sec2/table1-2-11.cfm>.

"U.S. Natural Gas Wellhead Price." U.S. Department of Energy, Energy Information Administration. 30 April 2007. Available from <http://tonto.eia.doe.gov/dnav/ng/hist/n9190us3A.htm>.

"World Proved Reserves of Oil and Natural Gas." U.S. Department of Energy, Energy Information Administration. 9 January 2007. Available from <http://www.eia.doe.gov/emeu/international/reserves.html>.