



U.S. DEPARTMENT OF THE INTERIOR
U.S. GEOLOGICAL SURVEY

Open-File Report 2004-1290

Mineral Commodity Profiles

Nitrogen

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2004

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CONTENTS

Overview	4
History	4
Description.....	5
Uses.....	6
Ammonia.....	6
Urea.....	8
Ammonium nitrate.....	8
Ammonium sulfate.....	8
Nitric acid.....	8
Environmental impact.....	8
Sources of nitrogen	9
Mining and processing.....	9
Chilean nitrate deposits.....	9
Ammonia.....	10
Urea.....	11
Ammonium nitrate.....	12
Ammonium sulfate.....	12
Nitric acid.....	12
The industry.....	12
The market.....	12
Prices.....	16
Supply, demand, sustainable development	16
U.S. supply and demand.....	16
World production, consumption, trade.....	16
Sustainable development.....	19
Nitrogen soil inputs.....	31
Nitrogen soil outputs.....	31
Nitrogen air emissions.....	32
Economic factors.....	33
Costs.....	36
Transportation.....	37
Outlook.....	38
References cited.....	40
Appendix. Selected nitrogen data, 1970–2002.....	42

FIGURES

1. Flow diagram that shows nitrogen fertilizer production routes.....	6
2. Flow diagram that shows principal downstream products of ammonia and their uses	7
3. Flow diagram that shows basic ammonia steam reforming production process	10
4. Pie chart that shows world ammonia production capacity, by region	15
5. Graph that shows U.S. ammonia production capacity and natural gas prices	16
6. Pie chart that shows U.S. ammonia production capacity, by State.....	17
7. Graph that shows average ammonia prices, 1970–2002	18
8. Graph that shows ammonia and natural gas prices	18
9. Figure that shows ammonia supply-demand relationships, 2002.....	19
10. Graph that shows U.S. production and consumption of ammonia, 1970–2002.....	25
11. Map that shows U.S. fertilizer nitrogen consumption, by State, crop year 2001–02	25
12. Pie chart that shows U.S. nitrogen use and crop plantings, crop year 2000–01	26
13. Graph that shows world nitrogen fertilizer nutrient consumption, in crop years	26
14. Map that shows ammonia world trade, by region, 2002	27
15. Map that shows urea world trade, by region, 2002	28
16. Map that shows ammonium nitrate world trade, by region, 2002.....	29
17. Map that shows ammonium sulfate world trade, by region, 2002.....	30
18. Figure that shows the nitrogen cycle.....	31
19. Pie chart that shows nitrous oxide emissions, by source, in the United States, 2001.....	33
20. Graph that shows nitrous oxide emissions in developed countries	34
21. Graph that shows nitrous oxide emissions in developed countries, by region	34
22. Figure that shows the projection of nitrous oxide emissions based on various model scenarios	35

23.	Graph that shows estimated average ammonia production costs of North American producers at various levels of natural gas prices	36
24.	Pie chart that shows projected world ammonia capacity, by region, 2008.....	38
25.	Graph that shows world ammonia trade.....	39

TABLES

1.	Ranges of nutrient contents in multinutrient fertilizers	6
2.	World production in 2002 and production capacity in 1992, 1997, and 2002.....	13
3.	World ammonia production, by country	20
4.	Global sources of atmospheric NO _x , NH ₃ , and N ₂ O, 1990.....	37
A-1.	Salient ammonia statistics	43
A-2.	Major downstream nitrogen compounds produced in the United States.....	44
A-3.	U.S. imports of major nitrogen compounds	45
A-4.	U.S. exports of major nitrogen compounds.....	47
A-5.	Price quotations for major nitrogen compounds at yearend.....	49

OVERVIEW

Nitrogen (N) is an essential element of life and a part of all animal and plant proteins. As a part of the DNA and RNA molecules, nitrogen is an essential constituent of each individual's genetic blueprint. As an essential element in the chlorophyll molecule, nitrogen is vital to a plant's ability to photosynthesize. Some crop plants, such as alfalfa, peas, peanuts, and soybeans, can convert atmospheric nitrogen into a usable form by a process referred to as "fixation." Most of the nitrogen that is available for crop production, however, comes from decomposing animal and plant waste or from commercially produced fertilizers.

Commercial fertilizers contain nitrogen in the form of ammonium and/or nitrate or in a form that is quickly converted to the ammonium or nitrate form once the fertilizer is applied to the soil. Ammonia is generally the source of nitrogen in fertilizers. Anhydrous ammonia is commercially produced by reacting nitrogen with hydrogen under high temperatures and pressures. The source of nitrogen is the atmosphere, which is almost 80 percent nitrogen. Hydrogen is derived from a variety of raw materials, which include water, and crude oil, coal, and natural gas hydrocarbons. Nitrogen-based fertilizers are produced from ammonia feedstocks through a variety of chemical processes. Small quantities of nitrates are produced from mineral resources principally in Chile.

In 2002, anhydrous ammonia and other nitrogen materials were produced in more than 70 countries. Global ammonia production was 108 million metric tons (Mt) of contained nitrogen. With 28 percent of this total, China was the largest producer of ammonia. Asia contributed 46 percent of total world ammonia production, and countries of the former U.S.S.R. represented 13 percent. North America also produced 13 percent of the total; Western Europe, 9 percent; the Middle East, 7 percent; Central America and South America, 5 percent; Eastern Europe, 3 percent; and Africa and Oceania contributed the remaining 4 percent (International Fertilizer Industry Association, 2003b, p. 1-4).

In 2002, world ammonia exports were 13.1 Mt of contained nitrogen. Trinidad and Tobago (22 percent), Russia (18 percent), Ukraine (10 percent), and Indonesia (7 percent) accounted for 57 percent of the world total. The largest importing regions were North America with 36 percent of the total followed by Western Europe with 23 percent and Asia with 22 percent (International Fertilizer Industry Association, 2003b, p. 5L-11).

In 2002, world urea production was 51.4 Mt of contained nitrogen, and exports were 12.0 Mt of contained nitrogen. China and India, which were the two largest producing countries, accounted for 48 percent of world production. The United States and Canada produced about 10 percent of the total. Russia and Ukraine together accounted for 28 percent of total urea exports; Central America and South America, 27 percent; and Asia, North America, and Western Europe, 10 percent each. North America accounted for 36 percent of the total urea imports; Western Europe, 23 percent; and Asia, 22 percent (International Fertilizer Industry Association, 2003f, p. 1-15).

Ammonia production capacity in North America and Western Europe is projected to decline through 2004, and capacity in other world regions is projected to increase. Fluctuating natural gas prices are mainly responsible for the capacity decline in North America. Ammonia production capacity is continuing to shift to world regions that have abundant sources of natural gas, and away from those where costs (raw material, labor, environmental compliance) are higher.

HISTORY

Natural fertilizers, such as manures and ground animal bones, have been used since ancient times. The ideas of rotating crops, letting soil lie fallow, and planting certain crops to enrich the soil are also very old. The modern study of plants, soils, and the chemical requirements for growth was not established until the 1840s in Europe. The first production of fertilizers from inorganic chemical sources also began at this time.

Scientific study established the following elements as being necessary in large quantities for plant growth: nitrogen, phosphorous and potassium. From the 1840s to the present, various deposits of phosphate rock and potash have been found to provide adequate sources of the elements phosphorus and potassium. For nitrogen, however, one source, Chilean saltpeter (NaNO_3), accounted for more than 60 percent of the world's supply for most of the 19th century. Other sources of nitrogen, such as guano, usually were depleted within a few years. Ammonia and nitrates were produced from the distillation of coal and as industrial byproducts of other chemical processes.

Prior to the 20th century, sources of fixed nitrogen compounds were limited to natural organic materials, natural nitrates, and coke-oven byproducts. Two techniques for nitrogen fixation—the cyanamide process and the electric-arc process—were commercially established by 1910, but both required significant quantities of energy. During the first decade of the 20th century, the worldwide demand for nitrogen-based fertilizers exceeded the existing supply. The largest source of the chemicals necessary for fertilizer production was the nitrate deposits along the coast of Chile.

Sodium nitrate mined from natural deposits in Chile was imported into Europe and North America beginning in about 1830. During the 1920s, sodium nitrate imports from Chile were still a very important source of nitrogen in the United States with consumption of about 550,000 metric tons per year (t/yr). Byproduct ammonium sulfate from coke-oven gases became the most important nitrogen fertilizer from the 1920s until 1944 when it was overtaken by ammonium nitrate. Ammonium nitrate, which was imported from Germany, first was used in the United States in 1926. Significant quantities of this nitrogen source were not available to American farmers until 1943, when supplies exceeded the need for munitions. Additional surplus quantities of this material were released for fertilizer use in 1944 and 1945. With the commercialization of the Haber-Bosch process for producing ammonia in the 1950s, ammonia became the principal source of nitrogen in fertilizer in the United States and accounted for about 70 percent of the total (Beaton, undated).

Fritz Haber developed a commercial-scale ammonia production process. Haber invented a large-scale catalytic synthesis of ammonia from elemental hydrogen and nitrogen gas, which are abundant and inexpensive reactants. In the presence of an iron catalyst, Haber forced relatively unreactive gaseous nitrogen (N_2) and hydrogen (H_2) to combine into ammonia at a temperature of about $500^\circ C$ and a pressure of approximately 204 atmospheres (atm) [3,000 pounds per square inch (psi)]. To improve the process and produce greater quantities of ammonia, Haber substituted osmium and uranium catalysts.

Carl Bosch commercialized this process on a large industrial scale by developing an apparatus that safely operated at high pressure and high temperature. Haber's original catalysts, osmium and uranium, had to be replaced by materials that would be cheaper and more easily available. Bosch and his collaborators found the solution by using pure iron with certain additives. Further problems that had to be solved were the construction of safe high-pressure blast furnaces and an inexpensive way of producing and cleaning the gases necessary for the synthesis of ammonia. Bosch went on to use increasingly larger manufacturing units and thus created the industry that produces synthetic ammonia. The resulting industrial-scale process was termed the Haber-Bosch process. The original laboratory-scale process was first demonstrated in 1909 and patented by Haber in 1910. Haber received the Nobel Prize in Chemistry in 1918 for his ammonia production process and, Bosch received the Nobel Prize for Chemistry, jointly with Friedrich Bergius, for their contributions to the invention and development of chemical high-pressure methods in 1931 (Nobel Foundation, undateda, b). Although the Haber-Bosch process has been modified since its development, mostly to improve processing efficiencies, it remains the basis of ammonia production facilities. Introduction of single-train ammonia units in the mid-1960s led to economies of scale, which lowered production costs.

Urea was the first organic compound to be synthesized from inorganic starting materials. It was first discovered in human urine by H.M. Rouelle in 1773. It was synthesized in 1828 by Friedrich Wohler when he attempted to synthesize ammonium cyanate. When treating silver cyanate with an ammonium chloride solution, he obtained a white crystalline material that proved identical to urea obtained from urine. In 1870, urea was produced by heating ammonium carbamate in a sealed vessel, providing the basis for the current [2002] industrial production process.

Johann R. Glauber first synthesized ammonium nitrate in 1659 when he combined ammonium carbonate and nitric acid. The principal use for this material was as a replacement for dynamite and other high explosives. After World War II, ammonium nitrate's use as a fertilizer increased.

DESCRIPTION

Ammonia (NH_3) has a molecular weight of 17.03 and contains 82.2 percent nitrogen and 17.8 percent hydrogen. At standard temperature and pressure, ammonia is a colorless gas with a pungent, readily identifiable odor when it is present in concentrations of greater than 50 parts per million (ppm). Its boiling point is $-33.35^\circ C$, and its melting point is $-77.7^\circ C$.

Urea (NH_2CONH_2 or CH_4N_2O) has a molecular weight of 60.06 and typically contains 45.9 percent nitrogen. At room temperature, urea is colorless, odorless, and tasteless. When it is dissolved in water, it hydrolyzes very slowly to ammonium carbamate and eventually decomposes to ammonia and carbon dioxide (CO_2). This reaction is the basis for the use of urea as fertilizer. Commercially available urea-ammonium nitrate (UAN) solutions typically contain from 28 to 32 percent nitrogen.

Ammonium nitrate (NH_4NO_3) has a molecular weight of 80.04 and contains 33.9 percent nitrogen. It is a white, crystalline salt that is highly soluble in water. The solid salt picks up water from the air when the vapor pressure of water exceeds that of a saturated aqueous ammonium nitrate solution; solid ammonium nitrate does not occur in nature.

Ammonium sulfate [$(NH_4)_2SO_4$] is a white, soluble, crystalline salt that has a molecular weight of 132.14, and contains about 21.2 percent nitrogen. The salt begins to decompose at $100^\circ C$, and forms ammonia and ammonium bisulfate. Above $300^\circ C$, ammonium sulfate decomposition becomes more extensive and forms nitrogen, sulfur dioxide, sulfur trioxide, and water in addition to ammonia.

Nitric acid (HNO_3), which has a molecular weight of 63.01, is a strong acid, a powerful oxidizing compound, and a nitrating agent that contains about 22.2 percent nitrogen. Crystals of pure nitric acid are colorless and stable. Above its melting point of $-41.6^\circ C$, nitric acid is a colorless liquid that fumes in moist air and has a tendency to decompose and forms oxides of nitrogen. The rate of decomposition is accelerated by exposure to light and increases in temperature. It is miscible with water in all proportions. It forms an azeotrope (constant-boiling mixture) with a composition of 68 percent nitric acid and 32 percent water that boils at $120.5^\circ C$. Nitric acid is typically sold as a solution of from 52 to 68 percent nitric acid in water.

Any natural or manufactured material, which contains at least 5% of one or more of the three primary nutrients [nitrogen, phosphate (P_2O_5), potassium oxide (K_2O)], can be called fertilizer. Industrially manufactured fertilizers are called mineral fertilizers. Fertilizers that contain only one primary nutrient are called straight fertilizers. Those that contain two or three primary nutrients are called multinutrient fertilizers, sometimes they are also called binary (two-nutrient) or ternary (three-nutrient) fertilizers. Some of the most important (as well as the regionally important) straight fertilizers that contain nitrogen are as follows:

- Urea is the world's major source of nitrogen because of its high concentration and its usually attractive price per unit of nitrogen. Its application, however, requires exceptionally good agricultural practices to avoid evaporation losses of ammonia to the air. Urea should be applied only when it is possible to incorporate it into the soil either immediately after spreading or when rain is expected within the few hours following the application.
- Ammonium sulfate is not as concentrated as urea. In addition to nitrogen, however, it contains 23 percent sulfur, which is a plant nutrient that is of growing importance. It is used by preference on irrigated crops and where sulfur has to be applied. The same holds true for ammonium sulfate nitrate with 26 percent nitrogen (about $\frac{2}{3}$ in the form of ammonia and $\frac{1}{3}$ in the form of nitrate) and from 13 to 15 percent sulfur.

- Calcium ammonium nitrate with up to 27 percent nitrogen (equal parts of ammonia and nitrate nitrogen) is the preferred fertilizer on crops in semiarid regions of the subtropics.

In general, the three distinct types of multinutrient fertilizers are as follows:

- Complex fertilizers—manufactured through processes that involve a chemical reaction between the constituents that contain the primary plant nutrients (each granule contains the declared ratio of nutrients);
- Compound fertilizers—granulated straight fertilizers or intermediates; the granules containing the nutrients in varying ratios; and
- Mixed fertilizers or blends—simple mechanical mixtures of straight fertilizers (Food and Agriculture Organization of the United Nations and International Fertilizer Industry Association, 2000, p. 32–35).

Table 1 lists the ranges of nutrients in nitrogen multinutrient fertilizers.

Table 1. Ranges of nutrient contents in multinutrient fertilizers.
[Food and Agriculture Organization of the United Nations and International Fertilizer Industry Association, 2000, p. 44. —, Zero.]

Fertilizer type	Percentage		
	Nitrogen	Phosphate	Potassium oxide
Nitrogen-phosphorous-potassium.....	5-26	5-35	5-26
Ammonium phosphates:			
Diammonium phosphate.....	16-18	42-48	—
Monoammonium phosphate.....	11	52	—
Nitrophosphates.....	20-26	6-34	—

USES

Most nitrogen is used in the form of a nitrogen compound, most of which is derived from ammonia. Elemental nitrogen is used extensively by the aerospace, electronics, food, and metals industries because of its cryogenic and inert properties. Nitrogen can be used to prevent fires and explosions, as a purging agent for cleaning and processing equipment, and as a controlling atmosphere for annealing and heat treating and other metal preparation processes in which oxygenation is a concern.

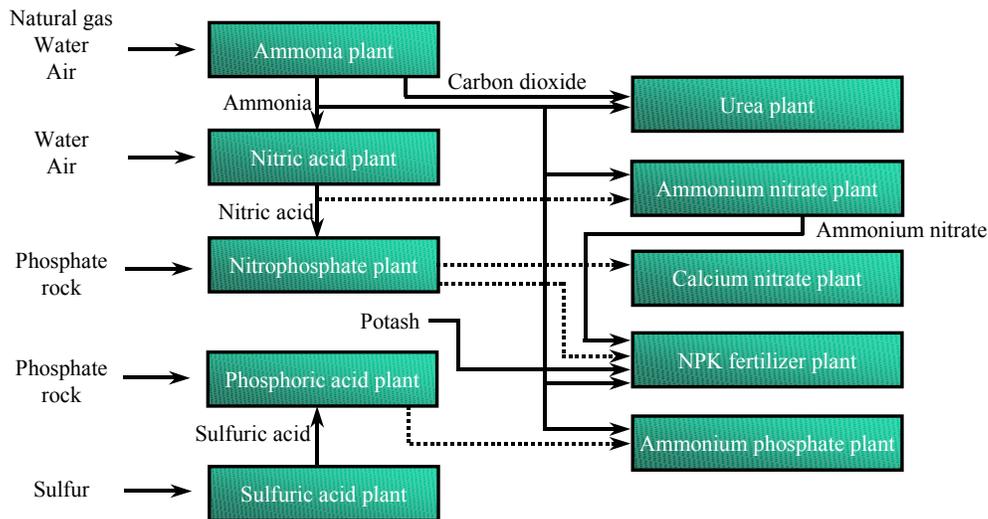


Figure 1. Nitrogen fertilizer production routes. (Food and Agriculture Organization of the United Nations and International Fertilizer Industry Association, 2000.)

AMMONIA

More than 85 percent of the ammonia used in the United States is used for fertilizer applications. Ammonia can be directly applied to the field as a fertilizer, or more often, it is converted into another compound, such as ammonium nitrate, diammonium phosphate, UAN solution, or urea and then used as a fertilizer (figure 1). Figure 2 lists some of the uses for ammonia and the complex relationships among some ammonia-derived products.

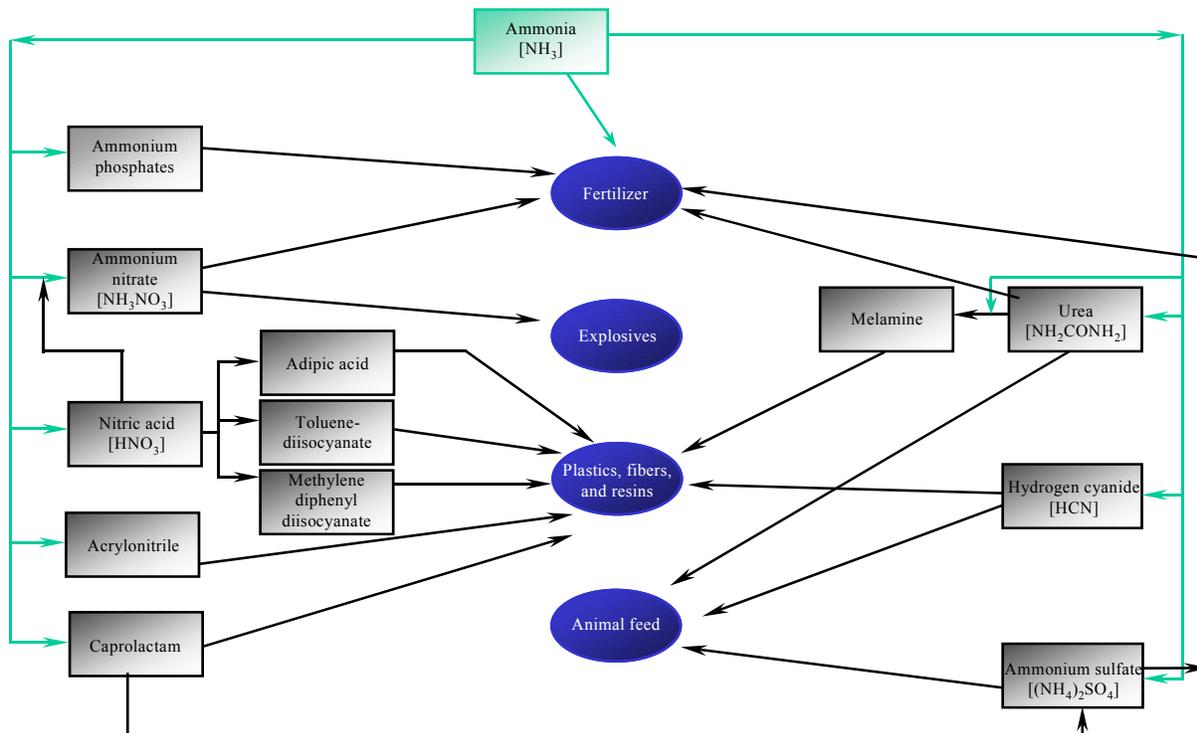


Figure 2. Principal downstream products of ammonia and their uses.

An average corn crop in North America will remove more than 2.7 billion kilograms (Gg) (6 billion pounds) of nitrogen from the soils every year. Each year, hay, which is grown to feed livestock, removes 3.4 Gg (7.4 billion pounds) of nitrogen from the fields, alfalfa hay, 2.2 Gg (4.9 billion pounds); and wheat, which is the most commonly used grain for human foods, 1.1 Gg (2.4 billion pounds). Fruits and vegetables are also big users of nitrogen. Bell peppers, grapes, snap beans, and sweet corn all take up about 112 kilograms per hectare (kg/ha) (100 pounds per acre) of nitrogen. Onions, peas, pineapple, and tomatoes take up from 168 to 224 kg/ha (150–200 pounds per acre) of nitrogen, and potatoes remove more than 280 kg/ha (250 pounds per acre) of nitrogen (Potash Corp. of Saskatchewan, 2001).

Fiber production is the principal nonagricultural use of ammonia. By means of the production of nitric acid, ammonia is used in the production of adipic acid, which is a key intermediate in nylon production. Ammonia also is used to produce caprolactam, which also is used for nylon production, by reaction with cyclohexanone. The caprolactam production process serves as the main source of the world's ammonium sulfate, which is a byproduct. Nitrogen & Methanol (2000) estimated that about 4.5 million metric tons per year (Mt/yr) of caprolactam is produced worldwide, which accounts for about 6.0 Mt/yr of ammonia consumption. Acrylonitrile is another ammonia-based product that is used in fiber production and is manufactured primarily through a catalytic reaction of ammonia with propylene. Global acrylonitrile production, which uses about 2.5 Mt/yr of ammonia, was estimated to be about 5.5 Mt/yr. Hydrogen cyanide, which is manufactured by catalytic synthesis from ammonia and hydrocarbons, is used in the manufacture of adiponitrile, which is used in the production of nylon.

Plastics production is another large nonagricultural use for ammonia. In addition to its use in fiber production, acrylonitrile also is used in the production of acrylonitrile-butadiene-styrene plastics and of synthetic rubber and other elastomers. Hexamethylenetetramine, which is produced from ammonia and formaldehyde, is used in the manufacture of phenolic thermosetting resins. Through urea production, ammonia also is a component of melamine, which is used in adhesives, laminates, paper and textiles, and surface coatings. Global melamine production was estimated to be 450,000 t/yr. Ammonia can be converted, by means of nitric acid, to toluene diisocyanate, which is used in polyurethane production. Ammonia is also converted to nitrobenzene, which is used to make aniline dyes. In addition to its use as a dye, aniline is an intermediate in the formation of methylene diisocyanate, which, in turn, is a component of urethane foams. Acetone cyanohydrin, which is used in acrylic plastics, is manufactured from hydrogen cyanide.

Nitrogen & Methanol (2000) estimated that about 10 percent of nonagricultural ammonia, or about 2 Mt/yr, is used as a refrigerant gas, mainly in large commercial or industrial refrigeration systems. As a refrigerant gas, ammonia is highly energy efficient, relatively inexpensive, noncorrosive, and tolerant of impurities. Also, because of its distinctive odor, small leaks can be identified and repaired before they become serious. Although a significant portion of ammonia has been replaced by halogenated hydrocarbons in this use, the ozone-damaging potential of the hydrocarbons has resulted, in some cases, in a switch back to ammonia. Because ammonia refrigeration systems operate at elevated pressures, these systems must be maintained and operated to prevent releases; ammonia is considered to be a significant health hazard because it is corrosive to the eyes, lungs, and skin.

Ammonia can be a component in the synthesis of methamphetamine, which is of particular concern to drug and law enforcement agencies. Methamphetamines are synthetic amphetamines, or stimulants, that are produced and sold illegally in capsule, chunk, pill,

and powder forms. Methamphetamines stimulate the central nervous system, and the effects may last anywhere from 8 to 24 hours depending on the dosage and concentration of the drug. Methamphetamines can be manufactured in small laboratories by using common ingredients. In one common manufacturing technique referred to as the “Nazi method,” lithium that has been extracted from batteries and anhydrous ammonia are used to convert ephedrine from over-the-counter cold remedies to make methamphetamine. As a result, theft of anhydrous ammonia fertilizer from farms, retail outlets, and even ammonia pipelines for production of methamphetamines has escalated.

UREA

Solid urea, which contains from 0.8 to 2.0 weight percent biuret ($\text{NH}_2\text{CONHCONH}_2$), is primarily used for direct application to the soil as a nitrogen-release fertilizer; biuret is an undesirable component produced by heating urea at a high temperature, which causes the condensation of two urea molecules. Weak aqueous solutions of low biuret urea (0.3 weight percent maximum) are used as plant food applied to foliage spray. Mixed with additives, urea is used in solid fertilizers of various formulations, which include urea-ammonium phosphate, urea-ammonium sulfate, and urea-phosphate (urea plus phosphoric acid). Concentrated solutions of UAN (80–85 weight percent) have a high nitrogen content but a low crystallization point, and are suitable for easy transportation, pipeline distribution, and direct spray application.

Urea is used as a feed supplement for ruminants because it assists in the digestion of protein. Urea also is one of the raw materials used to manufacture urea-formaldehyde resins. At high temperature and pressure, urea (with ammonia) pyrolyzes to form melamine plastics. Urea is used in the preparation of lysine, which is an amino acid widely used in poultry feed. It also is used in some pesticides. Partially polymerized resins of urea are used by the textile industry to impart permanent-press properties to fabrics.

AMMONIUM NITRATE

Before World War II, most ammonium nitrate was used as an ingredient in high explosives. After World War II, its use as a fertilizer grew rapidly to reach about 90% of production in 1975. Most ammonium nitrate manufactured for the explosives market is used in blasting agents prepared by adding a fuel component, such as diesel oil, to the prilled product. This mixture is commonly referred to as “ANFO” (ammonium nitrate-fuel oil). More than 65 percent of the ammonium nitrate-based explosives is used in coal mining; the remainder is used in, in declining order, metal mining, nonmetal mining and quarrying, and highway construction. When used in blasting, ammonium nitrate is mixed with fuel oil and sometimes sensitizers such as powdered aluminum. Lower density ammonium nitrate is preferred for explosive formulation because it absorbs the oil more effectively.

A small but important use of ammonium nitrate is in the production of nitrous oxide gas; during the 1980s, consumption for this purpose averaged about 30,000 t/yr. The gas is generated by controlled heating ammonium nitrate to above 200° C. Nitrous oxide is used primarily as an anesthetic and an aerosol propellant for food products.

AMMONIUM SULFATE

Ammonium sulfate is used mainly as a nitrogenous fertilizer and accounts for about 4 percent of the world’s nitrogen fertilizer market (Nitrogen & Methanol, 2002). Ammonium sulfate has been replaced in some fertilizer applications because of its lower nitrogen content (about 21 percent compared with 34 percent for ammonium nitrate and 46 percent for urea). Ammonium sulfate, however, has about 45 percent sulfur by weight; this is a desirable attribute in areas where soils are deficient in sulfur. Nonfertilizer uses for ammonium sulfate, which account for about 5 percent of world ammonium sulfate consumption, include cattle feed, fire control, food processing, and tanning.

NITRIC ACID

The largest use of nitric acid, which accounts for about 75 percent of total U.S. production, is for the manufacture of ammonium nitrate. The next three largest uses for nitric acid are in the manufacture of cyclohexanone (about 8–9 percent), dinitrotoluene (about 4 percent), and nitrobenzene (about 3–4 percent). Cyclohexanone is a raw material that is used to manufacture adipic acid, which reacts with hexamethylenediamine to make nylon-6,6. Dinitrotoluene is hydrogenated to toluenediamine, which is used to make toluene diisocyanate. Nitrobenzene is hydrogenated to make aniline, which is a raw material that is used to manufacture methylene diphenyl diisocyanate. Toluene diisocyanate is used to make coatings, elastomers, and flexible polyurethane foams, and methylene diphenyl diisocyanate is used for rigid foams. Other uses of nitric acid are in the production of explosives; metal nitrates; metal treatments, such as the pickling of stainless steels and metal etching; nitrocellulose; nitrochlorobenzene; nuclear fuel processing; and rocket propellants (Innovation Group, The, 2002).

ENVIRONMENTAL IMPACT

The production of ammonia generates substantial quantities of CO_2 , which contributes to global warming. If natural gas is used as the feedstock in a modern steam reforming plant, then about 2.7 metric tons (t) of CO_2 per metric ton of nitrogen is produced. If coal or fuel oil is used, then this figure is about 25 percent higher. The production of urea, however, requires an input of about 1.6 t of CO_2 per ton of nitrogen. The fertilizer industry’s share of the annual net addition of CO_2 to the atmosphere that results from human

activities is estimated to be 2 percent; and human activities account for only 7 percent of the quantity released annually by biological processes. Consequently, the share of fertilizer production in the total annual release of CO₂ to the atmosphere is very small (approximately 0.1–0.2 percent). Nevertheless, projected growth of fertilizer use makes it important that the industry keep CO₂ emissions as low as possible. Although ammonia plants continue to try to reduce CO₂ emissions through process improvements, future reductions of CO₂ emissions most likely will be from the replacement of old inefficient plants.

The production of nitric acid used for ammonium nitrate and nitrophosphate fertilizers leads to the emission of nitrous oxide (N₂O), which is a much more potent global warming agent than carbon dioxide. The U.S. Environmental Protection Agency (EPA) (2003, p. ES-10) estimated that N₂O is 310 times more effective at trapping heat in the atmosphere than carbon dioxide during a 100-year time period. It also is considered to be detrimental to the ozone layer. The rate of N₂O emission varies widely from 1 to more than 10 kilograms per metric ton (kg/t) of 100 percent nitric acid. Abatement techniques can reduce N₂O emissions significantly but are costly. The International Fertilizer Industry Association (1998, p. 43–44) estimated that fertilizer production accounts for about 6 percent of human-generated N₂O emissions compared with nearly 50 percent from motor vehicles. Most N₂O recycles to land and water, and as with CO₂, larger quantities are emitted through natural biological processes. N₂O is estimated to be responsible for 7.5 percent of the calculated global warming effect of human activities. Fertilizer production is estimated to be responsible for less than 0.5 percent of this effect.

Nitrogen oxides (NO_x) also are emitted from ammonia and nitric acid plants. Nitric oxide (NO) is oxidized over a few days to nitrogen dioxide (NO₂), which has an atmospheric residence time of about a week and is deposited in air, rain, or as nitrate particulates. This contributes to acid rain and smog. In the case of ammonia, NO_x emissions are about 1 to 2 kg/t of converted nitrogen. For nitric acid, however, NO_x emissions amount to 6 to 9 kg/t of converted nitrogen. Selective catalytic reduction, which uses ammonia to convert NO_x to nitrogen, can be an effective means of abatement, and more than 0.5 Mt of ammonia is used annually for this purpose (International Fertilizer Industry Association, 1998, p. 43–44).

SOURCES OF NITROGEN

The Atacama Desert in South America contains the largest nitrate deposits in the world. Until the 1920s, this was the most important resource for nitrogen fertilizers in the world. Because of these rich nitrate deposits, Bolivia, Chile, and Peru fought to claim the area. Much of the area originally belonged to Bolivia and Peru, but the mining industry was controlled by Chile. Chile emerged victorious in the War of the Pacific, which was fought among the three countries from 1879 to 1883. The Treaty of Ancón gave Chile permanent ownership of the nitrate-containing land. Chile acquired Atacama, which was Bolivia's only coastal territory, now known as Antofagasta. Peru ceded Tarapacá to Chile and surrendered control of Arica and Tacna.

The origin of this unique deposit has been the subject of many theories. Ericksen (1981, p. 1–2) attributed these deposits primarily to the long-term aridity of the environment rather than to an unusual source of saline materials. According to Erickson, saline material came from the spray and evaporation from the Pacific Ocean, from volcanic emissions from the nearby Andes Mountains, and from the nutrient-rich Humboldt Current. The material accumulated slowly on land surfaces that had had little or no modification since the Miocene. It also accumulated on hillsides and at breaks in slopes as the result of redeposition by rainwater and in saltpan and saline ponds. Because the nitrate ores show great local and regional variations in chemical composition, an average composition cannot be determined. The nitrate minerals that are contained in the deposit are soda niter (NaNO₃), niter (KNO₃), darapskite [Na₃(SO₄)(NO₃)•H₂O], and humberstonite [K₃Na₇Mg₂(SO₄)₆(NO₃)₂•6H₂O] (Ericksen, 1981, p. 21).

Other theories that have been proposed for the origin of these deposits are decay of seaweed and other marine vegetation in waters and marshes of partially cut-off inland arms of the sea, nitrification and leaching of seabird guano at the margins of saline lakes, bacterial decay of plant and animal remains during the time of a less arid climate, nitrification and fixation of atmospheric nitrogen from soil bacteria, reaction of feldspathic igneous rocks with atmospheric nitric acid, accumulation of nitrogen compounds of volcanic origin, and nitrate accumulation from diverse sources (Ericksen, 1981, p. 21–23).

The mining right of Sociedad Química y Minera de Chile S.A.'s (SQM) cover an area in excess of 2.2 million hectares, which amounts to more than 75% of the caliche ore in the world. Caliche mainly is rich in sodium nitrate and iodine, with contents of 6 to 9 percent and 350 to 600 ppm, respectively. Crushing and leaching processes are the starting points for the recovery of the salts contained in the ore. SQM's proven sodium nitrate reserves are estimated to be 55 Mt, which is equivalent to 55 years of production. Probable reserves amount to almost another 80 years of nitrate and iodine extraction at current output levels (Sociedad Química y Minera de Chile S.A., undated a).

MINING AND PROCESSING

CHILEAN NITRATE DEPOSITS

The only mined nitrogen material is that from the above-mentioned nitrate deposits in Chile. SQM uses bulldozers to remove the overburden from the deposit and then uses explosives to break up the caliche ore. The broken ore pieces then are loaded into trucks by front-end loaders. Depending on the mine from which the mineral is obtained, it is processed by different methods. The trucks unload the mineral from the Maria Elena Mine over a mobile primary crusher located at the mine site, and then the crushed mineral is transported to the Maria Elena plant by a belt. Ore from the Pedro de Valdivia Mine is stockpiled near temporary train stations where it is loaded onto railroad cars and sent to the Pedro Valdivia production plant. In the Maria Elena and Pedro Valdivia plants, the caliche is mechanically ground to about 12.5 millimeters. The ground mineral is then transferred in containers or cylinders to a

leaching plant where iodine, nitrates, and sulfates are extracted. In the Pampa Blanca Mine, which is located in the Sierra Gorda, the mineral is heap leached to obtain solutions for iodine production. These solutions are transported to solar evaporation pits where the high nitrate salts are crystallized. These salts are transported by truck to the Coya Sur plants where they are used to produce potassium nitrate (Sociedad Quimica y Minera de Chile S.A., undated b).

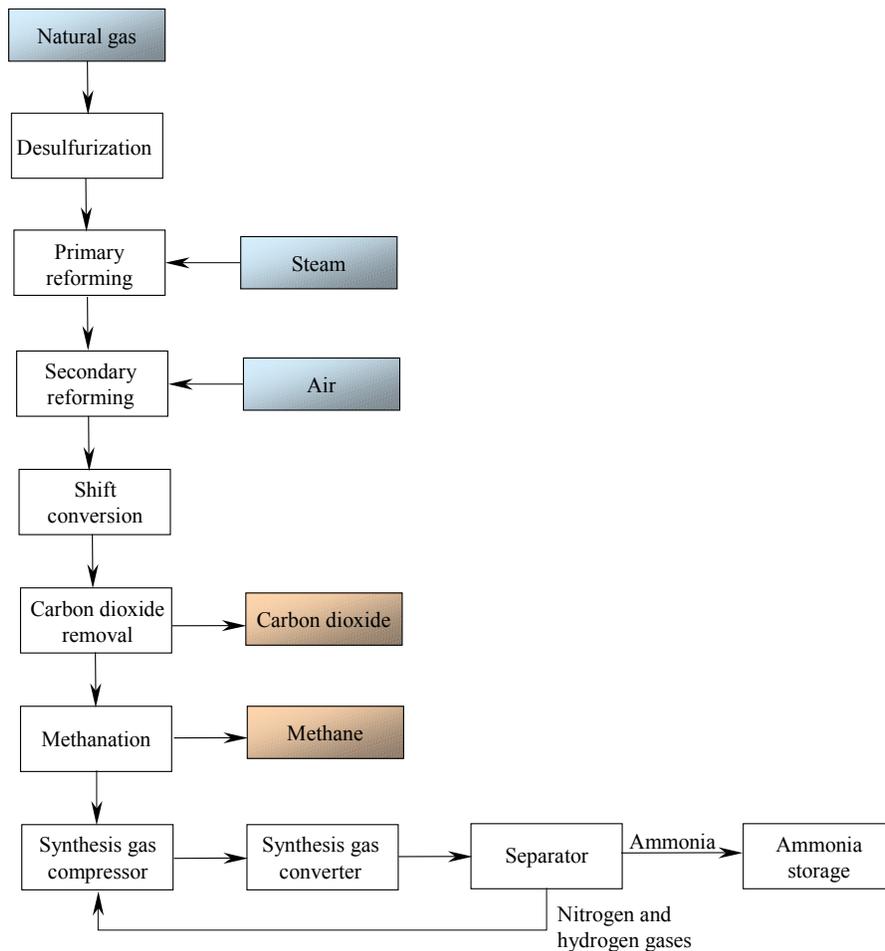


Figure 3. Basic ammonia steam reforming production process.

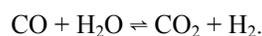
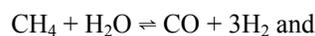
AMMONIA

The raw materials used in most ammonia plants are coal, natural gas, and petroleum fractions. Natural gas is the principal source of hydrogen in most commercial plants in the United States. About 75 to 80 percent of the ammonia produced worldwide is produced by the steam reforming process. This process, which is shown in figure 3, consists basically of the following steps: desulfurization, primary and secondary reforming, shift conversion, CO₂ removal, synthesis gas purification, and ammonia synthesis and recovery. The overall process for producing ammonia from air, natural gas, and water is



where CH₄ is methane.

In the first step (desulfurization), sulfur compounds in the natural gas are removed most commonly by adsorption with activated carbon that ranges in temperature from 15° to 50° C or by reaction with a zinc oxide catalyst at from 350° to 400° C. If sulfur compounds remain in the natural gas stream, then they can poison the catalysts that are used in the remaining process steps. After the sulfur compounds are removed, the feedstock goes through two reforming steps. These steps are designed to break down CH₄ in the natural gas into H₂, CO₂, and carbon monoxide (CO). The reactions that occur during the two reforming stages are



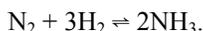
The water (H₂O) component of the above reactions is in the form of steam. The natural gas-steam mixture flows through tubes that contain a nickel catalyst bed. The exit gas is heated to a temperature that ranges from 750° to 850° C and a pressure that ranges from about 28 to 35 atm (415–515 psi). The design of the primary reformer catalyst tubes varies slightly depending on the manufacturing process. A precious metal catalyst can be substituted for the nickel catalyst; precious metals catalysts are used in the Kellogg Advanced Ammonia Process. Undesirable reactions can occur in reforming that generate elemental carbon. Operating conditions must be controlled to minimize these reactions, otherwise the carbon can physically break down the nickel catalyst.

In the secondary reformer, air, which is the source of nitrogen, is introduced. The secondary reformer is a refractory-lined vessel that also contains a nickel catalyst. Combustion of oxygen from the air is used to produce the heat needed to carry out the second reaction, which generates CO₂. The product of the second reforming stage is a mixture of carbon oxides, H₂, N₂, and other gases.

Before ammonia is produced, the CO and CO₂ must be removed from the gas mixture. This is accomplished in a two-step shift conversion, which converts the CO to CO₂, followed by a CO₂ removal step. (The shift conversion is so named because the change in temperature and addition of a catalyst shifts the reaction equilibrium and allows the CO to be converted to CO₂.) The hot effluent gases from the secondary reformer are cooled to a temperature of about 30° C above their dew point and fed to a high-temperature shift converter that operates at temperatures that range from 350° to 450° C. Water vapor in the gas mixture reacts with some of the CO to produce more H₂ and CO₂. An iron oxide-chromium oxide catalyst is used to aid in the reaction. The gas mixture then is fed to a low-temperature shift converter that operates at temperatures that range from 200° to 250° C. Here, most of the remaining CO is converted to CO₂ with the aid of a copper oxide-zinc oxide catalyst.

The CO₂ removal operation also is done in two steps—a bulk CO₂ removal in which the CO₂ concentration is reduced to a few parts per million and a final purification step. The most common bulk CO₂ removal operation is performed by scrubbing the gas with a methyldiethanolamine or monoethanolamine solution, although other chemical or physical absorption methods have been used, such as washing with a potassium carbonate liquid stream. If the ammonia plant is associated with a nearby urea plant, then the CO₂ that is removed may be recovered and used for urea production. Any residual CO₂ and CO then must be removed from the gas stream. This is normally done by converting the CO₂ and CO back to CH₄ by introducing H₂ gas with a nickel catalyst (the reverse of the reforming reactions). After methanation, cryogenic purification is used to remove the methane from the gas stream. In cryogenic purification, the gas is dried to a very low dew point, and then cooled and expanded in a turbine to liquefy a portion of the stream. The vapor from the partially liquefied stream is scrubbed in a rectifying column to remove almost all the CH₄ and about one-half of any unreacted CO₂.

At this point the gas is compressed to between 136 and 340 atm (2,000 and 5,000 psi) and then passed over an iron catalyst where the nitrogen and hydrogen react to form ammonia by the following reaction:



The design of the ammonia synthesis section varies from plant to plant and is dependent upon such factors as the pressure chosen for synthesis, the capacity of the plant, and the thermal requirements for process operation. During the ammonia synthesis, not all the N₂ and H₂ are converted to ammonia. Unreacted gases are separated from the ammonia and recycled to the compressor. The ammonia then is chilled to –33° C to liquefy it and stored in tanks at atmospheric pressure.

After production, ammonia may then be used to produce a variety of downstream products, which include ammonium nitrate, ammonium sulfate, nitric acid, and urea (Czuppon, Knez, and Rovner, 1992, p. 645–673).

UREA

Urea is produced from liquid NH₃ and gaseous CO₂ at high pressure and temperature. Both reactants often are obtained from an ammonia synthesis plant; because of this, many urea plants are collocated with ammonia plants. The CO₂ is a byproduct stream, which is vented from the CO₂ removal section of the ammonia-synthesis plant. The two feed components are delivered to the high-pressure urea reactor usually at a molar ratio of greater than 2.5 to 1. Urea forms by the following reactions:



where NH₂COONH₄ is ammonium carbamate. The formation of NH₂COONH₄ and the dehydration to urea take place simultaneously for all practical purposes.

Urea production yields an aqueous solution that contains from 70 to 87 percent urea. This solution can be used directly for nitrogen-fertilizer suspensions or solutions such as urea-ammonium nitrate solution, or it can be concentrated by evaporation or crystallization for the preparation of granular compound fertilizers and other products. Concentrated urea is solidified in essentially pure form as crystals, flakes, granules, or prills. Solid urea can be shipped, stored, distributed, and used more economically than in solution. In addition, in the solid form, urea is more stable, and biuret formation is less likely. The manufacture of prills, however, is decreasing rapidly owing to environmental problems and product quality compared with granules.

AMMONIUM NITRATE

Historically, ammonium nitrate was manufactured by a double decomposition method that used sodium nitrate and either ammonium sulfate or ammonium chloride. Modern commercial processes, however, rely almost exclusively on the neutralization of nitric acid with ammonia. Manufacturers commonly use on-site ammonia, although some ammonium nitrate is made from purchased ammonia. Solid product used as fertilizer has been the predominant form produced. Sale of ammonium nitrate as a component in urea-ammonium nitrate liquid fertilizer, however, has grown to where about one-half of the ammonium nitrate produced is actually marketed as a solution. The following steps are essential to ammonium nitrate manufacture: neutralization of nitric acid with ammonia to produce a concentrated solution, evaporation to give a melt, and processing by granulation or prilling to produce the commercial solid product (Weston, 1992, p. 698–705).

AMMONIUM SULFATE

Ammonium sulfate is produced—by synthesis from coke-oven byproduct gases, as a byproduct of either caprolactam production or methyl methacrylate production, by direct synthesis from ammonia and sulfuric acid, and from sulfur oxide-rich tail gas that is treated with ammonia. Because of its increasing availability as a byproduct, it is not normally produced by direct synthesis. Ammonium sulfate has been produced for centuries from coke-oven gases that are generated when converting coal to coke. Coke-oven gas is mainly H_2 and CH_4 with small quantities of ammonia, carbon oxides, hydrogen sulfide and other heavier fractions. To produce ammonium sulfate, either ammonia that has been recovered by scrubbing the gas stream with water is then neutralized with sulfuric acid, or the gas stream is scrubbed directly with sulfuric acid.

Byproduct production from caprolactam is the principal source of ammonium sulfate throughout the world. Caprolactam is generally produced by the Beckman rearrangement of cyclohexanone oxime. This process, which requires strong sulfuric acid as a catalyst, initially produces caprolactam sulfate. This sulfate is hydrolyzed with ammonia to produce caprolactam and byproduct ammonium sulfate. The caprolactam production process generates as much as 5 t of byproduct ammonium sulfate for every metric ton of caprolactam produced (Nitrogen & Methanol, 2002).

NITRIC ACID

Almost all commercial quantities of nitric acid are manufactured by the oxidation of ammonia with air to form nitrogen oxides that are absorbed in water to form nitric acid. Because nitric acid has a maximum boiling azeotrope at 69 weight percent, the processes are usually categorized as either weak (subazeotropic) or direct strong (superazeotropic). Typically, weak processes make from 50 to 65 weight percent acid, and direct strong processes make up to 99 weight percent acid.

To produce nitric acid, ammonia and air are mixed so that there is an excess of oxygen. This mixture is then passed over a platinum catalyst to produce NO , water vapor, and a significant quantity of heat. The resulting gases are cooled, thus generating steam that can be exported or used internally. As the process gases cool, NO is further oxidized to form NO_2 in equilibrium with dinitrogen tetroxide (N_2O_4). Because hot liquid nitric acid is corrosive, the extent to which heat can be usefully recovered from the hot process gas is limited by a need to remain above the dew point for HNO_3 . The process gases are further cooled, and condensate is removed in a cooler-condenser, which is constructed of materials that are resistant to corrosion by hot acid. The process gases then enter a column where the equilibrium mix of NO_2 and N_2O_4 is absorbed into water to produce nitric acid. Nitric oxide, which is released by formation of the nitric acid, must be oxidized to complete the conversion of nitrogen oxides to nitric acid. Spent gases from absorption contain residual levels of NO_x , which, for environmental reasons, have to be removed before discharge to the atmosphere (Clarke and Mazzafro, 1997, p. 84–96).

THE INDUSTRY

Because of its importance as a fertilizer, nitrogen is used in virtually every country in the world, and as a result, many countries have the facilities for producing ammonia. In 2002, ammonia was produced in 71 countries, and urea was produced in 55. The countries with the largest ammonia production capacity, in descending order, were China, the United States, India, and Russia. Together, these countries accounted for about 50 percent of the total world ammonia production capacity. Countries with the largest urea production capacities were, in descending order, China, India, the United States, and Indonesia. Together, these countries accounted for nearly 55 percent of the total world urea production capacity.

Production capacity by country for ammonia and urea is listed in table 2. Figure 4 shows the percentage of ammonia production capacity by world region for 1992, 1997, and 2002; China is separated because of its importance in the world nitrogen industry and it has seen the greatest changes. The most significant gains in production capacity during these years were in Asia. China increased its share of the world total to 23 percent from 17 percent. Some of this increase, however, may not actually be an increase; it may have resulted from additional knowledge gained during this time period about the number and size of the ammonia plants in China. In the rest of Asia, the percentage of total world capacity has increased to 19 from 15 during the same period. Significant contributors to the increase were India and Indonesia. Europe's ammonia production capacity dropped during this period to 14 percent from 19 percent of the world total. Significant declines occurred in Eastern Europe after the dissolution of the U.S.S.R. in 1991. After 1991, Eastern European countries struggled to change from centrally planned economies to market economies. As a result, some of the least

efficient plants were closed, and some plants did not have enough financial support to operate. Production capacity in Western Europe declined as well—to 8 percent from 11 percent of the world total.

Ammonia production capacity in the United States has increased to 16,700 Mt/yr in 2002 from 15,200 Mt/yr in 1970, although it fluctuated quite a bit during this time. Figure 5 shows the total U.S. ammonia production capacity from 1970 to 2002 relative to natural gas prices. In general, production capacity increased throughout the 1970s, then fell dramatically in the 1980s, and recovered in the 1990s. Part of the reason for the decline in the 1980s was the result of the energy crisis of the late 1970s and the recession in the early 1980s. Natural gas prices also had a significant effect on ammonia production capacity. Notwithstanding the influences mentioned above, as natural gas prices increased, U.S. ammonia production capacity decreased and as natural gas prices decreased, U.S. ammonia production capacity increased, although there is a time lag between the two events.

Table 2. World production of ammonia and urea in 2002 and production capacity in 1992, 1997, and 2002.

[Thousand metric tons of contained nitrogen. International Fertilizer Industry Association 1991a, b, 2003d, e; International Fertilizer Development Center, 1996, 1999. NA, Not available. XX, Not applicable. —, Zero. Data are rounded to three significant digits; because of independent rounding, components may not add to totals shown]

Country	Ammonia				Urea			
	Production, 2002	Capacity			Production, 2002	Capacity		
		1992	1997	2002		1992	1997	2002
Afghanistan	20	58	58	58	18	47	47	47
Albania	10	72	147	NA	—	36	83	—
Algeria.....	563	816	816	816	—	67	—	—
Argentina.....	617	88	110	676	517	60	92	584
Australia	686	545	490	855	92	113	113	113
Austria.....	440	410	380	380	110	138	175	175
Bahrain.....	377	396	360	326	290	—	—	258
Bangladesh.....	1,290	1,100	1,580	1,550	1,070	1,070	1,320	1,370
Belarus	760	XX	700	740	459	XX	471	362
Belgium	842	805	799	839	—	—	—	—
Bosnia and Herzegovina...	1	XX	—	—	—	XX	—	—
Brazil	1,020	952	1,160	1,240	594	558	694	794
Bulgaria	328	1,130	1,070	959	10	498	359	359
Burma	21	200	213	200	20	191	—	191
Canada.....	3,590	3,320	4,120	4,520	1,850	1,410	1,940	1,940
China	30,100	19,700	23,800	30,000	16,000	6,760	12,800	16,300
Colombia.....	108	136	136	106	4	—	5	5
Croatia	235	XX	370	369	122	XX	207	228
Cuba	135	321	NA	190	—	108	17	83
Czech Republic	215	XX	847	300	61	XX	92	100
Czechoslovakia	XX	876	XX	XX	XX	270	XX	XX
Egypt.....	1,840	1,220	1,270	1,910	1,080	493	452	1,120
Estonia.....	39	XX	164	164	24	XX	92	83
Finland	6	65	NA	NA	—	—	—	—
France.....	1,050	1,840	1,570	1,480	120	332	337	262
Germany.....	2,560	2,860	2,670	2,790	430	905	809	1,070
Georgia.....	90	XX	328	328	—	XX	—	—
Greece	66	338	99	262	—	—	—	—
Hungary.....	238	791	316	328	76	232	91	91
Iceland	—	8	9	—	—	—	—	—
India	9,830	8,660	11,000	11,500	8,580	7,050	8,060	9,810
Indonesia	4,200	2,870	3,700	4,670	2,820	2,290	2,950	3,380
Iran	1,120	905	1,300	1,170	733	587	812	812
Iraq	200	272	900	816	220	—	202	795
Ireland	400	366	452	407	100	144	175	175
Israel.....	—	66	68	—	—	18	—	—
Italy	391	1,120	411	502	165	541	385	290
Japan.....	1,190	1,640	1,640	1,610	225	534	437	259
Kazakhstan.....	—	XX	362	357	—	XX	—	—
Korea, North.....	100	867	923	867	65	586	508	786

Table 2. World production of ammonia and urea in 2002 and production capacity in 1992, 1997, and 2002—Continued.
 [Thousand metric tons of contained nitrogen. International Fertilizer Industry Association 1991a, b, 2003d, e;
 International Fertilizer Development Center, 1996, 1999. NA, Not available. XX, Not applicable. —, Zero. Data are
 rounded to three significant digits; because of independent rounding, components may not add to totals shown]

Country	Ammonia				Urea			
	Production, 2002	Capacity		2002	Production, 2002	Capacity		
		1992	1997			1992	1997	2002
Korea, Republic of	153	688	670	674	161	409	454	152
Kuwait.....	414	—	534	609	255	—	364	466
Libya	533	598	598	543	390	412	418	418
Lithuania	467	XX	370	370	168	XX	125	125
Malaysia	848	326	685	1,050	567	276	275	591
Mexico	537	2,380	2,070	2,260	—	595	766	859
Netherlands	1,970	3,090	2,570	2,070	480	704	587	520
New Zealand	109	74	76	107	108	74	106	106
Nigeria.....	—	272	300	272	—	228	228	228
Norway.....	330	440	354	395	—	—	—	—
Pakistan	1,960	1,490	1,920	2,290	1,720	1,160	1,290	1,930
Peru	5	128	22	47	—	77	—	—
Poland.....	1,310	2,190	1,990	2,280	394	644	407	671
Portugal	190	244	234	234	36	38	40	40
Qatar.....	1,170	488	1,020	895	799	304	744	642
Romania	930	3,710	3,080	2,740	444	1,250	1,170	1,170
Russia.....	8,600	XX	11,800	10,900	2,110	XX	2,360	2,470
Saudi Arabia.....	1,740	862	1,300	1,820	1,240	731	941	1,200
Serbia and Montenegro	115	XX	293	247	21	XX	39	39
Slovakia	226	XX	354	214	56	XX	138	58
South Africa	492	602	771	440	—	120	151	—
Spain	415	717	487	495	164	289	204	177
Sweden.....	—	—	—	—	—	—	—	—
Switzerland.....	33	40	33	41	—	—	—	—
Syria	143	272	272	256	89	156	145	137
Taiwan.....	—	247	249	—	—	146	85	—
Tajikistan.....	15	XX	101	102	12	XX	87	97
Trinidad and Tobago	3,300	1,440	2,210	3,260	310	246	270	270
Turkey	301	577	710	572	255	258	258	258
Turkmenistan	75	XX	328	328	—	XX	—	—
Ukraine.....	3,700	XX	5,000	4,090	1,490	XX	1,660	1,550
U.S.S.R. ¹	XX	22,900	XX	XX	XX	5,180	XX	XX
United Arab Emirates.....	364	272	271	272	285	227	252	227
United Kingdom.....	837	1,100	1,180	1,130	—	—	—	—
United States	10,100	13,200	14,400	13,700	3,360	3,220	3,720	3,880
Uzbekistan.....	740	XX	1,290	1,600	118	XX	276	276
Venezuela.....	884	651	657	1,410	497	477	477	786
Vietnam	58	54	54	80	49	51	55	55
Yugoslavia ¹	XX	1,150	XX	XX	XX	419	XX	XX
Zambia	—	69	69	69	—	—	—	—
Zimbabwe.....	61	49	66	64	—	—	—	—
Total.....	108,000	115,000	123,000	131,000	51,400	42,700	51,900	61,200

¹ Although the U.S.S.R. was dissolved in December 1991 and Yugoslavia was dissolved in April 1992, individual country data for 1992 were not available.

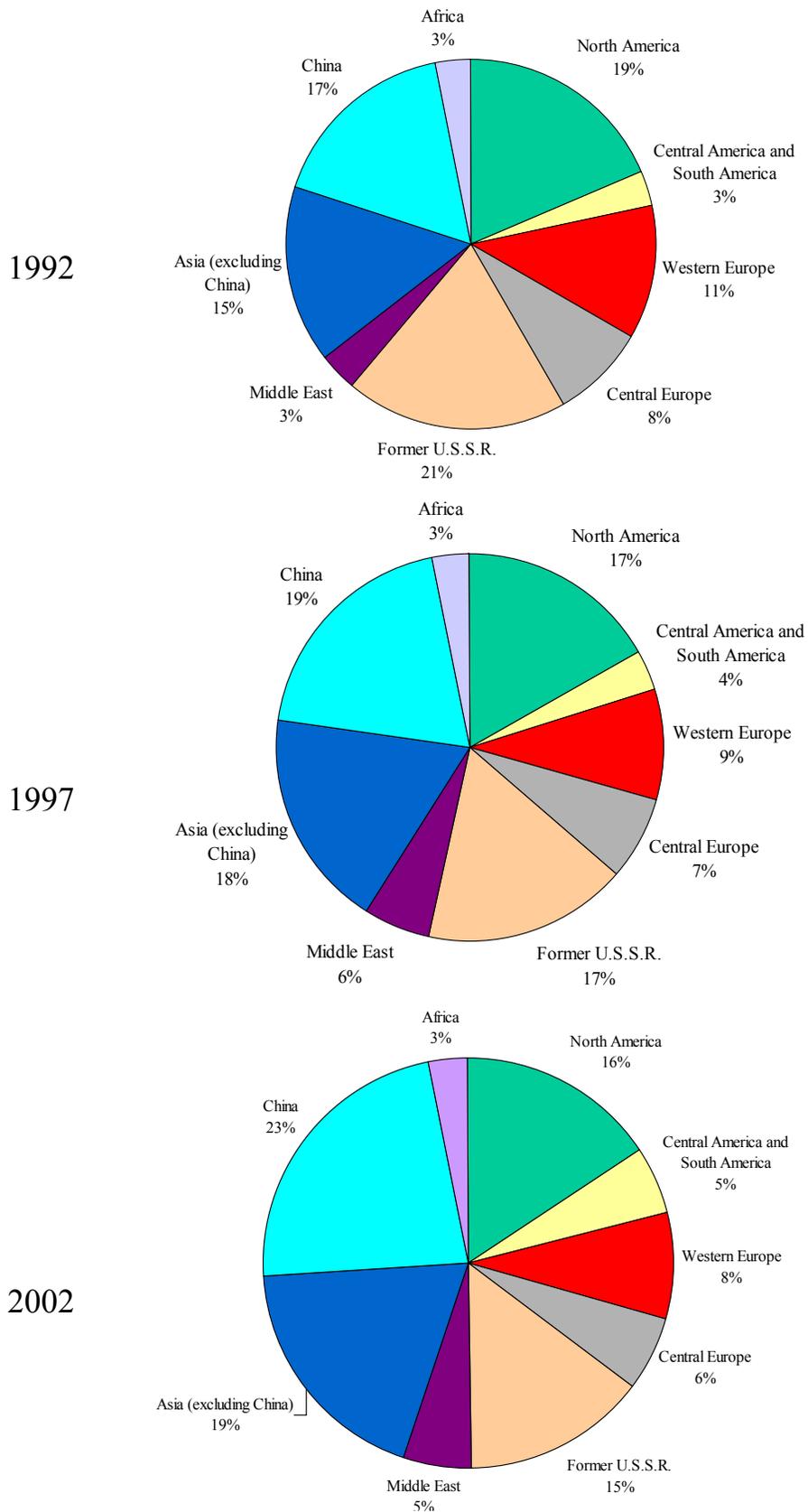


Figure 4. World ammonia production capacity, by region.

Although U.S. production capacity increased since 1970, the number of firms involved in ammonia production and the total number of plants in the United States decreased. In 1972, 61 companies operated 91 plants; the average plant size was slightly less than

170,000 t/yr. By 2002, only 28 companies operated 37 plants; the average plant size was 450,000 t/yr. Figure 6 shows the changes in the U.S. ammonia production capacity in 10-year increments from 1972 to 2002. Of the plants that operated in 2002, 52 percent of total U.S. ammonia production capacity was concentrated in Louisiana (32 percent), Oklahoma (14 percent), and Texas (6 percent) because of large reserves of feedstock natural gas. The following companies, in descending order, accounted for 78 percent of total U.S. ammonia capacity: Farmland Industries Inc., Terra Industries Inc., PCS Nitrogen Inc., CF Industries Inc., Agrium Inc., and Mississippi Chemical Corp.

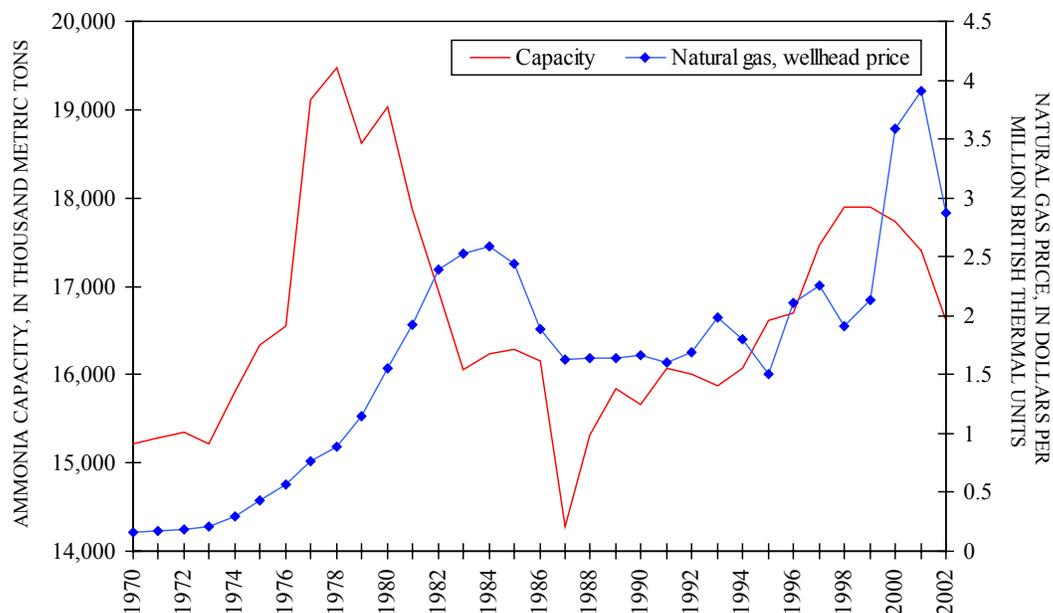


Figure 5. U.S. ammonia production capacity and natural gas prices. Prices were converted from dollars per thousand cubic feet using by using an average heat content of 1,027 British thermal units per cubic foot.

THE MARKET

Fertilizer products are diverse, and each product usually has a range of possible distribution processes. In addition, the structure of the industry varies widely. Fertilizer producers include many large multinational companies, which may be integrated from ammonia production through fertilizer blending and retail sales. At the other extreme, many small companies purchase primary fertilizer materials to make blends, compounds, and mixtures. Adding to this complicated scene, ammonia, mineral phosphate, potassium salts, and sulfur may all be applied to the soil directly so that one company's raw material may be another's finished fertilizer.

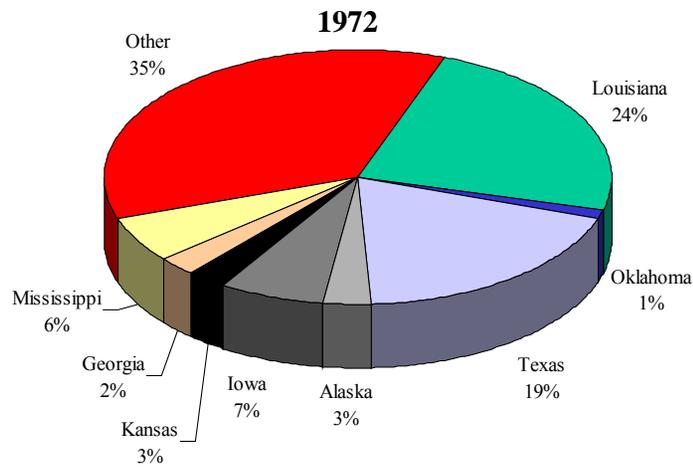
PRICES

Ammonia prices from 1970 to 2002 are shown in figure 7. In 1973, rising energy costs were reflected in the cost of ammonia. Because natural gas costs are such a high percentage of the cost of ammonia production, ammonia prices readily respond to changes in natural gas prices. Figure 8 shows in more detail the similar changes that take place in natural gas and ammonia prices and that the change in ammonia pricing tends to lag behind natural gas price changes.

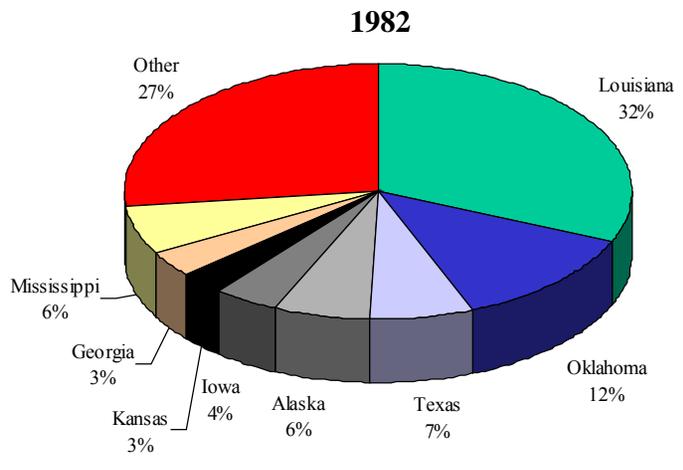
SUPPLY, DEMAND, SUSTAINABLE DEVELOPMENT

U.S. SUPPLY AND DEMAND

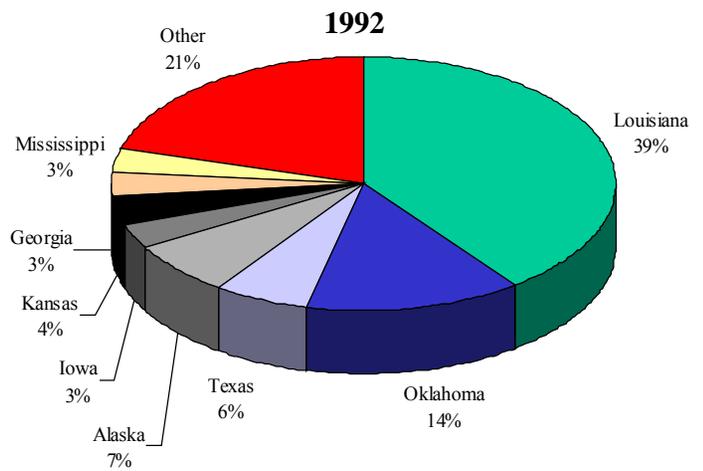
The U.S. supply-demand relationships for ammonia in 2002 are shown in figure 9. Although the United States produced much of its nitrogen needs, a significant portion of its ammonia requirements were imported. In 2002, more than one-half of the total ammonia imported was from Trinidad and Tobago; significant quantities also were imported from Canada and Russia. New ammonia production capacity, which totaled about 1.2 Mt/yr, was completed in Trinidad and Tobago in 1998; most of its output was targeted to the U.S. market; additional capacity was planned in the future. The trend of locating ammonia production capacity near natural gasfields and then shipping the product to the consumer increases the probability of additional production capacity installed in regions such as Central America, the Middle East, and South America. As a result, the United States is likely to become more import dependent in the future.



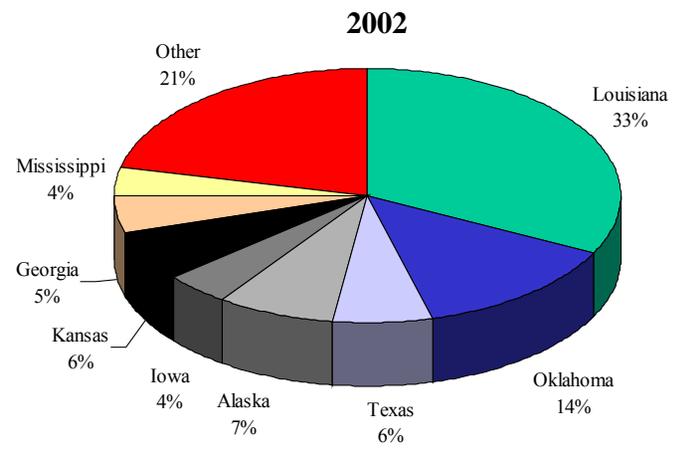
Total capacity 15.3 million metric tons per year at 91 plants



Total capacity 16.9 million metric tons per year at 74 plants



Total capacity 16.0 million metric tons per year at 48 plants



Total capacity 16.7 million metric tons per year at 37 plants

Figure 6. U.S. ammonia production capacity, by State.

Figure 10 shows the trends in U.S. production, net imports, and apparent consumption from 1970 to 2002. Although apparent consumption of nitrogen varies from year to year in the United States, it has historically trended upward. Fertilizers, which remain the most important use for nitrogen, accounted for more than 85 percent of the total in 2002. The United States continues to supply its domestic crop needs and to provide food for export; increased crop production generally leads to increased use of fertilizer. In addition, as the land available for farming diminishes, farmers increase the density of the crops they grow to maintain or increase production. This intensive cropping removes nutrients from the soil at a faster rate, and as a result, a greater quantity of nutrients, which include nitrogen, needs to be replenished. With proper nitrogen application practices and other factors, such as crop rotation, pest management, and soil conservation, however, the quantity of nitrogen that needs to be added to the soil can be minimized.

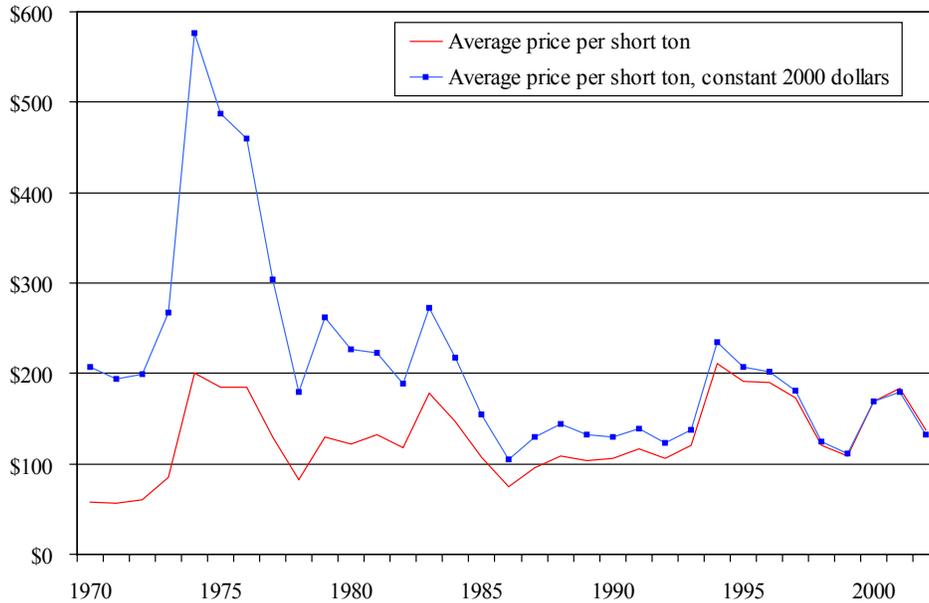


Figure 7. Average ammonia prices, 1970-2002.

Figure 11 shows the fertilizer nitrogen consumption by State for crop year 2001–02. More than 40 percent of the nitrogen consumed in the United States was used to fertilize corn, yet corn accounted for only 21 percent of the total plantings (figure 12). Not surprisingly, most of the nitrogen was consumed in the Corn Belt States of Illinois, Iowa, Kansas, and Nebraska.

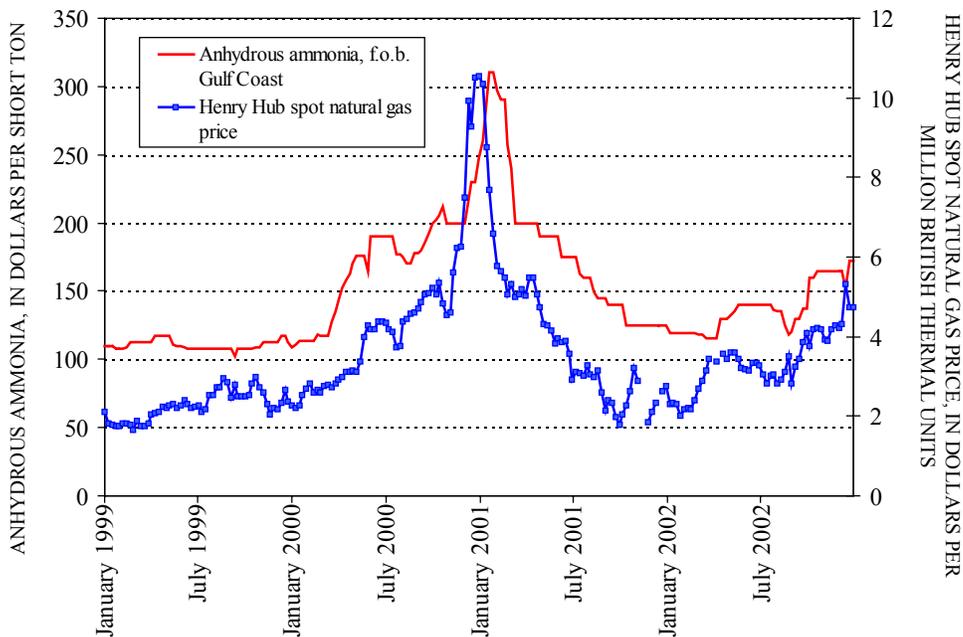


Figure 8. Ammonia and natural gas prices. (Green Markets and U.S. Department of Energy, Natural Gas Weekly).

WORLD PRODUCTION, CONSUMPTION, TRADE

World ammonia production has increased steadily from 56.9 Mt of contained nitrogen in 1976 (the earliest year for which data are available by country) to 108 Mt of contained nitrogen in 2002 (table 3). In 1976, the leading producing regions were North America (26 percent), Western Europe (22 percent), Asia (18 percent), and the U.S.S.R. (18 percent). By 2002, Asia (46 percent) had become the largest producing region and was followed by countries from the former U.S.S.R and North America, each with 13 percent. Some of this increase may have been the result of having more reliable information about China, which was the largest producer in the world in 2002. Closure of high-cost, inefficient, or poorly located plants during this time period was partially responsible for the shift in production. In addition, when new plants were constructed, they were constructed in areas that had an abundance of low-cost natural gas, which accounts for some of the decline in production in North America and Western Europe.

World consumption of ammonia also increased from 1970 to 2002. According to data from the International Fertilizer Industry Association (2002), consumption of nitrogen has increased from 31.8 Mt of contained nitrogen in crop year 1970–71 to 82.8 Mt of contained nitrogen in crop year 2001–02 (figure 13). With 53 percent of the total, Asia was the largest consuming region and was followed by North America with 15 percent and Western Europe with 11 percent. Generally, the leading ammonia-producing countries also are the largest consumers. Most ammonia is consumed within the producing country in direct agricultural application or in the manufacture of other nitrogen compounds, mainly fertilizer materials. These compounds are, in turn, consumed within the country or exported.

World ammonia trade, by region, in 2002 is shown in figure 14. In 2002, world ammonia exports were 13.1 Mt of contained nitrogen, or about 12 percent of total world production. Trinidad and Tobago (22 percent), Russia (18 percent), Ukraine (10 percent), and Indonesia (7 percent) accounted for 57 percent of the world total. The United States imported 35 percent of global ammonia trade and was followed by Western Europe (23 percent) and Asia (22 percent). These figures include intraregional trade; for example, ammonia shipped from Canada to the United States. Trade in urea, ammonium nitrate, and ammonium sulfate is shown in figures 15 to 17. In general, the former U.S.S.R. is the leading exporter, and North America and Western Europe are the leading importers.

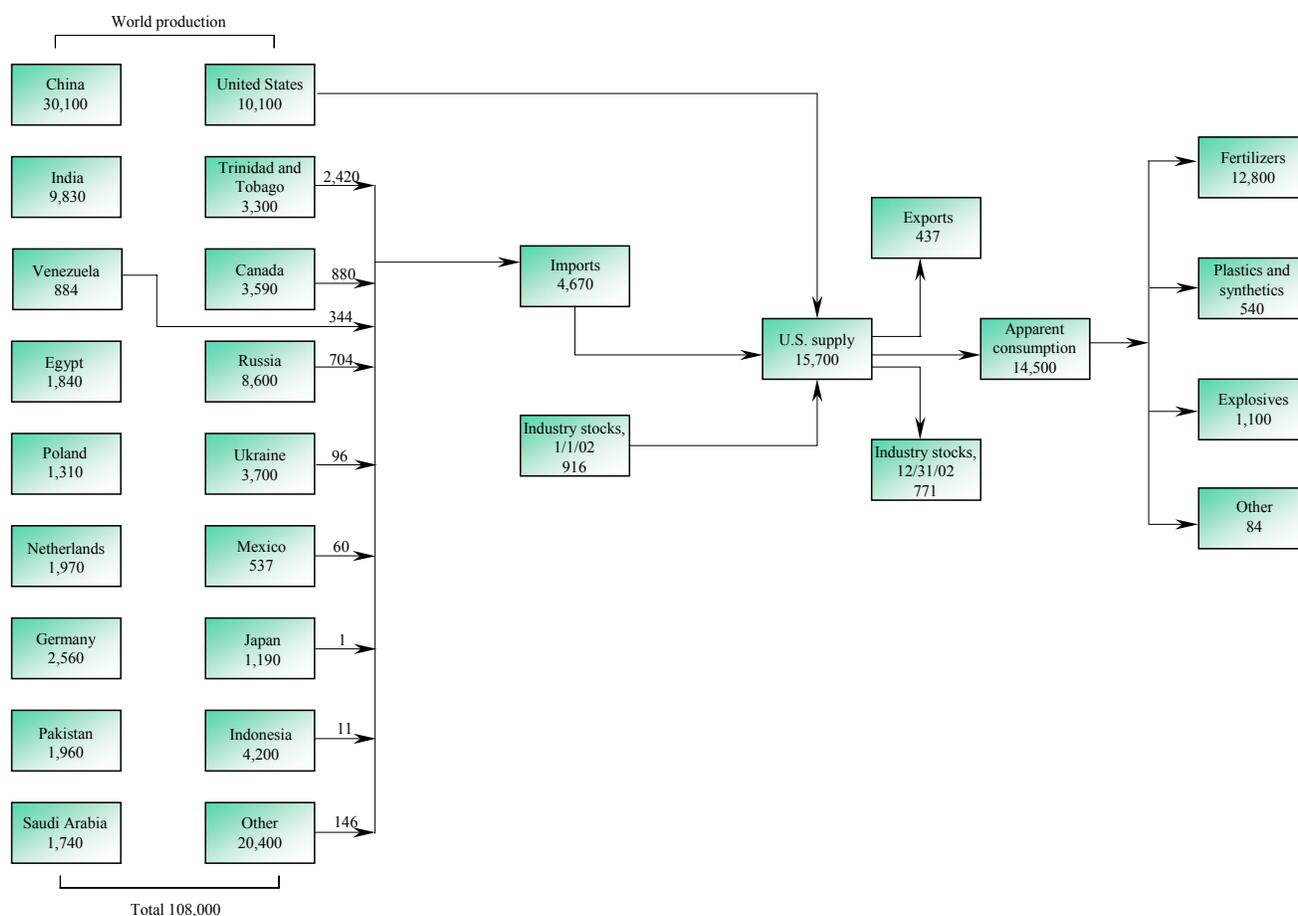


Figure 9. Ammonia supply-demand relationships, 2002. Totals are in thousand metric tons of contained nitrogen. Data are rounded to no more than three significant digits.

Table 3. World ammonia production, by country.

[In thousand metric tons of contained nitrogen. e, Estimated. NA, Not available. XX, Not applicable. —, Zero. World totals, U.S. data, and estimated data are rounded to no more than three significant digits; because of independent rounding, components may not add to totals shown]

Country	1976	1977	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989
Afghanistan ^e	36	36	27	27	10	9	8	8	41 ¹	45	40	40	40	40
Albania ^e	59	65	75	72	75	76	76	76	80	80	91	95	100	110
Algeria	21	32 ^e	45	21	30	44	164	132	146	150 ^e	150	174	197	132
Argentina	37	42	47	61	65	40	58	57	49	65	63	81	78	74
Australia	308	317	294	308	353	319	245	385	376	405	340	414	386	344
Austria ^e	456 ¹	465 ¹	470 ¹	520 ¹	490 ¹	486	485	495	499	499	449	449	408	410
Bahrain	—	—	—	—	—	—	—	—	—	110	288	276	296	319
Bangladesh	148	107	105	167	140	152	182	179	353	358	390	435	673	775
Belarus	XX	XX	XX	XX	XX	XX	XX	XX	XX	XX	XX	XX	XX	XX
Belgium	539	584	540	530	542	589	509	449	452	388	306	269	365	292
Bosnia and Herzegovina ^e	XX	XX	XX	XX	XX	XX	XX	XX	XX	XX	XX	XX	XX	XX
Brazil	144	145	203	266	352	376	503	738	874	945	882	952	935	935
Bulgaria	921	816	787	780	827	1,023	1,032	1,123	1,138	1,138	1,091	1,070	1,342	1,326
Burma	54	58 ^e	55 ^e	55 ^e	60 ^e	59 ^e	51 ^e	54 ^e	57 ^e	126	133	118	112	120
Canada	1,258	1,764	1,926	1,981	2,096	2,176	2,062	2,888	2,871	2,976	2,910	2,887	3,289	3,339
China ^e	4,082	5,625	7,637	8,821	9,990	12,193	12,710	13,789	13,971	14,969	15,513	16,003	16,500	17,000
Colombia	91	65	64	70	70	92	98	102	93	100	93	89	84	92
Croatia	XX	XX	XX	XX	XX	XX	XX	XX	XX	XX	XX	XX	XX	XX
Cuba	73	58	39	155	136	167	98	86	169	163	163	149	135	134
Czech Republic	XX	XX	XX	XX	XX	XX	XX	XX	XX	XX	XX	XX	XX	XX
Czechoslovakia	725	788	809	801	844	850	850 ^e	591	821	812	760	776	771	797
Denmark	33	33	33	33	31	31	31 ^e	12 ^e	—	—	—	—	—	—
Egypt	209 ^e	210	250	263	400	518	639	647	686	684	679	789	788	728
Estonia	XX	XX	XX	XX	XX	XX	XX	XX	XX	XX	XX	XX	XX	XX
Finland	169	132	150	114	70	69	64	68	69	65	67	50	43	42
France	1,781	2,034	2,017	2,150 ^e	2,085 ^e	2,268 ^e	1,996 ^e	1,996 ^e	2,342	2,011	2,022	2,029	1,832	1,476
Germany	2,981	3,118	3,092	3,239	3,226	3,167	2,733	2,908	3,166	3,113	2,763	3,107	2,980	2,932
Georgia	XX	XX	XX	XX	XX	XX	XX	XX	XX	XX	XX	XX	XX	XX
Greece	238	225	229	287	226	234	223	227	255	243	241	254	263	242
Hungary	703	729	746	803	795	818	792	813 ^e	838	790	762	787	692	673
Iceland	8 ^e	6 ^e	7 ^e	7 ^e	7 ^e	7	7 ^e	7 ^e	7 ^e	7	8	9	9	9
India ²	1,910	2,037	2,220	2,256	2,221	3,181	3,469	3,565	3,832	4,270	4,933	5,300	6,205	6,661
Indonesia	185	410	1,096	623	938	920	1,028	1,150	1,658	2,057	2,299	2,364	2,367	2,526
Iran	230	271	179	183	218	200 ^e	26 ^e	29 ^e	22	27	66	119	146 ^e	336
Iraq ^e	136	136 ¹	181 ¹	450 ¹	500 ¹	80 ¹	80	80	80	60	60	60	313	474
Ireland	34	28	24	171	254	291	371	294	371	338	355	399	417	386
Israel ³	64	69	68	69	54	43	49	54	57	57	57	62	48	48

See footnotes at end of table.

Table 3. World ammonia production, by country—Continued.

[In thousand metric tons of contained nitrogen. e, Estimated. NA, Not available. XX, Not applicable. —, Zero. World totals, U.S. data, and estimated data are rounded to no more than three significant digits; because of independent rounding, components may not add to totals shown.]

Country	1976	1977	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989
Italy.....	1,219	1,168	1,514	1,430	1,397	1,207	1,046	1,061	1,460	1,215	1,553	1,435	1,561	1,446
Japan.....	2,236	2,292	2,368	2,328	2,110	1,833	1,652	1,545	1,675	1,646	1,508	1,556	1,524	1,539
Kazakhstan.....	XX	XX	XX	XX	XX	XX	XX	XX	XX	XX	XX	XX	XX	XX
Korea, North ^e	272	408	450	450	450	450	450	450	450	450	450	450	500	500
Korea, Republic of.....	602	725	897	961	848	747	543	430	464	442	426	474	506	480
Kuwait.....	422	402	431	435 ^e	214	213	183	313	289	323	451	578	498	665
Libya.....	—	—	80 ^e	133 ^e	150 ^e	150 ^e	244	445	494	411	352	350	217	212
Lithuania.....	XX	XX	XX	XX	XX	XX	XX	XX	XX	XX	XX	XX	XX	XX
Malaysia.....	43	34	40	52	41	37	28	29	39	54	250	321	301	279
Mexico.....	716	780	1,304	1,359	1,548	1,795	2,029	1,936	1,773	1,859	1,602	1,744	2,067	2,100
Netherlands.....	1,980	2,140	2,148	1,916	1,874	1,814	1,655	1,744	2,382	2,516	2,185	2,287	2,695	2,901
Netherlands Antilles.....	84	34	—	—	—	—	—	—	—	—	—	—	—	—
New Zealand.....	—	—	—	—	—	—	—	44	58	73	73	73	73	70
Nigeria ^e	—	—	—	—	—	—	—	—	—	—	—	129	310 ¹	364
Norway.....	474	504	526	544	515	545	525	513	637	458	299	347	424	382
Pakistan.....	327	316	309	386	430	706	937	1,099	1,128	1,107	1,155	1,179	1,173 ^e	1,175
Peru.....	75 ^e	83 ^e	81 ^e	80 ^e	62 ^e	97 ^e	84 ^e	85 ^e	85 ^e	85 ^e	100 ^e	80 ^e	95 ^e	91
Philippines.....	41 ^e	41 ^e	41 ^e	40	39	33	15	20	16	17 ^e	—	—	—	—
Poland.....	1,726	1,665	1,611	1,525	1,478	1,389	1,380	1,425	1,822	1,812	2,124	2,177	2,338	2,360
Portugal.....	159	185	252	222	200	133	132 ^e	111	160	154	118	155	191	151
Qatar.....	91 ^e	105	166	303	418	367	434	482	519	524	544	561	598	587
Romania.....	1,659	1,792	2,257	2,335	2,248	2,381	2,587	2,727	2,861	2,880	3,041	2,788	2,795	2,736
Russia.....	XX	XX	XX	XX	XX	XX	XX	XX	XX	XX	XX	XX	XX	XX
Saudi Arabia.....	102 ^e	125	140	155	167	170	208	293	415	436	466	637	867	863
Serbia and Montenegro.....	XX	XX	XX	XX	XX	XX	XX	XX	XX	XX	XX	XX	XX	XX
Slovakia.....	XX	XX	XX	XX	XX	XX	XX	XX	XX	XX	XX	XX	XX	XX
Somalia.....	—	—	—	—	—	—	—	—	24	26 ^e	15 ^e	7 ^e	—	—
South Africa.....	470	508	563	563	549	552	571	575	580	581 ^e	581 ^e	547	472	455
Spain.....	1,051	965	880	826	742	743	538	506	670	602	464	449	476	552
Sri Lanka.....	—	—	—	—	—	44	103	63	71	5	—	—	—	—
Sweden.....	108	102	96	89	86	79	77	49	49	18	46	34	—	—
Switzerland ^e	45	45	45	45	45	33	33	33	33	31	30	39	32	32
Syria.....	23 ^e	23	19	76	39	30	65	113	112	132	137	93	79	123
Taiwan.....	319	326	438	391	415	406	318	310	269	207	265	244	279	203
Tajikistan ^e	XX	XX	XX	XX	XX	XX	XX	XX	XX	XX	XX	XX	XX	XX
Tanzania.....	—	—	—	—	—	—	—	—	6	—	—	—	—	—
Thailand.....	7 ^e	7 ^e	9 ^e	—	—	—	—	—	—	—	—	—	—	—
Trinidad and Tobago.....	163	177	401	388	459	397	701	993	1,080	1,080	1,141	1,128	1,388 ^e	1,550

See footnotes at end of table.

Table 3. World ammonia production, by country—Continued.

[In thousand metric tons of contained nitrogen. e, Estimated. NA, Not available. XX, Not applicable. —, Zero. World totals, U.S. data, and estimated data are rounded to no more than three significant digits; because of independent rounding, components may not add to totals shown]

Country	1976	1977	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989
Turkey	91 ^e	107	217	205	184	284	255	279	290	217	191	330	309	380
Turkmenistan.....	XX	XX	XX	XX	XX	XX	XX	XX	XX	XX	XX	XX	XX	XX
Ukraine.....	XX	XX	XX	XX	XX	XX	XX	XX	XX	XX	XX	XX	XX	XX
U.S.S.R. ⁴	10,090	10,744	11,300	12,200	12,610	12,900	13,971 ^e	16,900	17,699	18,300	19,600	20,003	20,200	19,400
United Arab Emirates.....	—	—	—	—	—	—	—	—	226	282	291	311	297	324
United Kingdom.....	1,347	1,631	1,600	1,666	1,633	1,780	1,716	1,720	1,836	1,767	1,388	1,415	1,105	1,037
United States ⁵	12,600	13,300	12,900	14,000	14,700	14,300	11,800	10,200	12,500	12,900	10,800	12,000	12,500	12,300
Uzbekistan.....	XX	XX	XX	XX	XX	XX	XX	XX	XX	XX	XX	XX	XX	XX
Venezuela.....	254	271	271	259	360	415	440	379	470	410 ^e	518	524	563	532
Vietnam.....	—	9 ^e	NA	NA	NA	NA	NA	NA	36	36 ^e	36	36	36 ^e	36
Yugoslavia ⁴	387	417	416	418	404	421	422	410	497	766	814	937	858	680
Zambia.....	18 ^e	18 ^e	20 ^e	20 ^e	20	18	27	28	28	17	24	34	16	12
Zimbabwe ^e	73	73	60	60	57	52	84 ¹	71 ¹	69 ¹	69 ¹	49 ¹	54 ¹	64 ¹	62
Total.....	56,900	62,000	67,200	71,100	73,600	77,000	77,900	82,400	90,600	93,000	93,100	97,099	101,000	101,000

Country	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002
Afghanistan ^e	40	40	40	15	15	10	5	5	5	5	20	20	20
Albania ^e	100	80	15	15	15	15	15	10	10	10	10	10	10
Algeria.....	288	269	438	380	243	176	150	379	350	455	458	469	563
Argentina.....	70	75	72	72	73	79	80	107	86	88	199	597	617
Australia.....	385	414	392	398	413	433	446	432	435	431	576	762	686
Austria ^e	410	400	410	400	400	400	450	450	450	450	450	440	440
Bahrain.....	325	320	323	348	338	358	323	356	336	370	350	372	377
Bangladesh.....	701 ³	667 ³	937 ³	991 ³	1,027 ³	1,271 ³	1,233	1,080	1,129	1,240	1,255	1,273	1,289
Belarus.....	XX	XX	916	619	650 ^e	668	678	590 ^e	685	765	730	725	760
Belgium.....	274	272	514	535	633	720	750	760	756	840	863	788	842
Bosnia and Herzegovina ^e	XX	XX	5	2	1	1	1	1	1	1	1	1	1
Brazil.....	938	940 ^e	940 ^e	914	939	993	977	1,019	949	1,084	925	769	1,021
Bulgaria.....	1,310	1,093	905	885	995 ^e	1,203	1,194	808	448	315	533	477	328
Burma.....	77	111	110 ^e	79 ^e	70	66	57	62	52	66	78	28	21
Canada.....	3,050	3,016	3,104	3,410	3,470	3,773	3,840	4,081	3,900	4,135	4,130	3,439	3,594
China ^e	17,500	18,000	18,000	19,000	20,100	22,600	25,200	24,800	25,800	28,300	27,700	28,200	30,100 ^e
Colombia.....	90	92 ^e	86 ^e	99 ^e	112	99	102	81	100	75	93	95	108
Croatia.....	XX	XX	426	345	311	310	307	331	248	318	325	259	235
Cuba.....	140 ^e	140 ^e	135 ^e	135 ^e	130 ^e	135 ^e	135 ^e	135 ^e	135 ^e	135 ^e	135 ^e	135 ^e	135 ^e
Czech Republic.....	XX	XX	XX	149	284	254	304	251	258	223	246	206	215
Czechoslovakia.....	793	551	385 ^e	XX	XX	XX	XX	XX	XX	XX	XX	XX	XX
Denmark.....	—	—	2 ^e	2	2 ^e	2 ^e	2 ^e	2 ^e	2 ^e	2 ^e	2 ^e	2	2

See footnotes at end of table.

Table 3. World ammonia production, by country—Continued.

[In thousand metric tons of contained nitrogen. e, Estimated. NA, Not available. XX, Not applicable. —, Zero. World totals, U.S. data, and estimated data are rounded to no more than three significant digits; because of independent rounding, components may not add to totals shown]

Country	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002
Egypt.....	735	863	943	941	1,021	1,096	1,126	1,061	1,141	1,407	1,511	1,801	1,839
Estonia.....	XX	XX	115	150 ^e	170 ^e	170	137	153	175	164	145	151	39
Finland.....	23	24	10	10 ^e	12	6	5 ^e	6 ^e	6 ^e	6 ^e	6 ^e	6	6
France.....	1,590	1,604	1,848	1,871	1,480	1,470	1,570 ^e	1,757	1,570 ^e	1,580 ^e	1,620 ^e	1,380	1,050
Germany.....	2,690	2,123	2,113	2,100	2,170	2,518	2,485	2,471	2,512	2,406	2,599	2,522	2,560
Georgia.....	XX	XX	96	58	35 ^e	52	77	84	64	104	135	60	90
Greece.....	257	210	140	57	45	65	90	83 ^e	178	160	121	57	66
Hungary.....	443	261	152	237	302	307	347	339	288	261	352	324	238
Iceland.....	8	8	9	9 ^e	9	7	7	7	6	7 ^e	7 ^e	3	—
India ²	7,010	7,132	7,452	7,176	7,503	8,287	8,549	9,328	10,240	10,376	10,148	10,081	9,827
Indonesia.....	2,790	2,706	2,688	2,888	3,012	3,336	3,647	3,769	3,600	3,450	3,620	3,655	4,200
Iran.....	420	468	664	723	696	715	882	880	1,034	865	965	1,087	1,119
Iraq ^e	240	40	200	220	220	220	220	220	220	220	200	200	200
Ireland.....	395 ^e	429	384	367	451	408	377	465	458	405	410	443	400 ^e
Israel ³	42	35	37	39	46	70	65	57	1	—	—	—	—
Italy.....	1,200	1,147	1,100 ^e	729	504	487	397	446	409	367	408	434	391
Japan.....	1,530	1,553	1,545	1,471	1,483	1,584	1,490	1,509	1,389	1,385	1,410	1,318	1,188
Kazakhstan.....	XX	XX	220	231	100 ^e	49	75	75 ^e	— ^e	— ^e	—	—	—
Korea, North ^e	500	550	550	600	600	600	600	600	100	100	100	100	100
Korea, Republic of.....	411	407	442	386	574	616	611	526	496	489	369	368	153
Kuwait.....	292	—	140	317	389	493	412	432	452	397	410	400	414
Libya.....	200 ^e	200 ^e	200 ^e	358	407	534	546	537	545	552	552	495	533
Lithuania.....	XX	XX	275	275 ^e	277	442	461	467	407	401	420	440	467
Malaysia.....	229	286	331	334	313	333	329	243	351	432	605	726	848
Mexico.....	2,160	2,221	2,203	1,758	2,030	1,992	2,054	1,448	1,449	1,003	701	548	537
Netherlands.....	3,190	3,033	2,588	2,472	2,479	2,580	2,652	2,478	2,350 ^e	2,430 ^e	2,540 ^e	1,940	1,970
Netherlands Antilles.....	—	—	—	—	—	—	—	—	—	—	—	—	—
New Zealand.....	70 ^e	70 ^e	68	78	81	79	68	80	94	110	105	117	109
Nigeria ^e	405 ¹	367	337 ¹	350	200	170	164	134	168	148	—	—	—
Norway.....	431	384	343	315	270	289	295	279	245	122	334	323	330
Pakistan.....	1,210	1,154	1,144	1,446	1,505	1,493	1,606	1,549	1,797	1,999	1,884	1,966	1,958
Peru.....	90 ^e	95 ^e	90 ^e	15	15 ^e	24	18	15 ^e	15 ^e	—	—	5 ^e	5 ^e
Philippines.....	—	—	—	—	—	—	—	—	—	—	—	—	—
Poland.....	1,960	1,531	1,222	1,163	1,230	1,726	1,713	1,824	1,683	1,474	1,862	1,735	1,311
Portugal.....	198	198	100	91	58	155	198	196	204	223	246	202	190
Qatar.....	584	569	622	627	646	653	635	943	1,127	1,130	1,097	1,159	1,166
Romania.....	1,790	1,128	1,421	1,328	1,182	1,487	1,513	781	378	686	1,016	949	930

See footnotes at end of table.

Table 3. World ammonia production, by country—Continued.

[In thousand metric tons of contained nitrogen. e, Estimated. NA, Not available. XX, Not applicable. —, Zero. World totals, U.S. data, and estimated data are rounded to no more than three significant digits; because of independent rounding, components may not add to totals shown]

Country	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002
Russia.....	XX	XX	8,786	8,138	7,300	7,900	7,900	7,150	6,500	7,633	8,735	8,690	8,600 ^e
Saudi Arabia	942	827	904	1,097	1,340	1,327	1,386	1,405	1,418	1,402	1,743	1,774	1,737
Serbia and Montenegro	XX	XX	148	100	159	135	235	235	172	57	60 ^e	66	115
Slovakia	XX	XX	XX	263	255	178	197	229	234	247	271	215	226
Somalia	—	—	—	—	—	—	—	—	—	—	—	—	—
South Africa.....	456	457	541	683	754	759	770	752	723	785	560	506	492
Spain	466	557	479	354	452	453	466	497	460	437	442	436	415
Sri Lanka.....	—	—	—	—	—	—	—	—	—	—	—	—	—
Sweden.....	—	—	—	—	—	—	—	—	—	—	—	—	—
Switzerland ^e	32 ³	33 ³	31 ³	28 ³	30	30	32	32	31	32	33	31	33
Syria.....	104	17	81	67	93	64	80	84	129	112	91	138	143
Taiwan	216	243	224	220	215	226	252	289	231	146	11	—	—
Tajikistan ^e	XX	XX	50	40	20	15	10	10	10	10	15	5	15
Tanzania.....	—	—	—	—	—	—	—	—	—	—	—	—	—
Thailand.....	—	—	—	—	—	—	—	—	—	—	—	—	—
Trinidad and Tobago	1,520	1,595	1,568	1,462	1,649	1,696	1,801	1,772	2,271	2,720	2,680	3,036	3,300 ^e
Turkey.....	373	357	344	326	350 ^e	366	519	558	560	82	53	67	301
Turkmenistan.....	XX	XX	50	50	50 ^e	52 ^e	70	61	75 ^e	75 ^e	75 ^e	75	75
Ukraine	XX	XX	3,908	3,242	3,000 ^e	3,100	3,300	3,400 ^e	3,300	3,711	3,577	3,700	3,700
U.S.S.R. ⁴	18,200	17,100	XX	XX	XX	XX	XX	XX	XX	XX	XX	XX	XX
United Arab Emirates.....	295	286	275	306	287	363	331	373	331	380	348	358	364
United Kingdom	1,150	1,011	869	873	1,006	799	850	642	871	902	814	850	837
United States ⁵	12,700	12,800	13,400	12,600	13,300	13,000	13,400	13,300	13,800	12,900	11,800	9,120	10,140
Uzbekistan	XX	XX	1,309	1,105	900 ^e	906	950	950	875	790	810	670	740
Venezuela	557	450	404	535	505	600	605	612	526	522	423	808	884
Vietnam	36 ^e	30 ^e	45 ^e	52	54	54	54	54	33	33 ^e	42	53	58
Yugoslavia ⁴	802	700 ^e	XX	XX	XX	XX	XX	XX	XX	XX	XX	XX	XX
Zambia	4	5 ^e	7 ^e	10	4	1	2	1 ^e	— ^e	— ^e	— ^e	—	—
Zimbabwe ^e	63	66	67	70	70	43	61	64	57	61	58	58	61
Total	99,500	93,800	93,400	91,600	93,500	100,000	105,000	103,000	104,000	107,000	108,000	105,000	108,000

¹ Reported figure.

² Data are for years beginning April 1 of that stated.

³ May include nitrogen content of urea.

⁴ The U.S.S.R. was dissolved in December 1991, and Yugoslavia was dissolved in April 1992.

⁵ Synthetic anhydrous ammonia; excludes coke oven byproduct ammonia.

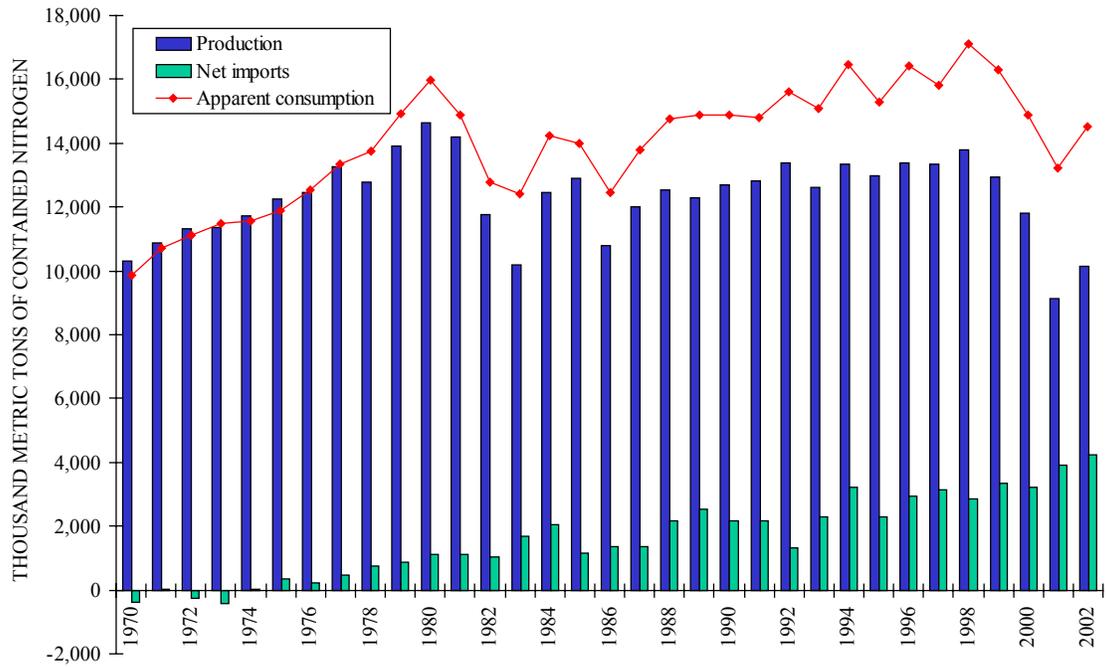


Figure 10. U.S. production and consumption of ammonia, 1970-2002.

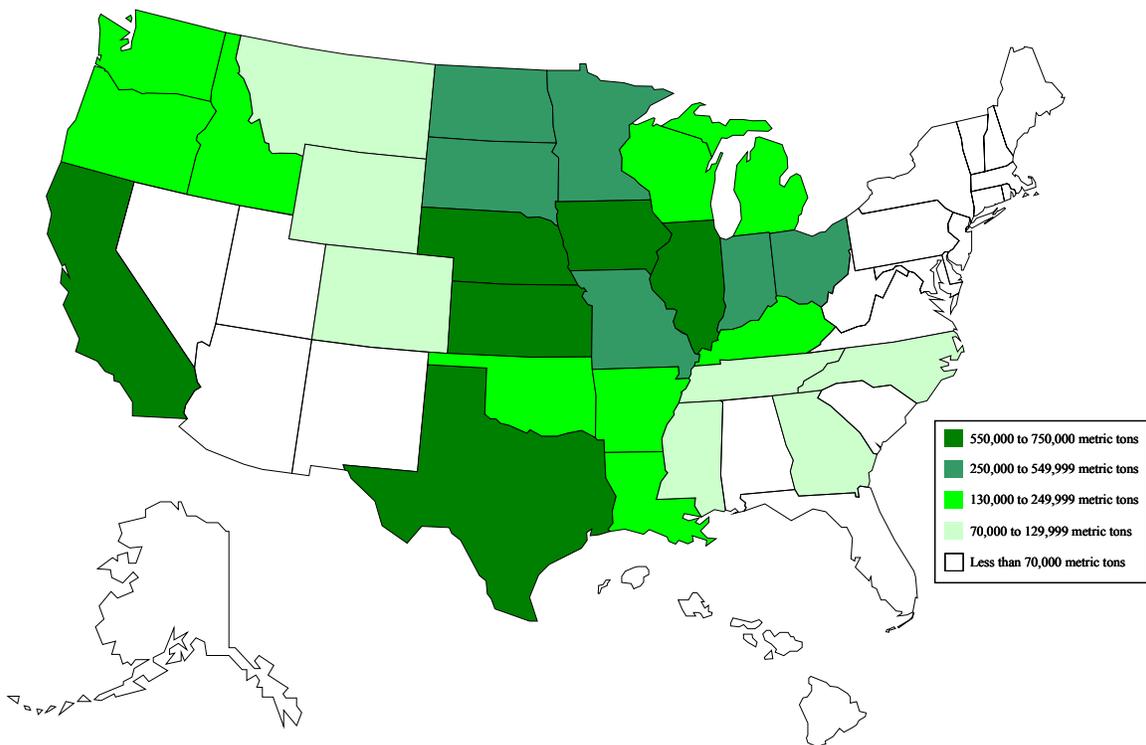


Figure 11. U.S. fertilizer nitrogen consumption, by State, crop year 2001-02. (Terry and Kirby, 2003, p. 16).

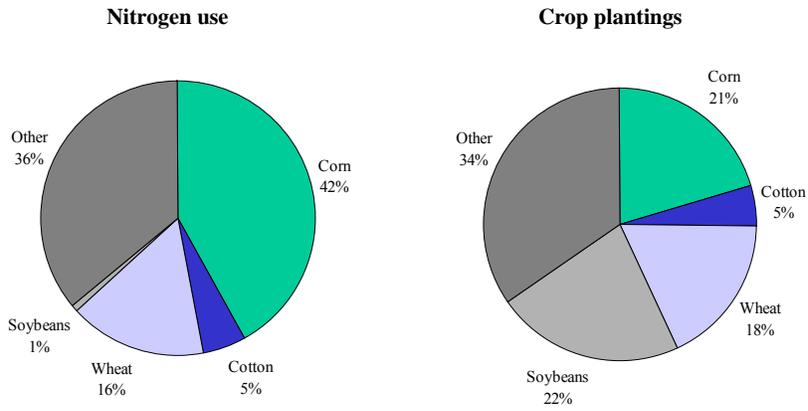


Figure 12. U.S. nitrogen use and crop plantings, crop year 2000-01. (IMC Global Inc., 2001, p. 19; U.S. Department of Agriculture, 2001).

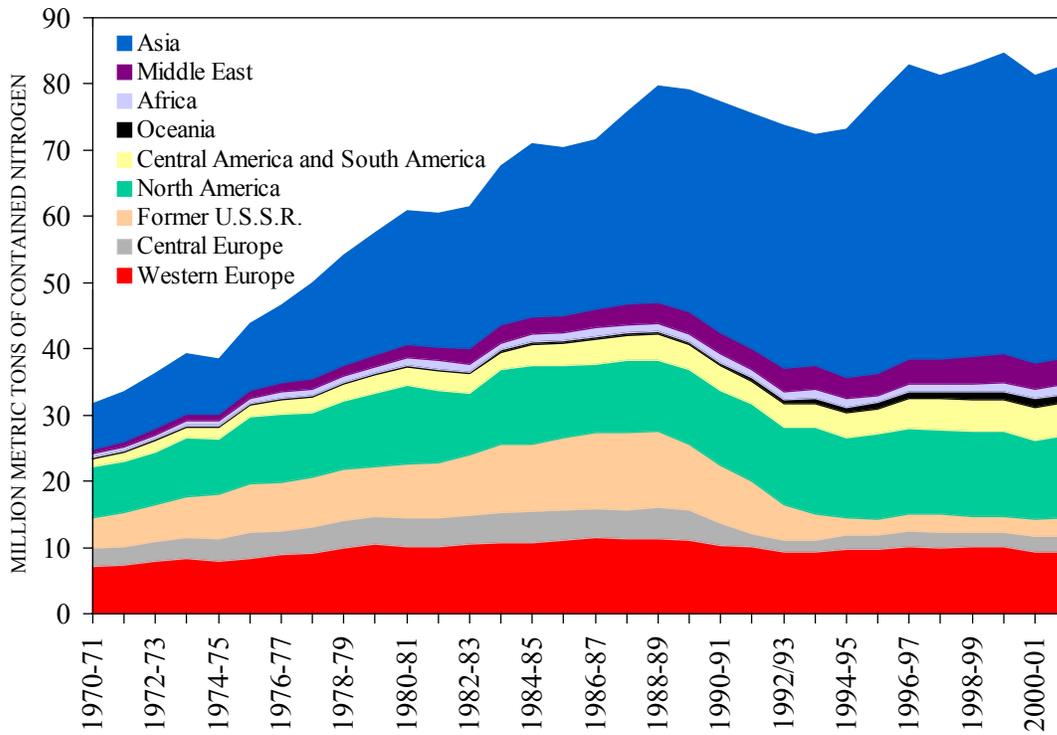
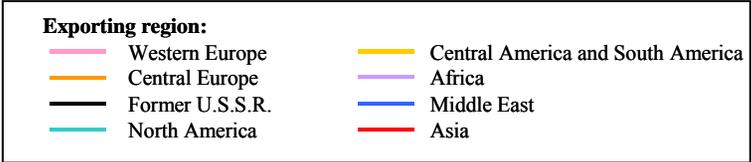


Figure 13. World nitrogen fertilizer nutrient consumption, in crop years. (International Fertilizer Industry Association, 2002).



Total trade: 13.1 million metric tons

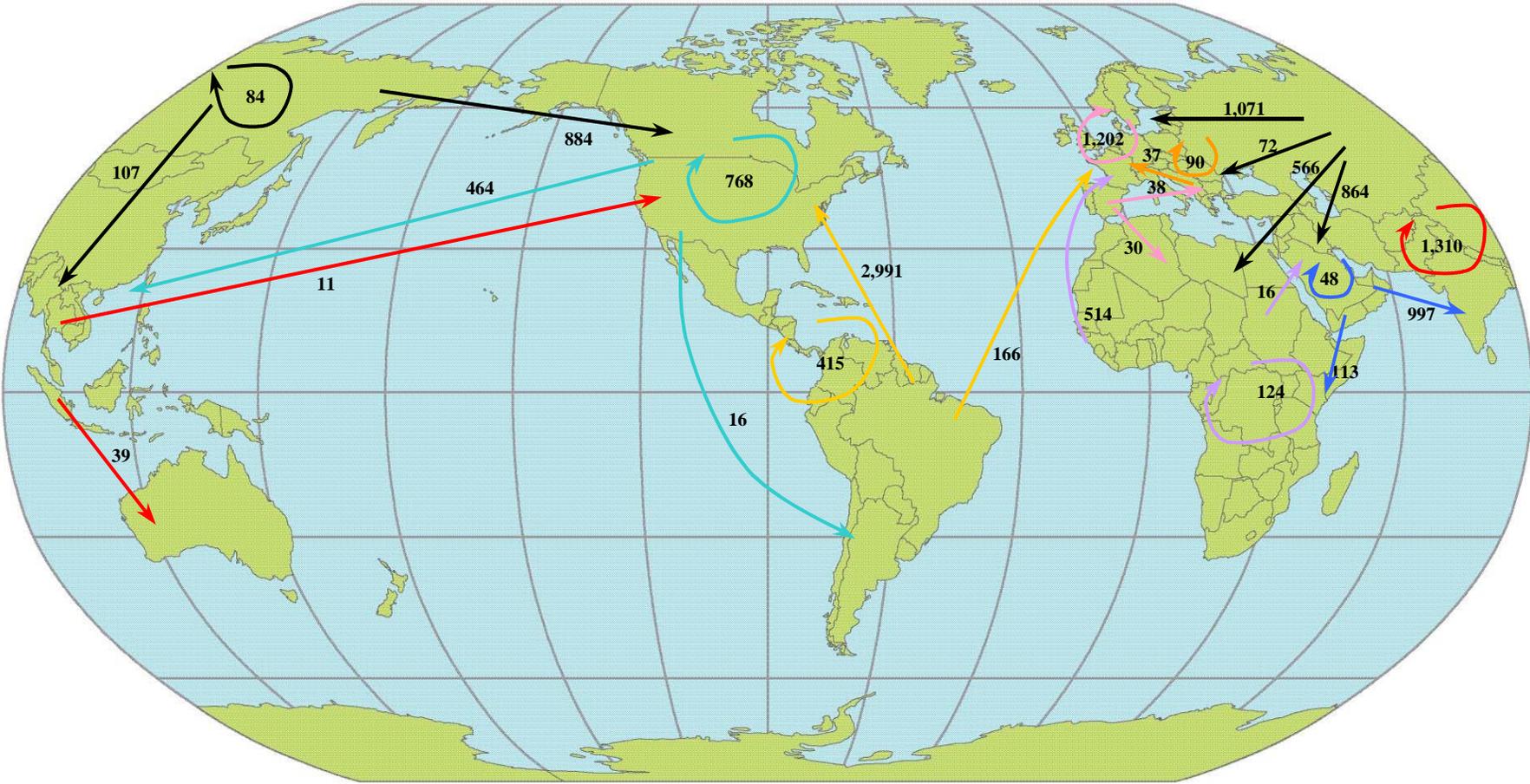
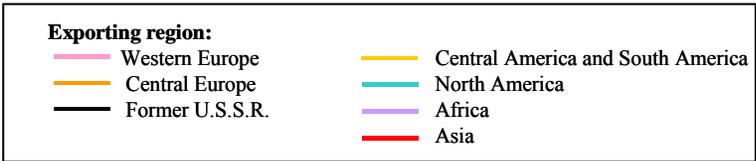


Figure 14. Ammonia world trade, by region, 2002. Totals are in thousand metric tons of contained nitrogen. (International Fertilizer Industry Association, 2003b).



Total trade: 3.29 million metric tons

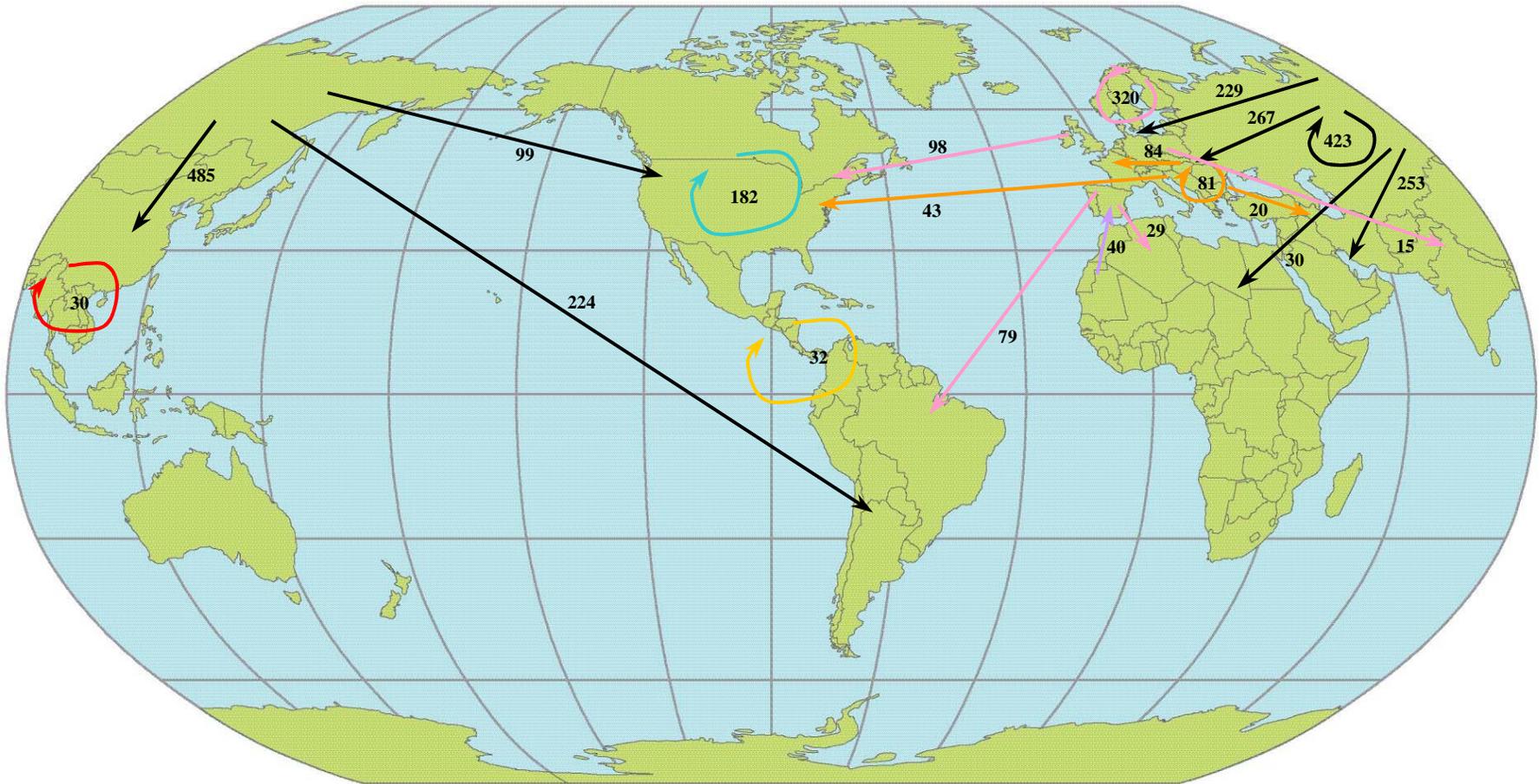
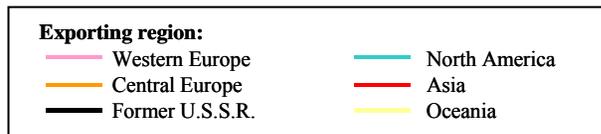


Figure 16. Ammonium nitrate world trade, by region, 2002. Totals are in thousand metric tons of contained nitrogen. (International Fertilizer Industry Association, 2003a).



Total trade: 1.53 million metric tons

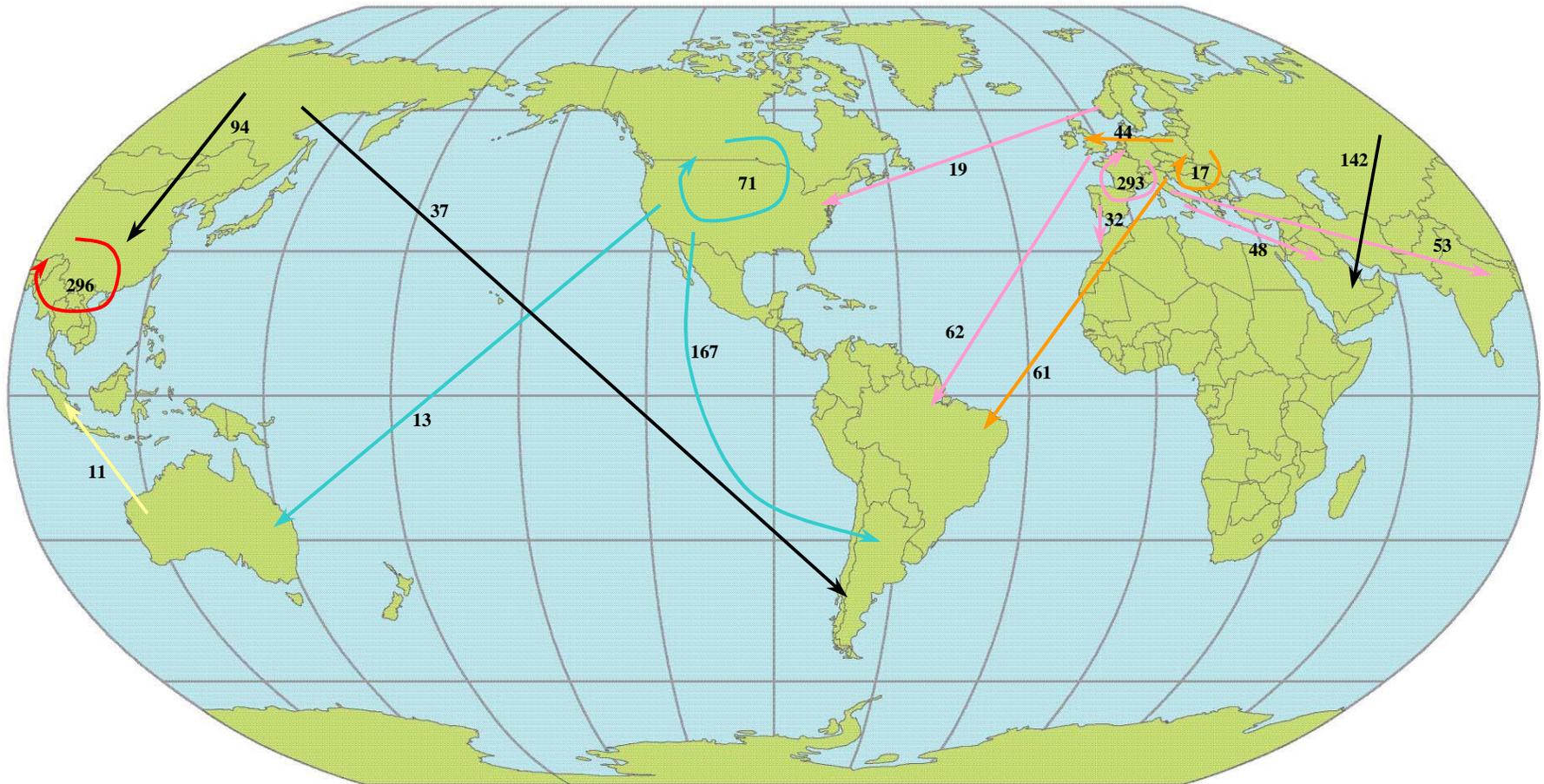


Figure 17. Ammonium sulfate world trade, by region, 2002. Totals are in thousand metric tons of contained nitrogen. (International Fertilizer Industry Association, 2003c).

SUSTAINABLE DEVELOPMENT

One of the generally accepted definitions of sustainable development was first proposed in 1987—development that meets the needs of the present without compromising the ability of future generations to meet their own needs (SD Gateway, undated). No firm definition of the concept has been written, however, and, perhaps, one is not needed. This is because sustainable development concerns a process of change and is heavily reliant upon local contexts, needs, and interests.

With nitrogen, the outputs to the biosphere have become a controversial issue. N_2O is considered to be a greenhouse gas and is emitted from such anthropogenic processes as, agriculture, biomass burning, industrial activities, and livestock management. Excess nitrogen in water can cause hypoxic zones along the world’s coastlines; hypoxia means “low oxygen” and is referred to as a “dead zone.” Because of these factors, scientists have been attempting to identify the sources of nitrogen and to mitigate its effects from these sources. Because nitrogen is under such scrutiny, a wide range of data, much of which is specific to certain geographic areas or to specific emissions, such as N_2O , NO_x , from specific sources, has been published. Some data represent a time series, and other data present a “snapshot” of a particular time period. In addition, data are reported in a variety of units that are not easily related to a common value. Therefore, finding a common basis with which to compare these available data sets is difficult. As scientists continue to study the effects of nitrogen in the biosphere, the complexity of the relationships between it and other chemicals that affect the biosphere is just beginning to be understood. The following discussion presents some of the available data on nitrogen inputs and outputs to the biosphere.

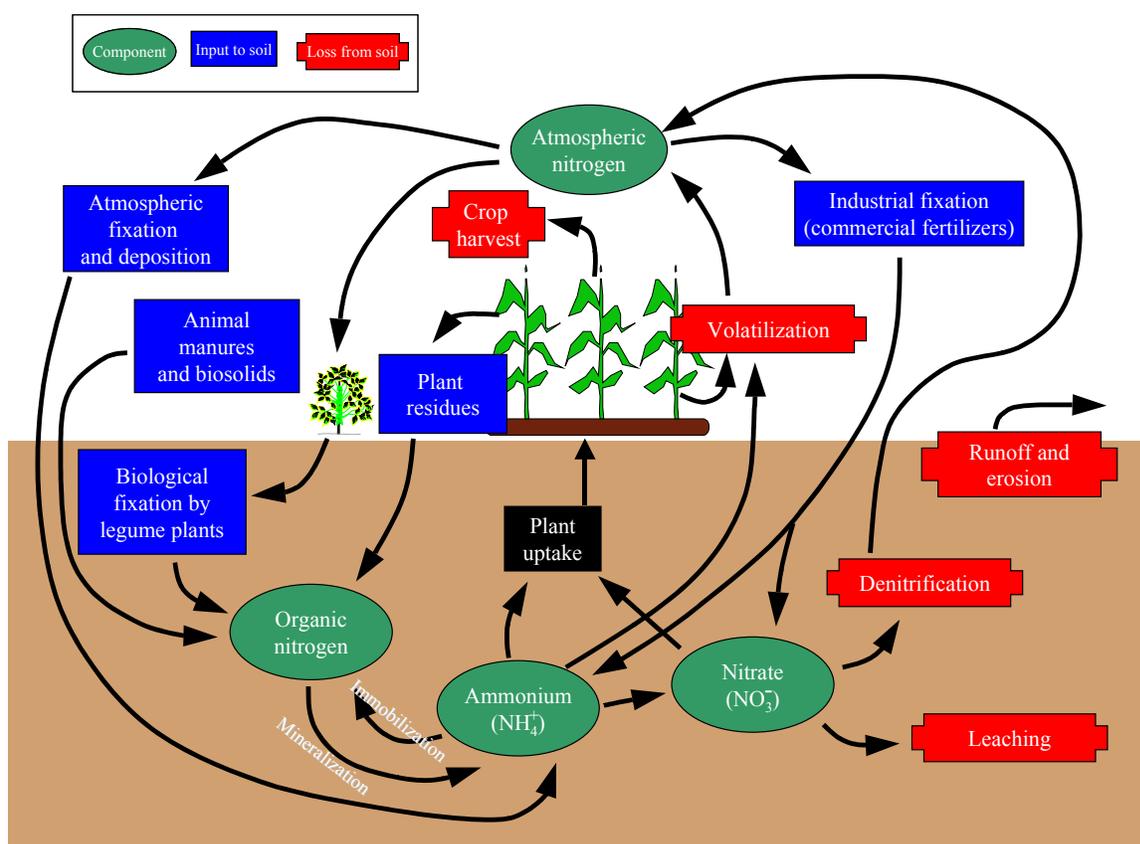


Figure 18. Nitrogen cycle. (Agerton, 2000).

NITROGEN SOIL INPUTS

The nitrogen cycle shows the sources and releases of nitrogen in the environment (figure 18). The five sources of nitrogen to the soil are atmospheric fixation and deposition, biological fixation by legume plants, plant residues, animal manures and biosolids, and industrial fixation (commercial fertilizers). Atmospheric fixation takes place when lightning transforms atmospheric nitrogen into nitrates. According to Vitousek and others, (1997), worldwide, lightning is estimated to contribute from 5 to 10 Mt of nitrogen to the total nitrogen fixed per year. In addition, a small number of algae and bacteria can convert gaseous nitrogen from the atmosphere directly into plant-usable forms of nitrogen, thus providing an additional source of nitrogen to the earth. Bacterial fixation is estimated to contribute between 90 and 140 Mt of nitrogen annually. Certain leguminous plants, including alfalfa, peanuts, peas, and soybeans can fix nitrogen; this process is carried out by certain groups of soil bacteria and takes place in nodules that develop on legume roots. Vitousek and others (1997) estimated that nitrogen-fixing crops contribute an average of 40 Mt/yr of nitrogen to the soil. Decaying plants also are sources of nitrogen to the soil.

Animal manures and biosolids represent a significant source of nitrogen to the soils. Although highly variable in nitrogen content, manure is a good source of plant food and can improve the physical condition of the soil when properly applied. A study by the U.S. Department of Agriculture (Golleshon and others, 2001, p. 20) estimated the quantity of manure nutrients produced in the United States and the cropland and pasture available to receive it. In 1997, total recoverable nitrogen was estimated to be 1.23 Mt, and of this, 0.74 Mt, or nearly 60 percent, was considered to be excess. The principal reason for this accumulation is because much livestock production is away from crop-producing areas. Where livestock are confined in large numbers, such as dairies, feedlots, and poultry buildings, the accumulation of manure is often significant. Transportation of manure for any but short distances is prohibitively expensive.

The largest anthropogenic source of nitrogen to the soil is commercial fertilizers. Vitousek and others (1997) estimated that about 80 Mt of nitrogen in the form of various fertilizers is applied to the land each year.

NITROGEN SOIL OUTPUTS

Soil nitrogen can be taken up and used by plants, tied up in decaying plant residues, immobilized by reactions with some types of soil clays, or lost in any of a number of ways. Tremendous quantities of nitrogen are removed in the harvested portion of crops. A significant portion of these crops are eaten by animals, and some of the nitrogen is returned in the form of animal wastes. Large quantities are lost each year from soils as a result of erosion. Most soil nitrogen is present in organic matter in the surface layers, which is the first part of the soil to be lost in water and wind erosion. Losses of soil nitrogen are controlled by soil texture, the amount of rainfall or irrigation, quantities and types of plant residues returned to the soil, and other conditions, such as soil temperature. Regardless of how the nitrogen was originally added to the soil, bacterial actions eventually convert it to ammonium nitrogen and nitrate nitrogen. If nitrate leaches below the soil levels where plant roots are using nutrients, then the nitrate may eventually undergo nitrification or find its way into ground water. Nitrate occurs naturally in ground water, but high concentrations can become a potential health hazard.

Nitrogen runoff from overfertilization has become a controversial issue among environmental organizations and fertilizer producers. Fertilizer applications are inherently uneven, and overfertilization may result in the runoff of fertilizer into lakes, rivers, and streams. Excess nitrogen from the fertilizer may lead to hypoxia. In estuaries, lakes, and coastal waters, low oxygen usually means a concentration of less than 2 ppm. Two conditions are necessary for the formation of hypoxia—stratification of the water and the presence of organic matter to consume oxygen. Increased algae growth in the surface water, whether from excess nutrients or other factors, leads to algal blooms. Organic material from the algae and other organisms settles into the bottom water where it is decomposed by bacteria, which consume oxygen in the process. Stratification blocks the replenishment of oxygen from the surface, and hypoxia develops.

One particular area that has received significant study is the Gulf of Mexico. Each year during the summer, a hypoxic area develops in the Gulf. In 2001, an action plan for controlling hypoxia in the Gulf of Mexico was prepared by members of the Mississippi River/Gulf of Mexico Watershed Nutrient Task Force and submitted as a report to Congress. A major goal of the action plan is to reduce the size of the hypoxic zone to less than 5,000 square kilometers, which is a reduction of about one-half of the average, by 2015. States, tribes, and relevant Federal agencies with jurisdiction in the Mississippi and Atchafalaya River Basins and the Gulf agreed to the actions in the plan, which included preparing watershed strategies to reduce the amount of nutrients, particularly nitrogen, that enter their waters. These groups would have the flexibility to develop the most effective and practical strategies to reduce discharges of excess nutrients to their waters. The strategies were expected to rely heavily on voluntary and incentive-based approaches for dealing with agricultural and urban runoff, restoring wetlands, and creating vegetative or forested buffers along rivers and streams within priority watersheds. The best current [2002] scientific understanding of the hypoxic zone indicated that these strategies should aim at achieving a 30% reduction in nitrogen discharges to the Gulf by 2015 (U.S. Environmental Protection Agency, 2001a).

The Gulf of Mexico is not the only area in which hypoxic zones have developed. Areas along the Atlantic and Pacific coastlines have shown some damage from agricultural runoff. A report prepared by the National Research Council of the National Academy of Sciences stated that the Federal Government and State and local agencies should develop a comprehensive regulatory solution to combat nitrogen and phosphorous runoff from agricultural fields, which was causing serious environmental damage along the Atlantic and Pacific coastlines. According to the report, a national strategy should strive to reduce the number of severely damaged coastal areas by 25 percent by 2020 and to ensure that no other areas become affected. Initiatives that were identified by the report to address the problem included expanding monitoring and assessment programs, exerting Federal leadership on issues spanning multiple jurisdictions or threatening federally protected natural resources, eliminating overlap and gaps among existing and proposed Federal legislation, providing data and technical assistance to local coastal authorities, and developing a classification scheme to provide better information on the likelihood that excess nutrients will damage coastal areas (Green Markets, 2000).

Potential methods for fertilizer producers and fertilizer consumers to combat some of the environmental problems associated with nitrogen runoff include improvements in manure management, cropping system management, prediction of seasonal soil nitrogen mineralization, and timing of nitrogen applications; and site-specific precision agriculture, biotechnology, and advanced fertilizer products.

Another way nitrogen is lost from the soil is through the conversion of nitrate into inert elemental nitrogen and other gases. Soil bacteria perform denitrification when soil pores are saturated with water. Soil bacteria that decompose plant residues require oxygen. In the absence of adequate oxygen, which has been forced out of the soil by the excess water, the oxygen in nitrate is used by some

bacteria, which releases nitrogen to the atmosphere. This is a significant mechanism of nitrogen loss from warm, wet soils and takes place regardless of the original nitrogen source.

NITROGEN AIR EMISSIONS

Nitrogen generated by burning fossil fuels is a significant source of nitrogen to the air. Powerplants and manufacturing facilities that burn fuels, such as coal and oil, release NOx into the atmosphere. Automobile engine combustion also generates NOx. In the United States, motor vehicles were estimated to generate 49 percent; electric utilities (powerplants), 27 percent; industrial, commercial, and residential combustion, 19 percent; and a variety of other sources, 5 percent (U.S. Environmental Protection Agency, 2002b). Nitrogen oxides are regulated in the United States by the Clean Air Act; the Clean Air Act Amendments of 1990 directed the EPA to set standards for all major sources of air toxics, which included NOx. The Clean Air Act Amendments of 1990 set a goal of reducing NOx by 2 million short tons (1.8 Mt) from 1980 levels. Several programs are being implemented to reduce the total quantity of NOx; each is focused on a different segment that generates the compounds. An example is the acid rain program, which targets NOx emissions from coal-fired electric utility boilers. Various State-specific NOx trading programs have been developed to reduce the transport of ground-level ozone across long distances (U.S. Environmental Protection Agency, 2002a).

Figure 19 provides EPA estimates of N₂O emissions, by source, in the United States for 2001. Agriculture was the largest emitting source with 71 percent of the total. Figures 20 and 21 show the changes in N₂O emissions from 1990–2000 and project emissions to 2010 by world region and by emitting sector, although not all countries were included. These data were compiled from publicly available country-submitted estimates that were consistent with the Revised 1996 Intergovernmental Panel on Climate Change (IPCC) Guidelines for National Greenhouse Gas Inventories (U.S. Environmental Protection Agency 2001b, p. 3-1–3-7). Regionally, North America and Western Europe were the largest N₂O emitters with 48 percent and 31 percent, respectively, of the 2000 total. In 2000, agricultural soils were the largest emitter, with 60 percent of the total and was followed by mobile sources (mostly automobiles) with 11 percent.

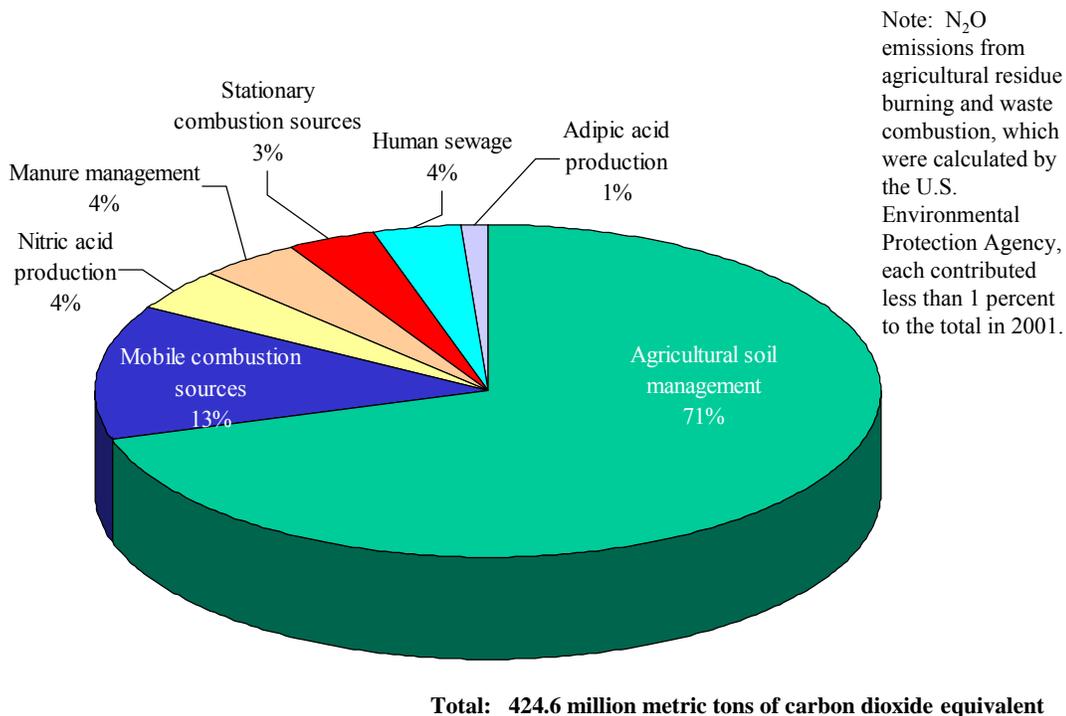


Figure 19. Nitrous oxide (N₂O) emissions, by source, in the United States, 2001. (U.S. Environmental Protection Agency, 2003).

For N₂O, emissions decreased only slightly between 1990 and 1995 in spite of the economic restructuring in several countries. Large agricultural countries with growing economies, such as the United States and the European Union, offset the emission reductions in other countries. A significant change began in 2000, however, as the second largest source of emissions shifted from industrial processes to mobile sources. In 1990, industrial processes accounted for about 15 percent of total emissions, but these emissions dropped dramatically from 1990 to 2000 and are expected to stay near 2000 levels through 2010. Total N₂O emissions remain essentially level because of the dramatic increase in mobile source emissions.

The Intergovernmental Panel on Climate Change (2002) estimated the emissions of N₂O and NOx, their effects on climate change (in terms of radiative effects), and projections of future emissions, which were modeled from 35 varying scenarios. According to estimates of the IPCC, the atmospheric concentration of N₂O has steadily increased during the Industrial Era and is now 16 percent (46 parts per billion) greater than that of 1750. The present N₂O concentration has not been exceeded during at least the past 1,000

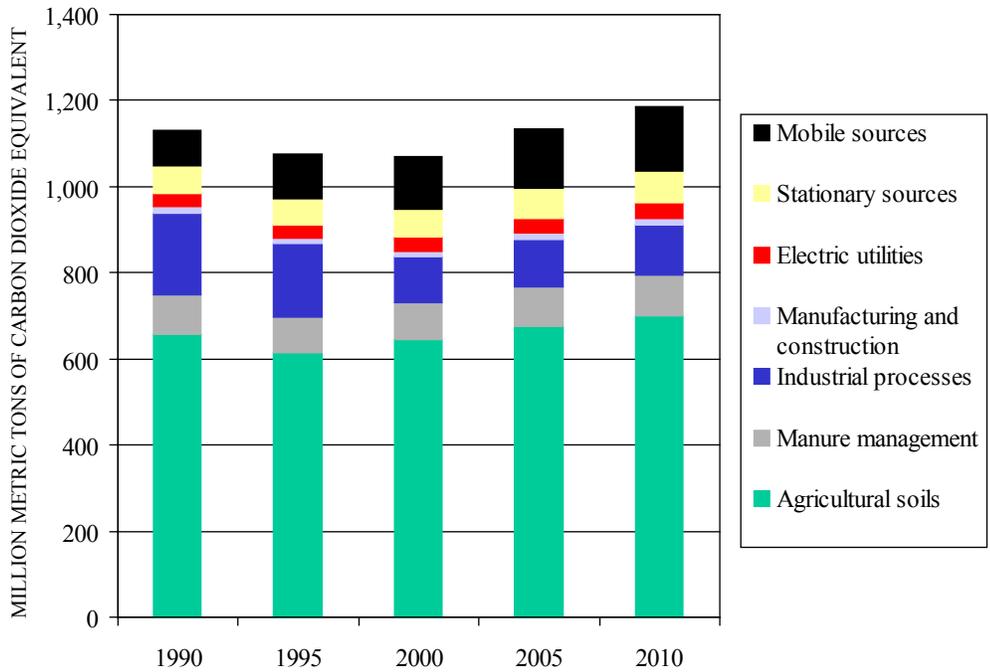


Figure 20. Nitrous oxide emissions in developed countries. (U.S. Environmental Protection Agency, 2001b).

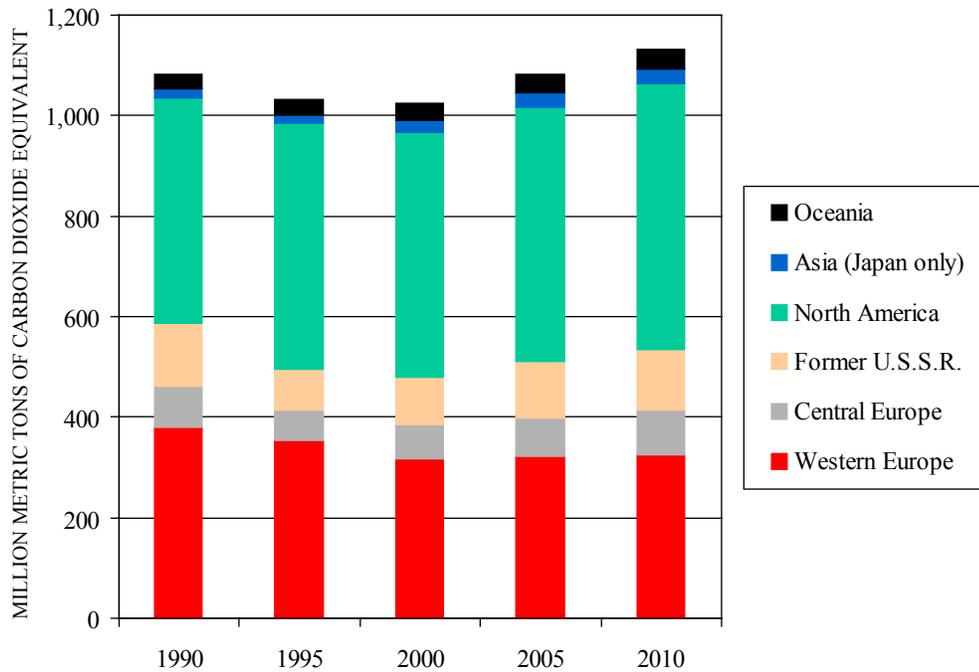


Figure 21. Nitrous oxide emissions in developed countries, by region. (U.S. Environmental Protection Agency, 2001b).

years. Nitrous oxide is another greenhouse gas that has natural and anthropogenic sources, and it is removed from the atmosphere by chemical reactions. Atmospheric concentrations of N_2O continued to increase at a rate of 0.25 percent per year from 1980 to 1998; significant interannual variations in the upward trend of N_2O concentrations, however, were observed, for example, a 50-percent reduction in the annual growth rate from 1991 to 1993. Suggested causes were a decrease in the use of nitrogen-based fertilizer, lower biogenic emissions, and larger stratospheric losses because of volcanic-induced circulation changes. Since 1993, the growth rate of N_2O concentrations has returned to a rate closer to those observed during the 1980s. Although this observed multiyear variance has provided some potential insight into what processes control the behavior of atmospheric N_2O , the multiyear trends of this greenhouse gas remain largely unexplained.

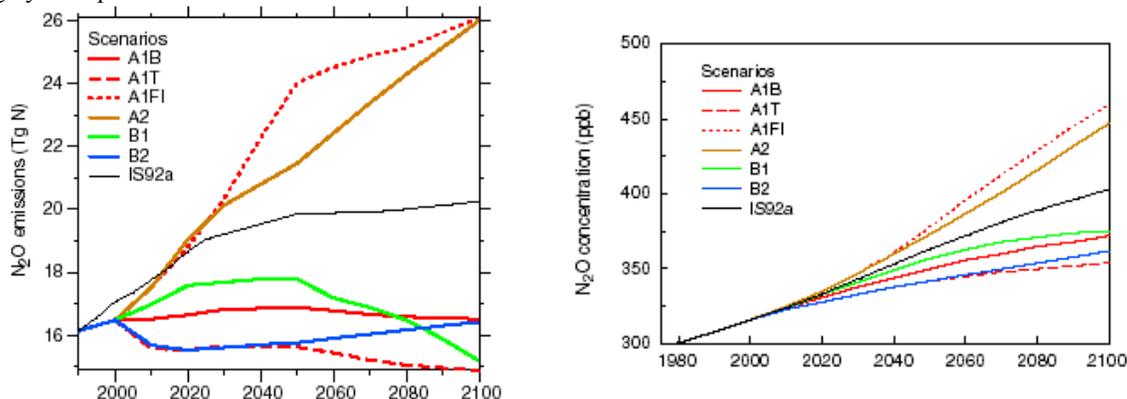


Figure 22. Projection of nitrous oxide emissions based on various model scenarios. (Intergovernmental Panel on Climate Change, 2002). N_2O is nitrous oxide, Tg N is teragrams of nitrogen content, and ppb is parts per billion.

The A1 scenario family describes a future world of very rapid economic growth, global population that peaks in mid-century and declines thereafter, and the rapid introduction of new and more efficient technologies. Major underlying themes are convergence among regions, capacity building, and increased cultural and social interactions, with a substantial reduction in regional differences in per-capita income. The A1 scenario family develops into three groups that describe alternative directions of technological change in the energy system. The three A1 groups are distinguished by their technological emphasis—fossil intensive (A1FI), nonfossil energy sources (A1T), or a balance across all sources (A1B), where balanced is defined as not relying too heavily on one particular energy source.

The A2 scenario family describes a heterogeneous world. The underlying theme is self reliance and preservation of local identities. Fertility patterns across regions converge very slowly, which results in continuously increasing population. Economic development is primarily regionally oriented, and per-capita economic growth and technological change are more fragmented and slower than other scenarios.

The B1 scenario family describes a convergent world with the same global population, that peaks in mid-century and declines thereafter, as in the A1 scenario with rapid change in economic structures toward a service and information economy, reductions in material intensity, and the introduction of clean and resource efficient technologies. The emphasis is on global solutions to economic, social, and environmental sustainability, but without additional climate initiatives.

The B2 scenario family describes a world in which the emphasis is on local solutions to economic, social, and environmental sustainability. It is a world with continuously increasing global population, at a rate lower than A2, intermediate levels of economic development, and less rapid and more diverse technological change than in the A1 and B1 scenarios. While the scenario is also oriented towards environmental protection and social equity, it focuses on local and regional levels.

The IS92a scenario, shown by the Intergovernmental Panel on Climate Change in a 1996 report, is shown for comparison (Intergovernmental Panel on Climate Change, 2002).

The IPCC (2002) estimated that emissions of N_2O from natural sources were approximately 10 Mt/yr of nitrogen; about 65 percent was from soils, and about 30 percent, from the oceans. New higher estimates of the emissions from anthropogenic sources of approximately 7 Mt/yr of nitrogen have brought the source-sink estimates closer in balance compared with the IPCC's previous assessment completed in 1996. The predictive understanding associated with this long-lived greenhouse gas has not improved significantly, however, since the 1996 assessment. The radiative forcing¹ is estimated to be 6 percent of the total from all the long-lived and globally mixed greenhouse gases. Figure 22 shows data from some of the modeling scenarios that the IPCC used to predict

¹A change in the net radiative energy available to the global Earth-atmosphere system is referred to as “radiative forcing” by the IPCC. Positive radiative forcings tend to warm the Earth’s surface and lower atmosphere. Negative radiative forcings tend to cool them.

the quantity of N₂O emissions to 2100. The important feature of these graphs is that N₂O emissions are projected to increase, but the total quantity will vary widely depending on the assumptions used in the model.

According to the IPCC (2002), the reactive nitrogen species in NO_x, which are NO and NO₂, are key compounds in the chemistry of the troposphere, but their overall radiative impact remains difficult to quantify. Reactive nitrogen in NO_x controls, in part, the oxidizing capacity of the troposphere and the abundance of ozone. It acts as an indirect greenhouse gas through its influence on ozone and the lifetimes of methane and other greenhouse gases. Deposition of the reaction products of NO_x fertilizes the biosphere, thereby decreasing atmospheric CO₂. Although difficult to quantify, the increases in NO_x that are projected to 2100 would cause significant changes in greenhouse gases.

The Food and Agriculture Organization of the United Nations and the International Fertilizer Industry Association (2001, p. 63–65) estimated the quantity of nitrogen emitted from the world’s agricultural lands and grasslands. By using models, they generated global annual estimates of 3.5 Mt of nitrogen content of N₂O emission and 2.0 Mt of nitrogen content of NO emission from croplands and grasslands. Of these total estimates, the emissions induced by fertilizers were estimated to be 0.9 Mt of nitrogen content and 0.5 Mt of nitrogen content, respectively, or approximately 0.8 percent and 0.5 percent, respectively, of the nitrogen input from fertilizer. An average ammonia loss of 14 percent of mineral fertilizer nitrogen use was estimated; this percentage was higher in developing countries. The ammonia loss from animal manure was estimated to be 22 percent, of which 60 percent was from developed countries. The results for ammonia volatilization agree with other inventories, although ammonia volatilization from some fertilizers appeared to be higher than previously thought. Table 4 lists the total nitrogen emitted as N₂O, NO_x, and ammonia from natural and anthropogenic sources.

ECONOMIC FACTORS

COSTS

Natural gas cost is the largest component in the total cost of producing ammonia and accounts for from 70 to 90 percent of the total production cost. According to The Fertilizer Institute’s 1999 production cost survey, the production of 1 short ton of ammonia required an average of 33.5 million British thermal units (Btu) of natural gas (36.9 million Btu per metric ton). By using U.S. Department of Commerce production data of about 17.3 million short tons of ammonia production in calendar year 1999, an estimated 580 trillion Btu of natural gas was used for ammonia manufacturing, which consumed about 3 percent of the total U.S. natural gas production. This estimate does not include the natural gas used as a fuel in processing ammonia into other fertilizer products, and some observers believe the fertilizer industry’s total use could represent up to 4 percent of U.S. natural gas production (Fertilizer Institute, The, 2001). Figure 23 shows the effect of the cost of natural gas on the production cost of ammonia. Each increase in the price of natural gas has a direct effect on the production cost of ammonia with gas making up 70 percent of the cost at \$2 per million Btu and 85 percent at \$5 per million Btu. The conversion costs shown are the average for the U.S. ammonia industry.

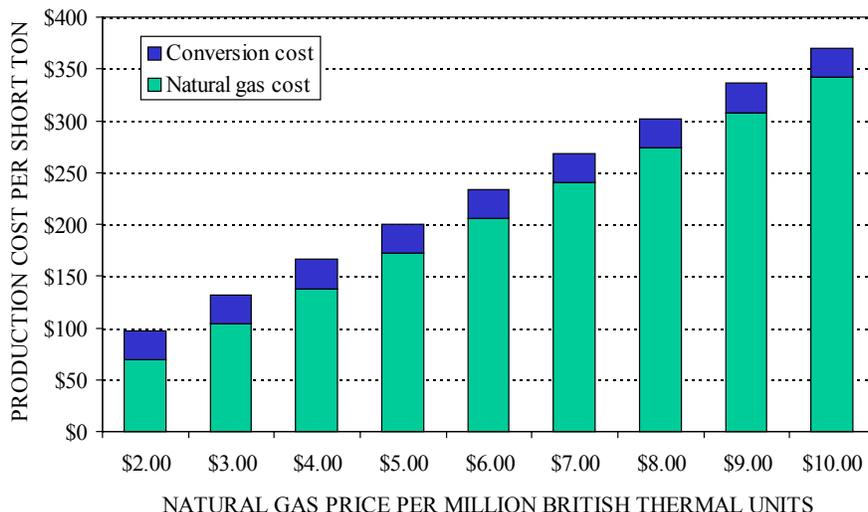


Figure 23. Estimated average ammonia production costs of North American producers at various levels of natural gas prices (Potash Corp. of Saskatchewan, 2003, p. 48).

Construction of a new ammonia plant normally takes about 3 years from inception to production. Depending on the location, additional support facilities, such as transportation equipment, may need to be included. On the basis of public announcements of construction costs for new ammonia plants in developed countries since 1998, the average capital cost for a stand-alone ammonia plant is estimated to range from about \$480 to \$500 per metric ton of annual capacity. Costs per metric ton of capacity are likely to be lower for ammonia plants that are constructed as part of a urea-ammonia complex. Because urea and urea derivatives have become

more commonly used than ammonia as a fertilizer source of nitrogen, many newly constructed ammonia plants are part of an ammonia-urea complex.

Table 4. Global sources of atmospheric NO_x¹, NH₃² and N₂O³, 1990.
 [Million metric tons of contained nitrogen per year. Food and Agriculture Organization of the United Nations and International Fertilizer Industry Association, 2001, p. 5. n.d., Not determined. —, Zero. ~, Approximately.]

Source	NO _x	NH ₃	N ₂ O
Anthropogenic sources:			
Fossil fuel combustion including aircraft	21.9	0.1	0.2
Industrial processes	1.5	0.2	0.3
Animal manure application, direct emission	0.7	~8	0.4
Animal manure, emission from other animal waste management systems ⁴	—	~13.6	2.1
Animal manure application, indirect emission	—	—	0.9
Mineral fertilizer use, direct emission	0.4	9	1.1
Mineral fertilizer use, indirect emission	—	—	0.5
Leguminous crops	n.d.	n.d.	0.1
Cultivated histosols	n.d.	n.d.	0.1
Biomass burning, including biofuel combustion	7.7	5.9	0.7
Crops and decomposition of crops	—	3.6	0.4
Human excreta	—	2.6	0.2
Coastal water	—	— ⁵	1.9
Atmospheric deposition	0.3	—	0.6
Natural sources:			
Soils under natural vegetation	13	2.4	6.6
Oceans	—	8.2	3.6
Excreta of wild animals	—	0.1	—
Lightning	12.2	—	—
Tropospheric chemistry	0.9	—	0.6
Stratospheric chemistry	0.7	—	—
Total	59	54	20⁶

¹ Nitrogen oxides.

² Ammonia.

³ Nitrous oxide.

⁴ Other animal waste management systems include storage, grazing, and so forth.

⁵ NH₃ emissions from coastal water are included in the estimate for oceans.

⁶ This total is based on mass balance calculations of atmospheric N₂O. The sum of the individual source estimates exceeds the global source by about 30%.

TRANSPORTATION

In 2002, 13.1 Mt of ammonia was exported; this represents about 12 percent of the total ammonia produced. This is a significant portion of production, and much of it is moved internationally by sea. International ocean-going shipments of ammonia are transported by refrigerated vessels whose capacities range from 3 to 38,000 t; most range from 12,000 to 75,000 cubic meters (m³) in volume. The ammonia trade uses from about 40 to 60 percent of the 16,000- to 38,000-t ammonia (25,000- to 58,000-m³)-capacity tankers depending on market conditions. The balance is used for liquefied petroleum gas and occasionally naphtha or other light clean products (Dietlin, 2001). Principal export points are Russia and Ukraine (exports total from about 3.8 to 4.0 Mt/yr), Trinidad and Tobago and Venezuela (exports total about 3.6 Mt/yr), the Arabian Gulf and Bangladesh (exports total about 1.6 Mt/yr), Indonesia and Malaysia (exports total about 1.1 Mt/yr), northern Africa and the United States (Alaska) (exports total about 0.7 Mt/yr each). In addition, the quantity of intra-European trade, which is located mostly in the northwestern Europe-Baltic Sea area, is significant.

In the United States, ammonia was transported by refrigerated barge, rail, pipeline, and truck. In 2002, three companies served 11 States with 4,900 kilometers (km) of pipelines. Ammonia also was transported by barge along 4,800 km of river and by rail and truck primarily for interstate or local delivery.

Kaneb Pipe Line Partners L.P. operated the Gulf Central ammonia pipeline. The 3,070-km pipeline originates in the Louisiana delta area where it has access to three marine terminals. It moves north through Louisiana and Arkansas into Missouri, where at Hermann, it splits—one branches east into Illinois and Indiana and the other branch continues north into Iowa and then turns west into Nebraska. The capacity of this pipeline is about 2 Mt/yr; storage capacity is more than 1 Mt. The ammonia pipeline connects with 3 third-party-

owned deepwater import terminals, 11 third-party-owned production and fertilizer-upgrading facilities, 23 third-party-owned delivery terminals, and to another fertilizer pipeline in the Midwest. Ammonia is supplied primarily to the pipeline from plants in Louisiana and from foreign-source product through the marine terminals.

CF Industries and Cargill Fertilizer Inc. jointly operate the 135-km long Tampa Bay Pipeline (TBP) system. TBP moves nitrogen compounds and ammonium phosphate for fertilizer producers in Hillsborough and Polk Counties, Fla. The Williams Companies Inc. pipeline and that of its subsidiary Mid-America Pipeline System covers 1,700 km from Borger in northern Texas to Mankato in southern Minnesota. The pipeline has a capacity of more than 1 Mt/yr and about 0.5 Mt of ammonia storage capacity.

Capacities for trucks and railcars are usually 20 t and 100 t, respectively. Depending on the product loaded and the volume of the container, barges can accommodate from 400 to 2,000 t.

According to a study conducted by The Fertilizer Institute, the rail cost of shipping ammonia in the United States in 1997 was approximately \$22.30 per short ton, the average distance shipped was 559 miles, and the cost of shipment was about \$3.35 per ton-mile. The cost of shipping urea by rail was \$21.63 per short ton, the average shipping distance was 671 miles, and the cost was \$3.22 per ton-mile (Klindworth, 2001). Inland barges, however, were the most important means for shipping ammonia. This was because most of the ammonia plants were located on the Gulf Coast, and the largest fertilizer-consuming States were up the Mississippi River in the Corn Belt.

Ammonium nitrate is transported by rail, road, and water, but its transportation on U.S. navigable waterways is restricted because of its use in explosives. Urea is shipped either in bulk or as bagged material.

The development of fertilizer blends is due partly to the location of fertilizer production and consumption, which favors handling in bulk. In the United States, the principal production points of the primary fertilizer materials are located far from each other—phosphates in Florida and the Southeast, potash in Canada or New Mexico, and nitrogen on the Gulf Coast. These materials need to be brought together in yet another location—the major consuming area of the Corn Belt. These fertilizer ingredients are transported to the area of consumption and mixed there. The river transport to the Corn Belt and, in the case of fluid fertilizers, a well-developed pipeline system have facilitated these developments.

OUTLOOK

Because nitrogen is essential to plant and animal health and nitrogen has no substitute, its use will continue to increase as the world's population continues to grow. Data that project the world nitrogen supply-demand balance, which was prepared by the Food and Agriculture Organization of the United Nations (2001), indicated that nitrogen demand will increase, on average, by 1.7 percent per year through the 2005–06 crop year, and the potential supply was projected to increase by 1.3 percent per year during the same period. Because the nitrogen supply has been in a surplus, the projected increase in demand, which is greater than that for supply, was expected to reduce the surplus somewhat. The gains will not be equivalent in all the world regions. Such regions as Asia, North America, and Western Europe were projected to have an internal deficit in supply, whereas countries from the former U.S.S.R. and Central America and South America would have an internal surplus of supply. This regional supply imbalance will continue the trend of exports from these two regions to provide a significant share of the North American demand.

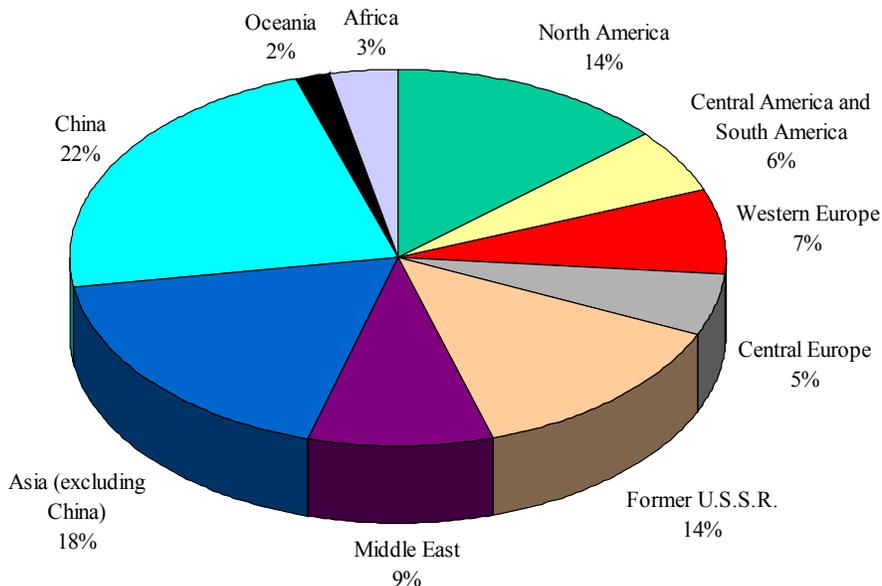


Figure 24. Projected world ammonia capacity, by region, 2008. (International Fertilizer Industry Association, 2003d).

Corn will remain the principal crop use for nitrogen in fertilizer. In addition to corn planted for human consumption, ethanol production in the United States is expected to continue to expand at a rapid rate as the United States phases out the use of methyl-tert-butyl-ether (MTBE) as an oxygenate in gasoline and replaces it with ethanol. This expansion in ethanol production will encourage farmers to plant corn because it is the principal feedstock for ethanol production. In the 2002–03 crop year, corn consumption for ethanol production rose by 15 percent compared with that of 2002, and additional growth is expected during the next 5 years (Baker, Allen, and Chambers, 2004). Increased meat consumption also is expected to lead to an increase in corn production. This increased consumption will produce an immediate multiplier effect on grain consumption. It takes approximately 7 kg of feed grain to produce 1 kg of beef, 4 kg of grain per 1 kg of pork, and 2 kg of grain per 1 kg of poultry.

The International Fertilizer Industry Association (2003d) projects that the total world ammonia production capacity will increase by about 8 percent between 2002 and 2008; most of this increase will be in Asia and the Middle East. Production capacity in Europe and North America is expected to decline. Figure 24 shows the percentage of projected world capacity by region in 2008. On the basis of these projections, Asia will have about 40 percent of the total world capacity in 2008; about one-half of that capacity will be in China.

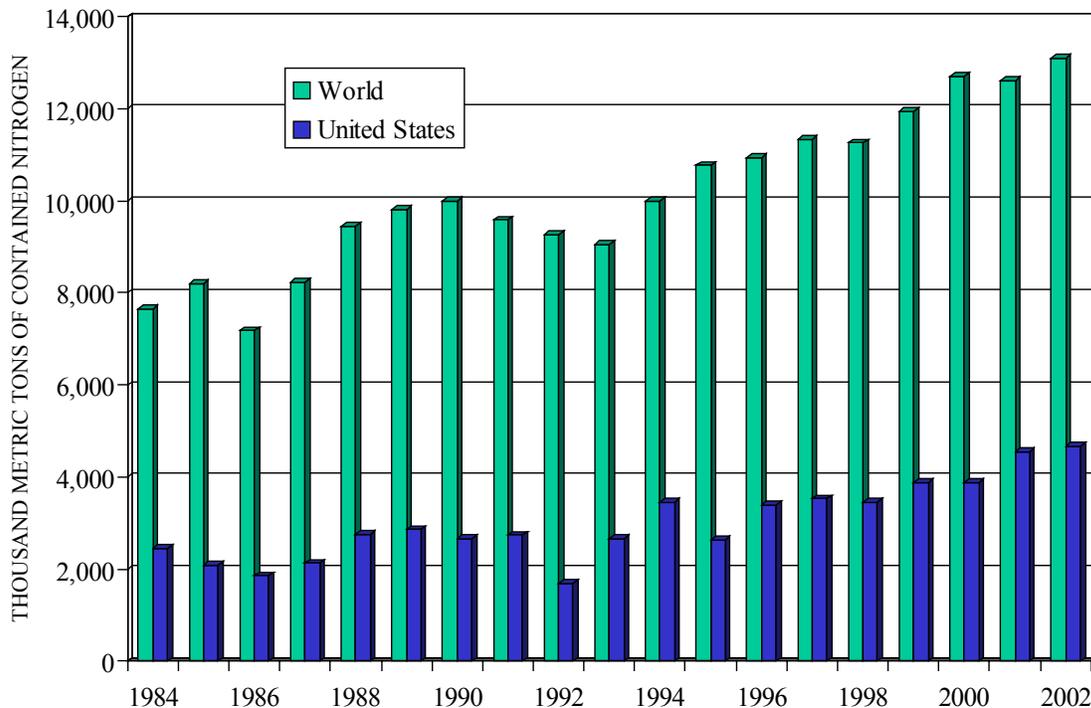


Figure 25. World ammonia trade.

Fluctuating natural gas prices and financial difficulties at some of the largest U.S. nitrogen producers continue to fuel the trend of moving ammonia production from the United States to such areas as Central America and South America and the Middle East, where resources of natural gas are large. Within the past 5 years, total ammonia production capacity in the United States has fallen by 10%, production has generally trended downward, and imports of ammonia have increased. In addition, the gap between production and production capacity has widened, reflecting extended capacity closures. These trends are expected to continue and, perhaps, accelerate depending mainly on the direction of the U.S. economy and the stability of natural gas prices.

Many countries produce natural gas for less than \$1.50 per million Btu and can produce ammonia for substantially less than U.S. producers. As natural gas prices climb in the United States, ammonia imports through the U.S. Gulf Coast likely will become more economical than domestically produced material. This may cause the higher cost U.S. producers in the Gulf region to curtail production permanently.

World ammonia trade has increased significantly to 13.1 Mt of contained nitrogen. The United States, which is the largest ammonia importer in the world, accounts for 35 percent of world trade and has shown the largest increase in ammonia imports over the past 5 years (figure 25). Western Europe accounts for an additional one-quarter of world ammonia imports, but this region's total has been declining because of closures of plants that produce finished fertilizer products.

U.S. ammonia imports have increased significantly during the last 5 years to 4.7 Mt of contained nitrogen. Imports from Trinidad and Tobago have doubled since 1997 and accounted for more than one-half of total U.S. ammonia imports by 2002; this increase resulted from the addition of more than 2 Mt/yr of production capacity in Trinidad and Tobago since 1997. The former U.S.S.R. remains a large supplier, as does Canada. Imports from Venezuela also have increased during the last 2 years because of a new plant coming onstream in that country. U.S. ammonia imports are expected to continue to increase over the next several years.

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APPENDIX. SELECTED NITROGEN DATA, 1970–2002

Table A-1. Salient ammonia statistics ¹.

[In thousand metric tons of contained nitrogen unless otherwise specified. E, Net exporter. NA, Not available. Data are rounded to three significant digits, except prices]

	1970	1971	1972	1973	1974	1975	1976	1977	1978	1979	1980	1981	1982	1983	1984	1985	1986
United States:																	
Production:																	
Synthetic plants.....	10,300	10,900	11,300	11,300	11,700	12,200	12,500	13,200	12,800	13,900	14,700	14,200	11,800	10,200	12,500	12,900	10,800
Ammonia liquor, coking plants.....	11	11	10	5	5	5	4	6	6	6	6	2	5	5	5	NA	NA
Production capacity (thousand metric tons of ammonia).....	15,200	15,300	15,300	15,200	15,800	16,300	16,500	19,100	19,500	18,600	19,000	17,900	16,900	16,000	16,200	16,300	16,100
Exports.....	727	369	530	672	296	262	327	314	394	587	607	459	553	270	397	916	482
Imports for consumption.....	361	379	288	246	338	601	543	802	1,130	1,450	1,740	1,560	1,580	1,970	2,450	2,090	1,860
Consumption, apparent ²	9,880	10,700	11,100	11,500	11,600	11,900	12,500	13,400	13,800	14,900	16,000	14,900	12,800	12,400	14,300	14,000	12,400
Stocks, December 31, producers'.....	1,070	1,240	1,190	640	849	1,540	1,680	2,060	1,800	1,630	1,460	1,900	1,910	1,410	1,550	1,630	1,370
Average annual price per short ton product, f.o.b. Gulf Coast ³	\$57	\$56	\$60	\$85	\$200	\$185	\$185	\$130	\$82	\$130	\$122	\$132	\$118	\$178	\$147	\$108	\$75
Net import reliance ⁴ as a percentage of apparent consumption.....	E	E	E	1	E	E	⁵	1	7	7	8	4	8	18	13	8	13
Natural gas price, wellhead ⁶	\$0.17	\$0.18	\$0.19	\$0.22	\$0.30	\$0.44	\$0.58	\$0.79	\$0.91	\$1.18	\$1.59	\$1.98	\$2.46	\$2.59	\$2.66	\$2.51	\$1.94
World:																	
Production.....	38,800	41,100	43,000	46,700	48,400	49,500	56,900	62,000	67,200	71,100	73,600	77,000	75,900	80,400	88,600	91,000	91,100
Trade ⁷	NA	NA	NA	NA	NA	NA	NA	NA	7,650	8,200	7,190						

43

	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002
United States:																
Production:																
Synthetic plants.....	12,000	12,500	12,300	12,700	12,800	13,400	12,600	13,300	13,000	13,400	13,300	13,800	12,900	11,800	9,120	10,100
Ammonia liquor, coking plants.....	NA	NA	NA	NA	NA	NA	NA	NA								
Production capacity (thousand metric tons of ammonia).....	14,300	15,300	15,800	15,700	16,100	16,000	15,900	16,100	16,600	16,700	17,500	17,900	17,900	17,700	17,500	16,700
Exports.....	769	582	346	482	580	354	378	215	319	435	395	614	562	662	647	437
Imports for consumption.....	2,140	2,750	2,860	2,670	2,740	1,690	2,660	3,450	2,630	3,390	3,530	3,460	3,890	3,880	4,550	4,670
Consumption, apparent ²	13,800	14,700	14,900	14,900	14,800	15,600	15,100	16,500	15,300	16,400	15,800	17,100	16,300	14,900	13,200	14,500
Stocks, December 31, producers'.....	955	925	849	797	936	1,060	852	956	959	881	1,530	1,050	996	1,120	916	771
Average annual price per short ton product, f.o.b. Gulf Coast ³	\$95	\$109	\$104	\$106	\$117	\$106	\$121	\$211	\$191	\$190	\$173	\$121	\$109	\$169	\$183	\$137
Net import reliance ⁴ as a percentage of apparent consumption.....	13	14	17	15	14	14	17	19	15	19	16	19	21	20	31	30
Natural gas price, wellhead ⁶	\$1.67	\$1.69	\$1.69	\$1.71	\$1.64	\$1.74	\$2.04	\$1.85	\$1.55	\$2.17	\$2.32	\$1.96	\$2.17	\$3.69	\$4.12	\$2.95
World:																
Production.....	95,100	99,300	99,300	97,500	93,800	93,400	91,600	93,800	100,000	103,000	104,000	104,000	107,000	108,000	105,000	109,000
Trade ⁷	8,240	9,450	9,820	10,000	9,590	9,270	9,060	10,000	10,800	10,900	11,300	11,300	12,000	12,700	12,600	13,100

¹ Synthetic anhydrous ammonia, calendar year data, U.S. Census Bureau; excludes coke oven byproduct.² Calculated from production, plus imports minus exports, and industry stock changes.³ Source: Green Markets.⁴ Defined as imports minus exports, adjusted for industry stock changes.⁵ Less than ½ unit.

Table A-1. Salient ammonia statistics ¹—Continued.⁶ Monthly Energy Review, U.S. Department of Energy. Average annual cost at wellhead in dollars per thousand cubic feet.⁷ Source: International Fertilizer Industry Association Statistics, World Anhydrous Ammonia Trade.

Note: Prior to 1984, yearend Gulf Coast price for ammonia; before 1978, delivered east of Rocky Mountains, except East coast. Prior to 1973, exports include aqua ammonia.

Table A-2. Major downstream nitrogen compounds produced in the United States ¹.

[In thousand metric tons. Current Industrial Reports (MA28B, MQ28B, MQ325A, and MQ325B); U.S. Census Bureau. NA, Not available. Data are rounded to three significant digits]

Compound	1970	1971	1972	1973	1974	1975	1976	1977	1978	1979	1980	1981	1982	1983	1984	1985	1986
Urea:																	
Gross weight	2,830	2,790	3,150	3,210	3,440	3,230	3,560	4,030	5,690	6,350	7,100	7,310	5,910	5,240	7,030	6,330	5,680
Nitrogen content	1,300	1,280	1,440	1,480	1,580	1,480	1,640	1,850	2,610	2,920	3,260	3,360	2,710	2,400	3,230	2,900	2,610
Ammonium nitrate:																	
Gross weight	5,870	5,990	6,240	6,490	6,840	6,430	6,520	6,510	6,540	7,520	8,280	8,040	6,430	6,010	6,500	6,490	5,530
Nitrogen content	1,990	2,030	2,120	2,200	2,320	2,180	2,210	2,210	2,220	2,550	2,810	2,730	2,180	2,040	2,200	2,200	1,870
Ammonium phosphates: ²																	
Gross weight	4,730	5,340	5,900	6,140	6,180	6,910	8,150	9,260	10,400	11,000	12,100	10,900	9,350	11,600	13,400	12,500	9,980
Nitrogen content	NA	2,230	2,100	1,690													
Ammonium sulfate: ³																	
Gross weight	2,300	2,140	1,800	1,980	1,870	2,370	2,300	2,490	2,630	2,250	2,030	1,980	1,600	1,780	1,880	1,900	1,890
Nitrogen content	487	454	382	419	396	503	487	529	558	477	430	420	340	378	398	403	400
Nitric acid:																	
Gross weight ⁴	6,070	6,120	7,240	7,660	7,370	6,830	7,070	7,250	7,200	8,090	8,370	8,250	6,700	6,680	1,960	1,830	1,760
Nitrogen content	1,330	1,350	1,590	1,690	1,620	1,500	1,560	1,590	1,580	1,780	1,840	1,820	1,480	1,470	430	402	387
Compound	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	
Urea:																	
Gross weight	6,740	7,180	7,260	7,450	7,380	7,950	7,520	7,230	7,370	7,740	7,430	8,140	8,080	6,910	6,080	7,040	
Nitrogen content	3,100	3,300	3,340	3,430	3,390	3,660	3,460	3,330	3,440	3,550	3,410	3,740	3,710	3,170	2,790	3,230	
Ammonium nitrate:																	
Gross weight	12,100	13,700	7,140	7,000	7,090	7,240	7,490	7,740	7,700	8,190	7,810	8,240	7,230	6,800	5,830	6,330	
Nitrogen content	4,110	2,350	2,500	2,450	2,480	2,530	2,620	2,710	2,700	2,780	2,650	2,790	2,450	2,310	1,980	2,140	
Ammonium phosphates: ²																	
Gross weight	5,940	6,810	14,900	15,900	16,400	17,200	15,900	15,600	16,500	16,900	17,500	16,200	16,700	15,900	14,500	15,500	
Nitrogen content	2,080	2,380	2,520	2,670	2,710	2,920	2,680	2,660	2,850	2,820	2,980	2,790	2,820	2,550	2,320	2,490	
Ammonium sulfate: ³																	
Gross weight	1,990	2,120	2,160	2,290	2,040	2,170	2,200	2,350	2,400	2,420	2,460	2,560	2,610	2,600	2,350	2,580	
Nitrogen content	421	445	459	485	432	460	466	495	509	512	521	542	533	552	498	547	
Nitric acid:																	
Gross weight ⁴	1,880	1,890	1,950	1,680	1,610	1,680	1,840	1,710	1,770	8,350	8,560	8,420	8,120	7,690	6,420	6,940	
Nitrogen content	413	420	434	374	357	373	408	381	407	1,840	1,880	1,850	1,790	1,690	1,410	1,530	

¹ Ranked in relative order of importance by nitrogen content.² Diammonium phosphate, monoammonium phosphate, and other ammonium phosphates.³ Excludes coke plant ammonium sulfate (1981–2002).⁴ Before 1996, gross nitric acid production netted for use in production of ammonium nitrate.

Table A-3. U.S. imports of major nitrogen compounds.

[In thousand metric tons and thousand dollars. U.S. Census Bureau. NA, Not available. Data are rounded to three significant digits; because of independent rounding, components may not add to totals shown.]

Compound	1970			1971			1972			1973			1974		
	Gross weight	Nitrogen content	Value ¹	Gross weight	Nitrogen content	Value ¹	Gross weight	Nitrogen content	Value ¹	Gross weight	Nitrogen content	Value ¹	Gross weight	Nitrogen content	Value ¹
Ammonium nitrate ²	297	101	\$15,200	342	116	\$16,300	347	118	\$16,800	310	105	\$15,600	342	116	\$26,000
Ammonium sulfate ²	198	42	6,500	208	44	5,060	239	51	7,310	271	58	10,600	234	50	20,200
Anhydrous ammonia ³	440	362	20,700	419	345	20,400	350	288	17,000	299	246	16,200	413	339	52,200
Diammonium phosphate.....	NA	NA	NA												
Monoammonium phosphate.....	NA	NA	NA												
Nitrogen solutions.....	112	34	5,200	152	46	5,520	135	40	4,760	175	52	7,380	79	24	7,190
Urea.....	394	181	22,400	298	137	16,100	504	232	\$25,600	611	281	38,900	650	299	87,900
Total.....	1,440	719	\$70,000	1,420	687	\$63,400	1,580	728	71,500	1,670	742	\$88,700	1,720	827	\$194,000

Compound	1975			1976			1977			1978			1979		
	Gross weight	Nitrogen content	Value ¹	Gross weight	Nitrogen content	Value ¹	Gross weight	Nitrogen content	Value ¹	Gross weight	Nitrogen content	Value ¹	Gross weight	Nitrogen content	Value ¹
Ammonium nitrate ²	225	76	\$25,300	286	97	\$24,500	355	120	\$35,100	435	148	\$39,900	346	117	\$33,200
Ammonium sulfate ²	199	42	21,400	513	109	23,500	297	63	16,400	296	63	19,800	222	47	16,900
Anhydrous ammonia ³	732	602	124,000	662	544	70,800	978	804	103,000	1,360	1,120	133,000	1,770	1,460	166,000
Diammonium phosphate.....	83	15	14,100	129	23	18,600	155	28	19,300	108	19	14,300	132	24	17,900
Monoammonium phosphate.....	NA	NA	NA												
Nitrogen solutions.....	106	32	11,700	274	82	21,800	449	134	40,300	300	90	33,000	109	33	12,400
Urea.....	593	272	87,900	764	351	84,700	1,280	589	154,000	1,290	594	169,000	1,020	470	137,000
Total.....	1,940	1,040	\$284,000	2,630	1,210	\$244,000	3,520	1,740	\$368,000	3,800	2,030	\$409,000	3,600	2,150	\$383,000

Compound	1980			1981			1982			1983			1984		
	Gross weight	Nitrogen content	Value ¹	Gross weight	Nitrogen content	Value ¹	Gross weight	Nitrogen content	Value ¹	Gross weight	Nitrogen content	Value ¹	Gross weight	Nitrogen content	Value ¹
Ammonium nitrate ²	367	124	\$41,400	419	142	\$51,100	396	134	\$54,800	463	157	\$60,900	596	202	\$71,600
Ammonium sulfate ²	262	56	22,300	297	63	28,600	289	61	28,100	259	55	24,100	514	109	28,900
Anhydrous ammonia ³	2,120	1,740	234,000	1,900	1,560	245,000	1,920	1,580	293,000	2,390	1,970	344,000	2,980	2,450	474,000
Diammonium phosphate.....	134	24	23,900	106	19	20,100	63	11	12,200	47	8	9,330	48	9	9,980
Monoammonium phosphate.....	NA	NA	NA												
Nitrogen solutions.....	161	48	23,600	133	40	18,000	116	35	15,400	210	63	23,900	231	69	26,600
Urea.....	923	423	140,000	774	355	131,000	1,920	880	173,000	1,740	799	236,000	2,000	916	270,000
Total.....	3,970	2,420	\$486,000	3,630	2,180	\$494,000	4,700	2,700	\$577,000	5,110	3,050	\$699,000	6,360	3,750	\$880,000

See footnotes at end of table.

Table A-3. U.S. imports of major nitrogen compounds—Continued.

[In thousand metric tons and thousand dollars. U.S. Census Bureau. NA, Not available. Data are rounded to three significant digits; because of independent rounding, components may not add to totals shown.]

Compound	1985			1986			1987			1988			1989		
	Gross weight	Nitrogen content	Value ¹	Gross weight	Nitrogen content	Value ¹	Gross weight	Nitrogen content	Value ¹	Gross weight	Nitrogen content	Value ¹	Gross weight	Nitrogen content	Value ¹
Ammonium nitrate ²	598	203	\$68,000	556	189	\$54,200	344	117	\$30,300	358	121	\$33,000	411	139	\$48,400
Ammonium sulfate ²	904	192	34,000	264	56	20,600	259	55	18,400	337	71	27,300	305	65	27,800
Anhydrous ammonia ³	2,550	2,090	380,000	2,260	1,860	273,000	2,570	2,110	228,000	3,310	2,720	351,000	3,480	2,860	388,000
Diammonium phosphate.....	45	8	8,240	32	6	5,510	26	5	5,040	10	2	2,430	15	3	3,900
Monoammonium phosphate.....	NA	NA	NA	NA	NA	NA	NA	NA	NA	27	3	6,920	30	3	10,500
Nitrogen solutions.....	171	51	20,900	303	91	26,100	467	140	27,600	532	159	46,600	595	178	60,100
Urea.....	1,960	902	262,000	3,160	1,450	306,000	2,270	1,040	205,000	2,020	926	230,000	1,970	905	262,000
Total.....	6,230	3,450	\$774,000	6,570	3,650	\$686,000	5,930	3,470	\$515,000	6,590	4,000	\$697,000	6,810	4,150	\$801,000

Compound	1990			1991			1992			1993			1994		
	Gross weight	Nitrogen content	Value ¹	Gross weight	Nitrogen content	Value ¹	Gross weight	Nitrogen content	Value ¹	Gross weight	Nitrogen content	Value ¹	Gross weight	Nitrogen content	Value ¹
Ammonium nitrate ²	406	138	\$49,000	421	143	\$52,800	444	151	\$55,500	485	164	\$58,500	612	207	\$74,000
Ammonium sulfate ²	361	77	34,400	311	66	29,100	336	71	30,200	367	78	32,000	455	96	38,000
Anhydrous ammonia ³	3,250	2,670	357,000	3,340	2,740	391,000	3,270	2,690	366,000	3,230	2,660	415,000	4,200	3,450	725,000
Diammonium phosphate.....	11	2	3,270	7	1	2,200	23	4	4,910	38	7	7,100	15	3	4,270
Monoammonium phosphate.....	51	6	13,500	91	10	20,200	162	18	28,800	157	17	26,000	203	22	41,400
Nitrogen solutions.....	402	120	31,400	218	65	21,000	108	32	10,900	391	117	38,200	312	93	31,500
Urea.....	1,860	854	251,000	1,620	743	209,000	1,560	716	205,000	2,960	1,360	396,000	3,160	1,450	436,000
Total.....	6,340	3,870	\$739,000	6,000	3,770	\$726,000	5,900	3,680	\$701,000	7,630	4,400	\$973,000	8,960	5,320	\$1,350,000

Compound	1995			1996			1997			1998			1999		
	Gross weight	Nitrogen content	Value ¹	Gross weight	Nitrogen content	Value ¹	Gross weight	Nitrogen content	Value ¹	Gross weight	Nitrogen content	Value ¹	Gross weight	Nitrogen content	Value ¹
Ammonium nitrate ²	721	245	\$103,000	718	251	\$110,000	708	240	\$104,000	759	257	\$99,900	935	198	\$111,000
Ammonium sulfate ²	434	91	40,700	373	79	38,300	478	101	47,000	319	68	29,800	342	58	34,500
Anhydrous ammonia ³	3,200	2,630	877,000	4,130	3,390	793,000	4,300	3,530	722,000	4,210	3,460	565,000	4,730	3,890	548,000
Diammonium phosphate.....	21	4	6,010	77	16	18,300	57	10	14,500	44	8	11,100	36	11	8,360
Monoammonium phosphate.....	219	24	52,500	181	22	52,400	115	13	33,500	126	14	35,600	47	7	18,800
Nitrogen solutions.....	628	189	83,000	877	264	119,000	780	233	89,900	633	189	60,700	614	92	54,600
Urea.....	2,940	1,350	487,000	2,520	1,170	447,000	2,530	1,160	425,000	3,320	1,530	520,000	3,260	1,500	486,000
Total.....	8,160	4,530	\$1,650,000	8,870	5,200	\$1,580,000	8,970	5,290	\$1,440,000	9,420	5,520	\$1,320,000	9,970	5,750	\$1,260,000

See footnotes at end of table.

Table A-3. U.S. imports of major nitrogen compounds—Continued.

[In thousand metric tons and thousand dollars. U.S. Census Bureau. NA, Not available. Data are rounded to three significant digits; because of independent rounding, components may not add to totals shown.]

Compound	2000			2001			2002		
	Gross weight	Nitrogen content	Value ¹	Gross weight	Nitrogen content	Value ¹	Gross weight	Nitrogen content	Value ¹
Ammonium nitrate ²	818	277	\$93,700	953	323	\$127,000	990	336	\$115,000
Ammonium sulfate ²	347	74	32,400	335	71	28,700	347	74	27,400
Anhydrous ammonia ³	4,720	3,880	768,000	5,540	4,550	992,000	5,680	4,670	763,000
Diammonium phosphate.....	123	22	21,900	133	24	22,300	156	28	32,800
Monoammonium phosphate.....	188	21	40,700	262	29	48,600	229	25	46,700
Nitrogen solutions.....	1,310	390	129,000	2,000	597	235,000	997	298	98,400
Urea.....	3,900	1,790	621,000	4,800	2,200	773,000	3,840	1,760	556,000
Total.....	11,400	6,460	\$1,710,000	14,000	7,800	\$2,230,000	12,200	7,190	\$1,640,000

¹ Cost, insurance, and freight (c.i.f.) value.

² Includes industrial chemical products.

³ Includes industrial ammonia.

Table A-4. U.S. exports of major nitrogen compounds ¹.

[In thousand metric tons. U.S. Census Bureau. NA, Not available. Data are rounded to three significant digits; because of independent rounding, components may not add to totals shown.]

Compound	1970		1971		1972		1973		1974		1975		1976	
	Gross weight	Nitrogen content												
Ammonium nitrate ²	61	21	35	12	20	7	37	13	16	6	42	14	11	4
Ammonium sulfate ²	474	128	468	126	472	127	479	129	481	130	659	178	584	158
Anhydrous ammonia ³	886	729	450	370	646	531	820	674	361	297	320	263	399	328
Diammonium phosphate.....	NA	NA												
Monoammonium phosphate.....	NA	NA												
Urea.....	422	194	356	163	454	208	387	178	287	132	505	232	483	222
Total.....	1,840	1,070	1,310	671	1,590	873	1,720	994	1,150	564	1,530	687	1,480	711

Compound	1977		1978		1979		1980		1981		1982		1983	
	Gross weight	Nitrogen content												
Ammonium nitrate ²	14	5	42	14	98	33	92	31	67	23	68	23	44	15
Ammonium sulfate ²	454	122	748	202	946	255	743	201	670	181	508	137	662	179
Anhydrous ammonia ³	383	315	476	391	715	588	751	617	559	459	673	553	329	271
Diammonium phosphate.....	NA	NA	3,930	707	4,030	725	5,000	899	3,940	710	3,710	667	4,270	769
Monoammonium phosphate.....	NA	NA												
Urea.....	524	241	1,370	630	1,360	626	1,760	809	1,430	657	1,500	687	997	458
Total.....	1,370	682	6,570	1,950	7,150	2,230	8,340	2,560	6,670	2,030	6,450	2,070	6,300	1,690

See footnotes at end of table.

Table A-4. U.S. exports of major nitrogen compounds ¹—Continued.

[In thousand metric tons. U.S. Census Bureau. NA, Not available. Data are rounded to three significant digits; because of independent rounding, components may not add to totals shown.]

Compound	1984		1985		1986		1987		1988		1989		1990	
	Gross weight	Nitrogen content												
Ammonium nitrate ²	24	8	116	39	141	48	259	88	82	28	132	45	42	14
Ammonium sulfate ²	619	167	660	178	1,050	284	679	183	791	214	774	209	1,020	275
Anhydrous ammonia ³	484	397	1,120	916	586	482	935	769	709	582	420	345	586	482
Diammonium phosphate.....	6,350	1,140	6,130	1,100	4,120	742	5,650	1,020	5,950	1,070	8,290	1,490	7,760	1,400
Monoammonium phosphate.....	NA	NA	NA	NA	NA	NA	537	59	857	94	809	89	737	81
Urea.....	1,150	529	1,050	481	498	229	1,020	468	966	443	1,140	523	854	392
Total	8,630	2,240	9,070	2,720	6,400	1,780	9,080	2,580	9,360	2,430	11,600	2,700	11,000	2,640

See footnotes at end of table.

Compound	1991		1992		1993		1994		1995		1996	
	Gross weight	Nitrogen content										
Ammonium nitrate ²	41	14	40	14	66	22	55	18	90	30	62	21
Ammonium sulfate ²	751	203	801	169	757	159	762	160	917	193	824	173
Anhydrous ammonia ³	705	579	431	354	460	378	261	215	387	319	530	435
Diammonium phosphate.....	9,740	1,750	8,270	1,490	7,240	1,300	9,190	1,660	10,100	2,140	7,920	1,680
Monoammonium phosphate.....	769	85	890	98	1,100	121	1,480	162	1,200	145	1,510	183
Urea.....	1,070	491	914	420	659	303	912	419	881	406	1,470	675
Total	13,100	3,130	11,300	2,540	10,300	2,280	12,700	2,630	13,600	3,230	12,300	3,170

Compound	1997		1998		1999		2000		2001		2002	
	Gross weight	Nitrogen content										
Ammonium nitrate ²	45	15	55	19	28	9	22	7	19	6	98	33
Ammonium sulfate ²	840	227	1,050	284	1,070	288	983	265	668	180	874	236
Anhydrous ammonia ³	481	395	747	614	684	562	805	662	787	647	532	437
Diammonium phosphate.....	8,500	1,530	9,870	1,780	9,860	1,780	7,240	1,300	6,410	1,150	6,820	1,230
Monoammonium phosphate.....	1,630	180	1,680	185	1,790	197	2,300	253	2,580	284	2,210	243
Urea.....	824	378	841	386	890	409	663	304	792	364	963	442
Total	12,300	2,730	14,200	3,270	14,300	3,240	12,000	2,790	11,300	2,640	11,500	2,620

¹ Value data suppressed by U.S. Census Bureau.

² Includes industrial chemical products.

³ Includes ammonia content of aqua ammonia (1970–77).

Table A-5. Price quotations for major nitrogen compounds at yearend.

[Per short ton product. Chemical Marketing Reporter, 1970-77; Green Markets, 1978-2000. NA, Not available.]

Compound	1970		1971		1972		1973		1974		1975		1976		1977		1978		1979		1980	
Ammonium nitrate; free on board (f.o.b.) Corn Belt ¹ ...	\$41-	\$45	\$40-	\$46.50	\$47-	\$49	\$47-	\$48	\$91-	\$115	\$91-	\$115	\$91-	\$115	\$91-	\$115	\$86-	\$90	\$118-	\$120	\$110-	\$115
Ammonium sulfate; f.o.b. Corn Belt ¹	23-	31	12-	22	15-	27	15-	25		89		60		60		60	60-	65	75-	80		85
Anhydrous ammonia:																						
F.o.b. Corn Belt	55-	59	55-	55-57	55-	65	60-	110	190-	210	180-	190	180-	190	120-	140	104-	115	148-	155	150-	160
F.o.b. Gulf Coast ²																	80-	84	128-	132	120-	124
Diammonium phosphate; f.o.b. central Florida		65	55-	62	55-	66	75-	110	145-	165		135	110-	125	110-	125	116-	120	212-	215	190-	195
Urea:																						
F.o.b. Corn Belt, prilled and granular	61-	65	53-	60	60-	63	72-	107	160-	175	160-	175	120-	140	120-	140	125-	135	165-	170	155-	170
F.o.b. Gulf Coast, granular ²		NA		NA		NA		NA		NA		NA		NA		NA		NA		NA		NA
F.o.b. Gulf Coast, prilled ²		NA		NA		NA		NA		NA		NA		NA		NA	106-	110	145-	150	170-	175

Compound	1981		1982		1983		1984		1985		1986		1987		1988		1989		1990		1991	
Ammonium nitrate; free on board (f.o.b.) Corn Belt ¹ ...	\$138-	\$150	\$125-	\$145	\$135-	\$145	\$135-	\$150	\$112-	\$133	\$100-	\$120	\$100-	\$120	\$128-	\$135	\$105-	\$115	\$120-	\$125	\$98-	\$118
Ammonium sulfate; f.o.b. Corn Belt ¹	70-	86	89-	91	99-	113	112-	123	88-	119	88-	119	100-	102	95-	105	100-	120	120-	130	107-	113
Anhydrous ammonia:																						
F.o.b. Corn Belt	190-	195	155-	165	175-	85	175-	195	160-	170	100-	115	130-	140	143-	150	110-	115	140-	145	125-	140
F.o.b. Gulf Coast ²	131-	133	115-	120	175-	180	142-	147	107-	110	71-	73	103-	106	126-	129	86-	88	115-	118	105-	107
Diammonium phosphate; f.o.b. central Florida	168-	172	145-	148	176-	181	150-	152	139-	147		120	170-	173	165-	173	125-	126	145-	148	131-	135
Urea:																						
F.o.b. Corn Belt, prilled and granular	170-	180	135-	145	160-	167	168-	200	110-	137	90-	110	125-	135	150-	155	110-	120	155-	165	132-	145
F.o.b. Gulf Coast, granular ²		NA		NA		NA	157-	160	98-	101	76-	80	118-	122	153-	155	115-	117	155-	156	129-	130
F.o.b. Gulf Coast, prilled ²	130-	135	122-	125	135-	140	147-	149	82-	95	75-	78	114-	117	139-	145	98-	105	142-	145	121-	122

Compound	1992		1993		1994		1995		1996		1997		1998		1999		2000		2001		2002	
Ammonium nitrate; free on board (f.o.b.) Corn Belt ¹ ...	\$125-	\$135	\$125-	\$135	\$150-	\$160	\$162-	\$170	\$160-	\$170	\$122-	\$125	\$110-	\$115	\$110-	\$115	\$140-	\$150	\$120-	\$130	\$120-	\$130
Ammonium sulfate; f.o.b. Corn Belt ¹	110-	120	121-	133	113-	135	124-	136	119-	130	124-	130	118-	128	109-	112	130-	135	124-	129	120-	130
Anhydrous ammonia:																						
F.o.b. Corn Belt	133-	145	142-	155	230-	240	205-	220	233-	245	181-	195	131-	141	157-	165	280-	300	170-	180	233-	245
F.o.b. Gulf Coast ²	117-	118	130-	132	218-	230	185-	195		225		130		98		109		230		125	170-	175
Diammonium phosphate; f.o.b. central Florida	111-	115	138-	140	167-	172	212-	215	177-	180	174-	175	172-	175	138-	140	137-	142	133-	140	134-	138
Urea:																						
F.o.b. Corn Belt, prilled and granular	135-	145	128-	150	185-	195	220-	235	197-	210	125-	135	110-	125	115-	125	175-	180	130-	135	150-	160
F.o.b. Gulf Coast, granular ²	129-	132	126-	128	199-	205	217-	222	188-	190	102-	103	82-	85	107-	110	158-	161	104-	108	128-	132
F.o.b. Gulf Coast, prilled ²	126-	128	116-	118	185-	193	217-	220	181-	184	102-	103	75-	80		102	150-	155	103-	105		125

¹ Illinois, Indiana, Iowa, Missouri, Nebraska, and Ohio.

² Barge, New Orleans, Louisiana.

Note: Prior to 1988, prices shown for ammonium nitrate; anhydrous ammonia, corn belt; and urea, corn belt are delivered prices. Prior to 1978, anhydrous ammonia prices are delivered, east of the Rocky Mountains; urea prices are delivered, east of the Rockies.