Chapter 8

The Food System

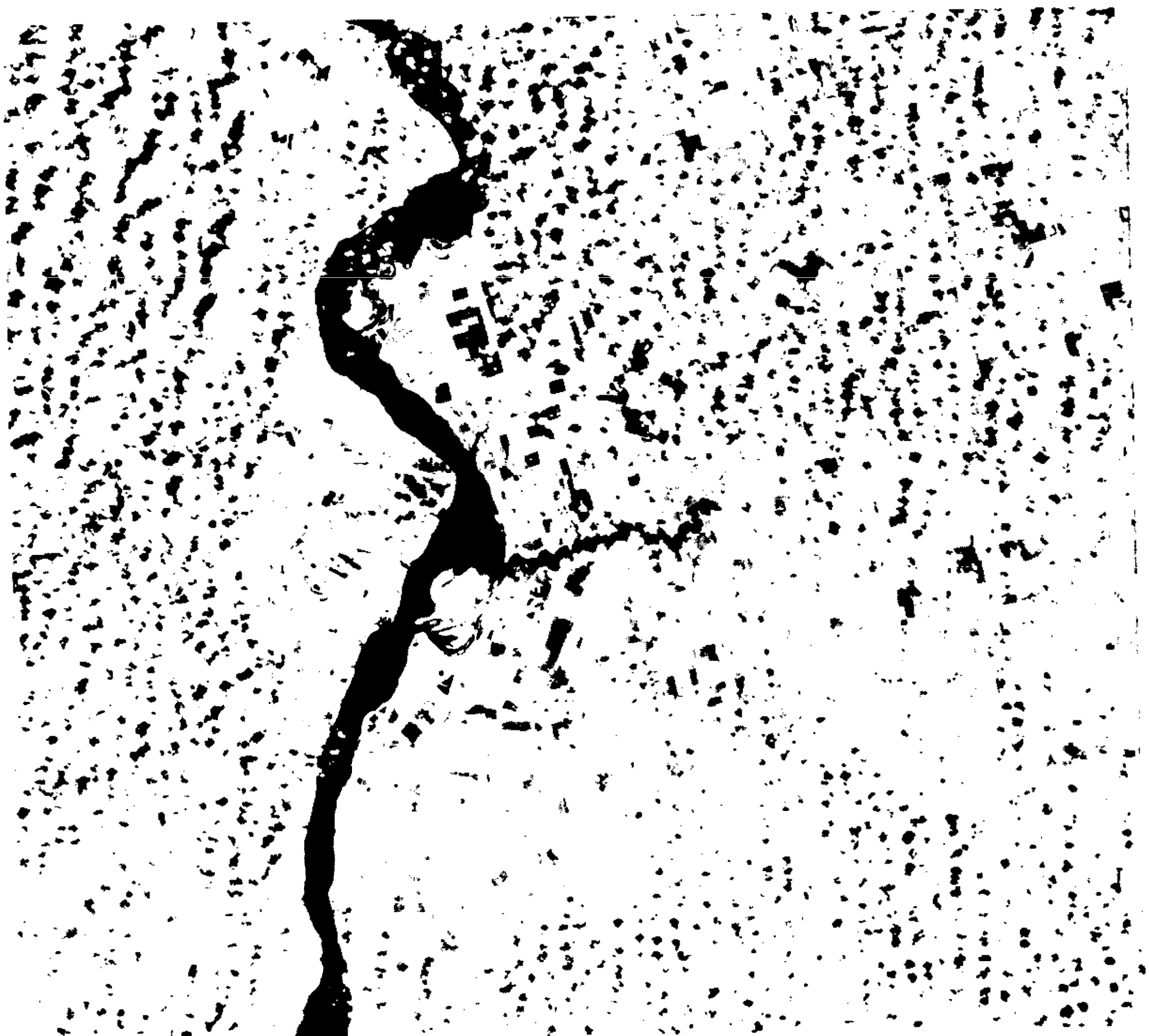

Photo credit: EOSAT

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The Food System

INTRODUCTION AND SUMMARY

The food system (see figure 8-1 and box 8-A) encompasses all the activities associated with providing food to consumers. These include food production (e.g., onsite clearing, cultivation, and harvesting, and off site production of fertilizer and other agricultural inputs) and post-harvest activities (e.g., food processing, transport, cooking) (see figure 8-1).

Congress has become increasingly aware of the environmental impacts of the food system and has begun to address some of these through legislation.[1] In addition to previously identified environmental impacts of agriculture (pollution of surface and groundwater by nitrate and pesticides, soil erosion, depletion of aquifers to meet irrigation needs, loss of natural habitat), the food system is now also recognized as a potential contributor to global climate change.

Figure 8-2 below shows the global food system's contribution to global warming in the 1980s.[2] Although estimates are uncertain, the food sector may account for one-third of global methane (CH_4) emissions; one-fifth of net global carbon dioxide (C)$_2$) emissions[3]; up to 15 percent of chlorofluorocarbon (CFC) emissions; and anywhere from one-tenth to one-fifth of current global nitrous oxide (N_2O) emissions. Food sector emissions of all these gases will grow, barring efforts to contain them, as efforts to provide food for the world's growing population intensify.

Uncertainty in agricultural emissions data currently makes it difficult to predict the efficacy of any of the control methods available to reduce this sector's contribution to global warming, yet many of these controls deserve consideration in their own right as a means to combat other agriculture-related environmental problems. Indeed, many have been or are being considered by Congress for reasons other than climate change,

In the United States and the industrialized world in general, several options are available to reduce food sector emissions in the near term. Methane emissions from livestock could be reduced by improving nutrient and manure management (and, possibly, by increasing productivity) or by reducing demand for livestock products.[4] Fertilizers and other sources of applied nitrogen, such as crop residues and animal wastes, could be used more efficiently; this may reduce N_2O emissions, as well as surface and groundwater contamination, and would help conserve soil organic matter. Nitrogen fertilizer manufacturing and onsite farm machinery and cultivation practices could be more energy efficient; while reductions in CO_2 emissions would be relatively small, other benefits such as decreased local air pollution from fossil fuel combustion would accrue. Land transformations that help remove carbon from the atmosphere (such as converting cropland to forest land) could be encouraged, while those that increase CO_2 emissions could be discouraged. In food refrigeration, emissions can be curbed by preventing the release of CFCs from existing refrigerators and eliminating their future use; and by improving energy efficiencies. Further CO_2 reductions could be achieved by designing stoves and ovens that use energy more efficiently and by increasing fuel efficiency in vehicles used in food transport (see chs. 4 and 5).

In developing countries, slowing deforestation, maintaining or increasing crop yields, and reducing emissions associated with cooking can be more effective, in the short term, than changing current

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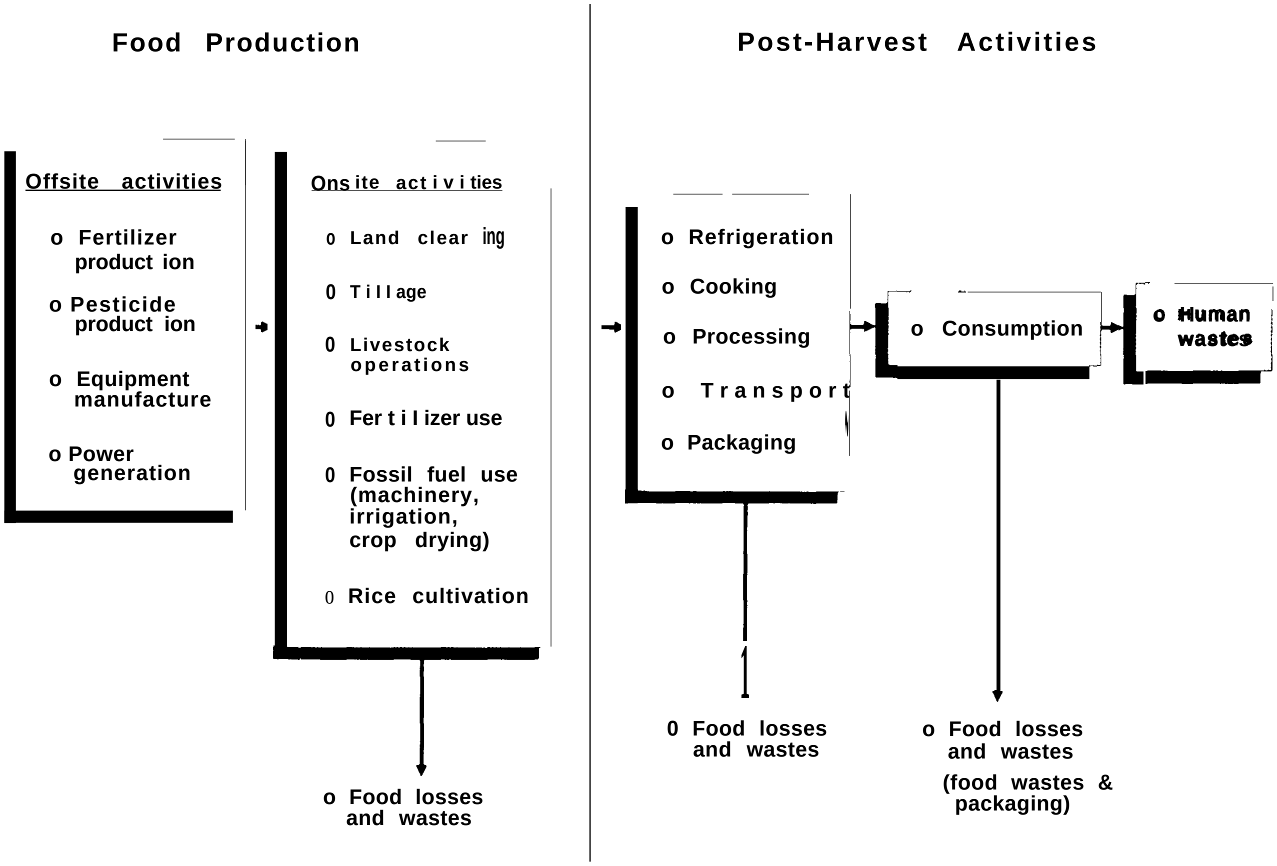
1 such as the Food Security Act of 1985 (Public Law 99-198) and the Food, Agriculture, Conservation and Trade Act of 1990 (Public Law 101-624).

2 These and other estimates throughout the chapter arc rough and should be considered as order-of-magnitude estimates.

3 This estimate refers primarily t. emissions from *food production* activities, including the clearing and burning of forests. Note that these emissions are already included in deforestation estimates presented in ch. 7 but are discussed here to provide a more systematic understanding of the food sector. In contrast, estimates of global CO_2 emissions from *post-harvest* activities (including processing, transportation, and cooking) are not included because data on which to derive such estimates arc lacking; however, cmissions from these activities in the United States arc discussed below. Accurate estimates of global emissions from cooking with biomass fuels arc also not available.

4 By increasing productivity (i.e., the output of meat or dairy products per unit of feed), the same amount of output could be obtained from a smaller herd size, thereby reducing total methane emissions. This assumes that the rate of output (e.g., milk, beef,) per animal due 10 productivity enhancements increases faster than emissions of methane per animal and that the level of demand remains relatively unchanged.

Figure 8-l—The Food System



SOURCE: Office of Technology Assessment, 1991.

patterns of fossil fuel use,[5] Alternatives to clearing of tropical forests include increased use of agro-forestry and "sustainable" agriculture, and decreased subsidies for cattle ranching on lands that cannot support livestock for more than a few years (see ch. 7). Crop yields maybe improved on existing agricultural land with increased agricultural inputs (e.g., fertilizers, irrigation, etc.), but this may increase greenhouse gas emissions per acre. Opportunities exist to reduce methane emissions from livestock through technololgy transfer to developing countries, but the relevant technologies may not be readily applicable in most developing countries. In general, direct U.S. Government influence in these areas tends to be through the U.S. Agency for International Development (A. I.D.), research programs, multinational corporations, and participation in multilateral lending institutions.

EMISSIONS FROM THE FOOD SYSTEM

Activities in the food system affect the flows of many substances to and from the atmosphere, including small particles (aerosols) and numerous trace gases. The system itself and key trends in global food production and consumption are summarized in box 8-A. In some developing countries, food production (i.e., activities up to and including harvest) is the dominant source of greenhouse gases, primarily because of CO_2 emitted through land transformations (e.g., land clearing and field burn-

[5]Fossil fuel use in the food sectors of developing countries might rise in the future if farm mechanization and refrigeration increase; an important opportunity for industrialized countries is to help developing countries increase the use of technologies that reduce costs of and emissions from such increases.

Box 8-A-Overview of the World Food System

Food production involves activities up to and including harvest-cultivation, manufacture and application of fertilizers and pesticides, irrigation, and other practices (see figure 8-l). In 1985, the world's production of plant crops exceeded 3 billion metric tons, 60 percent of which was grains; meat, fish, and dairy products amounted to an additional 0.75 billion metric tons (114, 133). In developed countries, agriculture represents about 3 percent of the gross domestic product (GDP) output, whereas in some developing countries it contributes as much as 48 percent of GDP (109).

World food production has increased rapidly during the last 40 years, although per-capita production leveled off in the mid-1980s (114, 133). For example, grain yields per hectare more than doubled between 1950 and 1984 (12). To achieve this, existing agricultural lands and marine fisheries have been exploited more intensively, with heavy dependence on fossil fuel, commercial fertilizers and pesticides, and water-worldwide fertilizer use increased ninefold, irrigated acreage tripled, and farm tractor fleets quadrupled. Worldwide consumption of nitrogen fertilizers increased by 60 percent from 1975-76 to 1985-86 alone, to about 70 million metric tons of nitrogen (111). Water use for agriculture also has grown rapidly; more water is consumed in global agriculture than in all other applications combined (2, 62).[1]

Agriculture also has expanded (and continues to expand) into previously uncultivated areas that are only marginality suited for farming or ranching, including many mountainous and tropical forest areas. Varied environmental stresses such as water pollution, soil erosion, downstream flooding, and loss of biodiversity have come with this expansion.

A substantial portion of world crops is fed to animals. Nearly 50 percent of world coarse grain (i.e., barley, corn, oats, rye, sorghum) production, and over two-thirds in the United States, as well as over 30 percent of the world's fisheries catch, is used for animal feed (89, 115). Livestock populations have increased rapidly since 1950 and exceeded 4 billion in 1988[2], with India having the largest share (152). About one-third were cattle, and 8 percent of these were in the United States. Chicken populations are also quite large, totaling about 9.7 billion worldwide and about 1.3 billion in the United States alone (152).

Post-harvest activities take food once harvested or killed, through a varying series of steps (i.e., transportation, processing, packaging, marketing, storage, and cooking) (see figure 8-l). In industrialized countries such as the United States, most of the fossil fuel-related and CFC emissions associated with the food system result from post-harvest activities. Cooking accounts for a relatively small portion of post-harvest emissions in industrialized countries. In developing countries, however, cooking (mostly with coal or biomass) is probably the most important post-harvest source of emissions.

[1]As used here, "consumed" refers to water withdrawn from surface or groundwater supplies and not promptly returned. Water that evaporates during use is considered consumed.

[2]Includes cattle, sheep, goats, pigs, horses, buffaloes, and camels.

SOURCE: Office of Technology Assessment, 1991.

ing) and CH_4 emitted through rice cultivation.[6] Although global data on emissions from post-harvest activities are poor, these activities are likely the most important source of emissions in *industrialized countries.*

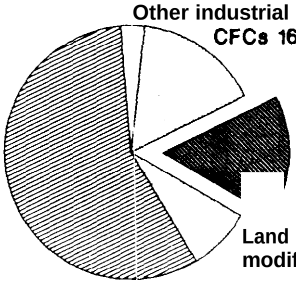
Food Production

Greenhouse gas sources from food production activities include:

1. flooded rice fields, which are significant sources of CH_4, particularly in the developing countries of Asia;
2. livestock, a significant source of CH_4 in many industrialized and developing countries, through direct emissions from animals as well as their manure;
3. nitrogenous fertilizers, the use of which results in N_2O;
4. large-scale land transformations (e.g., clearing tropical forests) in many developing countries

[6]Previous land transformations still play a large role in overall emissions. For example, rice paddies located on lands cleared thousands of years ago arc a major source of current methane emissions.

Figure 8-2-Contribution of Selected Food-Related Sources to Global Warming in the 1980s



Food-related sources include rice cultivation, enteric fermentation from domestic animals, nitrogenous fertilizers, biomass burning, and CFCs from refrigeration; half of the emissions from biomass burning are assumed to be food-related (1 43) (emissions from biomass burning may be greater; see ref. 19a.) his would increase the food related contribution by a few percent. The "CFC" slice includes CFCs not used in the food system. We assume that CO_2 from fossil fuels used in cooking, food processing, packaging, and transportation are included in the energy-use slice. The use of biomass for cooking is not included.

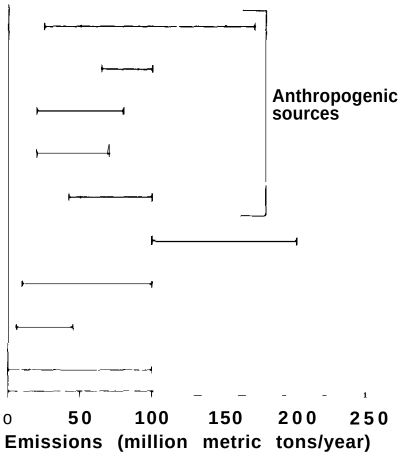
SOURCE: Office of Technology Assessment, 1991, adapted from U.S. Environmental Protection Agency, *Policy Options for Stabilizing Global Climate, Draft, Report to Congress* (Washington DC: June 1990).

(see ch. 7); and, to a lesser extent, land use changes in industrialized countries (e.g., urbanization), both of which result in COs emissions; and

5. burning of vegetation to clear and/or prepare land for agriculture (especially in developing countries), which adds to atmospheric concentrations of several gases, including CO_2, CH_4, N_2O, and carbon monoxide.

In general, emissions from food production and their contributions to climate change are difficult to quantify because of the complex interactions of biological and chemical processes in soils, water, plants, animals, and the atmosphere, and because studies are lacking for many topics and areas.[7] Nevertheless, some approximations and projections are possible. For example, EPA (143) estimates that if current agricultural practices continue, CH_A emissions from rice will increase by about 35 percent by 2025, those from livestock will rise by about 65 percent, and N_4O emissions from fertilizers could more than double.

Figure 8-3-Estimated Global Emissions of Methane



Total methane emissions are about 290 to 960 million metric tons per year; about 50 to 60 percent are from anthropogenic sources. About 60 percent of the anthropogenic emissions are from selected food-related emissions including rice cultivation, enteric fermentation from domestic animals, and roughly half of the emissions from biomass burning; we assume that about one-half of the biomass burning emissions are agricultural-related deforestation (143). The estimate for food-related emissions does not include animal wastes or post-harvest emissions from food losses and wastes (although landfills include some emissions from the latter category). Other anthropogenic sources include coal mining, and gas drilling, venting, and transmission.

SOURCES: Intergovernmental Panel on Climate Change, *Scientific Assessment of Climate Change,* Summary and Report (Geneva: World Meteorological Organization/U.N. Environmental Program, 1990); R.J. Cicerone and R.S. Oremland, "Biogeochemical Aspects of Atmospheric Methane," Global *Biogeochemical Cycles* 2(4):299-327, *1988,*

Methane (CH_4

Methane is produced when bacteria decompose organic material in oxygen-deficient (i.e., anaerobic) environments, such as sediments at the bottom of flooded or rainfed rice paddies, landfills, and the digestive tract of ruminant animals and termites; CH_4 is also emitted as a byproduct when wood and other biomass are burned. Emissions from these and other CH_4 sources are very poorly characterized, partly because they vary enormously on geographic scales and over time. Available evidence indicates that about one-third of total global CH_4 emissions comes from the food sector (16, 50); this represents about 60 percent of total emissions from anthropogenic sources, or roughly 10 percent of global warming in the 1980s.[8]

[7] Although the focus in this discussion is on CH_4, N_2O, CO_2, and CFCs, large quantities of particulate are also emitted when forests and grasslands are burned for agricultural purposes. These particulates are an important global source of cloud condensation nuclei, and clouds themselves are important climatic variables (see ch. 2; also see ref. 19a for more extensive discussion).

[8] This assumes global CH_4 emissions contributed about 19 percent of the global warming in the 1980s (143).

Photo credit: U.S. Department of Agriculture

Over 90 percent of the world's rice is grown in the developing countries of Asia. Global rice production has tripled between the late 1940s and 1985. Methane is produced when bacteria anaerobically decompose organic matter in sediments at the bottom of paddies.

Rice Paddies—Rice provided about one-fourth of the world's cereal grains in 1985. China and India produced well over half of the total, the United States only 1 percent. Global rice production increased by nearly 200 percent between the late 1940s and 1985, while acreage grew by 43 percent (1 14).

Estimates of CH_4 released from rice paddies in the mid-1980s range from roughly 25 to 170 million metric tons, or about 15 to 30 percent of world methane emissions from anthropogenic sources (16, 50) (see figure 8-3). Rice paddies thus accounted for about 3 to 6 percent of the contribution to global warming in the 1980s. These emissions estimates are based on a few studies conducted in temperate regions (California, Italy, and Spain), but because CH_4 emissions are likely to be highly site-specific, the extrapolation of these data to other regions (including tropical areas, where most of the world's rice is grown) is problematic. However, new data from Japan, China, and the Philippines are now becoming available (56, 78, 94, 154). Recent field tests, for example, have shown that during the growing season, rice fields in China emit up to 10 times more CH_4 per hectare per hour than rice fields in Europe and the United States (56). If new data from China are representative of conditions in the Far East (over 90 percent of the world's rice is produced in Asia), then CH_4 emissions from rice cultivation are higher than the estimates presented above, although it is difficult to estimate by how much.

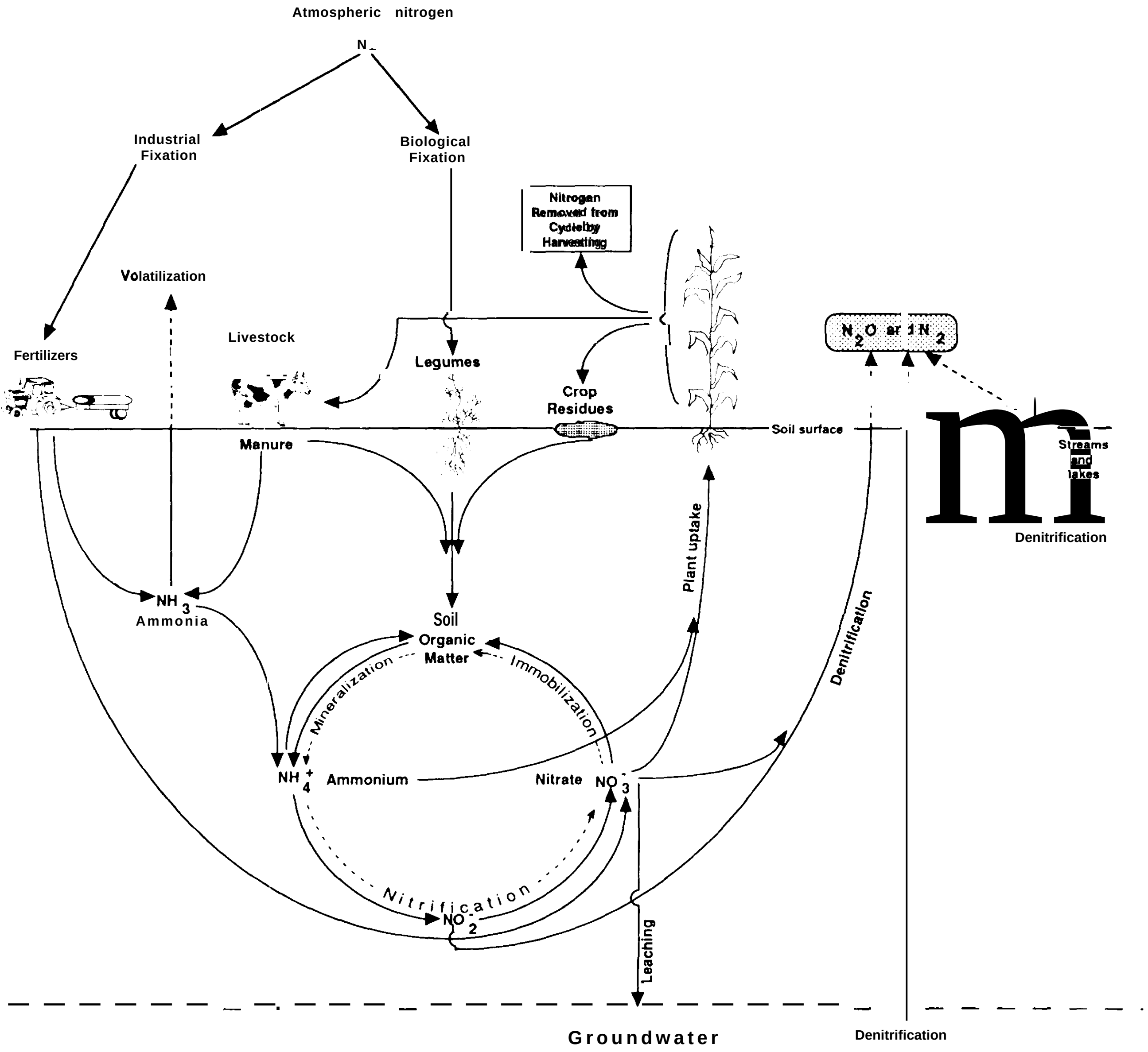
Ruminants—Much of the world's livestock consists of ruminant animals-sheep, goats, camels, cattle, and buffalo (see box 8-A). One of the unique features of ruminants is their four-chambered stomach, including one chamber called the rumen in which bacteria break down food and generate CH_4 as a byproduct. Ruminants emitted an estimated 65 to 100 million metric tons of CH_4 per year in the mid-1980s, perhaps 10 to 20 percent of global CH_4 emissions from all sources (16), or about 20 to 40 percent of total anthropogenic emissions.[9] Therefore, ruminant digestion accounted for about 4 to 7 percent of the global warming in the 1980s, given that all anthropogenic CH_4 sources accounted for a total of about 19 percent (143). Globally, cattle account for about three-fourths of livestock CH_4 emissions (58), or about 7 to 15 percent of total global CH_4 emissions from all sources. Beef and dairy cattle in the United States account for about 1 percent of total global CH_4 emissions (145).

The above estimates do not include CH_4 emissions from animal manure. If manure decomposes anaerobically, some of its organic matter is converted to CH_4. *In* industrialized countries, manure handling practices at feedlots, dairies, and swine and poultry farms may release significant methane. In developing countries, however, most manure is spread as fertilizer, burned for fuel, or left in pastures; the magnitude of CH_4 emissions from these practices is poorly quantified but likely is low since most decomposition takes place aerobically (however, this leads to more CO_2 emissions). Preliminary estimates suggest global CH_4 emissions from manure are on the order of about 20 to 40 million metric tons per year (91, 141).

Biomass Burning-Burning vegetation contributes 20 to 80 million metric tons of methane per year, or roughly 7 to 8 percent of global emissions from

[9]The amounts emitted per animal vary widely among species. A typical goat may emit 5 kg of methane per year, whereas a U.S. dairy cow might average 84 kg over the same period (20), These averages mask variability arising from other factors such as diets.

Figure 8-4-The Nitrogen Cycle



The cycling of nitrogen compounds from lightning and fires is not shown.

SOURCE: Office of Technology Assessment, 1991; F.J. Stevenson, "Soil Nitrogen," fertilizer Nitrogen, *Its* Chemistry and *Technology*, V. Sauchelli (ad.) (New York, NY: Reinhold Publishing Co., 1964), pp. 18-39.

anthropogenic sources and natural sources such as lightning-induced forest frees (16, 19a, 50, 87, 143).[10] This portion may be higher if recent data indicating higher deforestation rates are correct (72; see ch. 7). Substantial but unquantified CH_4 emissions result from fires ignited deliberately-forests burned to produce rangeland or cropland; grasslands burned to enhance forage; and crop residues burned

[10] We distinguish in-situ burning of vegetation to clear land for agricultural purposes from burning of "traditional biomass fuels" such as wood, crop residues, and manure for cooking and heating.

Box 8-B—Nitrogen in the Food System

Figure 8-4 shows how nitrogen flows through **the environment Molecular nitrogen (N_20--an element essential to all plant and animal life--makes up 78 percent of the atmosphere, but few organisms can use it until it has been "fixed" (i.e., made into usable compounds or ions). Much of the nitrogen stored in soil also is not readily available to plants.** Therefore, even though nitrogen is contained in relatively large amounts in the atmosphere and soil, it is often the limiting nutrient in agricultural systems.

Some microorganisms take molecular nitrogen from the atmosphere (or the air spaces in soil) and convert (or fix) it into ammonium and related nitrogen-containing compounds. Many microorganisms can do this, but the most famous are bacteria that live m the root nodules of many legumes (e.g., peas, beans). Bacteria and fungi also decompose organic materials (e.g., manure, crop residues) in the soil and release ammonia or ammonium as part of their metabolic processes. Other bacteria then oxidize the ammonia or ammonium to nitrite, and another group of **bacteria then oxidizes nitrite to nitrate. This process is called nitrification. Nitrate and ammonium ions can be directly taken up from the soil and used by plants. Animals then obtain nitrogen in the form of mom complex organic compounds manufactured by plants.**

Conversely, nitrogen compounds can be lost from the soil by leaching into ground and surface waters, and by soil erosion. Moreover, yet another group of bacteria can convert nitrate, in the absence of oxygen, into gaseous nitrogen compounds, including N_zO, that are emitted into the atmosphere. This process is known as denitrification. Other nitrogen-based gases, such as nitrogen oxide (NO) and nitrogen dioxide (NO_2) (both of which are involved in the formation of tropospheric ozone smog), are also emitted by these microbial processes. In fact, recent evidence indicates that in some soils the emission of NO far exceeds that of N_zO (106).

SOURCE: Office of Technology Assessment, 1991.

to return nutrients to the soil. These emissions are heavily concentrated in tropical countries, where large areas of savanna and forest are burned or cleared each year for agriculture (see ch. 7).[11]

Nitrous Oxide (N_2O)

Agriculture introduces nitrogenous compounds to the environment in the form of commercial fertilizers, legumes, and crop residues. N_20 emissions from soil and water occur through vitrification and denitrification of these compounds (see figure 8-4 and box 8-B) and also result when vegetation is cleared through burning (4, 19a, 27, 59, 146).

The magnitude of N_20 emissions from terrestrial and aquatic sources is very poorly characterized. Based on annual increases in N_20 atmospheric concentrations, the Intergovernmental Panel on Climate Change (50) estimates that total global N_20 emissions *should* be around 10 to 17.5 million metric tons per year; however, only 4.4 to 10 million metric tons can be accounted for from known sources (see ch. 2).

N_2O emissions associated with fertilizer use are not well understood and probably vary with factors such as fertilizer type, method of application, and amount applied. Worldwide nitrogen fertilizer con-

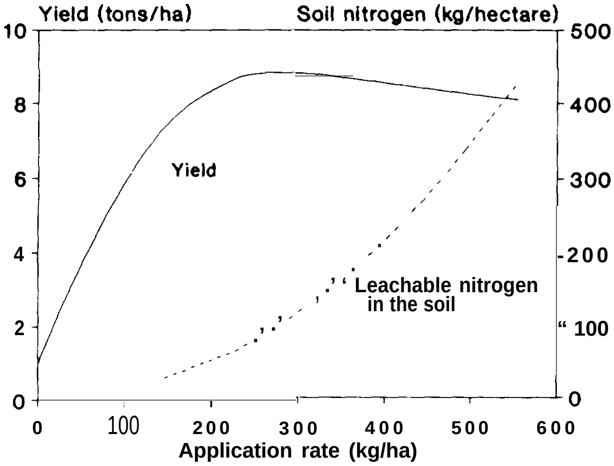
Photo credit: International Fertilizer Development Center

Nitrogen from agricultural sources such as nitrogenous fertilizers (e.g., anhydrous ammonia), crop residues, and leguminous plants, can be converted to N_20 through chemical processes called vitrification and denitrification which occur in both soils and water.

sumption is about 74 million metric tons per year. China accounted for nearly 20 percent of this consumption in 1987, the United States for about 13 percent (30). Current fertilizer-derived emissions are on the order of 0.01 to 2.2 million metric tons per year, about 0.2 to 20 percent of global emissions

[11] Large areas of temperate-zone vegetation are burned annually from forest and grassland fires (ch. 7).

Figure 8-5-Effect of Nitrogen Fertilizer Application Rate on Maize Yield and Soil Nitrogen



NOTE: Leachable nitrogen in the soil can be a significant source of N_2O emissions.

SOURCE: R.D. Hauck, "Agronomic and Public Aspects of Soil Nitrogen Research," *Soil Use and Management* 6(2):66-70, June 1990.

from all sources, or about 10 to 80 percent of all anthropogenic emissions (50).

The general relationship between nitrogen application rate and maize yields (see figure 8-5) illustrates that yields are highest at a certain optimal nitrogen application rate; further additions result in either stable or even lower yields (because nitrogen is no longer used as effectively by plants), and nitrogen concentrations build up in the soil. The potential for nitrogen losses through leaching, volatilization, or denitrification grows.

Nitrogen application rates are generally higher in developed countries. Although U.S. application rates for wheat are comparatively lower than those for many countries, U.S. rates for other crops (e.g., corn, rice) are among the highest in the world (64, 65). Although global fertilizer application data provide a picture of overall intensity of fertilizer use, they do not reveal whether nitrogen fertilizers generally are being over- or under-applied for specific crops and countries.

Leguminous crops (e.g., soybeans, peas, alfalfa) also add nitrogen to agricultural soils; legumes use atmospheric nitrogen directly and require much less nitrogenous fertilizers than non-leguminous crops (see pp. 121-122 in ref. 128; see also box 8-B above and "Alternative Practices" section below). Worldwide production of legumes increased by roughly 85 percent from the late 1940s to 1985. Two-thirds of the world's legume production is in developing countries; only 2 percent is in the United States (1 14).

Carbon Dioxide (CO_2)

The flow of CO_2 to and from the atmosphere is influenced by food production in two ways:

1. changes in terrestrial carbon stocks associated with land transformations, and
2. emissions from fossil fuel use. (See figure 2-9 inch. 2 for an illustration of the carbon cycle.)

Land Use Changes and Terresti"al Carbon— Land transformations have characterized the entire 10,000-year history of agricultural development and continue on a large scale today. Although concern over deforestation now focuses on tropical areas, many temperate forests have also been cleared at least once during the last few hundred years. CO_2 is emitted in this process, and also when grasslands and savannas are burned to enhance grazing conditions and when carbon contained in soil organic matter is carried off by erosion or converted into CO_2 by microorganisms. Urbanization claims additional forest and agricultural land each year. These land transformations greatly affect how carbon is distributed in organisms, soils, and sediments, and how it flows to and from the atmosphere. The net result has increased atmospheric carbon concentrations, mostly as CO_2 but also in the form of other carbon compounds such as methane.

Today, up to one-fifth of net global CO_2 emissions may be attributed to clearing and burning tropical forests for food production (see ch. 7). Additional CO_2 emissions result from burning savannas and agricultural wastes, and using biomass fuels for cooking (19a). Therefore, these activities might have accounted for roughly 8 to 10 percent of the global warming in the 1980s. As population and economic pressures increase, the rate of deforestation could accelerate. CO_2 emissions from soil erosion may account for about 1 to 2 percent of global emissions (85), but data on this pathway are sparse and very uncertain.

Fossil Fuel Combustion-Most food-related CO_2 emissions in the U.S. occur in the post-harvest phase (see "Post-Harvest Activities' below). However, fossil fuels are also used for food production, for example to drive farm machinery such as tractors and irrigation pumps and to produce, offsite, inputs such as fertilizers and pesticides. Collectively, these uses account for a relatively small share of world fossil fuel use and for about 2 percent of U.S. CO_2 emissions.[12]

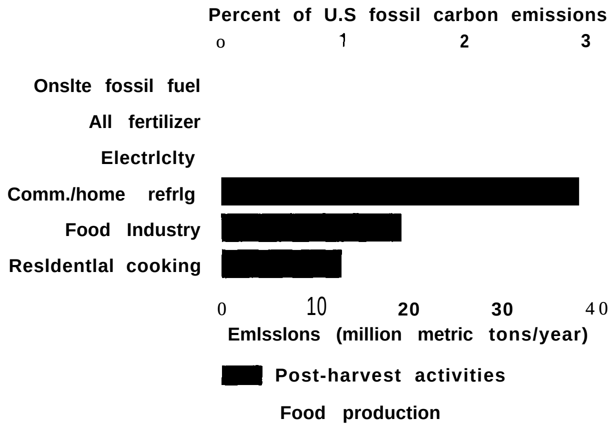
Onsite Fossil Fuel Use---Global data are relatively poor but suggest that farms released perhaps 76 million metric tons of carbon annually during the mid- 1980s through on site fossil fuel use (not including emissions from fertilizer and pesticide manufacture).[13] This represents about 1 percent of global carbon emissions from fossil fuel use and accounted for only about one-half percent of global warming in the 1980s. Similarly, CO_2 emissions from fossil fuel use on U.S. farms during this period (about 14 million metric tons per year) represented about 1 percent of U.S. CO_2 emissions from fossil fuels (see figure 8-6). However, both total and per-hectare energy use in the United States have declined sharply since the mid- 1970s.[14]

Offsite Nitrogen Fertilizer Manufacturing—Another 1 percent of world CO_2 emissions from fossil fuel use, or about 0.5 percent of the global warming in the 1980s,[15] results from commercial fertilizer manufacture.[16] Nitrogen fertilizers account for most of these emissions because they are produced in large amounts and their manufacture (often with natural gas as a feedstock) is very energy intensive.[17] In the United States, nitrogen fertilizer production accounted for about 0.8 percent of U.S. CO_2 emissions from fossil fuel use (see figure 8-6). World fertilizer production increased at a rate of 6.2 percent annually from 1965 to 1985, and the outlook is for continued growth, especially in developing countries (1 13).

Post-Harvest Activities

Once harvested, some food is consumed directly by livestock and humans. The bulk, however, is processed, preserved (often though cooking), stored,

Figure 8-6-The U.S. Food System: CO_2 Emissions From Selected Fossil Fuel Uses



SOURCE: Office of Technology Assessment, 1991.

and distributed with a certain amount of loss and waste during transport. The major emissions from these post-harvest activities include:

1, CFCs from refrigeration;
2. CO_2 from fossil fuels used in food processing, refrigeration, transport, and cooking, and from biomass fuels used for cooking; and
3. CH_4 from decomposition of food-related wastes (including packaging).

Some of these post-harvest activities (e.g., food transport, refrigeration) fall within sectors examined elsewhere in the report but are highlighted here.

Chlorofluorocarbons (CFCs)

CFCs used in refrigeration are emitted through refrigerant leaks, intentional venting (during manufacture, disposal, or repair), and deterioration of insulation. Worldwide, about 47,000 metric tons of CFC-11 and 85,000 metric tons of CFC-12—roughly 15 percent of total consumption-are used

[12] In 1987, 1.6 quads of energy were used in agriculture (103) (including direct use and energy used to manufacture fertilizers and pesticides), out Of about 79 quads (137), This does not include energy used in post-harvest activities such as processing and transportation nor biomass energy used for cooking.

[13] The U.N. Food and Agriculture Organization (101) projected that the amount of energy to be used in 1985/86 for operating farm machinery and for irrigation would be 3.6 quads (95 percent for machinery and 5 percent for irrigation). If all is assumed to be petroleum, then projected emissions would have been about 76 million metric tons (3.6 quads x 21 mg/Btu).

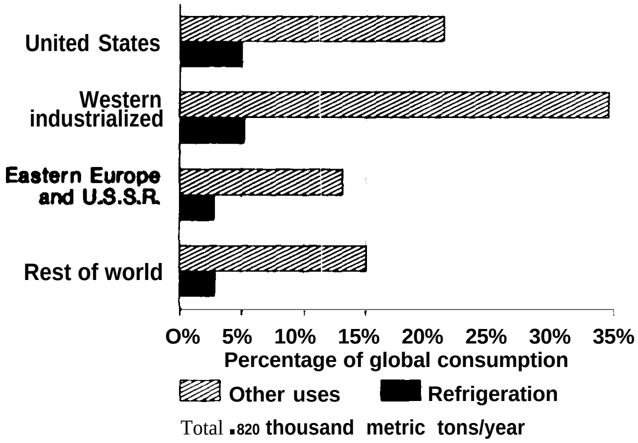
[14] Per-hectare usage of diesel, gasoline, and liquid petroleum gas fell by 30 percent between 1977 and 1986 (103).

[15] This estimate assumes total CO_2 emissions from fossil fuel combustion of about 5.5 billion metric tons/year; total production of nitrogen fertilizers of about 73 million metric tons (1986 estimate, from ref. 113); all fertilizer is produced with natural gas as a feedstock, which emits about 14.5 kg of carbon per *million* Btu; and a nitrogen production efficiency of between 54 and 76 million Btu/metric ton of nutrient (based on ammonia and prilled urea production, respectively) (8). This figure may be an underestimate since some production uses coal and other fossil fuel feedstocks.

[16] These emissions are included in the manufacturing sector (see ch. 6).

[17] Most commercial nitrogen fertilizers combine hydrogen from methane with nitrogen from the atmosphere to produce anhydrous ammonia.

Figure 8-7--Consumption of CFC-11 Plus CFC-12 for Food-Related Refrigeration and Other Uses in 1985, by Region



SOURCE: Derived from U.S. Environmental Protection Agency, Office of Air and Radiation, *Analysis of the Environmental Implications of the Future Growth in Demand for Partially-Halogenated Chlorinated Compounds*, draft report (Washington, DC: 1989).

for food-related refrigeration (see figure 8-7) (142).[18] CFCs used in the food system accounted for about 2 percent of the global warming in the 1980s, assuming that all are eventually emitted to the atmosphere and that *total* CFC-11 and -12 uses accounted for about 14 percent (143). Most CFC use in refrigeration occurs in cold storage warehouses, retail refrigeration, and refrigerated transport. Lesser, but still substantial, amounts are used in residential refrigerators and freezers.

Global use of CFCs has increased dramatically during the 60 years they have been commercially produced. From 1976 to 1986, despite mounting evidence of the ozone-depleting properties of CFCs, CFC-12 refrigerant sales increased by over 50 percent.[19] The United States used 41,000 metric tons of CFC-11 and CFC-12 for food refrigeration in 1985. This represents one-third of world use for food-related refrigeration and about 19 percent of total U.S. use of the compounds (142).

CFC use is expected to rise rapidly in developing countries. With the promise of funding from the industrialized world, however, key countries such as China and India are expected to join the Montreal Protocol and pledge to reduce and eventually phase out CFC use (97). (See box 2-C in ch. 2 for more details on the Montreal Protocol.)

Carbon Dioxide (CO_2)

In developing countries, residential cooking is by far the most significant source of post-harvest CO_2 emissions. In industrialized countries, the most significant post-harvest activities are processing in the food industry, residential cooking, and refrigeration (i.e., powerplant emissions attributed to the energy needs of refrigeration). In the United States, energy used for residential and supermarket refrigeration, residential cooking, and food processing and packaging accounted for about 5 percent of U.S. CO_2 emissions from fossil fuel use (see figure 8-6), or roughly 1 percent of global emissions from fossil fuels. Additional CO_2 emissions arise from other activities (e.g., energy use in food wholesaling, restaurants, and food transport).

In general, more fossil fuel is used in industrialized countries for post-harvest activities than during food production. Even so, CO_2 emissions from post-harvest activities are relatively small compared with those from the energy, building, transportation, and manufacturing sectors (chs. 3 through 6).

Food Refrigeration—Accurate estimates of worldwide CO_2 emissions from refrigeration are not readily available, although estimates for specific countries suggest they are important within the food sector but small relative to other sectors.

In the United States, energy use for household and supermarket refrigeration accounted for about 3 percent of total U.S. CO_2 emissions in 1985 (see figure 8-6).[20] Of this, two-thirds (24 million metric tons) can be attributed to domestic refrigeration, and about one-third to refrigeration at supermarkets. As refrigerators have ‘‘saturated” the market in industrialized countries and average energy efficiencies have improved (1, 107), growth in energy use for refrigeration in these countries has slowed.

By contrast, refrigeration in China accounts for only a small fraction of national energy use (only 0.4 percent of which goes to generate all electricity), but this is rapidly changing. Between 1979 and 1987, for example, China's production of refrigerators in-

[18] CFC-11 is used to produce foam insulation; CFC- 12 is used primarily as a refrigerant, although it also is used to produce insulation.

[19] This includes only reporting companies of the Chemical Manufacturers Association which includes most producers in countries with market economies at that time (15).

[20] This estimate does not include emissions from food transportation or from commercial refrigeration other than in supermarkets.

creased by a factor of 125, and many of the several hundred million households that still do not have one may acquire one in the next decade.

Processing, Transportation, and Cooking—h the United States, post-harvest activities accounted for over 19 million metric tons of emissions in 1985, or about 1.5 percent of U.S. fossil fuel CO_2 emissions (see figure 8-6); over 40 percent of this came from purchased electric power (136). Cooking in residences contributed approximately 12 million metric tons of emissions, roughly 1 percent of total U.S. carbon emissions. Emissions also result from transporting food, but they are poorly quantified. (See ch. 5 for details on transportation sources in general.) The overall magnitude of emissions from *other* sources-such as cooking in commercial establishments and heating of hot water for dish-washing--cannot be readily calculated, In the United States, these emissions could be important given that about half of all meals are prepared outside the home.

In developing countries, cooking is the major source of CO_2 emissions from post-harvest activities and accounts for most household energy use (92). Energy use in transportation and processing is relatively small. Although CO_2 emissions from cooking have not been quantified, the most common cooking fuels (e.g., biomass, coal) have high carbon content. Traditional biomass fuels (animal dung, crop residues, wood, etc.), which may account for as much as 15 percent of world energy use, are used extensively for cooking (44) and food processing (e.g., for drying). Coal also is very important in some regions. Over one-fourth of coal use in China, the world's largest coal consumer, is for domestic purposes, primarily for cooking (45; also see ch. 9).

Methane (CH_4)

Following preparation and consumption of food, solid wastes (e.g., food residues, packaging) and sewage are generated. Under some disposal conditions, these wastes result in the emission of CH_4 to the atmosphere. In landfills, for example, carbon-containing compounds decompose in two stages—frost aerobically, producing CO_2 emissions; then, once oxygen is used up, anaerobically (i.e., without oxygen) by methane-producing bacteria. Landfills may emit about 30 to 70 million metric tons of CH_4 annually worldwide (see figure 8-3), about one-half of what livestock emit (7, 16). In the United States, about 6,000 municipal solid waste landfills were operating in 1986 (127).

ALTERNATIVE PRACTICES

This section discusses alternative practices that could be pursued to reduce future greenhouse gas emissions from the food sector. While the overall costs and benefits of these practices are not clearly defined, collectively they could substantially reduce some emissions. Many would carry other environmental benefits as well----e. g., reducing water pollution from croplands, reducing soil erosion, conserving water supplies, preserving biological diversity, and reducing waste generation in food processing. However, tradeoffs may be associated with some alternatives. For example, some tillage practices used to conserve soils require more pesticides. Also, to reduce the pressure to open new lands to agriculture, crop yields must be increased on existing acreage, which may require greater use of fertilizer and other inputs.

Livestock

Livestock directly produce about 10 to 20 percent of the world's CH_4 emissions through digestive processes, and indirectly produce additional emissions from anaerobic decomposition of manure (see figure 8-3). They also indirectly account for emissions of CO_2 and N_2O by virtue of the land and agricultural inputs required to sustain them.

Decrease Methane Emissions Per Unit of Output

Opportunities exist for reducing, or at least limiting, the growth rate of CH_4 emissions from livestock by increasing digestion efficiency and/or animal productivity (i.e., the amount of animal product produced per unit of feed). Emissions reductions on the order of 25 to 75 percent per unit of product are thought to be possible[21] (141), with most potential for change in developing countries (industrialized countries have already made strides in raising more productive animals). This range of possible emission reductions roughly corresponds to

[21] The upper end of this range assumes that: techniques to improve the diet of animals can be successfully introduced into developing countries; these improvements will result in a twofold to threefold increase in productivity; and the number of livestock will decline as productivity increases, assuming demand for animal products remains constant.

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a 2- to 5-percent reduction in global CH_4 emissions (29).[22]

Specific options include (141):

1. supplement the diets of grazing animals to correct nutrient deficiencies often found in lower quality forage;
2. substitute feeds with low CH_4-producing potential for feeds with higher CH_4-producing potential in the diets of animals in confined (as opposed to free-ranging livestock);
3. develop feed additives that increase digestion efficiency and reduce methanogenesis in the rumen;
4. use growth promotants (e.g., bovine somatotropin); and
5. improve reproductive efficiency.

Enhancing animal productivity can reduce CH_4 emissions given the following assumptions: that by increasing productivity, the same amount of output could be obtained from a smaller herd size; that the rate of output (e.g., milk, beef) per animal increases faster than emissions of CH_4 per animal; and that consumer demand for these products remains relatively stable. It is also assumed that more productive cattle could be brought to market sooner, decreasing the total lifetime CH_4 emissions per animal. The assumption that increased productivity could lead to fewer livestock (and, thus, lower total CH_4 emissions) could be challenged, though. In fact, a large unmet demand for cattle products in developing

[22] Excluding possible reductions from animal wastes; and assuming little penetration of technologies to improve livestock productivity in developing countries.

countries could lead to greater livestock populations even if productivity increases.

Many productivity-enhancing/methane-reducing strategies have been used with great success in the United States and could be transferred to other countries, However, for some countries, especially in the developing world where most cattle graze in unconfined situations, it is difficult to determine how effective some of these options would be.

For example, feed additives called 'ionophores,' which can increase digestion efficiency, currently are feasible only for confined cattle and therefore may not be of immediate utility in developing countries.[23] Growth hormones, such as bovine somatotropin, have been used in nondairy cattle to increase productivity per animal.

Another option, increasing the reproductive efficiency of animals, could help reduce CH_4 emissions by decreasing the number of cattle needed to produce calves. This could be accomplished by increasing nutrient-use efficiency, as described above, as well as by improving breeding techniques.[24] However, some highly productive breeds developed in industrialized countries may not adapt well to the different environmental and feeding conditions of some developing countries.

Reduce Methane From Animal Wastes

Manure storage piles, pits, and lagoons are commonly used to reduce runoff from feedlots into surface water and groundwater (e.g., 19, 32). Methane could be collected from these sources for later use as a fuel, with technologies such as specially designed biogas generators (141). About 50 to 90 percent of CH_4 generated from waste lagoons could potentially be recovered (28), achieving reductions of up to 1 percent of total CH_4 emissions (29). This option is applicable where animals are kept in confined situations, that is, primarily in industrialized countries.

In many developing countries, dried animal manure is an important fuel for cooking and heating; that not used for cooking generally remains in unconfined, pasture/forage systems. However, if manure were collected and processed in anaerobic digesters (see box 3-A in ch. 3), the CH_4 generated from this process could offset some of the demand for wood fuels.[25]

Reduce Demand for Livestock Products

Finally, CH_4 emissions might be reduced by shifting meat production and consumption from ruminants to non-ruminant animals, such as fish, hogs, or broiler chickens, or to more vegetarian diets.[26] For example, to produce a given amount of protein, feedlot beef require nearly five times as much feed as catfish raised in intensive aquiculture systems (82). Lowering livestock numbers could also help reduce: nitrogenous fertilizer used in growing feed for livestock (and associated N_20 emissions); pressures to expand agricultural acreage in some countries; declines in soil productivity from overgrazing; water pollution from erosion and from runoff of wastes; and health costs of high cholesterol diets, depending on what other foods are substituted in diets (104).[27]

However, because animal products are also good sources of calcium, iron, zinc, and high-quality protein, reducing their consumption in developing countries may put further nutritional stress on people in some of these areas. In these countries, increased demand for vegetable protein substitutes may also create additional burdens on already stressed grain supplies and have adverse environmental impacts. For example, increased demand for poultry and hogs would require increased amounts of feed and expanded manure handling. Moreover, reducing livestock numbers in developing countries may be especially difficult because of the multifaceted economic and cultural role they play. In many developing countries where livestock are used

[23] It also may be possible to pretreat feeds with genetically engineered bacteria designed to inhibit methanogenesis (i.e., to decrease CH_4). However, this is seen as a more long-term option and would apply mostly to confined cattle (141).

[24] For example, selection for increased productivity in the dairy industry has enabled milk production to increase over the last several decades, even as the number of dairy cows has fallen.

[25] In the 1970s, China encouraged the building of family-sized biogas digesters and also built hundreds of "biogas stations" for motor vehicle fuels as well as small biogas-fueled electricity generators. However, because of poor construction and maintenance, and in some cases, inadequate supplies of fermentable materials, the number of family-sized digesters declined from about 7 million in the 1970s to about 3 to 4.5 million by 1984 (149).

[26] This is already occurring to some extent in the United States, mainly because of greater health consciousness and because non-ruminant protein sources are becoming more economical.

[27] The Surgeon General's report (104) noted that the major dietary sources of fat for Americans are animal products and recommended "[r]educe[d] consumption of fat (especially saturated fat) and cholesterol."

primarily for draft power and are kept as religious or status symbols, opportunities for emissions reductions may be limited.

Rice Cultivation

In the near term, our ability to reduce CH_4 emissions from rice appears very limited. However, according to a panel of experts convened by the IPCC, a long-term research effort begun today and focusing on new irrigation techniques, more efficient fertilizer use, and developing new high-yield rice species may someday (e.g., two decades) enable global emissions reductions on the order of 10 to 30 percent (29).

High-yield varieties grow more quickly, permitting more than one crop to be grown per year. In theory, increasing rice yields per hectare might reduce the need to expand production onto uncultivated lands, thus reducing total CH_4 emissions. However, annual CH_4 emissions per acre will also increase with double harvesting. It is unclear whether increasing harvests on existing lands would result in higher or lower net annual greenhouse gas emissions than clearing new lands for production.[28]

Average yields have not increased significantly since high-yield rice varieties were introduced in the mid-1960s, however, and are not expected to increase dramatically without new technological breakthroughs (12), for example, genetic engineering to enhance resistance to viruses (37, 67). Although existing high-yield varieties produce less methane than traditional varieties (because of a higher grain-to-straw ratio),[29] no new technologies to reduce per unit CH_4 emissions are anticipated in the near term (143).

Better flood control might help increase the production efficiency of high-yield varieties, which tend to show lower and more variable yields under flooded conditions than under controlled irrigation. Fertilizer losses from intermittent flooding would also decline. More research is needed to develop varieties that consistently produce high yields under different conditions (e.g., dry upland environments, rain-fed conditions); and to eliminate the need to flood rice fields where flooding is not natural (e.g., California, South American savannas). Although rice grown under dry-land conditions emits much less methane than rain-fed or flooded rice paddies, dry-land rice accumulates more soil cadmium (a potentially toxic trace metal) than paddy rice. This is a problem in some major rice-producing countries where soil cadmium levels are already high (55).

Nitrogenous Fertilizer Use

If current trends continue, world fertilizer use will double over the next few decades, rising 1.3 percent per year in industrialized countries and 4 percent per year in developing countries (150). Fertilizers often are used very inefficiently; in parts of Asia, for example, fertilizer losses are estimated to be about 50 to 60 percent of the amount applied (100).[30] Inefficient fertilization practices result in losses of soil nitrogen through several pathways. Denitrification is the predominant mechanism of loss, through N_20 formation (see box 8-B). The level of N_20 emissions from fertilized soils depends on many factors: fertilizer type and amount, application technique and timing, tillage and irrigation practices, use of pesticides, soil and crop type, and amount of residual nitrogen in the soil. N_2O emissions rates per hectare of cropland can vary by three orders of magnitude depending on how the above factors interact (9).

Several options are available to increase fertilizer efficiency or reduce the need for fertilizers and thereby reduce N_20 emissions, although the extent to which emissions can be reduced is not known. Nonetheless, other environmental benefits such as reduced nitrate contamination of groundwater and surface waters can also be achieved. These options include:

1. efficient fertilizer application,
2. low N_20-emitting fertilizers,
3. slow-release fertilizers,
4. vitrification inhibitors, and
5, leguminous sources of nitrogen.

More Efficient Fertilizer Application

The efficiency of fertilizer use can be increased by determining: how much nitrogen is already available in the root zone as well as how much crops can

[28] In addition, high-yield varieties often require greater amounts Of organic and chemical fertilizers.

[29] In addition to organic material at the bottom of rice paddies, straw or the stalk of the rice plant itself is an additional source of organic material that can also decompose to form methane.

[30] Fertilizer use efficiency refers to the amount of nitrogen in fertilizer applied to the soil that is ultimately taken up by plants.

optimally use; when during the growing cycle fertilizers are most needed; and at what depth they should be placed for various tillage systems. Under certain conditions, for example, fertilizers applied in the spring emit less N_2O than those applied during the fall (143). Efficiency also can be doubled under some conditions by placing fertilizers deep in the soil, rather than ''broadcasting' them on the surface (loo, 143).

Low N_2O-Emitting Fertilizers

The N_2O emission potential of various fertilizers has been studied only under highly site-specific conditions (10, 11, 35, 96), limiting generalizations about emissions reduction potential of particular fertilizers. Research is needed on emission levels under a variety of field and cropping conditions. Studies suggest, however, that emission rates may vary by one or two orders of magnitude, with generally higher emissions for anhydrous ammonia than for other nitrogenous fertilizers (143).[31]

Slow-Release Fertilizers and Vitrification Inhibitors

Greenhouse studies with flood-irrigated rice suggest that slow-release fertilizers can considerably reduce denitrification (46) and allow for more efficient plant uptake. Under certain conditions this can double fertilizer efficiency (100); whether N_2O emissions are simultaneously reduced is unclear. Also, slow-release fertilizers may continue releasing nitrogen after plants have been harvested, thereby creating the potential for nitrate production and leaching as well as additional N_2O emissions during the winter and early spring (48). Slow-release fertilizers are not likely to become a viable technology until production costs drop.

Chemical additives in fertilizers can limit soil vitrification processes and, in turn, reduce the amount of nitrate available for denitrification. A wide range of chemicals has been registered and sold in the United States for use as nitrification inhibitors, and under certain conditions these can reduce nitrogen losses and increase fertilizer efficiency by 30 percent (47). Like slow-release fertilizers, these compounds may only delay the emissions of N_2O. After the plants have been taken out of the ground at harvest and nutrient uptake ceases, more soil nitrogen becomes available for nitrification, which then can lead to further emissions.

Leguminous Sources of Nitrogen

Nitrogen can be added to the soil by growing ''nitrogen-ftig' legume crops such as peas or beans (see box 8-B) in rotation with grains. A few studies suggest that N_2O emission rates from legume-based systems are similar to those Ii-em fertilized crop systems, and possibly higher if no-till practices are used (43). If increased use of legumes reduces demand for nitrogenous fertilizers, then CO_2 emissions from fertilizer manufacturing might be lowered. However, the lack of data on N_2O emissions from legume cultivation and on the degree to which legumes could offset fertilizer use makes it difficult to determine the net effect on emissions. Regardless of their effect on N_20 emissions, the planting of legumes makes sense from a soil conservation standpoint (76).

Land Use Changes

As mentioned earlier, the food system's single largest contributor to global warming is deforestation (roughly 10 percent of the warming effect; see ref. 143 and ch. 7). In developing countries as a whole, deforestation is the dominant source of CO_2 emissions; techniques to discourage tropical deforestation are discussed in chapter 7. In this section we discuss other ways to encourage land use practices that store more carbon, techniques to maintain or increase yields on existing agricultural lands, and ways to cut production-related food losses and wastes.

Encouraging Transformations That Increase Carbon Storage

In developing countries a great deal of attention has been given to agroforestry--growing trees along with annual crops and livestock. The trees sequester carbon and generate products and revenues for small-scale farmers. (See ch. 7 regarding agroforestry's potential to reduce deforestation.)

Replacing annual crops on existing agricultural lands with perennial tree crops or woody plants could provide a long-term ''sink' for atmospheric carbon as well as produce desirable food products. Examples are hazelnuts and chestnuts in temperate

[31] In the United States, anhydrous ammonia accounts for about 38 percent of nitrogenous fertilizer use; ammonium nitrate, 21 percent; and urea, 11 percent. In Asia, urea accounts for about 60 to 65 percent of fertilizer use (100).

regions and palms in tropical regions. Whereas most of the CO_2 taken from the atmosphere during the growth cycle of annual crops is released again during post-harvest tillage, the roots of woody perennial plants reach much deeper and lock carbon out of the atmosphere for much longer periods (90). However, woody crops still require fertilizer and pesticides. Also, new varieties will have to be developed for various cropping systems, and economic and cultural obstacles (e.g., development of sufficient market demand, convincing farmers to switch farming practices) must be overcome.

With further research and development, several wild, non-tree perennials, such as eastern gama grass, giant wild rye, and Illinois bundleflower, may provide the germ for future perennial agricultural grains (26, 52, 84). Like their woody counterparts, perennial grains would conserve soil and water resources. However, the development of perennial grain crops into widely used agricultural staples still may be decades away.

Finally, taking highly erodible agricultural lands out of production and converting them (or allowing them to revert) to perennial grasslands or forests helps conserve soil organic matter, a major carbon reservoir.[32] This practice also helps protect surface waters from agricultural runoff (124, 129, 138, 139, 140). N_2O and CO_2 emissions may also be reduced through avoided fertilizer **and** fossil fuel use. Set-asides can also increase or help maintain biological diversity (129).

Maintaining or Increasing Yields

The rate of food production depends on crop acreage and crop yields which, in turn, are determined by a complex set of variables, ranging from soil and plant characteristics to pest outbreaks and varying weather conditions. If per-acre yields are limited or decline, food production can be maintained or increased only by expanding the area of land exploited. In tropical forest areas, for example, peasant farmers commonly respond to declining yields by converting additional forest areas into temporary croplands or by recultivating formerly abandoned areas that have regrown a ''secondary' forest. Such transformations are likely to continue unless efforts are made to redistribute land, slow population growth, and stabilize or even increase yields.

Several techniques can be pursued in both industrialized and developing countries to maintain yields while limiting greenhouse gas emissions and limiting area of land used. More efficient fertilization practices and techniques to maintain or increase yields for rice were discussed above. It is important to note that the push to increase yields may require additional fertilizer inputs. As maximum yields are reached, nitrogen efficiencies begin to drop (see figure 8-5), which could lead to greater N_2O emissions and other adverse environmental impacts.

Reducing Food Losses

Food losses from pest damage may cut world food production by one-third and rice production by up to 50 percent (74). Adverse weather conditions account for the largest annual variations in food production (74), which is ominous in view of possible future climate change. Yields also can be unintentionally reduced by human activities.[33]

Efforts could be increased to reduce various wastes and losses in the food system. Techniques for reducing erosion (e.g., conservation tillage, streamside tree plantings) would help maintain productivity (e.g., see 5,76, 120, 122). Post-harvest losses and wastes from pests, spoilage, and other factors could be reduced in several ways (see box 8-C). Nutrients from human wastes (e.g., food residues, sewage) can be recycled back into the food production system, rather than relegated to landfills or discharged into surface waters. Treated wastewater from sewage treatment plants is now being used for aquiculture (124) and for irrigation water in countries like Israel (95). Recycling food wastes and sewage wastewater can help improve soil quality, thereby reducing the need for supplemental fertilizer and other energy inputs. However, the costs of processing and transporting wastes and the problems associated with chemical and biological contaminants in the wastes (124, 127) pose disadvantages.

[32] The U.S. Department of Agriculture's Conservation Reserve Program is designed to do just this (see ch. 7 and ''Policy Options'' below). Note that this option is viable onty in areas that have excess amounts of land in production.

[33] For example, crop productivity can decline if soils become more saline as a result of excessive irrigation or are lost due to erosion. Soil erosion removed over 2.7 billion metric tons of soil in the United States in 1982 (131). Air pollution from nearby urban areas also carI undermine crop yields. For example, ozone from localized air pollution in the United States reportedly reduces yields of key crops by 1 to 20 percent in various crop-growing regions (63, 126).

Box 8-C—Post-Harvest Food Losses and Waste

From the moment of harvest to the time food reaches the consumer's mouth, food losses and waste occur; these range from deterioration in food quality to consumption by rodents or disposal as household garbage. Worldwide losses and wastes appear to be substantial. For example, the Food and Agriculture Organization estimated that about 5 to 16 million metric tons of fish are caught and subsequently discarded by fishing vessels each year; this represents 6 to 20 percent of the amount that is retained (115). Additionally, about 10 percent of fresh fish supplies may be lost because of post-harvest problems such as inadequate refrigeration. A study in the early 1980s suggested that individual American households may waste 6 to 25 percent, or more, of their food-perhaps $30 billion of food (34). Despite these and other examples, though, the magnitude of total losses and wastes remains very poorly defined at all levels, from the local to the global scale.

In industrialized countries, post-harvest food losses up to and including the storage, processing, and packaging steps (see figure 8-1) were relatively minor in the 1970s (1 to 2 percent) compared to developing countries, where such losses totaled at least 10 percent and often were higher (25a). However, for secondary food processing, marketing, and consumption, the situation is reversed. In industrialized countries, large amounts of food from eating establishments outside the home (e.g., restaurants, cafeterias, airlines, carry-out fast food outlets) are wasted on the plate and generally are discarded as garbage. In developing countries little food is wasted in this manner.

Cutting such losses and wastes offers an opportunity to increase food supplies without expanding food production. This would help alleviate pressures on land crops and on fisheries, thereby facilitating efforts to slow land transformations, and it also could help reduce the use of commercial fertilizers and fossil fuel inputs. Largely motivated by a desire to improve diets around the world, a variety of national and international organizations have called for efforts to reduce post-harvest losses and wastes (110, 117).

Serious obstacles impede progress in reducing losses, however. Even where losses can be quantified, solutions may not be cheap or easy. Where losses and wastes are large and they can be reduced in a cost-effective manner, a variety of opportunities are available. These range from encouraging education, training, and alternative technologies, to supporting economic and social changes and financing a broad spectrum of local, national, and international institutions (69, 75).

SOURCE: Office of Technology Assessment, 1991.

CFCs, CO_2, and Refrigeration

New refrigeration systems are significantly more energy efficient than older systems and, hence, emit less CO_2 from electricity requirements. However, efficiency improvements have not led to comparable reductions in CFC emissions; indeed, these improvements are partially attributable to greater use of CFCs in insulation. Political pressure, however, is building to reduce both CO_2 and CFC emissions, and some new systems and components can reduce or eliminate CFC use (both as a refrigerant and as insulation) and reduce CO_2 emissions. Some promising systems involve highly effective CFC-free insulation that improves energy efficiency (155, 156). Using smaller refrigerators also can reduce CFC and CO_2 emissions.[34]

Other opportunities include using different working fluids (41, 68, 142) and energy sources. For example, refrigerators can operate on energy sources such as natural gas, solar energy, and heat generated from waste materials (14, 79, 105), all of which would reduce CO_2 emissions and energy costs. The major drawback is the capital cost of shifting to new technologies.

Emissions from CFCs already in use as refrigerants could be limited by minimizing accidental emissions during repair (e.g., from leaks) and by sequestering and/or destroying CFCs instead of venting them during repairs or prior to final disposal of refrigeration systems (33, 51, 77).[35] The primary drawbacks are the costs of recovery and disposal and the costs of purifying CFCs for reuse (e.g., 73).

[34]U.S. refrigerators require more CFCs and energy to operate than units in most other industrialized countries. In 1983, the typical U.S. refrigerator consumed roughly 1,290 kWh, as compared to 480 kWh for the typical German unit (93), principally because of the much larger size of U.S. units.

[35]Some countries (e.g., West Germany) (80) and States (see app. B) have programs in place to encourage the use of repair equipment that prevents CFC 1oss (80). This technology can be implemented quickly.

Existing inefficient equipment also could be retired early in order to accelerate deployment of better technologies. The advantages include the possibility of rapid implementation, reduced fuel costs for new equipment, and, in some cases, reduced costs for electric utilities, which may be spared building additional generating capacity (39, 40). The primary disadvantages are the costs of collection and disposal and of purchasing a replacement unit.

Cooking, Food Processing, and Packaging

Emissions from cooking can be reduced, in theory, by changing the types of energy used or by improving fuel-use efficiency. Any strategy that promotes these changes, though, must consider fuel costs and availability, how cooking is normally conducted, and dietary and social preferences. In addition, improved cooking efficiencies may simply allow more cooking with the same amount of fuel, with no substantive change in emissions. Because these considerations have not been fully explored in different parts of the world, assessments of the global potential for limiting emissions from cooking cannot be made readily.

The United States and other industrialized countries emit far less CO_2 from cooking than from other activities (see chs. 3 through 6). Even so, emissions can be reduced by using more efficient ovens and stoves. In developing countries significant CO_2 and other emissions result from cooking with coal and biomass (see ch. 7). Shifts to other fuels have occurred fairly quickly in some cases.[36] Increases in cooking efficiency also have occurred-often through improved cookstove designs (53, 66, 112) (see ch. 7)--and can significantly reduce emissions per unit of delivered energy; however, they do not necessarily reduce total emissions. Where fuel availability is already constrained, improved efficiencies may allow people to cook more or to shift fuels to other end-uses such as heating (147).[37]

There are also opportunities in the areas of food processing and packaging to improve energy efficiencies and switch to low-emission energy sources. Options range from gas-fired cogeneration of electricity and process heat to more fundamental process modifications (3).

CO_2 and Machinery, Fertilizer Manufacture, and Irrigation

Although the impact of reducing emissions from farm machinery (e.g., engines, pumps) and fertilizer manufacture would be relatively small (see figure 8-6), technologies to improve energy efficiency could help reduce reliance on fossil fuels and hence save farmers considerable expense. Promising options to reduce fossil fuel use during food production involve changes in the character and efficiency of field operations (e.g., more efficient farm vehicles and irrigation, use of ethanol fuels, and innovative tillage practices and crop drying techniques) and improved efficiency in fertilizer manufacturing. Alternative energy sources such as wind and solar could be used for some operations (e.g., 38, 61).

Efficiency Improvements for Farm Vehicles

Over the next 10 to 15 years, for example, farm-tractor fuel efficiencies could be improved by 5 to 15 percent with new technologies such as adiabatic engines equipped with turbochargers, electronic controls, and onboard system diagnostics (6). However, these technologies require upfront capital expenditures and their long-term reliability is unknown. In developing countries their potential impact is unclear. In addition to costs, some analysts suggest that mechanization will be slow because tremendous labor supplies exist (85).

Fertilizer Manufacture

Energy efficiency in fertilizer manufacturing has improved substantially. By the mid-1980s, new plants were using about 20 percent less energy than in the early 1980s primarily due to energy recovery equipment (21). Several new urea processes could decrease energy requirements by another 25 to 50 percent relative to the U.S. plant average (24). CO_2 emissions reductions gained by improving energy efficiency could be negated, however, if more coal replaces gas as a primary feedstock in the production process.

[36] For example, one study of urban households in India (cited in 66) fourid that from 1979 to 1984, woodfuel use for heating and cooking fell from 42 to 27 percent of total energy use for those purposes, kerosene increased from 19 to 36 percent, and liquefied petroleum gas grew from 7 to 12 percent.

[37] In one region of China, for example, over 80 percent of rural households lack enough coal and biomass for cooking and heating; improving cooking efficiency may result in increasing fuel use for heating, with the result being higher comfort levels rather than reduced consumption or emissions (147).

Efficient Irrigation

The energy intensity of irrigation in the United States continues to rise, primarily because of increased pumping of groundwater (49); the same is true for some developing countries such as India and China (12). For U.S. food production activities, energy use for irrigation ranks third (behind pesticide and fertilizer manufacturing and use, and farm machinery use) (13). Worldwide, more than 60 percent of irrigation water, on average, is lost due to inefficient practices (86, 151). Technologies available to reduce water and energy use in irrigation include: Low Energy Precision Application (LEPA) designed to apply irrigation water and agrichemicals in small amounts and in precise locations (128); sprinkler and drip-irrigation systems to reduce evaporation; monitoring of soil moisture so water can be applied when needed; liners in canals to prevent seepage; and lasers to measure field levels so that water can be evenly distributed.[38] Recycling of agricultural runoff and municipal wastewater can also reduce demands for irrigation water, but energy requirements for pumping may be high.[39]

Ethanol Fuels

As discussed in the transportation sector (see ch. 5), corn-based ethanol emits from 10 percent less to 30 percent more CO_2 than gasoline (23a). In 1987, about 3.2 billion liters of ethanol were sold in the United States, making this country the world's second largest ethanol consumer after Brazil (98, 153). Over 80 percent of U.S. ethanol plant capacity in 1986 was dedicated to corn feedstocks (134).[40] Although the above estimates do account for the additional CO_2 emissions associated with the manufacture of fertilizers, pesticides, and other energy-intensive inputs needed for increased corn production, other impacts-such as additional N_2O emissions from fertilizer breakdown, increased soil erosion, and other environmental problems associated with corn crops grown in monoculture must also be recognized.

Innovative Tillage Practices

By simultaneously laying seed and herbicides onto unplowed soil, a farmer can limit tractor tips to just one per crop cycle. This can reduce fuel use and attendant emissions, as well as enhance the soil's ability to retain organically bound carbon and water. This and other ‘‘conservation tillage" practices are primarily used to control soil erosion. However, they tend to require more herbicides for weed control than conventional tillage and therefore may result in greater N_2O emissions (43). They also require more seed.

Crop Drying

In the United States, most crops sun-dry in the field. Some mops are dried with heated air, though; this accounted for about 3 percent of total on-farm energy use in 1978, mostly for corn and tobacco (102). Liquefied petroleum gas and natural gas are the most common energy sources. Alternative sources such as solar energy can reduce fuel use by as much as 20 percent (148). At present, 2 percent of U.S. crops are dried using active solar energy systems (123). Many passive solar crop drying systems (i.e., systems that rely on natural air convection) are in use in developing countries.

POLICY ISSUES AND OPTIONS

Most options discussed in the preceding section individually provide relatively small potential for reducing greenhouse gas emissions. But the sum of such efforts may someday provide substantial emissions reductions. In the case of livestock and CFCs for refrigeration-two categories that together accounted for about 6 to 9 percent of the global warming in the 1980s—promising, substantial opportunities may exist in the near term. While reductions in CH_4 emissions from rice cultivation are theoretically possible, technologies to achieve this are much farther off and will require significant research and development. Techniques to increase fertilizer-use efficiency are currently available and

38 Reducing water use also would alleviate pressures on existing water supplies, possibly reduce the costs of making water available (e.g., government costs of water projects, farmer costs for water rights), and cause fewer environmental problems (e.g., increased salt levels in soil), Sprinkler irrigation techniques can reduce water use but require more energy for water distribution compared with gravity-flow systems (49), On the other hand, pressurized irrigation systems may help reduce fertilizer requirements (49).

39 Energy from photovoltaic solar cells and wind power can be competitive with traditional diesel engines, particularly where fuel supplies and maintenance services are expensive and unreliable and where only a few thousand people are served (116; also see ch. 9).

40 Most ethanol is us@ for 10 percent blends with gasoline (i.e., “gasohol”). One study estimated that relying *on* ethanol for 10 percent of U.S. automotive fuel demands might require about 40 percent of the corn harvest (88). Another study estimated that 20 to 25 percent of the U.S. corn crop would be needed to completely replace gasoline use on farms (6).

will help reduce localized water pollution problems, but their effect on N_2O emissions is inconclusive and will require more study. Improvements in fuel efficiencies of farm equipment and fertilizer manufacturing are likely to result in minor CO_2 emissions reductions in developed countries, even less in developing countries where the level of mechanization is low and is likely to remain so in the near future.

This discussion focuses on policy mechanisms that Congress could use both to implement some of the technical options discussed above for the U.S. food system and to influence international emission reduction efforts. Policy considerations extend beyond technological factors to include many social, political, and economic issues. In the United States, for example, choices will be greatly influenced by farm support programs (see box 8-D). In many developing countries, efforts to limit food sector emissions and to gain associated environmental benefits will have to be linked with efforts to combat poverty, inadequate nutritional levels, inequitable land distribution, and rapid population growth (see chs. 7 and 9).

Research Issues

One of the most important research priorities for understanding the relationship between the food system and global climate change is the development of an emissions database representative of agricultural systems and growing conditions throughout the world. For example,

- better CH_4 emissions data are needed from the large rice-producing areas in Asia and the Pacific; the general biogeochemistry of CH_4 production in flooded rice paddies also needs to be established;
- factors affecting CH_4 emissions from rice cultivation, such as climate, soil and water, species type, use of fertilizers, cultural practices, site, seasonal and diurnal variations, and relationship to other greenhouse gas emissions (e.g., **N_2O) (145),** need to be studied to establish representative emission factors;
- the relationships between N_2O emissions and natural factors; fertilizer type, application rate, and placement; residual soil nitrogen; crop-specific nitrogen uptake; soil and water conditions; and timing need to be established;
- uniform, simple, and inexpensive techniques for measuring CH_4 emissions from rice paddies and N_2O emissions from all types of fertilized soils must be established so that comparable data can be collected worldwide; and
- how CH_4 emissions from livestock vary by type and age of the animal and by type of management system (e.g., how and what animals are fed; manure handling) needs to be enumerated for the many regions throughout the world with large livestock populations.
- the relationship between biomass burning and emissions of trace gases (including CH_4, N_2O, NO, and others) and the effects of such burning on the atmospheric and terrestrial environments.

Many international organizations already fund or coordinate agricultural research (e.g., International Fertilizer Development Center, International Board for Soil Research and Management, International Council for Research in Agroforestry, Inter-American Institute for Cooperation on Agriculture) (23, 125). However, there is no overall promotion or coordination of research on the relationship between agriculture and global climate change. The United States could promote an international program to focus greater attention on this issue and to develop research protocols so that results can be meaningfully compared on a global scale. The Consultative Group for International Agricultural Research (CGIAR), an association of 13 regional and international agricultural research centers, might appropriately house such an effort.

Livestock

U.S. Practices

On the domestic front, Congress could direct the U.S. Department of Agriculture (USDA) to determine the extent to which methane-reducing techniques, such as feed additives, ionophores, and other nutrient management techniques, as well as animal waste management, are currently used in the United States. Such a program could also identify both institutional and technical barriers that hinder more widespread development and use of such techniques. Congress could provide additional support (e.g., through the USDA Agricultural Research Service and the National Science Foundation) for research on these techniques.

Box 8-D—USDA's Environmental Mission and Commodity Programs

The USDA's mandate under the 1985 Food Security Act (Public Law 99-198), the Food, Agriculture, Conservation, and Trade Act of 1990 (Public Law 101-624) and other statutes includes considering agriculture's effects on water quality, and the agency has established programs that seek to lessen these effects. For example, through provisions such as the Conservation Compliance Program run by the Soil Conservation Service, about 800,000 farms were required to submit plans by 1990 to reduce erosion and to implement these plans by 1995. If this is enforced, failure to comply with these plans will preclude eligibility for various commodity price supports and other Federal programs.

However, other environmental effects are not explicitly included as part of USDA's statutory mission. Including a broader definition of environmental protection as a part of the agency's mission could ensure that issues such as the food sector's effects on climate change are factored dirctly into national farm policies.

This could be particularly important with respect to USDA commodity programs, which are maintained to stabilize and support crop prices and farmers' incomes, as authorized in the Food Security Act. About two-thirds of all U.S. cropland is enrolled in programs that support such crops as wheat, feed grains (e.g., corn, sorghum, barley, oats), cotton, and rice. The cost to the Federal Government was about $11.6 billion in fiscal year 1990 (76).

Price and income supports are based on the amount of acreage devoted to a given crop (called "base" acreage) and the average yield of that crop over the past 5 years (crop yields are currently frozen at the 1981-to-1985 average). Farmers who plant any other crop besides the one designated for that base acreage not only lose payments for that year, but also lower their base acreage for that crop and therefore lower future payments. **This encourages farmers to grow the same crop on the same plot of land, year after year, in order to maximize their Federal subsidies.** Furthermore, to comply with "cross-compliance" provisions (i.e., eligibility for a benefit depends on compliance with other provisions), farmers may not plant any other crop unless it is within their allotted base. Therefore, a farmer who wants to rotate crops using a crop in which he/she has little or no base acreage will lose all entitlements for that year.

All of this encourages a tendency to overuse fertilizers and other inputs, because **maintaining** yields on lands devoted to monoculture often requires significant amounts of these inputs. Excess fertilizer use, however, can cause groundwater contamination (128), surface water eutrophication, N_2O emissions from denitrification, and loss of soil organic carbon.

Decoupling the rigid connection between Federal subsidies and production decisions would allow farmers flexibility to plant crops based on market demand, without risking the loss of all income supports, and reduce Federal expenditures on crops already in surplus (60,118,128).[1] Proposals to achieve this include allowing farmers to: 1) obtain payments for an enrolled crop, even if a portion of base acreage is planted with other crops; 2) temporarily switch a portion of their base-acreage crop to another crop without losing the original base; and 3) plant any combination of crops (allowed by USDA) within a designated "normal" acreage, if a certain portion of other acreage on which these crops are grown is taken out of production. In fact, the 1990 farm bill (Public Law 101-624) now allows farmers to plant a limited amount of selected crops on lands designated for other crops, without losing commodity program benefits.

[1] These options assume that the Federal Government will continue providing financial assistance to farmers to compensate for droughts and other poor growing conditions.

SOURCE: Office of Technology Assessment, 1991.

To limit future growth in, or even reduce, livestock populations in the United States, Congress could reduce or remove price supports (see box 8-D) for feed grains, which might make beef and dairy products more expensive (although it is unclear if the costs would rise or fall in the long term). About two-thirds of the total Federal grain subsidies apply to livestock feed (76; also see box 8-D). Feed grain farmers might grow other crops that make more money and, if feed grain prices rose sufficiently, livestock producers might raise less meat. However, this could cause large near-term economic disruptions for some farmers and portions of the food industry.

Congress could also modify eligibility criteria in the Conservation Reserve Program so that farmers can choose to put more land now used to grow feed grains into reserve; this also would reduce CO_2 emissions from onfarm fossil fuel use and fertilizer manufacture and N_20 emissions from fertilizer use.

Developing-Country Practices

In developing countries, programs to increase productivity through improved breeding techniques or to enhance animal waste management systems must meet the special needs of livestock management systems in these countries, where livestock are primarily pasture-fed and are used for many purposes other than provision of food. With this in mind, Congress could contribute funds, through U.S. bilateral aid programs and through multilateral organizations (see ch. 9), to expand research programs in developing countries so that methane reductions become an additional research priority. For example, research institutes such as the International Livestock Centre for Africa and the International Laboratory for Research on Animal Diseases are part of the CGIAR system, which receives U.S. funding through A.I.D.

However, promoting technologies that lower per-animal emissions or policies that reduce livestock numbers will probably be difficult. Many of the technologies designed to reduce methane from individual animals are geared toward controlling the diets of animals in feedlot management systems, which are less common in developing countries. Also, efforts to introduce more productive livestock breeds into developing countries must first recognize that the unique genetic qualities of indigenous breeds that have evolved over thousands of years in adaptation to different ecological conditions.

Because livestock in developing countries are used for many purposes other than food production—as symbols of social status and wealth, for their religious values, for draft (construction) activities, for the energy value of their manure, and as alternative sources for income in the event of crop failures-convincing peasants to change their livestock management habits or to reduce their livestock numbers will probably be difficult.

Also, it may be difficult to decrease the lure of cattle ranching to middle- and upper-class landowners and investors. In many countries (particularly in Latin America), ranching is encouraged by national development policies, land ownership patterns, and land speculation (see ch. 7). Indirect opportunities exist for Congress to influence this particular situation, through its control of funding for bilateral aid programs and influence on multilateral lending institutions, but many obstacles must be overcome (see ch. 7).

CFCs, CO_2, and Refrigeration

In industrialized countries, obstacles to implementing energy efficiency options and other refrigeration improvements include consumer attitudes, regulatory barriers, and technical problems (e.g., lack of equipment that can directly use replacements for CFCs) (31, 108). The basic issues, though, are not whether refrigeration can be accomplished more efficiently and without CFCs, but how best to do this and at what costs compared with the benefits of emissions reductions.

Steering developing countries away from CFC production, CFC-based refrigerators, and low-efficiency equipment will be more problematic. Policy alternatives include encouraging these countries to sign and ratify the Montreal protocol, and transfer-ring information, technologies, and capital to enable them to pursue alternative and acceptable refrigeration practices economically. Box 2-C in chapter 2 discusses recent changes to the Montreal Protocol, including funding mechanisms to help developing countries.

Nitrogenous Fertilizer Use

Congress could promote more efficient fertilizer use in the United States by changing commodity programs so as not to encourage excessive production (see box 8-D) and to allow farmers to grow crops and adopt practices that rely less on commercial fertilizers and other energy-intensive inputs, without loss of program base acreage (41).[41]

Best Management Practices (BMPs) are designed by the Soil Conservation Service (SCS) to reduce soil degradation and water contamination from agricultural activities.[42] At present, the SCS does not have statutory authority to promulgate enforceable regulations. Congress could require implementation of BMPs through cross-compliance, i.e., make implementation a prerequisite for receiving Federal

[41] Congress could provide this cropping flexibility only to farmers who adopt environmentally sound alternatives. Congress could also provide incentives to adopt these alternative practices by linking crop decisions to support payments and by giving tax credits to ease the potentially negative financial impacts of adopting ''low-input" practices.

[42] They include, for example, improved fertilizer USe, water impoundments, Permanent vegetative cover, and manure storage.

price and income supports.[43] However, such a policy would not apply to the one-third of U.S. croplands that are not enrolled in Federal farm support programs. Congress also could provide incentives (i.e., special services from USDA extension agents) to farmers who voluntarily adopt BMPs.

Carbon Dioxide and Land Use Changes

Encouraging Land Use Changes That Increase Carbon Storage

The goal of the USDA's Conservation Reserve Program (CRP) is to take 40 percent (16 to 18 million hectares) of highly erodible croplands (about 10 percent of all cropland) out of production, and in some cases to plant trees or grasses on the land (see ch. 7). Farmers who take lands out of production for 10 years receive annual rental payments from the Federal Government. By the end of 1989, about 14 million hectares had been enrolled at a cost of over $1 billion annually (71, 130, 132)[44]; the Food, Agriculture, Conservation, and Trade Act of 1990 (Public Law 101-624) extended the sign-up period through 1995. The USDA (130) estimates that the CRP could reduce U.S. fertilizer use by as much as 3 percent.

Congress could modify the CRP by:

- increasing the acreage goal;
- including croplands eroding at moderate levels;
- including other environmental objectives such as groundwater protection;
- increasing incentives for enrollment (e.g., provide options to extend leases, lengthen lease periods, and/or increase rental payments); and
- providing incentives for managing existing croplands in an environmentally sound manner.

All of these options will require additional program appropriations. An expanded CRP could also have detrimental economic effects on communities that depend on local farm business (e.g., farm equipment dealers, repair shops, agrichemical dealers, etc.) (130), and consumers would likely protest if food costs went up substantially.

Discouraging Land Use Changes That Increase Emissions

Within the United States, limiting land transformations is primarily a local or State zoning issue. However, some Federal benefits (e.g., housing and infrastructure grants) and regulatory permits (e.g., for industrial facilities) affect the disposition of agricultural land (25). Efforts to consider long-term environmental issues in land-use decisions could be important symbolically for international attempts to influence land use decisions in developing countries.[45] Efforts to slow urbanization can also reduce urban infrastructure costs, limit automobile travel (see ch. 5), and otherwise contribute to more livable and affordable communities (18, 22, 81, 119).

Maintaining or Increasing Yields

Congress could require USDA to expand existing programs (i.e., "Low-Input Sustainable Agriculture") and develop new ones that focus on alternative practices, including techniques that maintain or increase crop yields and reduce emissions per unit of food output. Congress could also increase research funding to define relationships among agricultural practices, crop yields, and emissions (see 'Research Issues" above), and change existing U.S. domestic agricultural commodities programs that discourage farmers from pursuing alternative technologies and methods such as crop rotation and integrated pest management (76).

Congress also could promote alternative practices overseas, particularly in developing countries, by increasing support for:

- A.I.D. assistance programs in sustainable agriculture (e.g., technical assistance, research and development); and
- multilateral programs such as those of the Food and Agriculture Organization, CGIAR, and numerous other international agricultural research institutions.

Projects funded through these sources must recognize, however, that alternative agricultural practices developed by, and for, the industrialized world may not be the most appropriate for the developing

[43] Such a program could be extended to other energy-intensive inputs such as pesticides and irrigation water. For example, the SCS could establish guidelines on how, and in what quantities, various inputs should be applied to crops in specific regions of the country.

[44] Critics point to this price tag, while supporters argue that by reducing production of price-supported commodities, the CRP reduces prim-depressing crop surpluses and provides a net savings to the Federal Government. Estimates of the net effect of these factors are discussed briefly in ch. 7.

[45] Ch. 7 discusses options for reducing deforestation in developing countries.

world. For example, in the humid areas of the developing world, significant amounts of harvested crops are lost due to inadequate storage, while in other countries post-harvest losses may occur for different reasons.

CO_2 *and Machinery, Fertilizer Manufacture, and Irrigation*

Federal options for promoting efficiency in the production and use of energy for agriculture are numerous. They include increasing the cost of energy; setting efficiency standards; supporting research, development and! demonstration projects; and providing incentives to retire old equipment and deploy low-emission alternatives. Key issues range from concerns about the magnitude and distribution of costs and benefits to problems associated with altering energy usage in complex, integrated industrial systems. Chapters 5 and 6 discuss options for motor vehicles and manufacturing in general.

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Appendix 6-A: Calculations for Figure 8-6[1]

General

Total U.S. CO_2 emissions from fossil fuels in 1985: 1,300X10^{12} g,

SOURCE: USEPA (143).

Carbon emissions attributed to electricity use: 0.4 lb/kWh.

SOURCE: Office of Technology Assessment, based on national mix of energy sources used to produce electrical energy (see ch. 3).

Food Production

Fertilizer

All fertilizer: (707,000 X10'> Btu)X(14X10^3 g C/Btu) = 9.9 X1012 g. Assumes all energy consists of direct consumption of natural gas used as feedstock. While this is not the case, nitrogen fertilizer production accounts for the majority of energy used in fertilizer production, and natural gas supplies most of that energy.

Share of total US. CO_2 emissions: (9.9X10^{12} g)/(1 ,300 X10^{12} g) = 0.8%

SOURCE: Btu figure provided by ref. 42.

Elect riclt y

Electricity y consumed in "traditional" agricultural sector: (31,816X1 O^6 kWh)X(O.4 lb C/kWh) = 12,726.4X1 O^6 lb = 5.8x 10^{12} g. This does not include electricity consumed in producing inputs (e.g., fertilizer) for the agricultural sector.

Share of total U.S. CO_2 emissions: (5.8X10^{12} g)/(1 ,300 X1012 g) = 0.4°A

SOURCE: kWh figure provided by ref. 42.

Onsite Fossil Fuel Use

Gasoline: (1 ,900,000 X10^3 gal) X(5.48 lb C/gal)X(1 kg/2.25 Ibs) = 4.6X10^{12} g

Diesel: (2,870,000 X10^3 gal) X(6 lb/gal)X(1 kg/2.25 lb) = 7.65X10^{12} g

Fuel oil: (78,400X10^3 gal) X(6 lb/gal)X(1 kg/2.25 lb) =0.2X1012 g

LP gas: (955,000X10^3 gal) X(13.6 kg C/10^9 Joules) X(97X10^6 Joules/gal) = 0.01X1012 g
(Assumes LPG is 100% propane, 92,000 Btu/gal)

Natural gas: (48,800X10^6 cf)X(16.3 kg C/l O^9 Joules) X(37.3X106 Joules/35.3 cf) =0.8X1012 g

Coal: (42,500 tons) X(22X10^6 Btu/ton)X(26 mg/Btu) = 0.243X10^{12} g

Share of total U.S. CO_2 emissions: (13.5X10^{12} g)/(1 ,300 X1012 g) = 1.0%

SOURCE: Initial figure (i.e., quantity of fuel) in each calculation from ref. 103.

Post-Harvest

Food Industry

Electricity: (44,400 million kWh)X(0.18 kg/kWh) = 8X10^{12} g

Residual fuel oil: (6,290,000 barrels) X(6.289X10^6 Btu/barrel)X(20 mg/Btu) = 0.8 X1012 g

Distillate fuel oil: (4,360,000 barrels) X(5.82X10^6 Btu/barrel)X(20 mg/Btu) = 0.5 X1012 g

Natural gas: (464 billion cubic feet)X(1,020 Btu/cubic foot)X(14 mg/Btu) = 6.6X10^{12} g

LPG: (89 million gal) X(13.6 kg C/10^9 Joules) X(97X10^6 Joules/gal) = 0.1 X1012 g
(Assumes LPG is 100% propane, 92,000 Btu/gal)

Coal: (5,570,000 short tons) X(22X10^6 Btu/ton)X(26 mg/Btu) = 3.2X10^{12} g

Other: 121 trillion Btu

Total: 19.2X10^{12} g

Share of total U.S. $C0_2$ emissions: (19X10^{12}g)/(1,300X10 ^{12}g) = 1.5%

SOURCE: See ref. 136.

Residential Cooking Energy

Electric ranges/ovens: (0.63 X1015 Btu)X(1 kWh/11,500 Btu)X(181 g/kWh) = 9.9 X10^{12} g

Gas ranges/ovens: (0.21 X10^{15} Btu)X(14mg/Btu) = 2.94 X1012 g

Total, excluding small electric appliances: 12.8 X1012 g of C

Share of total U.S. CO_2 emissions: (12.8 X10^{12} g)/(1 ,300X10^{12} g) = 1.0%

SOURCE: Initial figures (i.e., Btu use) from ref. 135.

Supermarket/Domestic Refrigeration

Residential refrigeration: (1,850X1012 Btu)X(1 kWh/1 1,500 Btu)X(181 g/kWh) = 29X10^{12} g C
Based on total electricity use in 1985 of 1.85 quads (refrigerators: 1.41 quads; freezers: 0.44 quads)

Supermarkets: 9.5X10^{12} g. Based on: 1) 35,000 supermarkets in operation account for about 4% of all electric energy used, and approximately one-half of that (i.e., 2°A of all electric energy used) is attributable to refrigeration equipment (ref. 17); 2) emissions of CO_2 from utilities amounted to about 460 teragrams in 1985 (based on data in ref. 144); and 3) (460 Tg)X(0.02) = 9.2X10^{12} g.

Total supermarkets and residential: (29 + 9.2)X10^{12} g C =38.2X1012 g C

Share of total U.S. CO_2 emissions: (38.2 X10^{12} g)/(1 ,300 X1012 g) = 2.9%

SOURCES: Ref. 17,135,144.

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[1] Totals may not add up due to rounding.