Changes in This Year's Inventory Report

Each year the U.S. Greenhouse Gas Inventory Program recalculates and revises the emission and sink estimates for all years in the *Inventory of U.S. Greenhouse Gas Emissions and Sinks,* and attempts to improve both the analyses themselves, through the use of better methods or data, and the overall usefulness of the report. A summary of this year's revisions is presented in this chapter, including both changes in methodology and updates to historical data. The magnitude of each change's impact on emissions is also described. Table Changes-1 summarizes the quantitative effect of these changes on U.S. greenhouse gas emissions and Table Changes-2 summarizes the quantitative effect on U.S. sinks, both relative to the previously published U.S. Inventory (i.e., 1990-2000 report). These tables present the magnitude of these changes in units of teragrams of carbon dioxide (CO_2) equivalents (Tg CO_2 Eq.).

For methodological changes, differences between the previous report and this report are explained. In general, when methodological changes have been implemented, the entire time series (i.e., 1990 through 2000) has been recalculated to reflect the change.

Changes in historical data are generally the result of changes in statistical data supplied by other agencies. References for the data are provided for additional information.

Methodological Changes

CO_2 Emissions from Fossil Fuel Combustion

Storage factors for fossil fuels produced but not combusted (e.g., feedstocks) have been updated. The carbon storage factor for miscellaneous products under other petroleum for U.S. territories was reduced to 10 percent. This revision is based on the assumption that the carbon consumption for miscellaneous products is not used primarily for asphalt and road oil, which had been previously assumed, but for other uses which store much less carbon. The combination of this change, the historical changes described below, and the methodological changes in "Emissions and Storage from Non-Energy Uses of Fossil Fuels" (which affect the emissions from this source), resulted in an average annual increase of 52.0 Tg CO_2 Eq. (1.0 percent) in CO_2 emissions for the period 1990 through 2000.

Table Changes-1: Revisions to U.S. Greenhouse Gas Emissions (Tg CO_2 Eq.)

Gas/Source	1990	1995	1996	1997	1998	1999	2000
CO_2	**5.2**	**28.6**	**31.1**	**27.4**	**39.1**	**15.2**	**43.1**
Fossil Fuel Combustion	34.9	56.5	59.2	60.5	64.4	40.2	68.9
Natural Gas Flaring	NC	NC	NC	NC	NC	NC	(0.5)
Cement Manufacture	NC	NC	NC	NC	NC	NC	0.1
Lime Manufacture	NC	NC	NC	NC	NC	NC	+
Limestone and Dolomite Use	0.3	+	0.2	(1.3)	(0.9)	(1.4)	(3.4)
Soda Ash Manufacture and Consumption	+	+	+	+	+	+	+
Carbon Dioxide Consumption	0.1	0.1	+	(0.1)	(0.2)	(0.4)	(0.1)
Waste Combustion	+	(0.1)	(0.2)	(0.2)	2.2	2.1	2.9
Titanium Dioxide Production	NC	NC	NC	NC	NC	NC	+
Aluminum Production	NC	NC	NC	NC	NC	NC	NC
Iron and Steel Production	NC	NC	NC	(4.3)	NC	NC	+
Ferroalloys	NC	NC	NC	NC	NC	NC	NC
Ammonia Manufacture & Urea Application	0.8	1.5	0.8	1.2	1.8	1.7	1.6
International Bunker Fuels	+	+	+	+	(0.1)	(0.1)	(1.0)
CH_4	**(7.3)**	**(7.6)**	**(6.9)**	**(3.8)**	**(4.4)**	**(5.0)**	**(1.2)**
Stationary Sources	0.2	0.3	0.3	+	0.2	+	0.1
Mobile Sources	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Coal Mining	+	NC	NC	NC	NC	NC	+
Natural Gas Systems	0.8	1.6	0.8	3.3	1.8	1.7	4.8
Petroleum Systems	1.1	+	(0.1)	(0.4)	(0.5)	(0.7)	(0.6)
Petrochemical Production	NC	+	+	NC	NC	+	+
Silicon Carbide Production	NC	NC	NC	NC	NC	+	NC
Enteric Fermentation	(10.0)	(10.2)	(9.1)	(8.4)	(8.2)	(7.9)	(8.2)
Manure Management	2.1	1.4	0.7	0.7	1.0	1.3	0.8
Rice Cultivation	NC	NC	NC	NC	NC	NC	+
Field Burning of Agricultural Residues	NC	NC	NC	NC	NC	NC	+
Landfills	(1.3)	(0.5)	0.6	1.1	1.4	0.6	2.3
Wastewater Treatment	(0.2)	(0.2)	(0.2)	(0.2)	(0.2)	(0.2)	(0.4)
International Bunker Fuels	+	+	+	+	+	+	+
N_2O	**10.3**	**11.2**	**11.3**	**11.1**	**10.5**	**9.4**	**4.6**
Stationary Sources	(0.3)	(0.3)	(0.3)	(0.5)	(0.6)	(0.9)	(0.7)
Mobile Sources	(0.3)	0.5	0.6	0.7	0.5	0.1	(0.8)
Adipic Acid	0.3	(0.7)	(0.7)	(1.2)	(1.7)	(2.2)	(2.1)
Nitric Acid	+	+	+	+	+	+	(0.7)
Manure Management	0.1	0.2	0.2	0.2	0.2	0.2	0.4
Agricultural Soil Management	0.5	0.6	0.6	0.7	0.8	0.7	(3.0)
Field Burning of Agricultural Residues	NC	NC	NC	NC	NC	NC	+
Human Sewage	5.7	6.3	6.3	6.5	6.5	6.7	6.7
N_2O Product Usage[a]	4.3	4.5	4.5	4.8	4.8	4.8	4.8
Waste Combustion	NC	NC	NC	NC	NC	NC	+
International Bunker Fuels	+	+	+	+	+	+	+
HFCs, PFCs, and SF_6	**0.7**	**1.0**	**1.8**	**(0.1)**	**+**	**0.4**	**(0.4)**
Substitution of Ozone Depleting Substances	NC	(0.1)	(0.2)	(0.3)	(0.3)	(0.4)	(0.5)
Aluminum Production	NC	NC	NC	NC	NC	NC	+
HCFC-22 Production	NC	NC	NC	NC	NC	NC	NC
Semiconductor Manufacture	NC	NC	NC	NC	NC	NC	NC
Electrical Transmission and Distribution	0.9	1.0	0.9	0.7	0.7	0.9	1.0
Magnesium Production and Processing	(0.1)	0.1	1.1	(0.6)	(0.4)	(0.1)	(0.8)
Net Change in Total Emissions[b]	**8.9**	**33.1**	**37.2**	**34.5**	**45.2**	**20.1**	**46.1**
Percent Change	**0.1%**	**0.5%**	**0.6%**	**0.5%**	**0.7%**	**0.3%**	**0.7%**

+ Absolute value does not exceed 0.05 Tg CO_2 Eq.
[a] New source category relative to previous inventory.
[b] Excludes emissions from land-use change and forestry.
NC: (No Change)
Note: Totals may not sum due to independent rounding.

Table Changes-2: Revisions to Net CO_2 Sequestration from Land-Use Change and Forestry (Tg CO_2 Eq.)

Component	1990		1995	1996	1997	1998	1999	2000
Forests	NC		NC	NC	NC	NC	NC	14.7
Urban Trees	NC		NC	NC	NC	NC	NC	NC
Agricultural Soils	24.0		45.3	46.6	46.5	55.7	55.8	53.7
Landfilled Yard Trimmings	0.9		0.6	0.5	0.4	(0.3)	(0.5)	(0.5)
Net Change in Total Flux	**24.9**		**45.8**	**47.1**	**46.9**	**55.4**	**55.3**	**67.9**
Percent Change	**(2.3%)**		**(4.1%)**	**(4.2%)**	**(5.3%)**	**(6.3%)**	**(6.2%)**	**(7.5%)**

NC: (No Change)
Note: Numbers in parentheses indicate an *increase* in estimated net sequestration, or a decrease in net flux of CO_2 to the atmosphere. In the "percent change" row, negative numbers indicate that the sequestration estimate has decreased, and positive numbers indicate that the sequestration estimate has increased. Totals may not sum due to independent rounding.

Carbon Stored in Products from Non-Energy Uses of Fossil Fuels

The methods for estimating CO_2 emissions of non-energy uses (NEU) of fossil fuels were revised in several ways this year. A full time series (1990-2001) of net imports/exports of feedstock-related petrochemicals was incorporated into the NEU analysis. The storage versus emissions balance of NEU carbon was also updated to include the carbon emitted from consumption of personal cleansers (e.g., soaps, shampoo, and detergents) and the carbon flows in refinery wastewaters. These changes, in combination with historical data changes in "CO2 Emissions from Fossil Fuel Combustion" and other modifications to the NEU section, resulted in an average annual decrease in stored carbon of 12.9 Tg CO_2 Eq. (5.0 percent) for the period 1990 through 2000.

Stationary Combustion (excluding CO_2)

The activity data for estimating non-CO_2 emissions from stationary combustion previously included the consumption of some fuels used for non-energy purposes. For the current inventory, consumption for these purposes is now being removed from the activity data. The combination of this change and the historical data changes described below resulted in an average annual increase of 0.2 Tg CO_2 Eq. (2.8 percent) of CH_4 emissions and an average annual decrease of 0.4 Tg CO_2 Eq. (3.0 percent) in N_2O emissions for the period 1990 through 2000.

Mobile Combustion (excluding CO_2)

The methodology for estimating non-CO_2 emissions from mobile combustion was altered significantly. The changes consisted of revisions to the distribution of control technologies for gasoline and diesel highway vehicles, the estimation of emission factors for gasoline and diesel highway vehicles, the estimation of vehicle miles traveled for alternative fuel vehicles, and the development of emission factors for alternative fuel vehicles.

Control technology assignments for light and heavy-duty conventional fuel vehicles for model years 1972 (when regulations began to take effect) through 1995 were estimated in EPA (1998). Assignments for 1998 through 2001 were determined using confidential engine family sales data submitted to the EPA (EPA 2002b). Vehicle classes and emission standard tiers to which each engine family was certified were taken from annual certification test results and data (EPA 2002a). This was used to determine the fraction of sales of each class of vehicle that met Tier 0, Tier 1, and LEV standards. Assignments for 1996 and 1997 were estimated based upon the fact that Tier 1 standards for light-duty vehicles were fully phased in by 1996. The previous methodology, which estimated control technology and emissions for California separately from the other 49 states, is no longer used.

Previous emission factors for heavy-duty gasoline vehicles only included Tier 0, oxidation catalyst, non-catalyst control and uncontrolled. In 1996, heavy-duty gasoline engines underwent a significant change with most going to three-way catalysts and multi-point sequential fuel injection systems, and new emission factors for these vehicles were developed. Emission factors for methane (CH_4) for Tier 1 and LEV heavy-duty gasoline vehicles were estimated using emission factors from the California Air Resources Board (CARB 2000). Nitrous oxide emissions were estimated from the ratio of NO_x emissions to N_2O emissions for Tier 0 heavy-duty gasoline trucks. A NO_x to N_2O ratio of 60 was used.

Vehicle Miles Traveled (VMT) for alternative fuel and advanced technology vehicles were calculated from the Energy Information Administration Data Tables (EIA 2002a). The data obtained include vehicle fuel use and total number of vehicles in use from 1992 through 2001. Fuel economy for each vehicle type and calendar year was determined by estimating the gasoline equivalent fuel economy for each technology. Energy economy ratios (the ratio of the gasoline equivalent fuel economy of a given technology to that of conventional gasoline or diesel vehicles) were taken from full fuel cycle studies done for the California Air Resources Board (Unnasch and Browning 2000). These were used to estimate fuel economy in miles per gasoline gallon equivalent for each alternative fuel and vehicle type. Energy use per fuel type was then divided among the various weight categories and vehicle technologies that would use that fuel. Total VMT per vehicle type for each calendar year was then determined by dividing the energy usage by the fuel economy. Average VMT was then calculated by dividing total VMT per vehicle type by the number of vehicles. Average VMT for each vehicle type was checked against the Federal Highway Administration Highway Statistics Series for each calendar year (FHWA 1996 through 2001). Note that for alternative fuel vehicles capable of running on both/either traditional and alternative fuels, the VMT given reflects only those miles driven that were powered by the alternative fuel.

Light-duty alternative fuel vehicle emission factors are estimated in Argonne National Laboratory's GREET 1.5 – Transportation Fuel Cycle Model (Wang 1999). In addition, Lipman and Delucchi estimate emission factors for some light and heavy-duty alternative fuel vehicles (Lipman and Delucchi 2002). The approach taken here is to calculate CH_4 emissions from actual test data and determine N_2O emissions from NO_x emissions from the same tests. Since it is likely that most alternative fuel vehicles use the same or similar catalysts to their conventional counterpart, the amount of N_2O emissions will depend upon the amount of oxides of nitrogen emissions that the engine produces. Based upon gasoline data for Tier 1 cars, the tailpipe NO_x to N_2O ratio is 5.75. Lipman and Delucchi (2002) found NO_x to N_2O ratios for light-duty alternative fuel vehicles with three-way catalyst systems to vary from 3 to 5.5 for older technology.

- Methane emission factors for light-duty vehicles were taken from the Auto/Oil Air Quality Improvement Research Program dataset (CRC 1997). This dataset provided CH_4 emission factors for all light-duty vehicle technologies except for propane (LPG). Light-duty propane emission factors were determined from reports on propane-vehicle emissions from the California Air Resources Board (Brasil and McMahon 1999) and the University of California Riverside (Norbeck et al 1998).
- Heavy-duty emission factors for alternative fuel vehicles were determined from test data using the West Virginia University mobile dynamometer (DOE 2002). Emission factors were determined based on the ratio of total hydrocarbon emissions to CH_4 emissions found for light-duty vehicles using the same fuel. Nitrous oxide emissions for heavy-duty engines were calculated from NO_x emission results using a NO_x to N_2O ratio of 50, which is more typical for heavy-duty engines with oxidation catalysts.

The combination of these changes and the historical data revisions described below resulted in an average annual increase of 0.1 Tg CO_2 Eq. (1.8 percent) in CH_4 emissions and 0.1 Tg CO_2 Eq. (0.2 percent) in N_2O emissions for the period 1990 through 2000.

Coal Mining

There was a single alteration to the methodology for estimating the emissions from coal mining. The change consisted of incorporating EIA's updated coal production data for the year 2000. The combination of this change and the historical data revisions described below resulted in an average annual increase of 0.1 Tg CO_2 Eq. (0.1 percent) in CH_4 emissions for the period 1990 through 2000.

Natural Gas Systems

The methodology used to estimate the emissions from natural gas systems was modified in two ways. First, data from four additional states were added to the number of north central non-associated wells. These states were left out in previous analyses, because the number of wells in these states was negligible. Second, the reduction in emission factors due to technological improvement was removed. In the past, emission factors were reduced at an annual rate of 0.2 percent such that by year 2020, emission factors would have declined by 5 percent from 1995. These reductions were made to reflect the underlying technological improvements through both innovation and normal replacement of equipment. However, the analysis already incorporates the emission reductions from some of these technological improvements as reported by EPA's Natural Gas STAR Partners. This is done by subtracting emission reductions associated with each stage of the natural gas system (production, processing, transmission and distribution) from the corresponding total emissions estimates for each operating stage. Thus, the emission factors were held constant throughout the time series for this year's inventory to eliminate the possibility of double counting. See Annex G for more detailed information on the methodology and data used to calculate CH_4 emissions from natural gas systems. The combination of these changes and the historical data revisions described below resulted in an average annual increase of 1.3 Tg CO_2 Eq. (1.1 percent) in CH_4 emissions for the period 1990 through 2000.

Petroleum Systems

There were three alterations to the methodology for estimating CH_4 emissions from petroleum systems. First, the emission factor for gas engines in the production sector was adjusted. In the previous report, the emission factor for gas engines, 0.08 scf CH_4/ HP-hr, was based on the 1999 EPA draft report, *Estimates of Methane Emissions from the U.S. Oil Industry* (EPA 1999). The 1996 Radian Study, *Methane Emissions from the U.S. Petroleum Industry* (Radian 1996) cites an emission factor of 0.24 scf CH_4/ HP-hr, which is a more accurate estimate for the emission factor of gas engines. Therefore, the 1996 Radian Study is the basis for the gas engine emission factor used in this year's inventory. Second, in the previous report, the activity data in the CRF table for the refining and crude transportation were based on crude oil production. However, crude production accounts only for the crude that is produced in the country, not the crude that is imported. The total crude refined includes both crude that is produced in the country and crude that is imported. In this year's report, the activity data for refining and crude transportation were based on refinery crude feed data obtained from EIA (2001). The amount of refinery feed accounts for all crude produced and imported that is refined. The activity data for crude oil transport were unavailable. In this case, it was assumed that all the crude that is transported goes to refineries. Therefore, the activity data for refining sector was used also for the transportation sector. Changing the bases from the crude production to refinery feed more accurately estimates the activity data of refining and crude transportation. Third, the estimated emissions in last year's report did not account for any emissions reductions reported by members of EPA's Natural Gas STAR Program. In this year's report, these emission reductions are taken into account by subtracting from tank venting the amount of emission reductions that were reported by the Natural Gas STAR Program partners from installing vapor recovery units for the period 1990 through 2001 (EPA 1995- 2000). Incorporating the reported emission reductions into the estimated CH_4 emissions gives a more accurate inventory estimate. See Annex H for additional detail. These changes resulted in an average annual increase of 0.1 Tg CO_2 Eq. (0.2 percent) in CH_4 emissions for the period 1990 through 2000.

Municipal Solid Waste Combustion

The incorporation of new 2000 data in the municipal solid waste combustion section led to a change in methodology for estimating the activity data for the years 1999 and 2001. Values for 1999 were interpolated between 1998 and 2000 reported data; 2001 values were extrapolated from the 2000 data. The combination of this change and the historical data changes described below resulted in an average annual increase of 0.6 Tg CO_2 Eq. (2.6 percent) in CO_2 emissions for the period 1990 through 2000.

Ammonia Manufacture and Urea Application

The methodology for estimating CO_2 emissions from ammonia production was adjusted to account for the use of some of the CO_2 produced from ammonia production as a raw material in the production of urea. For each ton of urea produced, 8.8 of every 12 tons of CO_2 are consumed and 6.8 of every 12 tons of ammonia is consumed. The CO_2 emissions reported for ammonia production are therefore reduced by a factor of 0.73 multiplied by total annual domestic urea production, and that amount of CO_2 emissions is allocated to urea fertilizer application. Both ammonia production and urea application are included in the same section of the Industrial Processes chapter; therefore total CO_2 emissions resulting from nitrogenous fertilizer production does not change.

In addition to the allocation of some emissions to urea application within this section, urea application data were adjusted to account for imports and exports of urea. Since imports of urea were greater than exports of urea during the years 1990 through 2000, this resulted in a net increase of emissions. The combination of this change and the historical data change discussed below resulted in an average annual increase of 1.2 Tg CO_2 Eq. (6.5 percent) in CO_2 emissions for the period 1990 through 2000.

Nitrous Oxide (N_2O) Product Usage

The N_2O Product Usage source has been added to this year's report to account for emissions produced by the use of nitrous oxide and products containing it. Nitrous oxide is primarily used in carrier gases with oxygen to administer more potent inhalation anesthetics for general anesthesia and as an anesthetic in various dental and veterinary applications. The second principal use of N_2O is as a propellant in pressure and aerosol products, the largest application being pressure-packaged whipped cream. Emissions from this source category added an annual average of 4.5 Tg CO_2 Eq. in N_2O emissions over the period 1990 through 2000.

Electrical Transmission and Distribution

The primary change in the methodology for calculating emissions from electrical transmission and distribution was an increase in the assumed emission rate from equipment manufacturers. Previously, the emission rate of U.S. electrical equipment manufacturers was assumed to be 3 percent of the SF_6 charged into new equipment. In light of the final CIGRE paper, this estimate has been increased to 10 percent. This revision resulted in an average annual increase of 0.9 Tg CO_2 Eq. (3.7 percent) in SF_6 emissions for the period 1990 through 2000.

Magnesium Production and Processing

There was a single change to the methodology for estimating the emissions from magnesium production. The emission factor for die casting in 2000 was adjusted downward to reflect the fact that participants in EPA's SF_6 Emission Reduction Partnership for the Magnesium Industry, which have relatively low emission rates, accounted for a greater percentage of die casting (nearly 100 percent) than previously believed (60 percent). The combination of this change and the historical data revisions described below resulted in an average annual decrease of less than 0.1 Tg CO_2 Eq. (1.9 percent) in SF_6 emissions for the period 1990 through 2000.

Enteric Fermentation

The methodology for estimating CH_4 emissions from enteric fermentation now incorporates new diet information for grazing beef cattle and cattle in feedlots. The changes in diet information were based on comments received during the expert review period of the *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2000*. To revise the values for digestible energy (DE) and fraction of energy converted to CH_4 (Y_m) for grazing beef cattle (beef cows, beef replacements, heifer stockers, and steer stockers), the diet descriptions developed for the enteric fermentation model were combined with new diet characteristic information found in the Nutrient Requirements of Beef Cattle (NRC 2000). New DE values were estimated for both forage-only and supplemented diets. For forage diets, two separate DE values were used to account for the lower feed quality in the western United States. Where DE values were not available, total digestible nutrients as a percent of dry matter intake was used as a proxy for DE and is considered essentially the

[1] For example, in California the forage DE of 64.7 percent was used for 95 percent of the grazing cattle diet and a supplemental diet DE of 65.2 percent was used for five percent of the grazing cattle diet, for a total weighted DE of 64.9 percent.

same as the DE value. Weighted averages were developed for DE values for each region using both the supplemental diet and the forage diet.[1] For beef cows, the DE value was adjusted downward by two percent (assumed value) to reflect the reduced diet of the mature beef cow. For feedlot animals, diet characteristics were revised because of abrupt changes in emissions due to changes in DE and Y_m, as a result of the DE and Y_m originally being used for sets of years 1990 through 1992,1993 through 1995, and 1996 through 2000. It was also determined that the values used previously for 1990 through 1992 were too low for the DE and too high for the Y_m. To correct both of these issues, the values previously used for 1993 through 1995 were used for 1990, and this value was extrapolated linearly between the 1990 and the 1996 values. Values remain constant from 1996 onwards. See Annex L for more detailed information on the development of the diet information from cattle. The combination of these changes and the historical data revisions described below resulted in an average annual decrease of 9.3 Tg CO_2 Eq. (7.3 percent) in CH_4 emissions for the period 1990 through 2000.

Manure Management

The primary change in the methodology for estimating CH_4 and N_2O emissions from manure management was a change in the source for volatile solids excretion rates for cattle. This source was updated to be consistent with the results of the Enteric Fermentation Energy model.

In previous years, the method for calculating volatile solids production from dairy cows reflected the relationship between milk production and volatile solids production. Cows that produce more milk per year also produce more volatile solids in their manure due to their increased feed. Figure 4-1 in the *Agricultural Waste Management Field Handbook* (USDA 1996) was used to determine the mathematical relationship between volatile solids production and milk production for a 1,400 pound dairy cow. The resulting best-fit equation was used to estimate the volatile solids excretion rate for dairy cows given the estimated annual milk production data, published by USDA's National Agricultural Statistics Service (USDA 2000). State-specific volatile solids production rates were then calculated for each year of the inventory and used instead of a single national volatile solids excretion rate constant.

The volatile solids excretion rate for other animals were developed from published sources reviewed for U.S.-specific livestock waste characterization data. Data from the National Engineering Handbook, Agricultural Waste Management Field Handbook (USDA 1996) were chosen as the primary source of waste characteristics. In some cases, data from the American Society of Agricultural Engineers, Standard D384.1 (ASAE 1999) were used to supplement the USDA data.

This year, the method for calculating volatile solids production from beef and dairy cows, heifers, and steer is based on the relationship between animal diet and energy utilization, which is modeled in the enteric fermentation portion of the inventory. Volatile solids content of manure is equal to the fraction of the diet consumed by cattle that is not digested and thus is excreted as fecal material. The combination of this fecal material and urinary excretions constitutes manure. The enteric fermentation model requires the estimation of gross energy intake and its fractional digestibility, digestible energy, in the process of estimating enteric CH_4 emissions (see Annex M for details on the enteric energy model). These two inputs were used to calculate the indigestible energy per animal unit as gross energy minus digestive energy plus an additional 2 percent of gross energy for urinary energy excretion per animal unit. This was then converted to volatile solids production per animal unit using the typical conversion of dietary gross energy to dry organic matter of 20.1 MJ/kg (Garrett and Johnson 1983). The combination of this change and the historical data changes described below resulted in an average annual increase of 1.3 Tg CO_2 Eq. (4.0 percent) in CH_4 emissions and an average annual increase of 0.2 Tg CO_2 Eq. (1.2 percent) in N_2O emissions for the period 1990 through 2000.

Land-Use Change and Forestry

The Land-Use Change and Forestry chapter comprises four sections: 1) Forests; 2) Urban Trees; 3) Agricultural Soils; and 4) Landfilled Yard Trimmings. The methodologies used in the first, third, and fourth sections have changed relative to the previous Inventory. The changes to each section are described below.

- *Forests*. In this year's Inventory, revised estimates are reported for the amounts of harvested wood products and landfilled wood for 2000 to correct small errors in the results reported last year.

- *Agricultural Soils*. The current inventory is based on a modified version of the carbon accounting method developed by the Intergovernmental Panel on Climate Change (IPCC/UNEP/OECD/IEA 1997). The default IPCC method is a deterministic approach that provides general global parameters for estimating the impact of land use and management on soil organic carbon storage, and does not directly assess uncertainty in the resulting estimates. Previous years' inventories used the default method. For the current inventory, the method was modified in four ways to improve the method for application to U.S. soils and to assess uncertainty. First, probability density functions were developed for each management factor, instead of using the single values provided in the IPCC documentation (IPCC/UNEP/OECD/IEA 1997). Second, probability density functions were constructed for the activity data that were used in the previous inventory. Third, the mineral soil equation was modified so that the reference carbon stocks were based on soils under agricultural management instead of native vegetation. This was necessary due to the availability of data to construct probability density functions for the reference carbon stocks. Fourth, a Monte Carlo Analysis was used to select values from the probability density functions for repeated calculations of carbon stock change, generating a 95 percent confidence interval for the inventory. Overall, these changes should better reflect the impact of land use and management on soil organic carbon storage in U.S. agricultural lands. Four additional changes were made in the methods from the previous inventory to improve the estimates. First, the effect of wetland restoration in the Northern Great Plains was included, and represented an additional increase in carbon storage for wetlands enrolled in the Conservation Reserve Program and restored through the Partners for Wildlife Program (U.S. Fish and Wildlife Service). Second, changes in carbon stocks were not estimated for lands converted from agricultural uses to urban, miscellaneous non-cropland, and open water. In the previous inventory, carbon stocks were computed for these non-agricultural land uses using the factor values that were intended to represent changes from cultivated cropland to grasslands or forests. Consequently, applying these factor values to represent changes to non-agricultural land uses is highly questionable (e.g., converting a corn field into a subdivision or lake), and so those calculations were not included in the current inventory. Third, the previous inventory only accounted for manure applied to a portion of U.S. grazing lands based upon assumptions by Follett et al. (2001). The current inventory accounts for all of the manure and sewage sludge nitrogen that is available for application to agricultural land, based on information derived for the Agriculture Soil Management section of the Agriculture chapter of this volume. A national average rate of application was assumed, as was a national average rate of soil organic carbon change for croplands and grazing lands. This is a more complete and accurate assessment of manure and sewage sludge impacts on soil organic carbon storage than the previous inventory. Lastly, carbon stock changes for 1993 through 1997 in the previous inventory were based on land use and management differences between 1982 and 1997. To better reflect trends in carbon stock changes over the 1993 through 1997 time period, the current inventory is based on the activity data coinciding with those years (i.e., 1992 and 1997). However, the 1992 to 1997 carbon stock calculations for some areas were based on the 1982 land uses if a change had occurred between 1982 and 1992, but remained unchanged between 1992 and 1997. This modification allowed for continued accrual or loss of carbon that continues for 20 years following a land use and management change according to the IPCC carbon accounting approach (IPCC/UNEP/OECD/IEA 1997).
- *Landfilled Yard Trimmings*. The Carbon Storage Factors (CSFs), which are used to estimate the amount of yard trimmings carbon stored in landfills, were adjusted to correct for a mass balance problem in the experimental results that are the basis of these data (Barlaz 1998). These adjustments, which are based on the CH_4 yields for each yard trimmings component from Eleazer et al. (1997), resulted in a 5 percent decrease in the weighted average CSF for yard trimmings.

The combination of these changes and the historical data changes described below resulted in an average annual decrease in carbon sequestration from land-use change and forestry of 24.7 Tg CO_2 Eq. (2.3 percent) for the period 1990 through 1992 and 51.6 Tg CO_2 Eq. (5.3 percent) for the period 1993 through 2000.

Landfills

The methodological change for estimating CH_4 emissions from landfills was incorporating municipal solid waste generation data from U.S. territories. The combination of this change and the historical data changes described below resulted in an average annual decrease of less than 0.05 Tg CO_2 Eq. (less than 0.05 percent) in CH_4 emissions for the period 1990 through 2000.

Human Sewage (Domestic Wastewater)

Several changes were made to the methodology for estimating N_2O emissions from human sewage. Previously, the estimate included only N_2O emissions from wastewater treatment plant effluent. This year, the methodology was expanded to include direct emissions from wastewater treatment plants. In addition, the emissions now also reflect nitrogen from the use of garbage disposals, and from bath and laundry water, which represents an increase of approximately 75 percent. Another change was to subtract out the nitrogen in sewage sludge that leaves the treatment plant to be disposed on agricultural land, landfilled, or incinerated. In earlier estimates, this reduction was only accounted for partially. These changes resulted in an average annual increase of 6.3 Tg CO_2 Eq. (80.9 percent) in N_2O emissions for the period 1990 through 2000.

Changes in Historical Data

- In the CO_2 Emissions from Fossil Fuel Combustion section of the Energy chapter, energy consumption data have been updated by the Energy Information Administration (EIA 2002b) for all years. The major changes include: (1) reorganization of the electric power generation sector; (2) revisions to electric power fuel use statistics based on EIA's use of non-utility power plant data in place of fuel supplier data; and (3) revisions to historical data per extensive review and resolution of anomalies by EIA. These revisions specifically impacted natural gas and renewable energy estimates. The combination of these changes, the methodological change described above, and the methodological changes in "Emissions and Storage from Non-Energy Uses of Fossil Fuels" (which affect the emissions from this source) resulted in an average annual increase of 52.0 Tg CO_2 Eq. (1.0 percent) in CO_2 emissions for 1990 through 2000.
- In the Stationary Combustion (excluding CO_2) section of the Energy chapter, changes to emission estimates were entirely due to revised data from EIA (2002b). These revisions are explained in more detail in the section above on CO_2 Emissions from Fossil Fuel Combustion and Carbon Stored in Products from Non-Energy Uses of Fossil Fuels. One specific revision affecting stationary combustion is the inclusion of wood energy consumption by electric utilities and non-utilities in the electric power sector. EIA previously allocated this consumption under the industrial sector. The combination of these changes and the methodological change described above resulted in an average annual increase of 0.2 Tg CO_2 Eq. (2.8 percent) in CH_4 emissions and an average annual decrease of 0.4 Tg CO_2 Eq. (3.0 percent) in N_2O emissions for the period 1990 through 2000.
- In the Mobile Combustion (excluding CO_2) section of the energy chapter, the following historical data changes were made:
  - Vehicle Miles Traveled (VMT) Adjustment for Gasoline and Diesel Highway Vehicles: VMT for alternative fuel vehicles were calculated separately using EIA Data Tables (EIA 2002a). Since the VMT estimates from Federal Highway Administration include total VMT in the United States, it was necessary to subtract VMT from alternative fuel vehicles from this total.
  - Locomotive fuel consumption: The data source for locomotive fuel consumption was changed to AAR (2001), which reports annual diesel consumption for Class I railroad locomotives, and Benson (2002), which provided diesel consumption for Class II and Class III railroad locomotives.

The combination of these changes and the methodological revisions described above resulted in an average annual increase of 0.1 Tg CO_2 Eq. (1.8 percent) in CH_4 emissions and 0.1 Tg CO_2 Eq. (0.2 percent) in N_2O emissions for the period 1990 through 2000.

- In the Coal Mining section of the Energy Chapter, an error was corrected in the spreadsheet for recovery estimates for 1991 and 1992. For the year 2000, the recovery information was updated based on improved information from one underground mine. The combination of these changes and the methodological revision described above resulted in an average annual increase of 0.1 Tg CO_2 Eq. (0.1 percent) in CH_4 emissions for the period 1990 through 2000.
- In the Natural Gas Systems section of the Energy chapter, the following changes were made:
  - Methane emission estimates have been revised to incorporate new activity driver data for natural gas consumption in the transportation sector (EIA 2002e), the number of associated wells (API 2002), and the number of non-associated wells (EIA 2002d).
  - Updated emission reduction data has become available for the 1990 through 2001 time series from the EPA Natural Gas STAR Program. Historical data has been revised to incorporate the updated data.

  The combination of these changes and the methodological revisions described above resulted in an average annual increase of 1.3 Tg CO_2 Eq. (1.1 percent) in CH_4 emissions for the period 1990 through 2000.
- In the Municipal Solid Waste Combustion section of the Energy chapter, scrap tire weight data were updated to reflect information from the RMA/STMC website *Scrap Tires, Facts and Figures* (2002). New data on plastics, synthetic fibers, and synthetic rubber in 2000 from *Municipal Solid Waste in the U.S.: 2000 Facts and Figures* were also incorporated into the municipal solid waste analysis. The combination of these changes and the methodological revision described above resulted in an average annual increase of 0.6 Tg CO_2 Eq. (2.6 percent) in CO_2 emissions for the period 1990 through 2000.
- In the International Bunker Fuels section of the Energy chapter, there was a change in historical military fuel consumption reported by the DoD (DESC 2002). Based on available Service data and expert judgment, a small fraction of the total jet fuel was reallocated from the aviation subtotal to a new land-based jet fuel category for 1997 and subsequent years. This change resulted in reduced military aviation fuel consumption reported between 1997 and 2000. DoD is increasing the use of JP8 (a type of jet fuel) in land-based vehicles and equipment as the Department implements its policy of using a single fuel (JP8) for all tactical equipment. Total aviation emissions increased in the year 2000 due to revised historical data on total jet fuel expenditures by foreign air carriers in U.S. ports (BEA 2002). Military marine fuel consumption data provided by the DoD was revised downward for 2000, though this had little effect on total emissions. These changes resulted in an emissions decrease of 0.97 Tg CO2 Eq. (-1 percent) in a combination of CO_2, CH_4, and N_2O emissions for 2000.
- In the Iron and Steel Production section of the Industrial Processes chapter, 1997 and 2000 coal consumption data for U.S. coke plants were revised using updated estimates from EIA (EIA 2002c). These changes resulted in a decrease of 4.3 Tg CO_2 Eq. (5.6 percent) in CO_2 emissions for 1997 and an increase of less than 0.05 Tg CO_2 Eq. (0.1 percent) in CO_2 emissions for 2000.
- In the Cement Manufacture section of the Industrial Processes chapter, the clinker production data were updated to reflect the information in the *Mineral Industry Surveys, Cement, December 2001* (USGS 2002a). The revisions resulted in an increase of 0.1 Tg CO_2 Eq. (0.3 percent) in CO_2 emissions for 2000.
- In the Ammonia Manufacture and Urea Application section of the Industrial Processes chapter, ammonia production for 2000 was adjusted to reflect revised production information from the U.S. Census Bureau (U.S. Census Bureau 2002). The combination of this change and the methodological changes discussed above resulted in an average annual increase of 1.2 Tg CO_2 Eq. (6.5 percent) in CO_2 emissions for the period 1990 through 2000.

- In the Lime Manufacture section of the Industrial Processes chapter, the activity data was altered to incorporate revised production numbers (USGS 2002b) for dolomitic quicklime and high-calcium hydrated lime. The revision decreased the total lime production for 2000, leading to a decrease of less than 0.05 Tg CO_2 Eq. (less than 0.05 percent) in CO_2 emissions for that year.
- In the Limestone and Dolomite Use section of the Industrial Processes chapter, the limestone and dolomite consumption data used to calculate CO_2 emissions have been revised for the entire 1990 to 2000 time period. The revision included a change in the source of consumption data for flue gas desulphurization from an EIA document to the *Mineral Yearbook: Crushed Stone Annual Report* (Tepordei 2002). The comprehensive activity data revision was responsible for improving the accuracy of end-use consumption estimates for 1990 and 1992, years in which the USGS did not conduct a detailed survey of limestone and dolomite consumption. Additionally, the revision allowed for the more accurate estimation of the consumption data points withheld by the USGS to avoid disclosing proprietary company information. These changes resulted in an average annual increase in CO_2 emissions of 0.3 Tg CO_2 Eq. (5.4 percent) for the period 1990 through 1996 and an average annual decrease in CO_2 emissions of 1.8 Tg CO_2 Eq. (19.9 percent) for the period 1997 through 2000.
- In the Titanium Dioxide Consumption section of the Industrial Processes chapter, the activity data used to calculate CO_2 emissions have been revised to reflect an updated 2000 figure (USGS 2001). This change resulted in a decrease of less than 0.05 Tg CO_2 Eq. (2.3 percent) in CO_2 emissions for 2000.
- In the Carbon Dioxide Consumption section of the Industrial Processes chapter, the activity data used to calculate CO_2 emissions was revised to incorporate the most recent publication by the Freedonia Group, Inc. (2002). The Freedonia Group, Inc. report included data for 1992, 1996, and 2001. Remaining years were extrapolated rather compiling data from previous Freedonia Group, Inc. reports, to ensure data timeseries consistency. This change resulted in an average annual increase of 0.2 Tg CO_2 Eq. (14 percent) in CO_2 emissions from this source from 1990 through 2000.
- In the Petrochemical Production section of the Industrial Processes chapter, the activity data used to calculate CH_4 emissions were revised to reflect modified data from the American Chemistry Council (ACC 2002). The production data was altered for ethylene for the years 1995, 1996, 1999, and 2000. Methanol data was revised for 1995 only and styrene data was revised for 1996 only. These changes resulted in an average annual increase of less than 0.05 Tg CO_2 Eq. (0.2 percent) in CH_4 emissions for the period 1995 through 2000.
- In the Silicon Carbide section of the Industrial Processes chapter, the activity data used to calculate CH_4 emissions have been revised to correct an error in the 1999 calculation. This change resulted in a decrease of less than 0.05 Tg CO_2 Eq. (6.9 percent) in CH_4 emissions for 1999.
- In the Nitric Acid Production section of the Industrial Processes chapter, 2000 production data used last year were revised using updated estimates from Chemical and Engineering News (C&EN 2002). The change resulted in an average annual decrease of 0.1 Tg CO_2 Eq. (0.3 percent) in N_2O emissions for the period 1990 through 2000.
- In the Adipic Acid Production section of the Industrial Processes chapter, the 2000 capacity data for the smallest plant in the 1990-2000 report were based on projections of an expansion in capacity. However, no data exists to confirm the expansion. Consequently, this year's inventory keeps the 2000 capacity data for this plant equal to its 1998 capacity data. In addition, facility-specific emissions data were used directly for another plant. The change resulted in an annual average decrease of 0.7 Tg CO_2 Eq. (8.2 percent) in N_2O emissions for the period 1990 through 2000.
- In the Substitution of Ozone Depleting Substances section of the Industrial Processes chapter, a review of the current chemical substitution trends, together with input from industry representatives, resulted in updated assumptions for the Vintaging Model in the fire-extinguishing sector. These changes resulted in an average annual decrease of 0.3 Tg CO_2 Eq. (0.7 percent) in HFC and PFC emissions for the period 1994 through 2000.

- In the Aluminum Production section of the Industrial Processes chapter, the estimates of PFC emissions for 2000 have been revised due to the receipt of additional smelter-specific information on aluminum production and anode effect frequency and duration. These data were provided by the EPA in cooperation with participants in the Voluntary Aluminum Industrial Partnership program. The changes resulted in a decrease of less than 0.05 Tg CO_2 Eq. (0.3 percent) in PFC emissions for 2000.
- In the Magnesium Production and Processing section of the Industrial Processes chapter, the emissions estimates for this report were revised to reflect new activity data for magnesium produced and processed (particularly the quantities die cast). The revision of the estimates of the quantities of magnesium die cast was the most important of these changes, setting the pattern for the changes in the emission estimates. Both estimated die-casting and estimated emissions increased for the year 1996 and decreased for the years 1997 through 2000. The combination of these changes and the methodological revision described above resulted in an average annual decrease of 0.1 Tg CO_2 Eq. (1.9 percent) in SF_6 emissions for the period 1990 through 2000.
- In the Enteric Fermentation section of the Agriculture chapter, the majority of the change in cattle emissions is due to the diet assumption discussed above, but the animal population data were also updated to include revisions completed by the organizations that produce these estimates. Specifically, the Food and Agriculture Organization updated horse populations from 1990 through 2000 (FAO 2002a). Additionally, some cattle population data were revised to reflect updated USDA estimates. The combination of these changes and the methodological revisions described above resulted in an average annual decrease of 9.3 Tg CO_2 Eq. (7.3 percent) in CH_4 emissions for the period 1990 through 2000.
- In the Manure Management section of the Agriculture chapter, historical data for swine, turkey, sheep, and horse populations were updated. The changes are detailed below:
    - The 2001 inventory includes corrections made to the population data for swine. The 2000 inventory contained errors in the swine population for the following states and years: South Dakota, 1990; Wisconsin, 1992; and Georgia and Kentucky; 1999. These data were corrected. An additional error was identified in the N_2O emissions calculations, in which the total managed swine population reflected an incorrect sum of weight class populations. These formulas were corrected. An error was also identified in the previous inventory in which the swine population data listed for Pennsylvania in 1991 and 1992 were incorrect. This was due to an inaccuracy in the online USDA database from which these data were collected. USDA verified the correct data are published in the USDA publication *Hogs and Pigs - Final Estimates 1988-92* (USDA 1994). The results of all of these corrections are a slight change for the swine CH_4 emission estimates (up to a 4 percent increase) and a 19 percent increase in the N_2O emission estimates for all years of the swine inventory estimates.
    - The 2000 inventory contained incorrect population data for turkeys in 2000. These errors were due to incorrect spreadsheet linking and were corrected. The result is a slight change in poultry CH_4 and N_2O emissions for that year of the inventory.
    - The 2000 inventory contained incorrectly calculated sheep populations for sheep on-feed and not-on-feed for all years of the inventory for the "Other" state populations classification. This calculation was corrected, resulting in an estimated increase of 3 percent to 11 percent N_2O emissions. This calculation did not affect CH_4 emissions estimates.
    - The Food and Agriculture Organization of the United Nations has an online database that is used for horse population estimates. These data, from 1990 through 2000, have been updated from the data used in the previous Inventory. Therefore, all N_2O and CH_4 emission estimates for horses have changed slightly (up to 2 percent) relative to the previous inventory. The effect of the population changes on the predicted CH_4 emissions is less than the effect on the predicted N_2O emissions due to the nonlinear effect of the change on the CH_4 calculations.

The combination of these changes and the methodological change described above resulted in an average annual increase of 1.3 Tg CO_2 Eq. (4.0 percent) in CH_4 emissions and 0.2 Tg CO_2 Eq. (1.2 percent) in N_2O emissions for the period 1990 through 2000.

- In the Rice Cultivation section of the Agriculture chapter, one change has been made to the historical data. Acreage harvested in Missouri in the year 2000 has been revised based on the latest statistics from the USDA (2002d). This change resulted in a less than one percent change in total harvested rice area for that year. As a result, there was a decrease of less than 0.05 Tg CO_2 Eq. (0.1 percent) in CH_4 emissions for 2000.

- In the Agricultural Soil Management section of the Agriculture chapter, there were several changes to historical data that are described below:

  - Crop production figures for 2000 were revised using the most recent estimates provided by USDA (2002d).

  - New manure data were incorporated based on the following updated livestock population estimates: Swine population numbers were corrected for several years from 1990 through 1999. Spreadsheet errors affecting the year 2000 turkey and sheep population data were found and corrected. The horse population data for 1990 through 2000 were revised with the updated data from the FAO online database. (USDA 2002a-c,e-g; FAO 2002b).

  - Estimates of sewage sludge nitrogen applied to land were revised for 1990 through 1994. The percent of total sludge produced that gets land applied was modified to exclude surface disposal.

  - Commercial and organic fertilizer consumption data were updated for 2000 using the most recent AAPFCO estimates (2002).

  These revisions resulted in a decrease of 3.0 Tg CO_2 Eq. (1.0 percent) in N_2O emissions for 2000, and an average annual increase of 0.3 Tg CO_2 Eq. (0.1 percent) in N_2O emissions for the period 1990 through 2000.

- In the Field Burning of Agricultural Residues section of the Agriculture chapter, the year 2000 crop production data have been revised for all crops. The new data reflect the most current statistics from the USDA (2002d). This change resulted in a decrease of less than 0.05 Tg CO_2 Eq. (0.3 percent) in CH_4 emissions and a decrease of less than 0.05 Tg CO_2 Eq. (0.4 percent) in N_2O emission for 2000.

- In the Land-Use Change and Forestry chapter, the following changes were made:

  - In the Agricultural Soils section, probability density functions were constructed for management factors based on a statistical analysis of estimated changes in carbon stocks from published studies addressing land use and management impacts (Ogle et al. in review). The probability density functions were used in place of the management factors provided in the documentation for the default IPCC carbon accounting approach (IPCC/UNEP/OECD/IEA 1997). Similarly, probability density functions were constructed for reference carbon stocks based on a statistical analysis of field measurements recorded in the National Soil Survey Characterization Database (NRCS 1997). The probability density functions were used in place of the reference carbon stocks that are provided in the documentation for the default IPCC carbon accounting approach (IPCC/UNEP/OECD/IEA 1997).

  - In the Agricultural Soils section, the 1998 to 2001 estimates for the CRP enrollment were updated with data provided by the Farm Services Agency (Barbarika 2002).

  - In the Landfilled Yard Trimmings section, the landfilled yard trimmings data for 1998 through 2000 were updated to reflect revised estimates in EPA (2002c).

The combination of these changes and the methodological revisions described above resulted in an average annual decrease in carbon sequestration from land-use change and forestry of 24.7 Tg CO2 Eq. (2.3 percent) for the period 1990 through 1992 and 51.6 Tg CO_2 Eq. (5.3 percent) for the period 1993 through 2000.

- In the Landfills section of the Waste chapter, this report reflects an updated database of flare and landfill-gas-to-energy (LFGTE) projects. The CH_4 mitigated from LFGTE projects increased slightly from 1990 through 1999 and decreased slightly in 2000. The difference is primarily attributed to the availability of additional LFGTE projects included in this year's LFGTE database, as well as revised estimates of megawatt capacity for electricity projects and landfill gas flow for direct use projects. This year's estimate of CH_4 emissions avoided through flaring reflects new data on flares that became operational prior to 1990. In addition, new data in the LFGTE database led to increased matches between the flare data and the LFGTE data, resulting in the exclusion of additional flares from the estimate of emission reductions through flaring (note: emission reductions associated with landfills that have both a flare and a LFGTE project are counted in the LFGTE totals). The combination of these changes and the methodological change described above resulted in an average annual decrease of less than 0.05 Tg CO_2 Eq. (less than 0.05 percent) in CH_4 emissions for the period 1990 through 2000.
- In the Wastewater Treatment section of the Waste chapter, the U.S. population estimates were updated for the 1991 through 2000 period with data from the 2000 Census. The revision resulted in an average annual decrease of 0.2 Tg CO_2 Eq. (0.8 percent) in CH_4 emissions for the period 1990 through 2000.