Chapter 1: Introduction

1.1 Purpose of this Report

The U.S. Agriculture and Forestry Greenhouse Gas Inventory: 1990-2001 was developed to provide a comprehensive assessment of the contribution of U.S. agriculture and forestry to greenhouse gas (GHG) emissions. The document was prepared to support and expand on information provided in the official Inventory of U.S. GHG Emissions and Sinks (U.S. GHG Inventory), which is prepared annually by the U.S. Environmental Protection Agency to meet U.S. commitments under the United Nations Framework Convention on Climate Change (UNFCCC) (EPA 2003a). The U.S. Agriculture and Forestry GHG Inventory: 1990-2001 (USDA GHG Inventory) supplements the U.S. GHG Inventory, providing an in-depth look at agriculture and forestry emissions and sinks of GHGs and presenting additional information on GHG emissions from fuel consumption on U.S. farms.

The U.S. GHG Inventory provides national-level estimates of emissions of the primary GHGs (carbon dioxide, methane, nitrous oxide, and fluorine containing halogen substances) across a broad range of sectors (energy, industrial processes, solvent use, agriculture, land use change and forestry, and waste). Due to the national-level scale of reporting in the U.S. GHG inventory, the report does not provide extensive regional or State GHG emissions data for any one sector. However, in some cases, State and regional emissions data are part of the inventory development process and can be used for more disaggregated analyses. This report customizes the data from the U.S. GHG Inventory in a manner that is useful to agriculture and forestry producers and related industries, natural resource and agricultural professionals, as well as technical assistance providers, researchers, and policymakers. The analyses presented in this report are the result of a collaborative process and direct contributions from EPA, USDA (Forest Service, Natural Resources Conservation Service, Agricultural Research Service, Office of Energy Policy and New Uses, and the Global Change Program Office), and the Natural Resources Ecology Laboratory (NREL) of Colorado State University.

USDA administers a portfolio of conservation programs that have multiple environmental benefits including reductions in GHG emissions and increases in carbon sequestration. In June 2003, Secretary of Agriculture Ann M. Veneman announced a series of measures to incorporate GHG considerations into USDA conservation programs. The information provided in this inventory will be useful in improving our understanding of the magnitude of GHG emissions by State, region, and land use, and by crop, pasture, range, and forest management systems.

This and future USDA GHG Inventory reports will facilitate tracking of progress in promoting carbon sequestration and reducing GHG emissions through agriculture and forest management. This year, the USDA GHG Inventory describes the role of agriculture and forestry in GHG emissions and sinks, including discussions of GHG emissions reductions and carbon sequestration through agriculture and forest management. Extensive and in-depth emissions estimates are presented for all agricultural and forestry GHG sources and sinks for which internationally recognized methods are available. In many cases, emissions estimates are provided at State and regional scales in addition to the national levels provided in the U.S. GHG

Inventory. Emissions are categorized by additional information such as land ownership and management practices where possible. This report will help to:

- Quantify current levels of emissions and sinks at State, regional, and national scales in agriculture and forestry,
- Identify activities that are driving GHG emissions and sinks and trends in these activities, and
- Assess information needed to improve estimates of GHG emissions and sinks.

1.2 Overview of the Report Structure

The report provides detailed trends in agriculture and forestry GHG emissions and sinks, with information by source and sink at State and regional levels. The report is structured mainly from a land use perspective, addressing livestock operations, croplands, and forests separately; but it also includes a chapter on energy use. The livestock chapter inventories GHG emissions from livestock and livestock waste stored and managed in confined livestock operations as well as pasture and range operations. The cropland agriculture chapter addresses emissions from cropland soil amendments, rice production, and residue burning, as well as carbon sequestration in agricultural soils. The forest chapter details carbon sequestration in forest biomass and soils, urban trees, and wood products. Emissions of methane and nitrous oxide in forestry are not addressed since little information is currently available to develop estimates for these sources. The energy chapter provides information on carbon dioxide emissions from energy consumption on U.S. farms, covering GHG emissions from fuel use in livestock and cropland agriculture. While the U.S. GHG Inventory provides estimates of GHG emissions from energy consumption in the production of fertilizer, this indirect source of agricultural GHG emissions is not covered in this report.

Each chapter presents a summary of sources of greenhouse gas emissions and sinks in the land use or category of emissions covered by the chapter. A brief summary of GHG emissions at the national level is provided initially, followed by more detailed descriptions of emissions by each source at national and sub-national scales where available. Detailed accounts of the methods are provided for each source as well as information on the main sources of uncertainty in the methods. In some cases, text describing the methods and uncertainty are taken directly from the U.S. GHG Inventory, with permission from the EPA. In addition, some chapters include discussions of opportunities to mitigate greenhouse gas emissions, additional research underway for refining estimates, and future research priorities for improving estimation techniques.

The remainder of this section provides an overview of greenhouse gas emissions in agriculture and forestry from a global perspective and a summary of greenhouse gas emissions in U.S. agriculture and forestry from 1990 to 2001.

1.3 Global Change and Global Greenhouse Gas Emissions in Agriculture and Forestry

Global concentrations of GHGs in the atmosphere have increased measurably over the past 250 years. Carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O) concentrations in the atmosphere have increased by roughly 31 percent, 151 percent, and 17 percent, respectively, since 1750 (IPCC 2001). Agriculture and forestry practices have contributed greenhouse gases to the atmosphere over this time period through fuel consumption, land use conversions, cultivation and fertilization of soils, production of ruminant livestock, and management of livestock manure. The management of agriculture and forest land has helped offset GHG emissions by promoting the biological uptake of CO_2 through the incorporation of carbon into biomass, wood products, and soils.

Observed global increases in CO_2 emissions are primarily a result of fossil fuel combustion at present, but in the past, land use and land use change were major contributors. Currently, land use change is the second largest global cause of CO_2 emissions (IPCC 2001). Land use and land use change can be managed to rebuild carbon stocks in soil and biomass with the potential to essentially reverse past emissions from historical land use conversions. While land use conversion is a large global source of CO_2, within the United States, net forestland area has remained relatively stable for the last century with a relatively small net loss of roughly 4.2 million hectares (Kimble et al. 2003). Since the mid-20thcentury, forestland conversions have been primarily for development purposes. Forest conversions to cropland, pasture, and rangeland were more common prior to 1953 (Kimble et al. 2003).

Over half of global annual emissions of CH_4 and roughly a third of global annual emissions of N_2O are believed to derive from human sources, mainly from agriculture (IPCC 2001). Agricultural activities contribute to these emissions in a number of ways. While losses of N_2O to the atmosphere occur naturally as a result of the soil nitrogen cycle, the application of nitrogen to amend soil fertility can increase the rate of emissions. The rate is amplified when more nitrogen is applied than can be used by the plants. In agricultural practices, nitrogen is added to soils through the use of synthetic fertilizers, application of manure, cultivation of nitrogen-fixing crops/forages (e.g., legumes), and retention of crop residues. Rice cultivation uses periodic flooding of rice paddies, which promotes anaerobic decomposition of organic matter in soil such as rice residue and organic fertilizers by CH_4-emitting soil microbes. Finally, burning of residues in agricultural fields produces CH_4 and N_2O as by-products.

In addition, livestock and livestock waste cause CH_4 and N_2O emissions to the atmosphere. Ruminant livestock such as cattle, sheep, goats, buffalo, and camels emit CH_4 as a byproduct of their digestive processes (called "enteric fermentation"). Livestock waste can release both CH_4 through the biological breakdown of organic compounds and N_2O through nitrification and denitrification of nitrogen contained in manure; the magnitude of emissions depends in large part on manure management practices and to some degree on the energy content of livestock feed.

Agriculture and forest management can offset GHG emissions by increasing capacity for carbon uptake and storage in biomass, wood products, and soils. This process is referred to as carbon sequestration. The net flux of CO_2 between the land and the atmosphere is a balance between carbon losses from land use conversion and land management practices, and carbon gains from forest growth and sequestration in soils (IPCC 2001). Improved forest regeneration and management practices such as density control, nutrient management, and genetic tree

Box 1-1

Conventional Units for Reporting GHG Emissions

The USDA GHG Inventory report follows the international convention for reporting greenhouse gas emissions, as described in the introduction of the U.S. GHG Inventory (EPA 2003). Emissions of greenhouse gases are expressed in equivalent terms, normalized to carbon dioxide using Global Warming Potentials (GWPs) published by the IPCC (IPCC 1995). GWPs, which are based on physical and chemical properties of gases, represent the relative effect of a greenhouse gas on the climate, integrated over a given time period, relative to a single gas (IPCC 2001). The GWP values used in the U.S. GHG Inventory and this report are recommended by the IPCC for national greenhouse gas inventory reporting. These values are referenced to carbon dioxide and based on a 100-year time period (IPCC 1996):

Gas	Atmospheric lifetime (years)	GWP*
CO_2	50-200	1
CH_4	12	21
N_2O	120	310

*For consistency with international reporting standards, the U.S. GHG Inventory uses GWP values published in the IPCC Second Assessment Report (1996). GWP values and estimated atmospheric lifetime were revised for some gases in the IPCC Third Assessment Report (2001).

In the USDA and U.S. GHG Inventories, carbon dioxide equivalent units are expressed in teragrams, where a teragram (10^{12} grams) equals 1 million metric tons. The formula for converting gigagrams (1 gigagram = 10^9 grams) of a greenhouse gas to teragrams of carbon dioxide equivalent (Tg CO_2 eq.) is provided in the U.S. GHG Inventory and is repeated here for clarity:

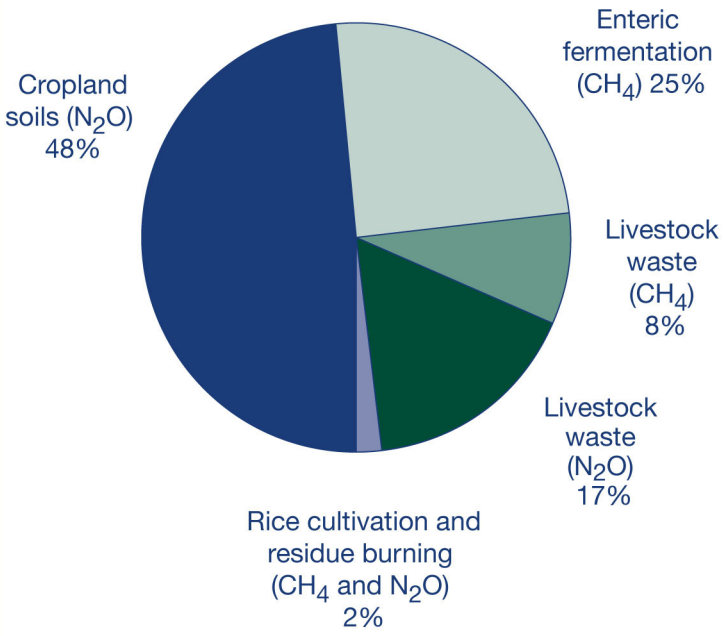
$$\text{Tg } CO_2 \text{ eq.} = (\text{Gg of gas}) \times (GWP) \times (1Tg/1{,}000Gg)$$

In the land use sector, where carbon dioxide gas is sequestered and stored as carbon in biomass and soils, greenhouse gas removals are often expressed in units of million metric tons of carbon equivalent (MMTCE). The formula below shows how to convert MMTCE to Tg CO_2 eq, and is based on the molecular weights of carbon and carbon dioxide.

$$\text{Tg } CO_2 \text{ eq.} = \text{MMTCE} \times (44/12)$$

improvement promote tree growth and result in additional carbon accumulation in biomass. In addition, wood products harvested from forests can serve as long-term carbon storage pools. The adoption of agroforestry practices like windbreaks and riparian forest buffers, which incorporate trees and shrubs into ongoing farm operations, represents a potentially large GHG sink nationally. In addition, agricultural practices such as conservation tillage and grassland practices such as rotational grazing can also reduce carbon losses and promote carbon sequestration in agricultural soils. These practices offset CO_2 emissions caused by land use activities such as conventional tillage and cultivation of organic soils.

Figure 1-1
Agricultural sources of greenhouse gas emissions in 2001



Agriculture and forestry provide opportunities to reduce GHG emissions through targeted management. Innovative practices to reduce GHG emissions from livestock include modifying energy content of livestock feed, inoculating feed with agents that reduce CH_4 emissions from digestive processes, and managing manure in controlled systems that reduce or eliminate GHG emissions. For example, anaerobic digesters are a promising technology for capturing and using CH_4 emissions from livestock waste as an alternative energy source. In addition, GHG emission from soils can be reduced with improved nitrogen use efficiency, involving both reduced nitrogen applications and improved nitrogen uptake by plants. These and other practices, many of which have additional benefits beyond GHG emission reductions, are discussed further in this report.

1.4 Summary of U.S. Greenhouse Gas Emissions in Agriculture and Forestry: 1990-2001

GHG emissions estimates reported here and in the U.S. GHG Inventory are in units of CO_2 equivalents. Box 1-1 describes this reporting convention, which normalizes all GHG emissions to CO_2 equivalents using Global Warming Potentials (GWP). Agriculture in the United States, including livestock, poultry, and crop production, contributed a total of 460 Tg CO_2 eq. (teragrams of carbon dioxide equivalents) to the atmosphere in 2001 (Table 1-1). This total includes an offset from agricultural soil carbon sequestration of roughly 15 Tg CO_2 eq. Agriculture accounted for close to 7 percent of U.S. GHG emissions across all sectors (total U.S. emissions, 6,936 Tg CO_2 eq.) (EPA 2003a). Forestry in the United States, including carbon sequestration in forest trees and soils, wood products, and urban trees, contributed a net

Table 1-1 Summary of agriculture and forestry GHG emissions and sinks, 1990, 1995-2001

	1990	1995	1996	1997	1998	1999	2000	2001
				Tg CO_2 eq.				
Livestock	225.03	240.09	236.61	234.44	234.12	233.28	231.38	230.73
Enteric fermentation, CH_4	117.90	123.00	120.50	118.30	116.70	116.60	115.70	114.80
Waste, CH_4	31.34	36.25	34.95	36.63	39.10	38.98	38.35	39.01
Waste, N_2O	75.79	80.85	81.16	79.52	78.32	77.70	77.33	76.92
Crops	202.83	213.57	223.50	230.73	235.86	234.25	230.14	229.10
Cropland soils, N_2O	207.93	219.77	229.00	235.93	238.16	236.65	235.14	235.40
Rice cultivation, CH_4	7.10	7.60	7.00	7.50	7.90	8.30	7.50	7.60
Residue burning, CH_4	0.70	0.70	0.70	0.80	0.80	0.80	0.80	0.80
Residue burning, N_2O	0.40	0.40	0.40	0.40	0.50	0.40	0.50	0.50
Agricultural soils[1] CO_2	(13.30)	(14.90)	(13.60)	(13.90)	(11.50)	(11.90)	(13.80)	(15.20)
Forestry	(1041.40)	(1037.70)	(1037.70)	(817.70)	(810.30)	(821.30)	(814.00)	(817.70)
Forests, CO_2	(773.70)	(773.70)	(773.70)	(546.30)	(546.30)	(546.30)	(546.30)	(546.30)
Wood products, CO_2	(209.00)	(205.30)	(205.30)	(212.70)	(205.30)	(216.30)	(209.00)	(212.70)
Urban trees, CO_2	(58.70)	(58.70)	(58.70)	(58.70)	(58.70)	(58.70)	(58.70)	(58.70)
Energy use, CO_2	NA	NA	NA	NA	NA	NA	NA	111.09
Net emissions from agriculture and forestry[2]	(613.55)	(584.04)	(577.59)	(352.53)	(340.32)	(353.76)	(352.48)	(357.87)
Agriculture	427.85	453.66	460.11	465.17	469.98	467.54	461.52	459.83
Forestry	(1041.40)	(1037.70)	(1037.70)	(817.70)	(810.30)	(821.30)	(814.00)	(817.70)

Note: Parentheses indicate net sequestration.
[1] Agricultural soil carbon sequestration includes sequestration on land set aside under the Conservation Reserve Program (CRP) and on range/grazing lands, in addition to cultivated mineral and organic soils.
[2] Does not include emissions from energy use.
NA = Not Available.

reduction from the atmosphere of 818 Tg CO_2 eq. in 2001, which is a near 12-percent offset in total U.S. GHG emissions (EPA 2003a).[1] Agriculture and forestry carbon sequestration more

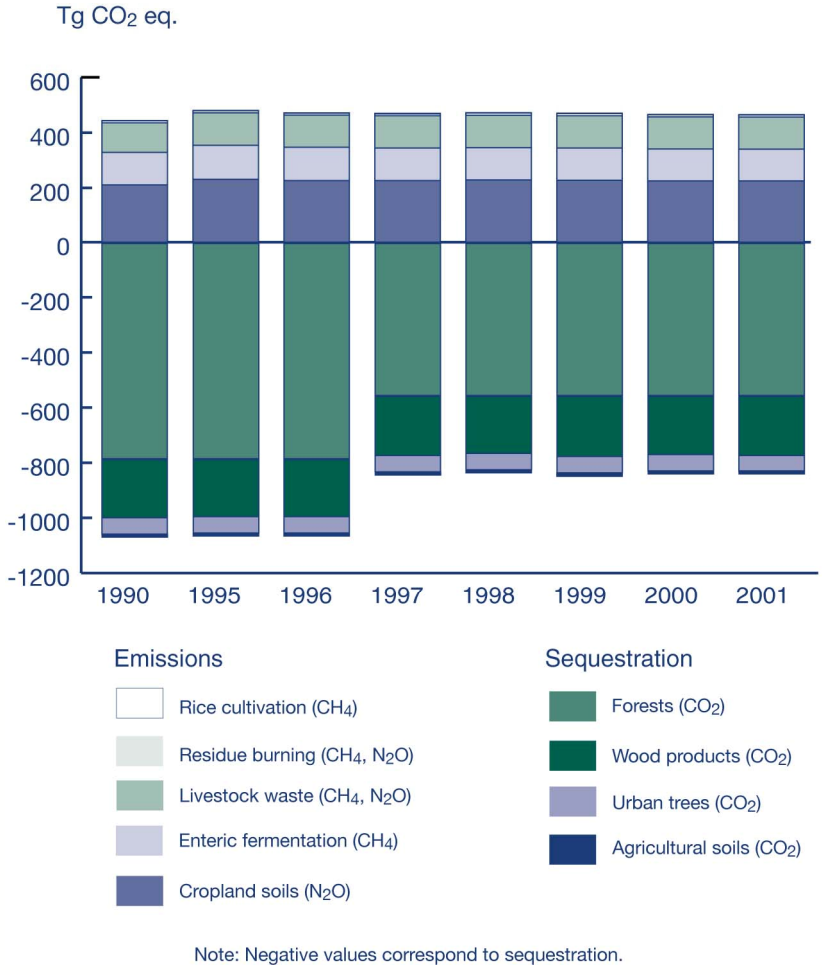
[1] This total does not include landfilled yard trimmings, which is included in the U.S. GHG Inventory, because this sink source is not managed or influenced by forest and agricultural practices. Landfilled yard trimmings contribute a small portion to overall sequestration of 5 Tg CO_2 eq.

than offset the total GHG emissions, with a net sequestration of 358 Tg CO_2 eq.

One-half of agriculture's GHG emissions in 2001 were due to crop production. Forty-eight percent were from nutrient amendments to cropland soils (Figure 1-1). Other crop sources—rice cultivation and residue burning—contributed 2 percent of overall agricultural emissions. Livestock production is responsible for the remaining half of agricultural emissions, with nearly 25 percent from enteric fermentation and 25 percent from waste.

Overall emissions profiles of the predominant agriculture and forestry sources and sinks appear relatively constant since 1990 with a few notable trends (Figure 1-2). Annual agricultural emissions from both livestock and crop production increased by 34 Tg CO_2 eq., or about 8 percent, since 1990 (Figure 1-2), with the largest increases from crop production. N_2O from nutrient amendments to cropland soils increased to a peak in 1998 and has declined slightly since; but by 2001, emissions from this source were 27 Tg CO_2 eq. greater than 1990 levels (Table 1-1). The second greatest increase in emissions was seen in livestock production. Emissions from livestock waste were 8 percent greater in 2001 than in 1990 (Table 1-1). Emissions from enteric fermentation have declined slightly over the same time period. Net sequestration, which includes carbon sequestration in agricultural soils and forests, declined by about 20 percent between 1990 and 2001, resulting primarily from a decline in the rate of net carbon accumulation in forests (EPA 2003a). An

Figure 1-2
Agriculture and forestry GHG emissions and sequestration for 1990, 1995-2001



Note: Negative values correspond to sequestration.

apparent abrupt change in net sequestration reported from 1996 to 1997 is a result of underlying data sources; the decline was likely more gradual through time. In contrast, annual carbon accumulation in agricultural soils increased from 1990 to 2001 by 2 Tg CO_2 eq.; wood products carbon storage pools also increased during this time (Table 1-1).

Annual CO_2 emissions from energy use in agriculture are small relative to total energy use across all sectors in the United States. In 2001, fuel and electricity consumption associated with crop and livestock operations resulted in 111 Tg CO_2 (Table 1-1), which is about 2 percent of overall energy-related emissions for 2001 (5,597 Tg CO_2). Electricity use led to about 53 percent of CO_2 emissions from energy use in agriculture; diesel fuel use led to about 30 percent, while gasoline, natural gas, and liquefied petroleum gas contributed less than 10 percent each to total CO_2 emissions from energy use in agriculture.