6. Land Use Issues

Overview

Land use and forestry issues are important to national and global inventories of greenhouse gases in two ways:

- Vegetation can "sequester" or remove carbon dioxide from the atmosphere and store it for potentially long periods in above- and below-ground biomass, as well as in soils. Soils, trees, crops, and other plants may make significant contributions to reducing net greenhouse gas emissions by serving as carbon "sinks."
- Humans can alter the biosphere through changes in land use and forest management practices and, in effect, alter the quantities of atmospheric and terrestrial carbon stocks, as well as the natural carbon flux among biomass, soils, and the atmosphere.

Land use issues are of particular interest to the United States because U.S. forests and soils annually sequester large amounts of carbon dioxide. Much of the forest land in the United States was originally cleared for agriculture, lumber, or fuel in the hundred years prior to 1920. Since then, however, much of the agricultural and pasture land has reverted to forest land, increasing its ability to sequester atmospheric carbon dioxide.

The amount of carbon being sequestered annually is uncertain, in part because of an absence of data and difficulties in measuring sequestration. Moreover, in addition to technical uncertainties, there are also policy and accounting questions about the aspects of the biological carbon cycle that would be included in national inventories as anthropogenic emissions and removals.

The revised guidelines for national emissions inventories published in 1997 by the Intergovernmental Panel on Climate Change (IPCC) stipulate the inclusion of carbon sequestration through land use and forestry in national greenhouse gas inventories as an offset to gross greenhouse gas emissions from other sources.[118] The U.S. Environmental Protection Agency (EPA),[119] based on data generated by the U.S. Department of Agriculture, estimates annual U.S. carbon sequestration for the year 2002 at 690.7 million metric tons carbon dioxide equivalent, a decline of approximately 27.9 percent from the 957.9 million metric tons carbon dioxide equivalent sequestered in 1990 (Table 32). In 1990 land use change and forestry practices represented an offset of 15.7 percent of total U.S. anthropogenic carbon dioxide emissions, but by 2002 that amount had declined to 10.0 percent.[120]

Table 32. Net Carbon Dioxide Sequestration from U.S. Land Use Change and Forestry, 1990 and 1996-2002
(Million Metric Tons Carbon Dioxide Equivalent)

Component	1990	1996	1997	1998	1999	2000	2001	2002
Forests	846.6[a]	964.1[a]	730.1[b]	617.8[b]	588.4[b]	602.3[b]	600.2[b]	600.8[b]
Urban Trees	58.7[a]	58.7[a]	58.7[a]	58.7[a]	58.7[a]	58.7[a]	58.7[a]	58.7[a]
Agricultural Soils	26.5[a]	19.0[a]	19.3[b]	16.9[b]	17.3[b]	19.0[b]	20.7[b]	21.2[b]
Landfilled Yard Trimmings and Food Scraps	26.0[a]	13.4[a]	12.9[b]	12.4[b]	11.3[b]	10.1[b]	10.2[b]	10.1[b]
Total	**957.9[a]**	**1,055.2[a]**	**821.0[b]**	**705.8[b]**	**675.8[b]**	**690.2[b]**	**689.7[b]**	**690.7[b]**

[a]Estimate based on historical data.
[b]Estimate based on a combination of historical data and projections.
Note: Totals may not equal sum of components due to independent rounding.
Source: U.S. Environmental Protection Agency, *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2002*, EPA-430-R-04-003 (Washington, DC, April 2004), web site http://yosemite.epa.gov/oar/globalwarming.nsf/content/ResourceCenter PublicationsGHGEmissions USEmissionsInventory2004.html.

[118]Intergovernmental Panel on Climate Change, *Greenhouse Gas Inventory Reference Manual: Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories,* Vol. 3 (Paris, France, 1997), web site www.ipcc-nggip.iges.or.jp/public/gl/invs1.htm.
[119]U.S. Environmental Protection Agency, *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2002*, EPA-430-R-04-003 (Washington, DC, April 2004), web site http://yosemite.epa.gov/oar/globalwarming.nsf/content/ResourceCenterPublicationsGHGEmissions USEmissionsInventory2004.html.
[120]EIA does not include sequestration from land-use change and forestry as part of its annual emissions inventory.

Land Use Change and Forestry Carbon Sequestration

The EPA's estimates for carbon sequestration from land use change and forestry in 2002 include four main components: (1) changes in forest carbon stocks (600.8 million metric tons carbon dioxide equivalent or 87.0 percent of the total), (2) changes in agricultural soil carbon stocks (21.2 million metric tons carbon dioxide equivalent or 3.1 percent of the total), (3) changes in carbon stocks in urban trees (58.7 million metric tons carbon dioxide equivalent or 8.5 percent of the total), and (4) changes in carbon stocks in landfilled yard trimmings and food scraps (10.1 million metric tons carbon dioxide equivalent or 1.5 percent of the total).[121]

IPCC Good Practice Guidance for Land Use, Land Use Change, and Forestry (LULUCF)

International guidelines—the *Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories (IPCC Guidelines)*—were adopted 8 years ago to support accounting for the storage and emission of greenhouse gases from various sources. The guidelines were developed before the adoption of the Kyoto Protocol and thus do not fully represent the new requirements for accounting for carbon fluxes resulting from LULUCF activities.

To address a variety of limitations of the *IPCC Guidelines*, the Parties to the UNFCCC in 1998 called for the IPCC to produce Good Practice Guidance to the *IPCC Guidelines*. The first volume of the *Good Practice Guidance* was completed in 2000 and adopted by the Sixth Conference of the Parties to the UNFCCC (COP-6) in May 2000. For several reasons, however, the first volume did not cover LULUCF activities. At the time that the *Good Practices Guidance* was being developed, the IPCC was also preparing a Special Report on LULUCF, and simultaneous work on the two documents carried the risk of delivering inconsistencies. Further, significant negotiations on LULUCF activities were underway in the UNFCCC international climate change negotiations, and the IPCC believed it would be best to develop the guidance for LULUCF after completion of the negotiations.

The IPCC was requested to develop Good Practice Guidance for LULUCF under decision 11/CP.7, agreed to at COP-7 in Marrakech in November 2001. As part of this process, a wide range of countries nominated expert authors to be involved in the development of LULUCF guidance. Three meetings of expert authors were held during 2002 in order to prepare a first draft of the *Good Practice Guidance* for LULUCF, which was released for review in December 2002. Submission of comments on the draft document was completed at the end of January 2003, with more than 6,000 comments received from governments and experts. The expert author teams considered the comments during meetings held in early April 2003, and a second draft document was issued.

The second draft of the *Good Practice Guidance* for LULUCF was released in May 2003 for review by experts and governments. Submission of comments—over 4,000 were received—on the second draft document was completed at the end of June 2003. In response, the IPCC expert author teams revised the second draft and provided a final draft to governments in October 2003 for final comment.[a, b] The report was adopted by the IPCC Plenary at its 21st session, held in Vienna in November 2003.[c]

The *Good Practice Guidance* for LULUCF provides methods and guidance for estimating, measuring, monitoring, and reporting on carbon stock changes and greenhouse gas emissions from LULUCF activities under the Kyoto Protocol. It provides guidance related to specific aspects of the LULUCF sector, including consistent representation of land areas, sampling for area estimates, estimating emissions and removals, and verification. The report assists countries in preparing inventories for the land use, land-use change and forestry sector, and is consistent with the available good practice guidance for other sectors. It represents another step in the IPCC's ongoing program of inventory development, and will support future revisions of the *IPCC Guidelines* themselves.

[a]The Cooperative Research Centre for Greenhouse Accounting, "Good Practice for Land Use, Land-Use Change, and Forestry," web site www.greenhouse.crc.org.au/goodpractice/.

[b]G.-J. Nabuurs and N.H. Ravindranath, "Task 1, Chapter 3: Good Practice Guidance for National GHG Inventory for LULUCF Sector." Presentation at the IPCC-NGGIP Side Event at SB-18 (Bonn, Germany, June 6, 2003).

[c]Intergovernmental Panel on Climate Change National Greenhouse Gas Inventories Programme (IPCC-NGGIP), "Good Practice Guidance for Land Use, Land-Use Change and Forestry" (2003), web site www.ipcc-nggip.iges.or.jp/public/gpglulucf/gpglulucf_contents.htm.

[121]U.S. Environmental Protection Agency, *Inventory of U.S. Greenhouse Gas Emissions and Sinks 1990-2002,* EPA-430-R-04-003 (Washington, DC, April 2004), web site http://yosemite.epa.gov/oar/globalwarming.nsf/content/ResourceCenterPublicationsGHGEmissionsUSEmissionsInventory2004.html.

The EPA's estimates for carbon sequestration in forests are based on carbon stock estimates developed by the U.S. Forest Service, U.S. Department of Agriculture (USDA), employing methodologies that are consistent with the *Revised 1996 IPCC Guidelines*. The USDA estimates of carbon stocks in urban trees were based on field measurements in ten U.S. cities and data on national urban tree cover, again employing a methodology consistent with the *Revised 1996 IPCC Guidelines*. Estimates for sequestration in agricultural soils were based on changes in carbon stocks in mineral and organic soils resulting from agricultural land use and land management, as well as emissions of carbon dioxide resulting from the use of crushed limestone and dolomite on soils. Methodologies drawn from the IPCC guidelines were used to derive all components of changes in agricultural soil carbon stocks. The EPA estimates for carbon stocks in landfilled yard trimmings and food scraps are based on the EPA's own method of examining life-cycle greenhouse gas emissions and sinks associated with solid waste management.[122]

The EPA's carbon flux estimates, with the exception of those from wood products, urban trees, and liming, are based on periodic surveys of U.S. forest land and soils, conducted on a less frequent basis. Carbon fluxes from forests (except wood products) and from agricultural soils (except liming) are collected over 5- or 10-year intervals and averaged annually for years between surveys. Each State is surveyed independently and at varying times, thus the estimates for carbon fluxes from forest carbon stocks differ at the national level from year to year. Forest soils, which are surveyed on a regional scale, have fluxes over multi-year periods, with large discontinuities in-between intervals. Agricultural soils exhibit a pattern similar to that of forest soils. The most current national forest and land-use surveys were completed for the year 1999, thus carbon flux estimates from forests and agricultural soils are derived in part from modeled projections for future years. Data on carbon fluxes from urban trees, collected over the period from 1990 through 1999, were applied to the entire time series.[123]

Inventory of Woody Residuals in the United States

The U.S. Forest Service (USFS) conducts analyses to estimate the quantity of woody residuals in the United States. The USFS estimates both the types and amounts of woody residuals generated, as well as the portion of those tonnages that are available for recovery.[a] The data from the USFS analyses are useful to wood recycling enterprises, because they help to identify sources for processing and markets for services that help foresters clear and process downed woody debris that poses a significant fire threat.

The major sources of solid waste wood generated in the United States that are analyzed by the USFS are municipal solid waste (MSW), construction and demolition debris, woody forest residues, and primary timber processing mill residues. Determining the amounts recoverable involves estimating total waste generated, less amounts currently recovered, combusted, or considered unusable. The total amounts of recoverable wood from these sources in 2002 were as follows: (1) 8.7 million tons from MSW, (2) 29.2 million tons from construction and demolition debris,[b] and (3) 86 million tons from woody forest residues and primary timber processing mill residues.[c]

Woody forest residues include logging residues, which represent the largest proportion of solid waste wood generated in the United States that is available for recovery. Currently, however, this material remains in the forest, contributing to "down woody material" (the portion of trees that have fallen and remain on the forest floor or in forest streams). Advances are being made in the collection, processing, and utilization of recoverable solid wood waste, but there still are some technical and economic obstacles to improved utilization.

[a]D. McKeever, "Taking Inventory of Woody Residuals," *BioCycle*, Vol. 44, No. 7 (July 2003), pp. 31-35.
[b]D. McKeever and R. Falk, "Recovering Wood for Reuse and Recycling: A United States Perspective," in C. Gallis, Editor, *European COST E31 Conference: Management of Recovered Wood Recycling, Bioenergy and Other Options* (Thessaloniki, Greece, April 22-24, 2004), pp. 29-40.
[c]D. McKeever and R. Falk, "Woody Residues and Solid Waste Wood Available for Recovery in the United States, 2002," in C. Gallis, Editor, *European COST E31 Conference: Management of Recovered Wood Recycling, Bioenergy and Other Options* (Thessaloniki, Greece, April 22-24, 2004), pp. 307-316.

[122]U.S. Environmental Protection Agency, *Solid Waste Management and Greenhouse Gases: A Life-Cycle Assessment of Emissions and Sinks*, 2nd Edition, EPA-530-R-02-006 (Washington, DC, May 2002), web site www.epa.gov/epaoswer/non-hw/muncpl/ghg/ghg.htm.
[123]U.S. Environmental Protection Agency, *Inventory of U.S. Greenhouse Gas Emissions and Sinks 1990-2002,* EPA-430-R-04-003 (Washington, DC, April 2004), web site http://yosemite.epa.gov/oar/globalwarming.nsf/content/ResourceCenterPublicationsGHGEmissions USEmissionsInventory2004.html.

Changes in Forest Carbon Stocks

In the United States, the most significant pressures on the amount of carbon sequestered through forest lands are land management activities and the continuing effects of past changes in land use. These activities directly affect carbon flux by shifting the amount of carbon accumulated in forest ecosystems.[124] Land management activities affect both the stocks of carbon that can be stored in land-based carbon sinks, such as forests and soils, and the flows, or fluxes, of carbon between land-based sinks and the atmosphere.

Forests are multifaceted ecosystems with numerous interrelated components, each of which stores carbon. These components include five forest carbon pools and two wood products carbon pools:

- Forest carbon pools:
  - Trees (living trees, standing dead trees, roots, stems, branches, and foliage)
  - Understory vegetation (shrubs and bushes, roots, stems, branches, and foliage)
  - Forest floor (fine woody debris, tree litter, and humus)
  - Down dead wood (logging residue and other dead wood on the ground, stumps, and roots of stumps)
  - Organic material in soil
- Wood products carbon pools:
  - Harvested wood products in use
  - Harvested wood products in landfills.

As a result of natural biological processes occurring in forests, as well as anthropogenic activities, carbon is constantly cycling through these components and between the forest and the atmosphere. The net change in overall forest carbon may not always be equal to the net flux between forests and the atmosphere, because timber harvests may not necessarily result in an instant return of carbon to the atmosphere. Timber harvesting transfers carbon from one of the five "forest carbon pools" to one of the two "wood products carbon pools." Once carbon is transferred to a product pool, it is emitted over time as carbon dioxide as the product combusts or decays. Emission rates vary significantly, depending on the type of product pool that houses the carbon.[125]

In the United States, enhanced forest management, regeneration of formerly cleared forest areas, and timber harvesting have resulted in the annual sequestration of carbon throughout the past decade. Since the 1920s, deforestation for agricultural purposes has become a nearly defunct practice. More recently, managed growth practices have become common in eastern forests, greatly increasing their biomass density over the past 50 years. In the 1970s and 1980s, federally sponsored tree planting and soil conservation programs were embraced. These programs resulted in the reforestation of formerly harvested lands, improvement in timber management activities, soil erosion abatement, and the conversion of cropland to forests. Forest harvests have also affected carbon sequestration. The majority of harvested timber in the United States is used in wood products. The bulk of the discarded wood products are landfilled, thus large quantities of the harvested carbon are relocated to long-term storage pools rather than to

USDA Agriculture and Forestry Greenhouse Gas Inventory

The U.S. Department of Agriculture (USDA) Global Change Program Office published its first national greenhouse gas inventory in March 2004. The *U.S. Agriculture and Forestry Greenhouse Gas Inventory: 1990-2001* (USDA GHG Inventory) provides an assessment of greenhouse gas emissions and sinks in the nation's agriculture and forests.[a] The publication details emissions and sinks estimates for livestock, cropland and forests, as well as energy consumption in livestock and cropland agriculture. These emissions estimates are provided at State, regional and national levels, and are categorized by land ownership and management practices whenever possible. The estimates in the USDA GHG Inventory are consistent with those published last year by the EPA in its *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2001*.[b]

[a]U.S. Department of Agriculture, Global Change Program Office, Office of the Chief Economist, *U.S. Agriculture and Forestry Greenhouse Gas Inventory: 1990-2001*, Technical Bulletin No. 1907 (March 2004), web site www.usda.gov/oce/gcpo/ghginventory.html.

[b]U.S. Environmental Protection Agency, *Inventory of U.S. Greenhouse Gas Emissions and Sinks 1990-2001*, EPA-430-R-03-004 (Washington, DC, April 2003), web site http://yosemite.epa. gov/ oar/ globalwarming. nsf/ content/ Resource Center PublicationsGHGEmissionsUSEmissionsInventory2003.html.

[124]U.S. Environmental Protection Agency, *Inventory of U.S. Greenhouse Gas Emissions and Sinks 1990-2002*, EPA-430-R-04-003 (Washington, DC, April 2004), web site http://yosemite.epa.gov/oar/globalwarming.nsf/content/ResourceCenterPublicationsGHGEmissions USEmissionsInventory2004.html.

[125]U.S. Environmental Protection Agency, *Inventory of U.S. Greenhouse Gas Emissions and Sinks 1990-2002*, EPA-430-R-04-003 (Washington, DC, April 2004), web site http://yosemite.epa.gov/oar/globalwarming.nsf/content/ResourceCenterPublicationsGHGEmissions USEmissionsInventory2004.html.

the atmosphere. The size of wood product landfills has increased over the past century.[126]

According to the EPA (Table 33), carbon sequestration by forests and harvested wood products totaled 600.8 million metric tons carbon dioxide equivalent in 2002. Between 1990 and 2002, U.S. forest and harvested wood components accounted for an average annual net sequestration of 736 million metric tons carbon dioxide equivalent, resulting from domestic forest growth and increases in forested land area; however, there was a decrease of approximately 28 percent in annual sequestration over the same period.[127]

The overall decline in forest carbon sequestration was driven largely by a 39.3-percent reduction in the rate of sequestration in the forest carbon pool (636.6 million metric tons carbon dioxide equivalent in 1990 versus 386.4 million metric tons in 2002). The reduction in the forest carbon pool sequestration rate can be attributed primarily to a 74.1-percent decline in the estimated rate of sequestration in forest soils. Forest soil carbon sequestration fell from an annual average of 212.7 million metric tons carbon dioxide equivalent during the period 1990-1996 to an annual average of 55 million metric tons during the period 1997-2002.

The net forest carbon flux has varied significantly from year to year, most notably from 1996 to 1997 and from 1997 to 1998 (Table 33). The U.S. Forest Service reports there are different reasons for these shifts, and those reasons encompass both substantive differences in the source of carbon stocks and the methodology utilized to determine the levels of sequestration for each year. The shift downward from 1996 to 1997 resulted primarily from changes in soil carbon stocks. However, the EPA's *Inventory of U.S. Greenhouse Gas Emissions and Sinks 1990-2002* utilized databases containing data on changes in forest area—and thus soil carbon—only for the years 1987, 1992, and 1997. Data for the missing years were interpolated. There was a large shift, however, in forest area—and soil carbon—between 1987 and 1992 and again between 1992 and 1997. Although forest area increased between 1992 and 1997, it increased at a lower rate than between 1987 and 1992, resulting in a shift downward in soil carbon stocks and total sequestration quantities. The shift downward between 1997 and 1998 is attributed primarily to changes in the carbon sequestration level of trees.[128]

Table 33. Net Carbon Dioxide Sequestration in U.S. Forests, 1990 and 1996-2002
(Million Metric Tons Carbon Dioxide Equivalent)

Description	1990[b]	1996[b]	1997[a]	1998[b]	1999[b]	2000[b]	2001[b]	2002[b]
Forest Carbon Stocks	**636.6**	**756.5**	**517.4**	**411.7**	**373.8**	**391.5**	**386.4**	**386.4**
Trees	354.2	464.6	401.0	307.5	275.0	289.9	285.5	285.5
Understory	-0.8	3.1	1.7	0.5	-2.2	-2.5	-2.2	-2.2
Forest Floor	38.1	12.7	-2.7	-11.0	-16.2	-17.2	-16.5	-16.5
Down Dead Wood	32.5	63.5	62.4	59.7	62.2	66.3	64.6	64.6
Forest Soils	212.7	212.7	55.0	55.0	55.0	55.0	55.0	55.0
Harvested Wood Carbon Stocks	**210.1**	**207.6**	**212.7**	**206.1**	**214.7**	**210.8**	**213.8**	**214.4**
Wood Products	47.6	56.1	57.7	51.9	61.5	58.7	59.0	59.2
Landfilled Wood	162.4	151.5	155.0	154.2	153.1	152.1	154.8	155.3
Total	**846.6**	**964.1**	**730.1**	**617.8**	**588.4**	**602.3**	**600.2**	**600.8**

[a]Estimates based on historical data.
[b]Estimates based on a combination of historical data and projections.

Notes: The sums of the annual net stock changes in this table (shown in the "Total" row) represent estimates of the actual net flux between the total forest carbon pool and the atmosphere. Forest values are based on periodic measurements; harvested wood estimates are based on annual surveys and models. Totals may not equal sum of components due to independent rounding.

Source: U.S. Environmental Protection Agency, *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2002*, EPA-430-R-04-003 (Washington, DC, April 2004), web site http://yosemite.epa.gov/oar/globalwarming.nsf/content/ResourceCenter PublicationsGHGEmissions USEmissionsInventory2004.html.

[126]U.S. Environmental Protection Agency, *Inventory of U.S. Greenhouse Gas Emissions and Sinks 1990-2002*, EPA-430-R-04-003 (Washington, DC, April 2004), web site http://yosemite.epa.gov/oar/globalwarming.nsf/content/ResourceCenterPublicationsGHGEmissions USEmissionsInventory2004.html.

[127]U.S. Environmental Protection Agency, *Inventory of U.S. Greenhouse Gas Emissions and Sinks 1990-2002*, EPA-430-R-04-003 (Washington, DC, April 2004), p. 208, web site http://yosemite.epa.gov/oar/globalwarming.nsf/content/ResourceCenterPublicationsGHG Emissions USEmissionsInventory2004.html.

[128]According to an August 31, 2004, personal communication with Linda Heath, Project Leader, U.S. Department of Agriculture, Forest Service, projections were used to estimate values for the years 1998 through 2002. After publication of EPA's *Inventory of U.S. Greenhouse Gas Emissions and Sinks 1990-2002*, it was discovered that the data provided for the years 1987, 1992, and 1997 had been updated, and those revisions were not reflected in the EPA publication. To avoid this situation in the future, the U.S Forest Service will utilize existing data in the U.S. Forest Service Forest Inventory and Analysis Program and will not make projections.

Wood products carbon stocks experienced a slight increase in overall annual sequestration levels between 1990 and 2002, reflecting accumulation of carbon in harvested wood pools.[129] There were small variations from year to year, but the trend in net sequestration amounts has generally been upward, from 210.1 million metric tons carbon dioxide equivalent in 1990 to 214.4 million metric tons carbon dioxide equivalent in 2002 (Table 33). This reflects an increase in both harvesting for wood products and in the amount of wood contained in wood product landfills.

The EPA employs methodology consistent with the *Revised 1996 IPCC Guidelines* to estimate the net sequestration resulting from harvested wood. The IPCC provides two alternative approaches to account for carbon emissions from harvested wood. These are: (1) assume that all harvested wood replaces wood products that decay in the inventory year, thus the amount of wood harvested annually equates to annual emissions from harvests; or (2) account for the variable rate of decay of harvested wood depending on its disposition (e.g., product pool, landfill, and combustion). The estimates used by EPA in its inventory, and reported in this chapter, result from using the second approach, employing estimates of carbon stored in wood products and landfilled wood.[130] EPA also employs the "production approach"; that is, carbon stored in imported wood products is not counted, but carbon stored in exports is counted, even when logs are processed in other countries.[131]

EPA estimates of carbon stocks in wood products and landfilled wood from 1910 onward are based on historical data and data derived from models utilized by the USDA Forest Service. These models (the forest sector modeling system) include an area change model, a timber market model, a pulp and paper model, and an inventory model. Estimates were derived using data on annual wood and paper production, and by tracking the disposition of carbon in harvested wood for each year from 1910 through 2002. Estimates include the change in carbon stocks in wood products and landfilled wood, and carbon emissions to the atmosphere both with and without energy recovery. Carbon in exported wood was counted as if it remained in the United States, and carbon in imported wood was not counted.[132]

EPA estimates of carbon stored in harvested wood products are currently being revised. Updated estimates will use more detailed wood products production and use data and improved parameters on disposition and decay of products. Estimation methods may also change as a result of discussions to be held by the UNFCCC in August 2004 regarding accounting for changes in harvested wood products (see box on page 77). Preliminary results suggest that estimates of carbon stored in harvested wood may in fact be lower than the estimates included in the EPA Inventory[133] and detailed in this chapter.

Changes in Urban Tree Carbon Stocks

Urban forests make up a considerable portion of the total tree canopy cover in the United States. Urban areas, which cover 3.5 percent of the continental United States, are estimated to contain about 3.8 billion trees, accounting for approximately 3 percent of total tree cover in the United States. The EPA's carbon sequestration estimates for urban trees are derived from estimates by Nowak and Crane,[134] based on data collected throughout the 1990s and applied to the entire time series in this report. Net carbon dioxide flux from urban trees is estimated at 58.7 million metric tons carbon dioxide equivalent annually from 1990 through 2002 (Table 32).[135]

[129]U.S. Environmental Protection Agency, *Inventory of U.S. Greenhouse Gas Emissions and Sinks 1990-2002*, EPA-430-R-04-003 (Washington, DC, April 2004), p. 208, web site http://yosemite.epa.gov/oar/globalwarming.nsf/content/ResourceCenterPublicationsGHGEmissionsUSEmissionsInventory2004.html.

[130]U.S. Environmental Protection Agency, *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2001*, EPA-430-R-03-004 (Washington, DC, April 2003), p. 6-6, web site http://yosemite.epa.gov/oar/globalwarming.nsf/content/ResourceCenterPublicationsGHGEmissionsUSEmissionsInventory2003.html.

[131]U.S. Environmental Protection Agency, *Inventory of U.S. Greenhouse Gas Emissions and Sinks 1990-2002*, EPA-430-R-04-003 (Washington, DC, April 2004), p. 210, web site http://yosemite.epa.gov/oar/globalwarming.nsf/content/ResourceCenterPublicationsGHGEmissionsUSEmissionsInventory2004.html.

[132]U.S. Environmental Protection Agency, *Inventory of U.S. Greenhouse Gas Emissions and Sinks 1990-2002*, EPA-430-R-04-003 (Washington, DC, April 2004), p. 211, web site http://yosemite.epa.gov/oar/globalwarming.nsf/content/ResourceCenterPublicationsGHGEmissionsUSEmissionsInventory2004.html.

[133]U.S. Environmental Protection Agency, *Inventory of U.S. Greenhouse Gas Emissions and Sinks 1990-2002*, EPA-430-R-04-003 (Washington, DC, April 2004), p. 214, web site http://yosemite.epa.gov/oar/globalwarming.nsf/content/ResourceCenterPublicationsGHGEmissionsUSEmissionsInventory2004.html.

[134]D.J. Nowak and D.E. Crane, "Carbon Storage and Sequestration by Urban Trees in the United States," *Environmental Pollution*, Vol. 116, No. 3 (2001), pp. 381-389.

[135]U.S. Environmental Protection Agency, *Inventory of U.S. Greenhouse Gas Emissions and Sinks 1990-2002*, EPA-430-R-04-003 (Washington, DC, April 2004), web site http://yosemite.epa.gov/oar/globalwarming.nsf/content/ResourceCenterPublicationsGHGEmissionsUSEmissionsInventory2004.html.

Accounting for Harvested Wood Products in Future Greenhouse Gas Inventories

Harvested wood products (HWP) are defined as "goods manufactured or processed from wood, including lumber and panels for end uses such as housing and furniture, and paper and paperboard for uses such as packaging, printing and writing, and sanitary applications."[a] HWP are an important part of the overall carbon cycle and are thus integral to any greenhouse gas (GHG) accounting system or inventory.

Preparation of the IPCC 2006 Guidelines for national greenhouse gas inventories under the UNFCCC—including methods for estimating and reporting of HWP—is underway. The issue of accounting for HWP, however, is a complex one, and involves the consideration of factors such as international trade (import-export) of wood products, timing of emissions accounting, determining whether emissions include those from existing wood product pools or solely from harvesting, and establishing how complex or simplistic the accounting approach should be so as not to create barriers to participation.[b] The choice of what accounting approach is to be used for HWP by the IPCC in its 2006 Guidelines remains to be determined. Three individual accounting approaches (i.e., stock-change approach, production approach, and atmospheric-flow approach) for reporting HWP in the national greenhouse gas inventories under the UNFCCC have been developed and debated. These three approaches were discussed at a UNFCCC-sponsored workshop held in Norway on August 30 through September 2, 2004, and are detailed below. Final guidance could be adopted late in 2004 based on the decisions made at this workshop.[c]

The first approach under consideration for HWP is the *stock-change approach*. This approach accounts for changes in carbon stock in forests in the country in which the wood is grown, deemed the producing country. Changes in the products pool are accounted for in the country where the products are used, deemed the consuming country. These stock changes are counted within national boundaries, where and when they occur.[d] Under this approach, the HWP stock change in a country may be estimated considering either transfers into and out of the HWP pool, or the difference between HWP carbon stocks at two different set points in time.

The next alternative—the *atmospheric flow approach*—accounts for emissions or sequestration of carbon to and/or from the atmosphere within national boundaries, both where and when emissions and sequestration occur. The producing country accounts for sequestration of carbon attributed to forest growth, while the consuming country accounts for emissions of carbon to the atmosphere from oxidation of HWP.[e] Under this approach, it is the net CO_2 flow from the pools to the atmosphere that would be reported as the equivalent emission, and the net flow in the opposite direction as the equivalent amount of carbon sequestration.[f]

The third approach for accounting for HWP is the *production approach*. While this approach also reports changes in carbon stock, it is the producing country that reports the stock changes in HWP regardless of the location of the stock (i.e., whether within country boundaries or exported).[g] This approach thus accounts for domestically produced stocks only; that is, stock changes are counted when, but not where, they occur if wood products are exported or traded.[h]

An additional method—the *simple decay approach*—was proposed by one Annex I country and is effectively a method falling under the production approach. This method assumes that HWP remain a part of the forest in which they were produced until decomposed.[i] This approach is therefore similar to the production approach in that it also estimates the stock changes in HWP when, but not where, they occur if wood products are exported or traded. Both sequestration of carbon from the atmosphere due to forest growth and emissions resulting from harvesting are accounted for in the producing country.[j]

[a]"United States Submission on the Views Related to Carbon Accounting and Wood Products," in United Nations Framework Convention on Climate Change, *Issues Relating to Harvested Wood Products*, Paper No. 7 (May 10, 2004), pp. 42-43, web site http://unfccc.int/resource/docs/2004/sbsta/misc09.pdf.

[b]M. Ward, "Harvested Wood Products, A Beginning Guide to Key Issues," Senior Counsel to the Government of New Zealand (July 2004).

[c]K. Pingoud et al., "Approaches for Inclusion of Harvested Wood Products in Future GHG Inventories Under the UNFCCC, and their Consistency with the Overall UNFCCC Inventory Reporting Framework," *IEA Bioenergy* (July 13, 2004).

[d]M. Ward (July 2004).

[e]M. Ward (July 2004).

[f]K. Pingoud et al. (July 13, 2004).

[g]K. Pingoud, et al. (July 13, 2004).

[h]M. Ward (July 2004).

[i]K. Pingoud et al. (July 13, 2004).

[j]M. Ward (July 2004).

Changes in Agricultural Soil Carbon Stocks

The amount of organic carbon in soils depends on the balance between addition of organic material and loss of carbon through decomposition. The quantity and quality of organic matter within soils, as well as decomposition rates, are determined by the interaction of climate, soil properties, and land use. Agricultural practices—including clearing, drainage, tillage, planting, grazing, crop residue management, fertilization, and flooding—can alter organic matter inputs and decomposition, causing a net flux of carbon to or from soils. The IPCC methodology, which is used by the EPA to estimate the net flux from agricultural soils (Table 34), is divided into three categories of land use and land management activities: (1) agricultural land use and land management activities on mineral soils;[136] (2) agricultural land use and land management activities on organic soils;[137] and (3) liming of soils. Of the three activities, the use and management of mineral soils is estimated to be the most significant contributor to total flux from 1990 through 2002. Sequestration in mineral soils in 2002 was estimated to be 64.7 million metric tons carbon dioxide equivalent, while emissions from organic soils and liming were estimated at 34.7 and 8.8 million metric tons carbon dioxide equivalent, respectively. In net, these activities resulted in 21.2 million metric tons carbon dioxide equivalent sequestered through agricultural soils in 2002.[138]

Changes in Landfilled Yard Trimming and Food Scrap Carbon Stocks

Carbon stored in landfilled yard trimmings can remain sequestered indefinitely. In the United States, yard trimmings (grass clippings, leaves, and branches) and food scraps make up a considerable portion of the municipal waste stream, and significant amounts of the yard trimmings and food scraps collected are discarded in landfills. Both the amount of yard trimmings and food scraps collected annually and the percentage that is landfilled have declined over the past decade. Net carbon dioxide sequestration from landfilled yard trimmings and food scraps has declined accordingly, from 26.0 million metric tons carbon dioxide equivalent in 1990 to 10.1 million metric tons carbon dioxide equivalent in 2002 (Table 35). Since 1990, programs limiting disposal of yard trimmings have led to an increase in backyard composting and the use of mulching mowers. The number of municipal composting facilities has also risen, further reducing the amount of trimmings that are discarded in landfills. The EPA's methodology for estimating carbon storage relies on a life-cycle analysis of greenhouse gas emissions and sinks associated with solid waste management.[139]

Table 34. Net Carbon Dioxide Sequestration in U.S. Agricultural Soils, 1990 and 1996-2002
(Million Metric Tons Carbon Dioxide Equivalent)

Description	1990	1996	1997	1998	1999	2000	2001	2002
Mineral Soils	70.3[a]	62.7[a]	62.8[a]	61.2[b]	61.1[b]	62.5[b]	64.4[b]	64.7[b]
Organic Soils	-34.3[a]	-34.7[a]	-34.7[a]	-34.7[b]	-34.7[b]	-34.7[b]	-34.7[b]	-34.7[b]
Liming of Soils	-9.5[a]	-8.9[a]	-8.7[a]	-9.6[a]	-9.1[a]	-8.8[a]	-9.0[a]	-8.8[b]
Total	**26.5[a]**	**19.0[a]**	**19.3[a]**	**16.9[b]**	**17.3[b]**	**19.0[b]**	**20.7[b]**	**21.2[b]**

[a]Estimates based on historical data.
[b]Estimates based on a combination of historical data and projections.
Source: U.S. Environmental Protection Agency, *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2002*, EPA-430-R-04-003 (Washington, DC, April 2004), web site http://yosemite.epa.gov/oar/globalwarming.nsf/content/ResourceCenter PublicationsGHGEmissions USEmissionsInventory2004.html.

[136]Mineral soils are soils consisting predominantly of, and having their properties determined predominantly by, mineral matter. They usually contain less than 200 grams of organic carbon per kilogram of soil (less than 120 to 180 grams per kilogram if saturated with water) but may contain an organic surface layer up to 30 centimeters thick.

[137]Organic soils are soils that, when saturated with water, have 174 grams or more of organic carbon per kilogram of soil if the mineral fraction has 500 grams per kilogram or more of clay, or 116 grams per kilogram organic carbon if the mineral fraction has no clay, or has proportional intermediate contents. If the soil is never saturated with water, organic soils have 203 grams per kilogram or more organic carbon.

[138]U.S. Environmental Protection Agency, *Inventory of U.S. Greenhouse Gas Emissions and Sinks 1990-2002,* EPA-430-R-04-003 (Washington, DC, April 2004), web site http://yosemite.epa.gov/oar/globalwarming.nsf/content/ResourceCenterPublicationsGHGEmissions USEmissionsInventory2004.html.

[139]U.S. Environmental Protection Agency, *Solid Waste Management and Greenhouse Gases: A Life-Cycle Assessment of Emissions and Sinks,* 2nd Edition, EPA530-R-02-006 (Washington, DC, May 2002), web site www.epa.gov/epaoswer/non-hw/muncpl/ghg/ghg.htm.

Land Use and International Climate Change Negotiations

In past international negotiations on climate change, the United States and many other countries have maintained that the inclusion of LULUCF activities in a binding agreement that limits greenhouse gas emissions is of the utmost importance; however, issues of whether and how terrestrial carbon sequestration could be accepted for meeting various commitments and targets have remained subjects of complex and difficult international negotiations on climate change.

Many of the countries involved in climate change negotiations have agreed that implementation of LULUCF activities under an international climate change agreement may be complicated by a lack of clear definitions for words such as "reforestation" and "forest." Further, implementation may be hindered by the lack of effective accounting rules. According to researchers at the Pew Center on Global Climate Change,[140] implementation of LULUCF provisions in an international climate change agreement raises many issues for such activities and/or projects, such as:

- What is a direct human-induced activity?
- What is a forest and what is reforestation?
- How will the issues of uncertainty and verifiability be addressed?
- How will the issues of (non) permanence and leakage be addressed?
- Which activities beyond afforestation, reforestation and deforestation (ARD), if any, should be included, and what accounting rules should apply?
- Which carbon pools and which greenhouse gases should be considered?

Uncertainties related to data issues have also slowed international negotiations on climate change.

The Ninth Session of the Conference of the Parties to the UN Framework Convention on Climate Change (COP-9) occurred in Milan, Italy, in December 2003. The parties at this meeting agreed on some of the rules for carbon sequestration projects under the Clean Development Mechanism (CDM), but the issue on how to treat the non-permanence of carbon sinks projects is still widely debated. Policymakers at COP-9 decided to limit the duration of credits generated from carbon sequestration projects, and also addressed the topics of additionality, leakage, uncertainties, and socioeconomic and environmental impacts.[141]

Land Use Data Issues

Uncertainties in the EPA estimates of U.S. carbon sequestration include sampling and measurement errors inherent to forest carbon estimates. The forest surveys engage a statistical sample that represents the expansive variety of growth conditions over large territories. Although more current inventories are conducted annually in each State, much of the existing data may have been collected over more than one year in any

Table 35. Net Carbon Dioxide Sequestration from Landfilled Yard Trimmings and Food Scraps, 1990 and 1996-2002
(Million Metric Tons Carbon Dioxide Equivalent)

Description	1990	1996	1997	1998	1999	2000	2001	2002
Yard Trimmings	**23.2**	**11.3**	**10.4**	**9.6**	**8.4**	**7.2**	**7.4**	**7.4**
Grass	2.5	1.0	0.9	0.8	0.7	0.6	0.7	0.7
Leaves	11.2	5.9	5.4	5.1	4.5	4.0	4.0	4.0
Branches	9.6	4.4	4.0	3.7	3.2	2.6	2.7	2.7
Food Scraps	**2.8**	**2.1**	**2.5**	**2.8**	**2.9**	**2.9**	**2.8**	**2.7**
Total	**26.0**	**13.4**	**12.9**	**12.4**	**11.3**	**10.1**	**10.2**	**10.1**

Note: Totals may not equal sum of components due to independent rounding.
Source: U.S. Environmental Protection Agency, *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2002*, EPA-430-R-04-003 (Washington, DC, April 2004), web site http://yosemite.epa.gov/oar/globalwarming.nsf/content/ResourceCenter PublicationsGHGEmissions USEmissionsInventory2004.html.

[140] G. Marland and B. Schlamadinger, *Land Use and Global Climate Change: Forests, Land Management, and the Kyoto Protocol* (Arlington, VA: Pew Center on Global Climate Change, June 2000), p. 5, web site www.pewclimate.org/docUploads/land_use.pdf.
[141] Pew Center on Global Climate Change, "Ninth Session of the Conference of the Parties to the UN Framework Convention on Climate Change" (Milan, Italy, December 1-12, 2003), web site www.pewclimate.org/what_s_being_done/in_the_world/cop_9_milan.cfm.

Global Forest Resources Assessment 2000

The Food and Agriculture Organization of the United Nations (FAO) is the main intergovernmental source of data on global forests. FAO's global forest assessments date back to 1948, with the most recent assessment—*Global Forest Resources Assessment 2000*—published in 2001. The 2000 assessment was the first to include a uniform definition of forests for all regions of the world—that is, areas with at least 10 percent of canopy cover (excluding stands of trees primarily used for agricultural production). Using this new definition, FAO estimated the world's forested area in 2000 at 3.9 billion hectares. This assessment indicated, however, that the world's forests experienced average net annual losses of 9.4 million hectares per year during the 1990 to 2000 period. This net figure results from annual losses of 14.6 million hectares due to deforestation, and annual gains of 5.2 million hectares due to reforestation, afforestation, and natural expansion of forests. Net losses were 12.3 million hectares annually for tropical forests, while non-tropical forests experienced average annual gains of 2.9 million hectares per year.[a]

The FAO *Global Forest Resources Assessment 2000* draws its forest data for the United States from U.S. Forest Service periodic forest inventories, which cover all forest land in the United States for more than 70 years. The national forest inventory measures samples on a 5- to 10-year cycle with an accuracy of ±1 percent per million hectares for forest area estimates. The FAO Assessment for 2000 cites total U.S. forest area at 226 million hectares. The change in U.S. forest area from 1990 to 2000 was 0.4 million hectares per year.[b]

A revised assessment is currently being prepared and will be published in 2005. *Global Forest Resources Assessment 2005* will involve more sophisticated datasets that result from satellite remote sensing.[c] EIA intends to include data on U.S. forests from the *Global Forest Resources Assessment 2005*, if available, in next year's report.

[a]Food and Agriculture Organization of the United Nations, *Global Forest Resources Assessment 2000*, "Executive Summary," web site www.fao.org/DOCREP/004/Y1997E/y1997e05.htm#bm05.
[b]Food and Agriculture Organization of the United Nations, *Global Forest Resources Assessment 2000*, Chapter 34, "North America, Excluding Mexico," web site www.fao.org/DOCREP/004/Y1997E/y1997e13.htm#bm39.
[c]T. Parris, "Global Forest Assessments," *Environment*, Vol. 45, No. 10 (2003), p. 3.

given State. Thus, there may be uncertainty about the year associated with the forest survey data. In addition, the existing forest survey data do not include forest stocks in Alaska, Hawaii, and the U.S. territories (although net carbon fluxes from these stocks are anticipated to be insignificant).[142]

Additional uncertainty results from the derivations of carbon sequestration estimates for forest floor, understory vegetation, and soil from models based on forest ecosystem studies. To extrapolate results of these studies to the forest land in question, an assumption was made that the studies effectively described regional or national averages. This assumption may result in bias from applying data from studies that improperly represent average forest conditions, from modeling errors, and/or from errors in converting estimates from one reporting unit to another.[143]

Aside from the land use data issues and uncertainties discussed above, which are specific to the methodologies used for the EPA estimates, there is concern about larger and more general uncertainty surrounding estimates of terrestrial carbon sequestration. It is anticipated to be difficult, as well as expensive, to determine carbon stock changes over shorter time periods, such as the 5-year periods suggested during international climate change negotiations. This concern is especially problematic if the carbon stocks are large and the stock changes are comparatively small.[144] Several countries involved in the negotiations have maintained that the accounting of terrestrial carbon stock changes over a 5-year commitment period fails to account for the differing dynamics of carbon stocks and fluxes over time.

In addition to concerns about uncertainty, permanence, and leakage, a recent scientific study published in the

[142]U.S. Environmental Protection Agency, *Inventory of U.S. Greenhouse Gas Emissions and Sinks 1990-2002*, EPA-430-R-04-003 (Washington, DC, April 2004), web site http://yosemite.epa.gov/oar/globalwarming.nsf/content/ResourceCenterPublicationsGHGEmissions USEmissionsInventory2004.html.
[143]U.S. Environmental Protection Agency, *Inventory of U.S. Greenhouse Gas Emissions and Sinks 1990-2002*, EPA-430-R-04-003 (Washington, DC, April 2004), web site http://yosemite.epa.gov/oar/globalwarming.nsf/content/ResourceCenterPublicationsGHGEmissions USEmissionsInventory2004.html.
[144]G. Marland and B. Schlamadinger, *Land Use and Global Climate Change: Forests, Land Management, and the Kyoto Protocol* (Arlington, VA: Pew Center on Global Climate Change, June 2000), p. 31, web site www.pewclimate.org/docUploads/land_use.pdf.

science journal *Nature* has raised questions about carbon sequestration through terrestrial sinks. The authors of the study, Dr. John Lichter and Dr. William Schlesinger, concluded that while forests do sequester carbon dioxide from the air and store it in the soil, the majority of the sequestered carbon is ultimately released back into the atmosphere as carbon dioxide when organic soil material decomposes. They maintain that their findings highlight the uncertainty of the role of soils as long-term carbon storage pools and assert that considerable long-term net carbon sequestration in forest soils may be unlikely.[145] Many scientists agree that much work remains to be done on the science surrounding terrestrial carbon sequestration; however, a number of the countries involved in international climate change negotiations assert that the potential for terrestrial carbon sequestration should be embraced, or at the very least, not discounted or overlooked.

Research by CarboEurope, a European program that has pioneered research into the carbon budget, reveals that soils in forests release more carbon than their trees will absorb in the first 10 years. Forest soils and the organic matter within them generally contain three to four times as much carbon as does vegetation on the ground. CarboEurope's researchers contend that, when ground is cleared for forest planting, rotting organic matter in the soil releases a surge of carbon dioxide into the air that will exceed the amount of carbon dioxide absorbed by growing trees for at least the first 10 years of forest growth; only later will the uptake of carbon by the trees begin to offset the release of carbon dioxide from the soil. In fact, their research indicates that some new forests planted on wet, peaty soils may never absorb as much carbon as they release.[146]

Thus, while there are methods available for estimating the amount of carbon sequestered through U.S. forests and soils, many uncertainties remain in the accounting methodology and overall conceptual feasibility of carbon sequestration both nationally and globally. For this reason, caution should be employed when accounting for the amount of carbon sequestered through land use and forestry practices, or when making decisions about the amount of sequestered carbon to be treated as an offset to national carbon dioxide emissions.

[145] W.H. Schlesinger and J. Lichter, "Limited Carbon Storage in Soil and Litter of Experimental Forest Plots Under Increased Atmospheric CO_2," *Nature*, Vol. 411 (2001), pp. 466-469.

[146] F. Pearce, "Tree Farms Won't Halt Climate Change," *New Scientist*, Print Edition (October 28, 2002), web site www.newscientist.com/news/news.jsp?id=ns99992958.

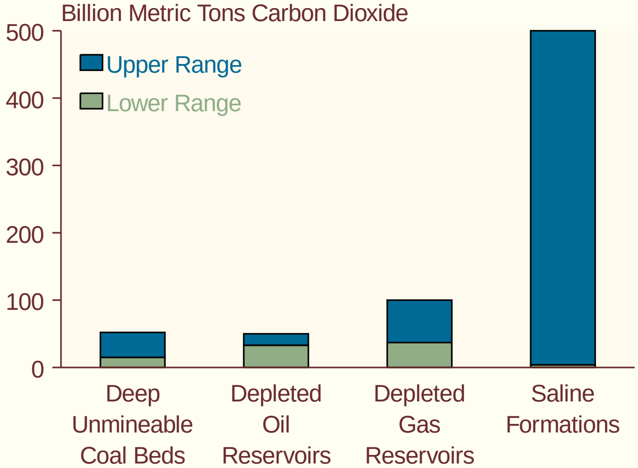
Carbon Dioxide Capture and Geologic Storage

The capture and permanent storage of carbon dioxide in geologic formations has gained increasing attention as an option for sequestering carbon dioxide emissions from industrial processes and coal-fired power generation. As part of the February 2002 introduction of the Global Climate Change Initiative, President Bush announced that the U.S. Government will develop policies to encourage geologic sequestration, which the Initiative describes as "critical to long-term emission reductions." Federal support for sequestration technologies include $20 million for seven regional partnerships spanning 40 States to test potential capture technologies and storage reservoirs, creation of the Carbon Sequestration Leadership Forum to encourage multilateral carbon sequestration projects, and the Integrated Sequestration and Hydrogen Research Initiative, FutureGen, which is a $1 billion government/industry partnership to design a "nearly emission-free" coal-fired plant to produce electricity and hydrogen.

The increased attention to geologic sequestration stems from the significant potential to store anthropogenic carbon dioxide in underground geologic formations. In the United States alone, geologic formations, such as depleted oil and gas reservoirs, deep unmineable coalbeds, and deep saline formations, may have the potential to store 140 to 670 billion metric tons of captured carbon dioxide.[a] These underground formations, which can be found all over the world, have the potential structure and porosity necessary for permanent sequestration, in that they already have stored crude oil, natural gas, brine, and naturally occurring carbon dioxide for millions of years. The two figures in this box show the estimated capacity range of each domestic geologic storage option in the United States and potential locations for geologic storage.

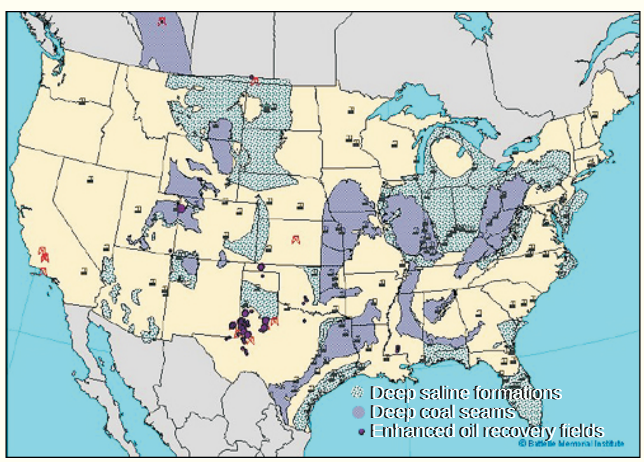
(continued on page 83)

Estimates of U.S. Geologic Storage Potential



Sources: Maximum and minimum estimates derived from: D.A. Beecy, V.A. Kuuskraa, and C. Schmidt, "A Perspective on the Potential Role of Geologic Options in a National Carbon Management Strategy," *Journal of Energy & Environmental Research*, Vol. 2, No. 1 (February 2002), pp. 47-53, web site www.netl.doe.gov/publications/journals/vol2/Papers/47-53.pdf; C.W. Byrer, "Sequestration of Carbon Dioxide in Geologic Formations." Presentation at COAL-SEQ 1 Forum (Houston, TX, March 14, 2002), web site www.coal-seq.com/Proceedings/CharlesByrer-CO2-Presentation.pdf; and CO_2 Capture and Storage Working Group, NCCTI Energy Technologies Group, Office of Fossil Energy, U.S. Department of Energy, *CO_2 Capture and Storage in Geologic Formations*, Revised Draft (Washington, DC, January 8, 2002), web site www.netl.doe.gov/coalpower/sequestration/pubs/CS-NCCTIwhitepaper.pdf.

Potential Geologic Storage Locations in the United States



Source: U.S. Department of Energy, Pacific Northwest National Laboratory.

[a]CO_2 Capture and Storage Working Group, NCCTI Energy Technologies Group, Office of Fossil Energy, U.S. Department of Energy, *CO_2 Capture and Storage in Geologic Formations*, Revised Draft (Washington, DC, January 8, 2002), web site www.netl.doe.gov/coal/Carbon%20Sequestration/pubs/CS-NCCTIwhitepaper.pdf.

Carbon Dioxide Capture and Geologic Storage (Continued)

The geologic storage process involves the separation and capture of carbon dioxide from an anthropogenic source, such as a power plant or industrial facility; compression and transport of the carbon dioxide to the storage reservoir; and injection of the carbon dioxide into a geologic reservoir. As shown in the table below, geologic carbon dioxide storage projects can be divided into two categories. The first category consists of *value-added* capture and storage projects, in which captured carbon dioxide is reused for chemical or other industrial processes or to enhance resource recovery, such as enhanced oil, gas, and coalbed methane production. For this type of project, some of the cost of

(continued on page 84)

Summary of Carbon Dioxide Capture and Geologic Storage Options

Capture and Separation of Waste Carbon Dioxide from Power Production and Industrial Processes	Transportation	Storage: Resource Recovery and Reuse	Storage: Other Geologic Storage
• Chemical absorption with liquid amine solution • Oxygen-fired combustion • Pre-combustion decarbonization (e.g., through gasification)	• Carbon dioxide pipeline • Shipping • Trucking[a]	• Enhanced oil, gas, and coalbed methane recovery • Food processing and carbonation, and synthesis of chemicals	• Deep saline formations • Deep, unmineable coal seams • Depleted oil and gas reservoirs • Shales
Sample Applications			
A new 600-megawatt IGCC plant could capture up to 90 percent of carbon dioxide emissions. Additional energy expenditures would reduce the total captured carbon dioxide to 85 percent of what would be emitted without the project.[b]	A 300-kilometer pipeline transports carbon dioxide from a North Dakota gasification plant to the Weyburn oil field in Saskatchewan.	Carbon dioxide is injected under pressure into a geologic formation to enhance fuel extraction. More than 70 enhanced oil recovery (EOR) projects worldwide, mostly in U.S., 10 percent of which rely on waste carbon dioxide.[c]	Since 1996, Statoil has avoided Norway's carbon tax by sequestering carbon dioxide in a sandstone aquifer below the North Sea. About 1 million metric tons of carbon is stored a year, equivalent to 3 percent of Norway's total annual carbon dioxide emissions.
Estimated Cost of Carbon Dioxide Emissions Avoided (Dollars per Metric Ton)			
Power Plant Technology[d]	**Transportation Options[e]**	**Resource Recovery Options[e]**	**Other Storage Options[e]**
IGCC: 19.5 Ultra-supercritical PC: 42.4 NGCC: 60.4 High-purity CO_2 industrial sources: 10[h]	100 km via pipeline: 1-3 500 km via tanker: 2 Trucking: NA	NA[f]	Sample storage sites:[g] 4-19

IGCC = integrated gasification combined cycle; NA = not available; NGCC = natural gas combined cycle; PC = pulverized coal.

[a]A.F.B. Wildenborg and L.G.H. van der Meer, "The Use of Oil, Gas and Coal Fields as CO_2 Sinks." Paper presented at IPCC Workshop on Carbon Capture and Storage (Regina, Canada, November 18-21, 2002), web site www.nrcan.gc.ca/es/etb/cetc/combustion/co2network/pdfs/ipcc_geological_storage2.pdf.

[b]Science Applications International Corporation, calculations based on data from K. Thambimuthu, J. Davison, and M. Gupta, "CO_2 Capture and Reuse." Paper presented at IPCC Workshop on Carbon Capture and Storage (Regina, Canada, November 18-21, 2002), web site http://www.nrcan.gc.ca/es/etb/cetc/combustion/co2network/pdfs/ipcc_co2cap_reuse.pdf.

[c]U.S. Department of Energy, Office of Fossil Energy, National Energy Technology Laboratory, *Carbon Sequestration Technology Roadmap and Program Plan* (Washington, DC, March 12, 2003), web site www.fe.doe.gov/programs/sequestration/publications/programplans/2003/sequestration_roadmap03-13-03.pdf.

[d]Electric Power Research Institute, *Updated Cost and Performance Estimates for Fossil Fuel Power Plants with CO_2 Removal*, Interim report (Palo Alto, CA, December 2002), web site www.netl.doe.gov/coalpower/gasification/pubs/pdf/1004483.pdf.

[e]International Energy Agency (IEA), *Solutions for the 21st Century: Zero Emissions Technologies for Fossil Fuels* (Paris, France, May 2002), web site www.iea.org/impagr/zets/strategy/strategic_layout.pdf.

[f]No estimates are available on the added cost benefits of resource enhancement and the impact on total injection and storage cost.

[g]Due to the wide variation in storage types and site parameters, cost estimates for carbon dioxide storage are based on site-specific data and are not distinguished by storage type.

[h]International Energy Agency (IEA), Greenhouse Gas Research and Development Programme, *Opportunities for Early Application of CO_2 Sequestration Technologies*, Report PH4/10 (Cheltenham, UK, September 2002).

Source: National Energy Technology Laboratory, *Greenhouse Gas Accounting Issues for Carbon Capture and Geologic Storage Projects* (Pittsburgh, PA, February 2003), p. 2.

Carbon Dioxide Capture and Geologic Storage (Continued)

carbon dioxide storage is mitigated by the potential revenue expected from the sale of recovered oil or natural gas. In addition, the technologies for value-added storage are already mature. About 10 percent of the carbon dioxide-based enhanced oil recovery operations in the United States use waste carbon dioxide from industrial processes rather than naturally occurring carbon dioxide extracted directly from the ground. The typical storage rate is 2,000 standard cubic feet of carbon dioxide per barrel of oil recovered.[b]

The second category includes storage projects undertaken *specifically* to reduce carbon dioxide emissions, without the incentive of other value-added benefits. So far, one such large-scale geologic sequestration project has been implemented. In 1996, prompted by the Norwegian tax on carbon dioxide, the oil company Statoil began taking unwanted carbon dioxide from the Sleipner West field in the Norwegian North Sea and storing it 1,000 meters beneath the seabed in a saline aquifer reservoir. Since 1996, about 1 million metric tons of carbon dioxide per year has been injected into the Utsira saline aquifer, an amount roughly equal to one-third of the carbon dioxide output of a 300-megawatt coal-fired power plant.

The main challenge to geologic storage of carbon dioxide is not the technical feasibility of injection and storage, but the economics of capturing carbon dioxide from a point source. Carbon dioxide is never produced in a pure form and must therefore be separated from other products of combustion, making it more economical and practical to collect carbon dioxide from large point sources or power plants. The cost of capturing carbon dioxide is competitive in cases where the waste carbon dioxide stream is relatively pure, such as from natural gas processing or fertilizer and methanol production. Capture from stationary power plants is more costly, however, particularly from natural-gas-fired plants where the carbon dioxide content of the flue gas is lower. A number of commercial technologies to capture carbon dioxide have been developed, but they are energy-intensive and reduce the power plant's net output while increasing cost and contributing to atmospheric emissions. The estimated "energy penalty" of installing capture technology at a power plant ranges from 14 to 40 percent, depending on the type of combustion technology used.[c]

As shown in the table on page 83, the cost of capturing carbon dioxide from integrated gasification combined cycle (IGCC), advanced pulverized coal (PC), natural gas combined cycle (NGCC) power plants, and high-purity carbon dioxide sources ranges from $10 to $60 per metric ton of carbon dioxide emissions avoided. Capturing and sequestering 90 percent of the carbon dioxide from a new power plant in the United States is estimated to add $0.02 per kilowatt-hour to the cost of electricity, with 75 to 80 percent of the added cost attributable to the capture and combustion process.[d] Because capture technology must be an integral part of plant design, installing capture technology at existing facilities would be even more expensive.

EIA's national inventory does not consider carbon dioxide injected into oil, natural gas, or other geologic reservoirs as an emission but, instead, requires the reporting of carbon dioxide vented and flared during the production and processing of oil and gas. For active operations using enhanced oil recovery techniques, however, no estimate of carbon dioxide emissions is included in the annual inventory, because most of the carbon dioxide recovered with the oil is recycled and reinjected, and because currently there is no sound basis for estimating the quantity of carbon dioxide leaked from such operations.

[b] U.S. Department of Energy, Office of Fossil Energy, National Energy Technology Laboratory, *Carbon Sequestration Technology Roadmap and Program Plan—2004* (Washington, DC, April 2004), web site www.netl.doe.gov/coal/Carbon%20Sequestration/pubs/SequestrationRoadmap4-29-04.pdf.

[c] International Energy Agency (IEA), *Solutions for the 21st Century: Zero Emissions Technologies for Fossil Fuels* (Paris, France, May 2002), web site www.iea.org/dbtw-wpd/textbase/papers/2003/strategic_layout.pdf.

[d] J. David, *Economic Evaluation of Leading Technology Options for Sequestration of Carbon Dioxide*. M.S. Thesis (Cambridge, MA: Massachusetts Institute of Technology, May 2000), web site http://sequestration.mit.edu/pdf/JeremyDavid_thesis.pdf.