6. Land Use Issues

Overview

Land use change 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.[117] The U.S. Environmental Protection Agency (EPA) estimates annual U.S. carbon sequestration for the year 2001 at 838.1 million metric tons carbon dioxide equivalent, a decline of approximately 21.9 percent from the 1,072.8 million metric tons carbon dioxide equivalent sequestered in 1990 (Table 31). In 1990 land use change and forestry practices represented an offset of 17.4 percent of total U.S. anthropogenic carbon dioxide emissions, but by 2001 that amount had declined to 12.3 percent.

Land Use Change and Forestry Carbon Sequestration

The EPA's estimates for carbon sequestration from land use change and forestry in 2001 include four main components: (1) changes in forest carbon stocks (759 million metric tons carbon dioxide equivalent or 90.6 percent of the total), (2) changes in agricultural soil carbon stocks (15.2 million metric tons carbon dioxide equivalent or 1.8 percent of the total), (3) changes in carbon stocks in

Table 31. Net Carbon Dioxide Sequestration from U.S. Land Use Change and Forestry, 1990 and 1995-2001
(Million Metric Tons Carbon Dioxide Equivalent)

Component	1990	1995	1996	1997	1998	1999	2000	2001
Forests	982.7[a]	979.0[a]	979.0[a]	759.0[b]	751.7[b]	762.7[b]	755.3[b]	759.0[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	13.3[a]	14.9[a]	13.6[a]	13.9[b]	11.5[b]	11.9[b]	13.8[b]	15.2[b]
Landfilled Yard Trimmings	18.2[a]	11.6[a]	9.7[a]	9.0[a]	8.7[a]	7.8[a]	6.9[a]	5.3[b]
Total	**1,072.8[a]**	**1,064.2[a]**	**1,061.0[a]**	**840.6[b]**	**830.5[b]**	**841.1[b]**	**834.6[b]**	**838.1[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-03-004 (Washington, DC, April 2003), web site http://yosemite.epa.gov/oar/globalwarming.nsf/content/ResourceCenterPublicationsGHGEmissionsUSEmissionsInventory2003.html.

[117]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.ch/pub/guide.htm.

urban trees (58.7 million metric tons carbon dioxide equivalent or 7.0 percent of the total), and (4) changes in carbon stocks in landfilled yard trimmings (5.3 million metric tons carbon dioxide equivalent or 0.6 percent of the total).[118]

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 are based on the EPA's own method of examining life-cycle greenhouse gas emissions and sinks associated with solid waste management.[119]

The EPA's carbon flux estimates, with the exception of those from wood products, urban trees, and liming, are based on surveys of U.S. forest lands and soils carried out at 5- or 10-year intervals by the U.S. Forest Service. The resulting annual averages are applied to years between surveys. Annual estimates of carbon fluxes

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 7 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 on the second draft document was completed at the end of June 2003. The IPCC author teams are currently in the process of revising the second draft in response to comments received. A final draft of the *Good Practice Guidance* for LULUCF will be provided to governments in October 2003 for final comment, before their anticipated acceptance at the COP-9 meeting in December 2003.[a, b]

[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/ (2003).

[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), web site http://www.ipcc-nggip.iges.or.jp/SBSTA18/LULUCF_SBSTA18_side-event.htm.

[118]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/ResourceCenterPublicationsGHGEmissionsUSEmissionsInventory2003.html.

[119]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.

between survey years are interpolated and, therefore, change little from year to year, except when a new assessment is made. For landfilled yard trimmings, periodic solid waste survey data are interpolated to derive annual storage estimates. The most current national forest and soil surveys were completed for the year 1997; thus, carbon flux estimates from forests 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.[120]

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.[121] 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:

- 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.

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 seven forest components or "forest pools" to a "product pool." 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.[122]

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 the atmosphere. The size of wood product landfills has increased over the past century.[123]

According to the EPA (Table 32), between 1990 and 2001, U.S. forest and harvested wood components accounted for an average annual net sequestration of 887 million metric tons carbon dioxide equivalent, resulting from domestic forest growth and increases in forested land area. Over the same period, however, increasing harvests and land-use changes have resulted in a decrease of approximately23 percent in annual sequestration.

[120]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/ResourceCenterPublicationsGHGEmissionsUSEmissionsInventory2003.html.

[121]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/ResourceCenterPublicationsGHGEmissionsUSEmissionsInventory2003.html.

[122]U.S. Environmental Protection Agency, *Inventory of U.S. Greenhouse Gas Emissions and Sinks 1990-2000*, EPA-430-R-02-003 (Washington, DC, April 2002), web site http://yosemite.epa.gov/oar/globalwarming.nsf/content/ResourceCenterPublicationsGHGEmissionsUSEmissionsInventory2002.html.

[123]U.S. Environmental Protection Agency, *Inventory of U.S. Greenhouse Gas Emissions and Sinks 1990-2000*, EPA-430-R-02-003 (Washington, DC, April 2002), p. 129, web site http://yosemite.epa.gov/oar/globalwarming.nsf/content/ResourceCenterPublicationsGHGEmissionsUSEmissionsInventory2002.html.

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,[124] based on data collected from 1990 through 2001. Net carbon dioxide flux from urban trees is estimated at 58.7 million metric tons carbon dioxide equivalent annually from 1990 through 2001 (Table 31).[125]

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 33), is divided into three categories of land use and land management activities: (1) agricultural land use and land management activities on mineral soils; (2) agricultural land use and land management activities on organic soils; 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 2001. Net carbon dioxide flux from agricultural soils is estimated at 15.2 million metric tons carbon dioxide equivalent in 2001.[126]

Changes in Landfilled Yard Trimming Carbon Stocks

Carbon stored in landfilled yard trimmings can remain indefinitely. In the United States, yard trimmings (grass clippings, leaves, and branches) make up a considerable portion of the municipal waste stream, and significant amounts of the yard trimmings collected are discarded

Table 32. Net Carbon Dioxide Sequestration in U.S. Forests, 1990 and 1995-2001
(Million Metric Tons Carbon Dioxide Equivalent)

Description	1990[a]	1995[a]	1996[a]	1997[b]	1998[b]	1999[b]	2000[b]	2001[b]
Forest Carbon Stocks	**773.7**	**773.7**	**773.7**	**546.3**	**546.3**	**546.3**	**546.3**	**546.3**
Trees	469.3	469.3	469.3	447.3	447.3	447.3	447.3	447.3
Understory	11.0	11.0	11.0	14.7	14.7	14.7	14.7	14.7
Forest Floor	25.7	25.7	25.7	-29.3	-29.3	-29.3	-29.3	-29.3
Down Dead Wood	55.0	55.0	55.0	58.7	58.7	58.7	58.7	58.7
Forest Soils	212.7	212.7	212.7	55.0	55.0	55.0	55.0	55.0
Harvested Wood Carbon Stocks	**209.0**	**205.3**	**205.3**	**212.7**	**205.3**	**216.3**	**209.0**	**212.7**
Wood Products	47.7	55.0	55.0	58.7	51.3	62.3	58.7	58.7
Landfilled Wood	161.3	150.3	150.3	154.0	154.0	154.0	150.3	154.0
Total	**982.7**	**979.0**	**979.0**	**759.0**	**751.7**	**762.7**	**755.3**	**759.0**

[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. 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 1990-2001*, EPA-430-R-03-004 (Washington, DC, April 2003), web site http://yosemite.epa.gov/oar/globalwarming.nsf/content/ResourceCenter PublicationsGHGEmissionsUSEmissionsInventory2003.html.

[124]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.

[125]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/ResourceCenterPublicationsGHGEmissions USEmissionsInventory2003.html.

[126]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/ResourceCenterPublicationsGHGEmissions USEmissionsInventory2003.html.

in landfills. Both the amount of yard trimmings collected annually and the percentage of trimmings landfilled have declined over the past decade, and net carbon dioxide sequestration in landfilled yard trimmings has declined accordingly (Table 31). Since 1990, programs limiting disposal of yard trimmings have led to an increase in backyard composting and the use of mulching mowers. 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.[127]

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

Table 33. Net Carbon Dioxide Sequestration in U.S. Agricultural Soils, 1990 and 1995-2001
(Million Metric Tons Carbon Dioxide Equivalent)

Description	1990	1995	1996	1997	1998	1999	2000	2001
Mineral Soils	57.1	58.6	57.3	57.4	55.8	55.7	57.3	59.1
Organic Soils	-34.3	-34.8	-34.8	-34.8	-34.8	-34.8	-34.8	-34.8
Liming of Soils	-9.5	-8.9	-8.9	-8.7	-9.6	-9.1	-8.8	-9.1
Total	**13.3**	**14.9**	**13.6**	**13.9**	**11.5**	**11.9**	**13.8**	**15.2**

[a]Estimates based on historical data.
[b]Estimates 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 1990-2000*, EPA-430-R-02-003 (Washington, DC, April 2002), web site www.epa.gov.

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 four 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, processing residues from primary timber mills, and logging 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 the four sources in 2001 were as follows: (1) 9.6 million tons from MSW, (2) 18.1 million tons from construction and demolition debris, (3) 1.9 million tons from primary timber processing, and (4) 74.5 million tons from logging residues.

Logging residues represent the largest fraction 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.

[127]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.

USDA Agriculture and Forestry Greenhouse Gas Inventory

The U.S. Department of Agriculture (USDA) Global Change Program Office is currently compiling an Agriculture and Forestry Greenhouse Gas Inventory for the United States. The USDA inventory is intended to provide a comprehensive assessment of the contribution of agriculture and forestry to nationwide greenhouse gas emissions. The document was prepared to support and expand on information provided in the U.S. Environmental Protection Agency's *Inventory of U.S. Greenhouse Gas Emissions and Sinks*. The USDA inventory provides detailed data on trends in agriculture and forestry greenhouse gas emissions and sinks, including information by source and sink at State and regional levels. The report is structured primarily from a land use perspective. It contains a chapter on forests, which details carbon sequestration in forests, soils, urban trees, and wood products for the year 2002. The USDA inventory is currently in draft form; however, EIA plans to publish the 2002 sequestration values in next year's report.

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,[128] 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.

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 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).[129]

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 forested lands 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.[130]

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

[128]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/global-warming-in-depth/all_reports/land_use_and_climate_change/index.cfm.

[129]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/ResourceCenterPublicationsGHGEmissionsUSEmissionsInventory2003.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), web site http://yosemite.epa.gov/oar/globalwarming.nsf/content/ResourceCenterPublicationsGHGEmissionsUSEmissionsInventory2003.html.

are comparatively small.[131] 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 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.[132] 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.

New 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.[133]

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 and accepting as fact 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.

[131]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/global-warming-in-depth/all_reports/land_use_and_climate_change/index.cfm

[132]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.

[133]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.

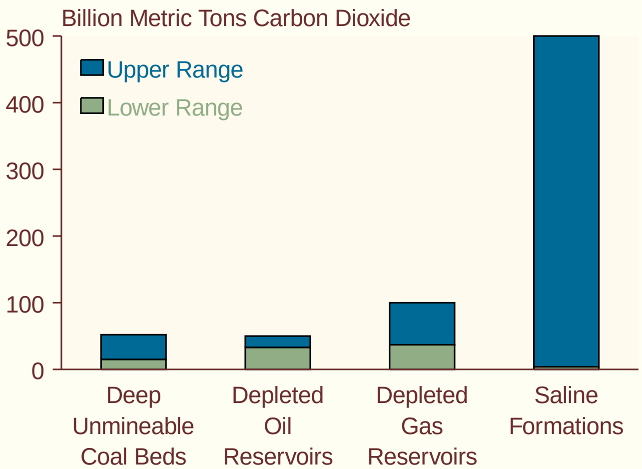
Carbon Dioxide Capture and Geologic Storage

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 regional partnerships 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 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 below show the estimated capacity range of each domestic geologic storage option in the United States and potential locations for geologic storage.

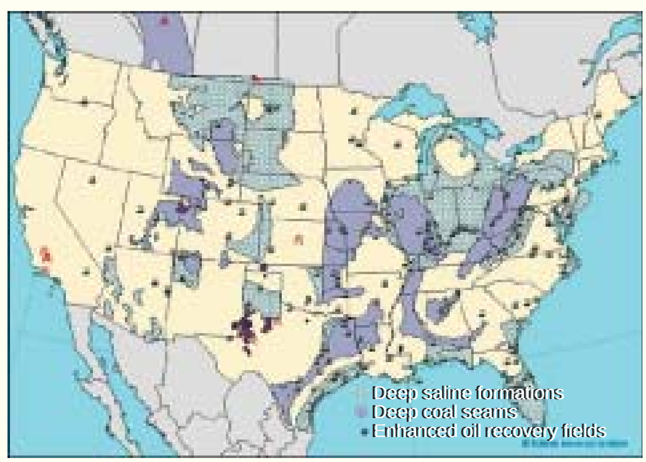
(continued on page 81)

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/coalpower/sequestration/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 82)

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	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 MW 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-km 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 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 MMTC 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	100 km via pipeline: 1-3	NA[f]	Sample storage sites:[g] 4-19
Ultra-supercritical PC: 42.4	500 km via tanker: 2		
NGCC: 60.4	Trucking: NA		

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/program_plans/03/.

[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.

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 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.[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 costs and contributing to atmospheric emissions. The estimated "energy penalty" of installing capture technology at a power plant ranges from 13 to 25 percent, depending on the type of combustion technology used.[c]

As shown in the table on page 81, the cost of capturing carbon dioxide from integrated gasification combined cycle (IGCC), new pulverized coal (PC), and natural gas combined cycle (NGCC) power plants range from $17 to $61 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 kilowatthour 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. Thus, current research to improve the feasibility of capture and storage is focused on methods to decrease costs and energy use, as well as demonstrating that geologic sequestration is safe and environmentally sound.

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* (Washington, DC, March 12, 2003), web site www.fe.doe.gov/programs/sequestration/publications/program_plans/03/.

[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/impagr/zets/strategy/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.