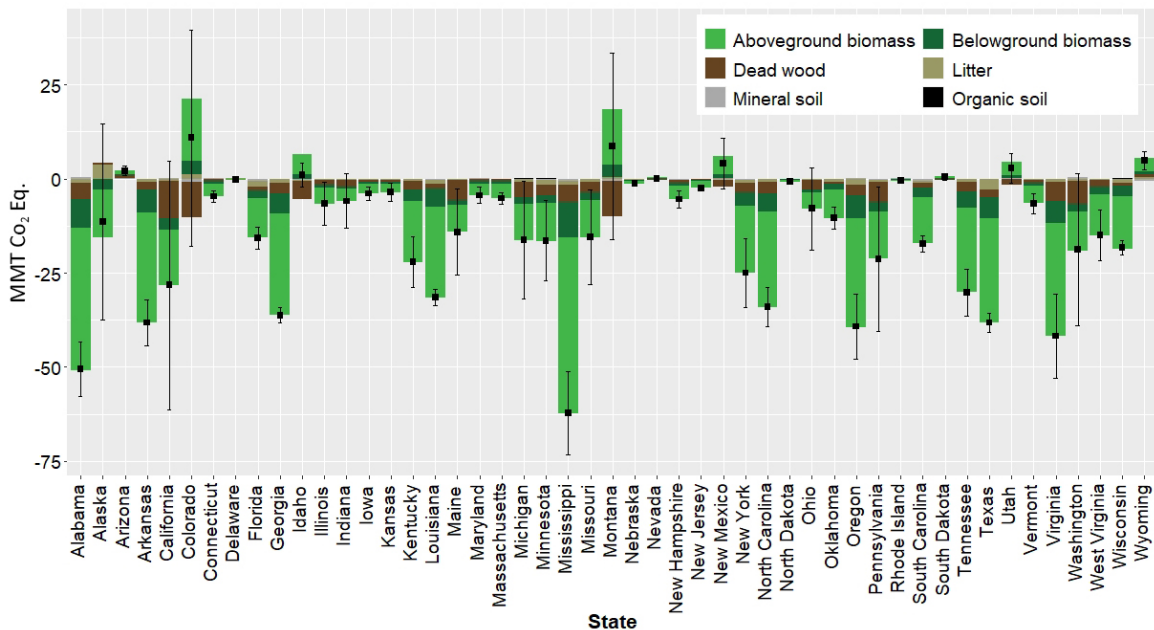


# Greenhouse Gas Emissions and Removals From Forest Land, Woodlands, Urban Trees, and Harvested Wood Products in the United States, 1990–2021

## Introduction

As a signatory to the United Nations Framework Convention on Climate Change (UNFCCC), the United States has reported an inventory of greenhouse gas (GHG) emissions and removals by sector, as defined by the Intergovernmental Panel on Climate Change (IPCC), since the mid-1990s (U.S. EPA 2023). In 2021, United States net GHG emissions increased by more than 6.8 percent relative to 2020 net emissions, which had decreased substantially from previous years and was due, in large part, to the global pandemic. Forest land, harvested wood products (HWP), woodlands, and urban trees within the land sector collectively continue to represent the largest net carbon sink in the United States, offsetting the equivalent of more than 12.4 percent of total (i.e., gross) GHG emissions in 2021 (U.S. EPA 2023). Estimates of GHG emissions and removals are compiled by U.S. Department of Agriculture (USDA), Forest Service researchers and partners and are based primarily on National Forest Inventory (NFI) data collected and maintained by the Forest Inventory and Analysis (FIA) Program within the Forest Service. This resource bulletin provides an overview of the status and trends of GHG emissions and removals from forest land, woodlands in the grassland category, HWP, and urban trees in settlements in the United States from 1990 to 2021. The estimates for the United States summarized here are based on the compilation reported in the “Land Use, Land-Use Change, and Forestry” chapter of the U.S. EPA (2023) submission to the UNFCCC. Most of the national scale estimates are also developed and reported at the individual State level (fig. 1) for the entire 1990–2021 time series and are available in a published research dataset (Walters et al. 2023). This report also includes regional carbon stock and stock change estimates by broad ownership category (i.e., private or public land) and National Forest System region.



**Figure 1.**—Estimated annual carbon stock changes by ecosystem pool for forest land remaining forest land and land converted to forest land in each of the conterminous 48 States and Alaska in 2021 (million metric tons of carbon dioxide equivalent [MMT CO<sub>2</sub> Eq.]). Note that points and uncertainties represented by confidence intervals (95 percent) reflect net flux for all ecosystem pools in each State. Negative estimates indicate net carbon uptake (i.e., a net removal of carbon from the atmosphere or transfer of carbon between ecosystem pools or land use categories).

## Forest Carbon Cycle

In forests, carbon is continuously cycled among ecosystem pools and the atmosphere as a result of biogeochemical processes (e.g., photosynthesis, respiration, decomposition, and disturbances such as fires or pest outbreaks) and anthropogenic activities (e.g., forest management). Carbon is removed from the atmosphere by living trees through photosynthesis and is allocated to and stored in aboveground and belowground biomass. Respiration returns carbon to the atmosphere. Carbon can also be transferred from live tree biomass to the dead wood pool through mortality. Stems, foliage, and other debris are deposited by live and dead pools on the forest floor, transferring carbon to either the dead wood or litter pool, depending on attributes (e.g., size) of the debris and how the pools are defined (see sidebar). Carbon is cycled between dead wood, litter, and soil pools by organisms that facilitate decomposition and released to the atmosphere through heterotrophic respiration.

The net change in forest carbon is not equivalent to the net flux between forests and the atmosphere because timber harvests do not result in an immediate release of all harvested biomass carbon to the atmosphere. Instead, following harvesting, a portion of the carbon stored in wood may be transferred to a “product pool.” Once in a product pool, the carbon is emitted over time as carbon dioxide (CO<sub>2</sub>) from decomposition, and as CO<sub>2</sub>, methane (CH<sub>4</sub>), nitrous oxide (N<sub>2</sub>O), carbon monoxide (CO), and other nitrogen oxides (NO<sub>x</sub>) when the wood product combusts, or the carbon in the product may be transferred and stored in solid waste disposal sites (SWDS). The rate of emission varies considerably among different product pools and SWDS.

In addition, carbon can cycle among forest land and other land use categories (e.g., grasslands, croplands, settlements, wetlands, or other lands). Carbon can enter or exit a forest ecosystem through processes such as lateral transport. Carbon can also be transferred from forest land to other land use categories through land conversion, or the reverse can occur through reforestation, afforestation, or both.

## Carbon Pools

**When estimating carbon stocks or stock change (flux), carbon in forest ecosystems can be divided into the following five storage pools (IPCC 2006):**

- Aboveground biomass—all living biomass above the soil including stems, stumps, branches, bark, seeds, and foliage. This pool includes live understory.
- Belowground biomass—all living biomass of coarse living roots with diameters greater than 2 millimeters.
- Dead wood—all nonliving woody biomass either standing, lying on the ground (but not including litter), or in the soil.
- Litter—all duff, humus, and fine woody debris above the mineral soil, including woody fragments with diameters of up to 7.5 centimeters.
- Soil organic carbon (SOC)—all organic material in soil to a depth of 1 meter but excluding the coarse roots of the belowground pools. Organic (e.g., peat and muck) soils have a minimum of 12 to 20 percent organic matter by mass and develop under poorly drained conditions of wetlands. All other soils are classified as mineral soil types and typically have relatively low amounts of organic matter.

**Two harvested wood pools are also included when estimating carbon flux:**

- Harvested wood products (HWP) in use.
- HWP in solid waste disposal sites (SWDS).

## Total Emissions and Removals

Forest land, HWP, woodlands, and urban trees in settlements individually and collectively represent a net GHG sink over the 1990–2021 time series, with interannual variability driven, in large part, by natural and anthropogenic forest disturbances (e.g., wildfire, harvesting), fluxes resulting from land conversions (e.g., forest land converted to cropland and settlements, reforestation/afforestation), and changes in HWP stocks in use and transfers to SWDS (table 1) (U.S. EPA 2023). In 2021, forest land, HWP, woodlands, and urban trees in settlements collectively represented an estimated net increase in carbon stocks of 785.0 million metric tons of carbon dioxide equivalent (MMT CO<sub>2</sub> Eq.). The forest land remaining forest land category is the largest net sink in the land sector, with an estimated uptake of 592.5 MMT CO<sub>2</sub> Eq. For categories included in this report, the largest source of emissions and/or transfers of carbon was from the conversion of forest land, with estimated emissions of 144.4 MMT CO<sub>2</sub> Eq. (table 1) (U.S. EPA 2023).

**Table 1.**—Emissions and removals (net flux) from land use, land-use change, and forestry (MMT CO<sub>2</sub> Eq.) by year

| Emissions and removals category <sup>a</sup>             | 1990           | 1995           | 2000           | 2005           | 2010           | 2019           | 2020           | 2021           |
|--|----------------|----------------|----------------|----------------|----------------|----------------|----------------|----------------|
| Forest land remaining forest land <sup>b</sup>           | (697.7)        | (690.4)        | (664.9)        | (608.2)        | (628.3)        | (559.8)        | (610.8)        | (592.5)        |
| Non-CO <sub>2</sub> emissions from fire                  | 5.5            | 1.0            | 12.3           | 18.3           | 3.4            | 10.8           | 23.0           | 24.4           |
| N <sub>2</sub> O emissions from forest soils             | 0.1            | 0.2            | 0.5            | 0.4            | 0.4            | 0.4            | 0.4            | 0.4            |
| Non-CO <sub>2</sub> emissions from drained organic soils | 0.1            | 0.1            | 0.1            | 0.1            | 0.1            | 0.1            | 0.1            | 0.1            |
| Forest land converted to nonforest land <sup>b</sup>     | 134.7          | 136.3          | 137.9          | 139.7          | 141.5          | 144.4          | 144.4          | 144.4          |
| Nonforest land converted to forest land <sup>b</sup>     | (98.5)         | (98.4)         | (98.4)         | (98.4)         | (98.4)         | (98.3)         | (98.3)         | (98.3)         |
| Harvested wood products                                  | (123.8)        | (112.2)        | (93.4)         | (106.0)        | (69.1)         | (89.6)         | (96.6)         | (102.8)        |
| Woodlands remaining woodlands <sup>c</sup>               | 2.5            | 2.5            | 2.5            | 2.4            | 2.3            | 2.2            | 2.1            | 2.1            |
| Urban trees in settlements <sup>d</sup>                  | (96.4)         | (103.3)        | (110.4)        | (117.4)        | (124.6)        | (129.3)        | (136.7)        | (137.8)        |
| <b>Total carbon stock change<sup>e</sup></b>             | <b>(879.1)</b> | <b>(865.6)</b> | <b>(826.6)</b> | <b>(787.9)</b> | <b>(776.5)</b> | <b>(730.4)</b> | <b>(795.9)</b> | <b>(785.0)</b> |
| <b>Total net emissions and removals<sup>f</sup></b>      | <b>(873.4)</b> | <b>(864.3)</b> | <b>(813.8)</b> | <b>(769.1)</b> | <b>(772.7)</b> | <b>(719.1)</b> | <b>(772.4)</b> | <b>(760.1)</b> |

<sup>a</sup> For details on how estimates were compiled, see U.S. EPA (2023).

<sup>b</sup> Estimated emissions and removals include the net changes to carbon stocks stored in all ecosystem pools. Note that in the forest land converted to nonforest land category, emissions and removals from forest land converted to other lands are not included in the U.S. EPA (2023) report; forest land converted to wetlands estimates were not compiled by the Forest Service but are included here based on methods used to compile estimates for other land conversion categories. Estimates of soil carbon change are not included for forest land converted to other lands and forest land converted to wetlands.

<sup>c</sup> Estimates for woodlands, which are included in the grassland land use category, were compiled using the same methods and models as those in the forest land category.

<sup>d</sup> Estimates of emissions and removals from urban trees in settlements were compiled using percentage tree cover in carbon sequestration density per unit of tree cover.

<sup>e</sup> Total carbon stock change includes any carbon stock gains and losses from all land use and land use conversion categories.

<sup>f</sup> Total net emissions and removals is the net sum of all non-CO<sub>2</sub> (CH<sub>4</sub> and N<sub>2</sub>O) emissions to the atmosphere plus net carbon stock changes in units of MMT CO<sub>2</sub> Eq.

Notes: Totals may not sum due to independent rounding. Parentheses indicate net carbon uptake (i.e., a net removal of carbon from the atmosphere).

## Forest Land Remaining Forest Land and Harvested Wood Products

Within the forest land remaining forest land category, aboveground live biomass is the largest contributor to the net uptake over the reporting period, followed by belowground live biomass and transfers from live biomass to dead wood (table 2). Harvested wood products in use and in solid waste disposal sites (SWDS) are also an important contributor to the net sink in the land sector, and in 2021 net uptake/transfer for both HWP pools increased slightly from previous years.

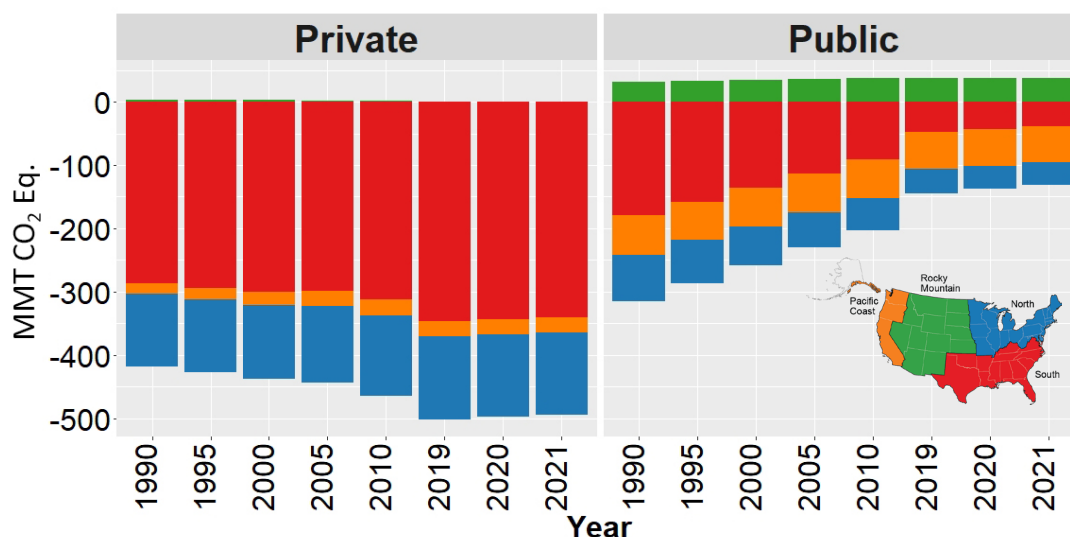
Private forest land accounted for nearly 84 percent (-493.9 MMT CO<sub>2</sub> Eq.) of the estimated net sink strength in the conterminous 48 States and coastal Alaska in 2021, and the private forests of the Southern United States continued to account for the majority of carbon uptake (fig. 2). Public forest land makes up a relatively small but important part of the U.S. forest carbon sink. Much of the public forest land is in the Western United States, where wildfire (see "Fire Emissions and Area Burned" section) and other disturbances have led to substantial emissions and transfers of carbon from live trees to the dead organic matter pools (i.e., dead wood and litter), altering the capacity of forests to sequester and store carbon. This is particularly true on forest land within the National Forest System, which accounts for approximately 47 percent (-43.5 MMT CO<sub>2</sub> Eq.) of the public land sink in 2021, although nearly all the annual net carbon sink (-38.1 MMT CO<sub>2</sub> Eq.) is due to transfers from the live biomass carbon pool to dead wood carbon pool in the Western United States (table 3).

**Table 2.**—Emissions and removals (net flux) from forest land remaining forest land and harvested wood pools (MMT CO<sub>2</sub> Eq.) by year

| Carbon pool <sup>a</sup>   | 1990           | 1995           | 2000           | 2005           | 2010           | 2019           | 2020           | 2021           |
|----------------------------|----------------|----------------|----------------|----------------|----------------|----------------|----------------|----------------|
| <b>Forest</b>              | <b>(697.7)</b> | <b>(690.4)</b> | <b>(664.9)</b> | <b>(608.2)</b> | <b>(628.3)</b> | <b>(559.8)</b> | <b>(610.8)</b> | <b>(592.5)</b> |
| Aboveground biomass        | (499.1)        | (485.0)        | (468.7)        | (443.8)        | (440.8)        | (410.8)        | (419.0)        | (409.1)        |
| Belowground biomass        | (101.8)        | (98.6)         | (95.1)         | (89.8)         | (88.6)         | (81.6)         | (83.1)         | (81.1)         |
| Dead wood                  | (100.8)        | (101.8)        | (101.1)        | (97.9)         | (101.1)        | (98.2)         | (102.3)        | (101.1)        |
| Litter                     | 0.9            | (7.7)          | (1.9)          | 22.5           | 2.6            | 30.4           | (1.9)          | 1.9            |
| Soil (mineral)             | 3.2            | 2.7            | 1.8            | 0.5            | (0.9)          | 0.7            | (5.4)          | (4.0)          |
| Soil (organic)             | (0.8)          | (0.7)          | (0.6)          | (0.4)          | (0.2)          | (1.1)          | 0.1            | 0.1            |
| Drained organic soil       | 0.8            | 0.8            | 0.8            | 0.8            | 0.8            | 0.8            | 0.8            | 0.8            |
| <b>Harvested wood</b>      | <b>(123.8)</b> | <b>(112.2)</b> | <b>(93.4)</b>  | <b>(106.0)</b> | <b>(69.1)</b>  | <b>(89.6)</b>  | <b>(96.6)</b>  | <b>(102.8)</b> |
| Products in use            | (54.8)         | (51.7)         | (31.9)         | (42.6)         | (7.4)          | (25.1)         | (32.0)         | (37.8)         |
| Solid waste disposal sites | (69.0)         | (60.5)         | (61.5)         | (63.4)         | (61.7)         | (64.5)         | (64.6)         | (65.1)         |
| <b>Total net flux</b>      | <b>(821.4)</b> | <b>(802.6)</b> | <b>(758.3)</b> | <b>(714.2)</b> | <b>(697.3)</b> | <b>(649.3)</b> | <b>(707.4)</b> | <b>(695.4)</b> |

<sup>a</sup>For details on these estimates and how they were compiled, see U.S. EPA (2023).

Notes: Totals may not sum due to independent rounding. Parentheses indicate net carbon uptake (i.e., a net removal of carbon from the atmosphere or transfer from another carbon pool).



**Figure 2.**—Carbon stock changes for forest land remaining forest land in private and public ownership for the conterminous 48 States and coastal Alaska (ownership information was not available for forest land in Interior Alaska so those lands were excluded from these estimates) by region and ownership (MMT CO<sub>2</sub> Eq.). Negative estimates indicate net carbon uptake (i.e., a net removal of carbon from the atmosphere or transfer from another carbon pool).

**Table 3.**—Carbon stock changes (net flux) from forest land remaining forest land within the National Forest System (NFS) by NFS region and year (MMT CO<sub>2</sub> Eq.)

| NFS region                        | 1990          | 1995          | 2000          | 2005          | 2010          | 2019          | 2020          | 2021          |
|-----------------------------------|---------------|---------------|---------------|---------------|---------------|---------------|---------------|---------------|
| Alaska                            | (2.9)         | (3.1)         | (3.4)         | (3.6)         | (3.9)         | (4.1)         | (4.0)         | (4.0)         |
| Eastern                           | (12.6)        | (12.2)        | (11.9)        | (12.0)        | (12.1)        | (11.7)        | (11.6)        | (11.5)        |
| Intermountain                     | 9.1           | 9.4           | 9.8           | 10.3          | 10.8          | 11.2          | 11.3          | 11.5          |
| Northern                          | (1.5)         | (1.1)         | (0.6)         | (0.1)         | 0.3           | 0.9           | 0.9           | 0.9           |
| Pacific Northwest                 | (25.7)        | (24.8)        | (25.1)        | (25.5)        | (26.6)        | (28.1)        | (28.2)        | (28.3)        |
| Pacific Southwest                 | (8.6)         | (8.4)         | (8.2)         | (7.9)         | (7.6)         | (6.2)         | (6.0)         | (5.7)         |
| Rocky Mountain                    | 13.0          | 13.2          | 13.4          | 13.5          | 13.6          | 12.3          | 12.3          | 12.2          |
| Southern                          | (31.4)        | (30.3)        | (29.4)        | (28.4)        | (27.7)        | (26.1)        | (25.8)        | (25.5)        |
| Southwestern                      | 5.1           | 5.3           | 5.5           | 5.7           | 6.0           | 6.7           | 6.8           | 6.9           |
| <b>Net emissions and removals</b> | <b>(55.6)</b> | <b>(51.9)</b> | <b>(49.8)</b> | <b>(48.0)</b> | <b>(47.0)</b> | <b>(45.1)</b> | <b>(44.4)</b> | <b>(43.5)</b> |

Note: Parentheses indicate net carbon uptake (i.e., a net removal of carbon from the atmosphere or transfers from another carbon pool).

Carbon stock estimates for forest ecosystem and harvested wood carbon storage pools are presented in table 4. Together, the estimated aboveground biomass and soil carbon pools account for more than 83 percent of total forest ecosystem carbon stocks. By maintaining current harvesting practices and regeneration activities on these forested lands, along with continued input of harvested products into the HWP pool, carbon stocks in forests are likely to continue to increase in the near term, though possibly at a lower rate. Because most of the timber harvested from U.S. forest land is used in wood products and many discarded wood products are disposed of in SWDS rather than by incineration, significant quantities of carbon in harvested wood are transferred to these long-term storage pools rather than being released rapidly to the atmosphere (Skog 2008).

**Table 4.**—Carbon stocks in forest land remaining forest land and harvested wood pools (MMT C) by year

| <b>Carbon pool<sup>a</sup></b> | <b>1990</b>   | <b>1995</b>   | <b>2000</b>   | <b>2005</b>   | <b>2010</b>   | <b>2020</b>   | <b>2021</b>   | <b>2022</b>   |
|--------------------------------|---------------|---------------|---------------|---------------|---------------|---------------|---------------|---------------|
| <b>Forest</b>                  | <b>51,354</b> | <b>52,308</b> | <b>53,237</b> | <b>54,098</b> | <b>54,952</b> | <b>56,623</b> | <b>56,790</b> | <b>56,951</b> |
| Aboveground biomass            | 11,899        | 12,573        | 13,226        | 13,849        | 14,453        | 15,635        | 15,749        | 15,861        |
| Belowground biomass            | 2,344         | 2,481         | 2,614         | 2,740         | 2,862         | 3,098         | 3,121         | 3,143         |
| Dead wood                      | 1,948         | 2,086         | 2,224         | 2,359         | 2,496         | 2,771         | 2,799         | 2,827         |
| Litter                         | 3,929         | 3,936         | 3,943         | 3,922         | 3,913         | 3,888         | 3,888         | 3,888         |
| Soil (mineral)                 | 25,920        | 25,916        | 25,913        | 25,911        | 25,911        | 25,914        | 25,915        | 25,916        |
| Soil (organic)                 | 5,315         | 5,316         | 5,317         | 5,318         | 5,318         | 5,317         | 5,317         | 5,317         |
| <b>Harvested wood</b>          | <b>1,895</b>  | <b>2,061</b>  | <b>2,218</b>  | <b>2,353</b>  | <b>2,462</b>  | <b>2,695</b>  | <b>2,721</b>  | <b>2,749</b>  |
| Products in use                | 1,249         | 1,326         | 1,395         | 1,447         | 1,471         | 1,530         | 1,539         | 1,549         |
| Solid waste disposal sites     | 646           | 735           | 823           | 906           | 991           | 1,165         | 1,182         | 1,200         |
| <b>Total stocks</b>            | <b>53,249</b> | <b>54,369</b> | <b>55,455</b> | <b>56,451</b> | <b>57,414</b> | <b>59,318</b> | <b>59,511</b> | <b>59,701</b> |

<sup>a</sup>For details on these estimates and how they were compiled, see U.S. EPA (2023).

Notes: Totals may not sum due to independent rounding. Forest carbon stock estimates include all forest land remaining forest land in the conterminous 48 States and Alaska. Forest ecosystem carbon stocks do not include U.S. Territories because managed forest land for U.S. Territories is not currently included in section 6.1, Representation of the U.S. Land Base, of the U.S. EPA (2023) report. Forest ecosystem carbon stocks also do not include Hawaii because there is not sufficient National Forest Inventory data to support inclusion at this time. Forest ecosystem carbon stocks on managed forest land in Alaska were compiled using the gain-loss method described in annex 3.13 in the U.S. EPA (2023) report. Harvested wood product stocks include exports, even if the logs are processed in other countries, and excludes imports. Harvested wood estimates are based on results from annual surveys and models. Totals may not sum due to independent rounding. Population estimates compiled using Forest Inventory and Analysis data are assumed to represent stocks as of January 1 of the inventory year. Flux is the net annual change in stock. Thus, flux estimates for 2021 require carbon stocks for 2021 and 2022.

## Forest Land Conversions

Land use conversions to and from forest land result in substantial emissions and removals each year. This section includes all emissions and removals for land conversions to and from forest land, as reported in U.S. EPA (2023) (table 5). It is important to note that in some cases the reported emissions or removals from one land use category are transfers to another land use category. Forest land conversion to settlements was the largest source of emissions in the conversion categories, while cropland conversion to forest land resulted in the largest annual uptake. Considering all forest land conversions included in the U.S. EPA (2023) report, there have been net emissions each year throughout the reporting period. Estimated net emissions of ~33.1 MMT CO<sub>2</sub> Eq. were recorded for the last 3 reporting years.

**Table 5.**—Carbon stock changes (net flux) from conversions to and from forest land (MMT CO<sub>2</sub> Eq.) by year

| <b>Land conversions<sup>a</sup></b>  | <b>1990</b> | <b>1995</b> | <b>2000</b> | <b>2005</b> | <b>2010</b> | <b>2019</b> | <b>2020</b> | <b>2021</b> |
|--------------------------------------|-------------|-------------|-------------|-------------|-------------|-------------|-------------|-------------|
| Forest land converted to cropland    | 48.0        | 48.1        | 48.1        | 48.1        | 48.2        | 48.5        | 48.5        | 48.5        |
| Forest land converted to grassland   | 20.0        | 20.1        | 20.1        | 20.0        | 19.8        | 19.4        | 19.4        | 19.4        |
| Forest land converted to other land  | 9.6         | 9.5         | 9.5         | 9.4         | 9.3         | 9.2         | 9.2         | 9.2         |
| Forest land converted to settlements | 53.3        | 54.9        | 56.7        | 58.6        | 60.6        | 63.4        | 63.4        | 63.4        |
| Forest land converted to wetlands    | 3.8         | 3.7         | 3.7         | 3.6         | 3.7         | 3.7         | 3.7         | 3.7         |
| Cropland converted to forest land    | (38.5)      | (38.4)      | (38.2)      | (38.1)      | (38.0)      | (37.8)      | (37.8)      | (37.8)      |
| Grassland converted to forest land   | (12.2)      | (12.2)      | (12.2)      | (12.2)      | (12.3)      | (12.3)      | (12.3)      | (12.3)      |
| Other land converted to forest land  | (9.9)       | (10.1)      | (10.2)      | (10.4)      | (10.6)      | (10.7)      | (10.6)      | (10.6)      |
| Settlements converted to forest land | (34.5)      | (34.3)      | (34.3)      | (34.2)      | (34.1)      | (34.0)      | (34.0)      | (34.0)      |
| Wetlands converted to forest land    | (3.4)       | (3.4)       | (3.4)       | (3.4)       | (3.4)       | (3.4)       | (3.4)       | (3.4)       |
| <b>Net emissions and removals</b>    | <b>36.2</b> | <b>37.9</b> | <b>39.7</b> | <b>41.3</b> | <b>43.2</b> | <b>46.0</b> | <b>46.0</b> | <b>46.0</b> |

<sup>a</sup>For details on these estimates and how they were compiled, see U.S. EPA (2023).

Notes: Totals may not sum due to independent rounding. Parentheses indicate net carbon uptake (i.e., a net removal of carbon from the atmosphere).

Emissions and removals from forest land converted to other lands are not currently included in the U.S. EPA (2023) report; forest land converted to wetlands estimates were not compiled by the Forest Service but are included here based on methods used to compile estimates for other land conversion categories. Estimates of soil carbon change are not included for forest land converted other lands and forest land converted to wetlands.

## Land Area

The land area covered in the U.S. EPA (2023) report includes lands directly influenced by human intervention. Direct intervention mostly occurs in areas accessible to human activity and includes altering or maintaining the condition of the land for the following reasons: to produce commercial or noncommercial products or services; to serve as transportation corridors or locations for buildings, landfills, or other developed areas for commercial or noncommercial purposes; to extract resources or facilitate acquisition of resources; or to provide social functions for personal, community, or societal objectives where these areas are readily accessible to society. FIA data from each of the conterminous 48 States and Alaska comprise an estimated 280 million hectares (ha) of forest land that are considered managed and are included in this report along with an additional 1.0 million ha of nonforest land converted to forest land. Some differences exist in forest land area estimates in the latest Resources Planning Act Assessment supporting publication (Nelson et al. 2020) and the forest land area estimates included in the U.S. EPA (2023) report, which are based on annual FIA data through 2021 for all States (USDA Forest Service 2023). These differences are mainly due to the separation of land categories and the managed land definition used in the U.S. EPA (2023) report (Nelson et al. 2020). Sufficient annual inventory data are not yet available for Hawaii, but estimates of these areas are included in Oswald et al. (2019). Even though Hawaii and U.S. Territories have relatively small areas of forest land that may not substantially influence the overall carbon budget for forest land, these regions will be added to the forest carbon estimates as sufficient data become available. Agroforestry systems that meet the definition of forest land are also not currently included in the U.S. EPA (2023) report since they are not explicitly inventoried (i.e., they are classified as agroforestry systems) by either the FIA Program or the Natural Resources Inventory of the USDA Natural Resources Conservation Service. Woodland area is included in the grassland remaining grassland category and is not explicitly separated in the U.S. EPA (2023) report as a subcategory of grasslands. Combined, managed forest land and woodland area account for more than 301 million ha (table 6). There is also forest land converted to nonforest land, which has increased over the 1990–2021 time series and in 2021 accounted for 1.2 million ha (table 6).



**Table 6.**—Annual estimates of forest land and woodland area (1,000 ha) by year

| Land area category <sup>a</sup>          | 1990           | 1995           | 2000           | 2005           | 2010           | 2020           | 2021           | 2022           |
|--|----------------|----------------|----------------|----------------|----------------|----------------|----------------|----------------|
| Forest land remaining forest land        | 282,150        | 281,956        | 281,709        | 281,096        | 280,844        | 280,120        | 279,962        | 279,800        |
| Nonforest land converted to forest land  | 1,114          | 1,146          | 1,175          | 1,159          | 1,182          | 1,043          | 1,043          | 1,043          |
| Woodland remaining woodland <sup>b</sup> | 23,893         | 23,544         | 23,164         | 22,585         | 21,846         | 19,997         | 19,812         | 19,626         |
| Forest land converted to nonforest land  | 1,153          | 1,181          | 1,211          | 1,206          | 1,211          | 1,205          | 1,205          | 1,205          |
| <b>Total area</b>                        | <b>307,158</b> | <b>306,646</b> | <b>306,049</b> | <b>304,841</b> | <b>303,872</b> | <b>301,160</b> | <b>300,817</b> | <b>300,470</b> |

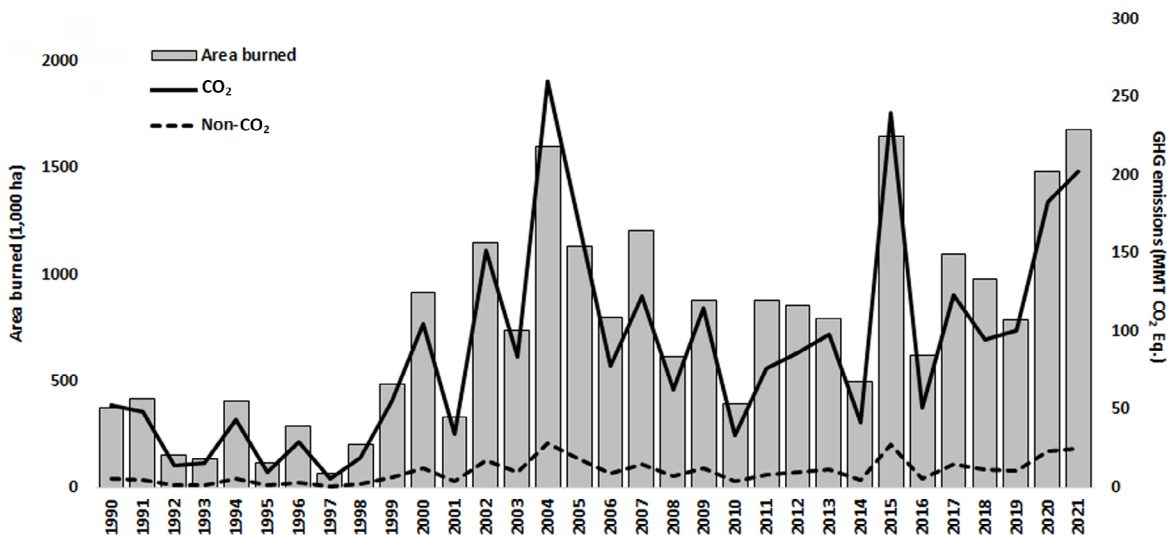
<sup>a</sup> For details on these estimates and how they were compiled, see U.S. EPA (2023).

<sup>b</sup> Woodland area is included in the grassland remaining grassland category and is not explicitly separated in the U.S. EPA (2023) report.

Notes: totals may not sum due to independent rounding. The estimates reported here may differ from the Land Representation section of the U.S. EPA (2023) report but are consistent with estimates used to compile emissions and removals in these categories. See annex 3.13 in the U.S. EPA (2023) for more details.

## Fire Emissions and Area Burned

Carbon dioxide emissions from wildfire and prescribed fire on forest land are inherently captured in the carbon stock change estimates described in tables 1 and 2. Fire emissions estimates from forest land are also compiled separately in the U.S. EPA (2023) report using field inventories, remotely sensed information, and models, and these estimates are reported for each year in the time series (fig. 3) and by individual State in Walters et al. (2023). There is substantial interannual variability in forest land area burned and associated GHG emissions resulting from fire over the last three decades. In 2021, the area of forest land burned was nearly 1.7 million ha, and GHG emissions were among the highest reported over the time series (fig. 3).



**Figure 3.**—Estimated annual CO<sub>2</sub> and non-CO<sub>2</sub> (N<sub>2</sub>O and CH<sub>4</sub>) emissions from wildfire and prescribed fire on forest land in the conterminous 48 States and Alaska, 1990–2021.



## Planned Improvements

Planned improvements to estimation and reporting include the following general topics: development of a robust estimation and reporting system, individual carbon pool estimation, coordination with other land-use categories, and annual inventory data incorporation. Research is underway to leverage auxiliary information (i.e., remotely sensed information) to operate at finer spatial and temporal scales. As in past submissions, emissions and removals associated with natural (e.g., wildfire, insects, disease) and human (e.g., harvesting) disturbances are implicitly included in the report given the design of the annual National Forest Inventory (NFI), but are not explicitly estimated. In addition to integrating auxiliary information into the estimation framework, alternative estimators are also being evaluated that will eliminate latency in population estimates from the NFI, improve annual estimation and characterization of interannual variability, facilitate attribution of fluxes to particular activities, and allow for easier harmonization of NFI data with auxiliary data products. Investments are also being made to leverage State-level wood products and harvest information to allow for the disaggregation of HWP estimates at the State level. Collectively, these improvements are expected to reduce uncertainties in the estimates at the national and State scales and facilitate entity-level estimation and reporting.

### 2021 Estimates at a Glance

#### **Summary statistics for 2021 from the compilation of the forest land, woodlands, HWP, and urban trees in settlements in the U.S. EPA (2023) report:**

- Economy-wide GHG emissions increased from 2020 to 2021 by more than 6.8 percent.
- Forest land, HWP, woodlands, and urban trees in settlements collectively offset more than 12.4 percent (785.0 MMT CO<sub>2</sub> Eq.) of total GHG emissions or 15.6 percent of CO<sub>2</sub> emissions in 2021.
- Private forest land accounts for nearly 84 percent (-493.9 MMT CO<sub>2</sub> Eq.) of the estimated net sink strength in the conterminous 48 States and coastal Alaska in 2021.
- Land conversions to and from forest land continue to result in net emissions and/or transfers of carbon to other land uses (33.1 MMT CO<sub>2</sub> Eq.).
- Soils store more than 55 percent of all the carbon in forest ecosystems, with small stock changes annually.
- Forest land area burned was nearly 1.7 million ha, and GHG emissions were among the highest reported over the time series from 1990 to 2021.
- Forest uptake averages 0.6 metric tons of carbon per hectare per year (MT C ha<sup>-1</sup> yr<sup>-1</sup>), with live vegetation accounting for more than 83 percent (0.5 MT C ha<sup>-1</sup> yr<sup>-1</sup>) of the uptake.

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