



# Greenhouse Gas Emissions and Removals from Forest Land and Urban Trees in the United States, 1990-2017

## Introduction

As a signatory to the United Nations Framework Convention on Climate Change (UNFCCC), the United States has been reporting an economy-wide inventory of greenhouse gas (GHG) emissions and removals since the mid-1990s (U.S. EPA 2019). Forest land, harvested wood products (HWPs), and urban trees within the land sector collectively represent the largest net carbon (C) sink in the United States, offsetting more than 11 percent of total GHG emissions annually (U.S. EPA 2019). Estimates of GHG emissions and removals are compiled by U.S. Department of Agriculture Forest Service scientists and are based primarily on national forest inventory (NFI) data collected and maintained by the Forest Inventory and Analysis (FIA) program within the USDA Forest Service. This report—the first in a new series of annual updates—provides an overview of the status and trends of GHG emissions and removals from forest land, HWPs, and urban trees in settlements in the United States from 1990 to 2017. The national estimates summarized here are based on the compilation reported in the *Land Use, Land-Use Change, and Forestry* chapter of the U.S. EPA (2019) submission to the UNFCCC. The national scale estimates reported here will also be disaggregated by individual State in future Resource Updates and are currently available upon request (see contact information, page 4).

## Forest Carbon Cycle

Carbon is continuously cycled among ecosystem pools and the atmosphere as a result of biogeochemical processes in forests (e.g., photosynthesis, respiration, decomposition, and disturbances such as fires or pest outbreaks) and anthropogenic activities (e.g., harvesting, thinning, and replanting). As trees photosynthesize and grow, C is removed from the atmosphere and stored in living tree biomass. As trees die and otherwise deposit litter and debris on the forest floor, C is released to the atmosphere and is also transferred to the litter, dead wood, and soil pools by organisms that facilitate decomposition.

The net change in forest C is not equivalent to the net flux between forests and the atmosphere because timber harvests do not cause an immediate flux of all harvested biomass C to the atmosphere. Instead, harvesting transfers a portion of the C stored in wood to a "product pool." Once in a product pool, the C is emitted over time as carbon dioxide (CO<sub>2</sub>) in the case of 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. The rate of emission varies considerably among different product pools.

### Box 1: Carbon Pools

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

- Aboveground biomass, which includes all living biomass above the soil including stem, stump, branches, bark, seeds, and foliage. This category includes live understory.
- Belowground biomass, which includes all living biomass of coarse living roots greater than 2 millimeters (mm) diameter.
- Dead wood, which includes all nonliving woody biomass either standing, lying on the ground (but not including litter), or in the soil.
- Litter, which includes the litter, fomic, and humic layers, and all nonliving biomass with a diameter less than 7.5 centimeters (cm) at transect intersection, lying on the ground.
- Soil organic C (SOC), including all organic material in soil to a depth of 1 meter but excluding the coarse roots of the belowground pools.

In addition, there are two harvested wood pools included when estimating C flux:

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



## Total Emissions and Removals

Forest land, HWPs, and urban trees in settlements have collectively represented a net GHG sink over the UNFCCC reporting period, with interannual variability driven, in large part, by natural and anthropogenic disturbance (e.g., wildfire, harvesting), land conversions, and changes in HWPs in use (Table 1.; U.S. EPA 2019). In 2017, forest land, HWPs, and urban trees in settlements collectively represented an estimated net update of 730.9 million metric tons of carbon dioxide equivalent (MMT CO<sub>2</sub> eq.). The category “Forest land remaining forest land” was the largest net sink in the land sector with an estimated uptake of 517.8 MMT CO<sub>2</sub> eq. Conversions of forest land were the largest source of emissions within the categories included in this report, with estimated emissions of 126.1 MMT CO<sub>2</sub> eq. (Table 1; U.S. EPA 2019).

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

Emissions and Removals Category <sup>a</sup>	1990	1995	2000	2005	2010	2015	2016	2017
Forest land remaining forest land <sup>b</sup>	(547.8)	(538.1)	(518.9)	(531.4)	(520.9)	(549.4)	(529.3)	(517.8)
Non-CO <sub>2</sub> emissions from fire	2.4	1.0	12.4	8.6	5.4	20.8	8.0	8.0
N <sub>2</sub> O emissions from forest soils	0.1	0.3	0.5	0.5	0.5	0.5	0.5	0.5
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 non-forest land <sup>b</sup>	121.7	123.1	124.5	126.1	127.8	126.2	126.2	126.1
Non-forest land converted to forest land <sup>b</sup>	(119.1)	(119.4)	(119.7)	(120.0)	(120.3)	(120.6)	(120.6)	(120.6)
Harvested wood products	(123.8)	(112.2)	(93.5)	(108.0)	(67.3)	(95.9)	(99.6)	(103.3)
Urban trees in settlements <sup>c</sup>	(96.2)	(103.1)	(110.1)	(116.8)	(124.3)	(124.5)	(123.9)	(123.9)
<b>Total Net Flux</b>	<b>(762.6)</b>	<b>(748.3)</b>	<b>(704.6)</b>	<b>(741.0)</b>	<b>(699.0)</b>	<b>(742.8)</b>	<b>(738.7)</b>	<b>(730.9)</b>

<sup>a</sup> For details on how estimates were compiled see U.S. EPA 2019.

<sup>b</sup> Estimated emissions and removals include the net changes to C stocks stored in all ecosystem pools.

<sup>c</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.

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

## Forest Land Remaining Forest Land and Harvested Wood Products

Within the category of “Forest land remaining forest land,” aboveground live biomass is the largest contributor to the net uptake over the reporting period followed by belowground live biomass and 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.

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

Carbon Pool <sup>a</sup>	1990	1995	2000	2005	2010	2015	2016	2017
<b>Forest Ecosystem</b>	<b>(547.8)</b>	<b>(538.1)</b>	<b>(518.9)</b>	<b>(531.4)</b>	<b>(520.9)</b>	<b>(549.4)</b>	<b>(529.3)</b>	<b>(517.8)</b>
Aboveground biomass	(378.7)	(371.0)	(353.8)	(361.2)	(365.8)	(377.5)	(371.3)	(357.1)
Belowground biomass	(90.7)	(88.9)	(84.8)	(86.1)	(86.6)	(88.6)	(87.1)	(83.9)
Dead wood	(76.0)	(76.9)	(77.1)	(78.9)	(78.3)	(82.6)	(81.9)	(77.4)
Litter	(4.2)	(2.8)	(3.9)	(5.1)	(1.6)	(3.3)	(1.2)	(3.8)
Soil (mineral)	1.2	0.8	(0.0)	(0.6)	5.8	0.5	9.2	2.3
Soil (organic)	(0.1)	(0.1)	0.0	(0.1)	4.8	1.3	2.2	1.3
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>(93.5)</b>	<b>(108.0)</b>	<b>(67.3)</b>	<b>(95.9)</b>	<b>(99.6)</b>	<b>(103.3)</b>
Products in use	(54.8)	(51.7)	(31.9)	(44.6)	(5.7)	(31.4)	(33.5)	(35.7)
SWDS	(69.0)	(60.5)	(61.5)	(63.5)	(61.6)	(64.4)	(66.1)	(67.6)
<b>Total Net Flux</b>	<b>(671.6)</b>	<b>(650.4)</b>	<b>(612.4)</b>	<b>(639.4)</b>	<b>(588.2)</b>	<b>(645.2)</b>	<b>(628.9)</b>	<b>(621.1)</b>

<sup>a</sup> For details on these estimates and how they were compiled see U.S. EPA 2019.

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

## Forest Land Conversions

Land use conversions to and from forest land result in substantial emissions and removals each year. In this section all emissions and removals included for land conversions to and from forest land, as reported in the U.S. EPA (2019), are included in Table 3. 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 (2019) report, there have been net emissions in each year over the reporting period, with the most recent estimated net emissions of 5.5 MMT CO<sub>2</sub> eq.

**Table 3.—Emissions and removals (net flux) from conversions to and from forest land (MMT CO<sub>2</sub> eq.)**

Land Conversions <sup>a</sup>	1990	1995	2000	2005	2010	2015	2016	2017
Forest land converted to cropland	50.0	49.5	48.9	48.2	47.5	47.1	47.1	47.1
Forest land converted to grassland	17.0	17.2	17.4	18.0	18.5	15.9	15.9	15.8
Forest land converted to settlements	54.7	56.3	58.2	59.9	61.8	63.2	63.2	63.2
Cropland converted to forest land	(47.4)	(47.5)	(47.7)	(47.8)	(48.0)	(48.0)	(48.0)	(48.0)
Grassland converted to forest land	(11.0)	(11.1)	(11.0)	(11.0)	(10.9)	(11.1)	(11.1)	(11.2)
Other land converted to forest land	(18.1)	(18.1)	(18.2)	(18.2)	(18.3)	(18.3)	(18.3)	(18.3)
Settlements converted to forest land	(41.1)	(41.2)	(41.3)	(41.4)	(41.6)	(41.7)	(41.7)	(41.7)
Wetlands converted to forest land	(1.4)	(1.5)	(1.5)	(1.5)	(1.5)	(1.5)	(1.5)	(1.5)
<b>Total Net Flux</b>	<b>2.6</b>	<b>3.7</b>	<b>4.9</b>	<b>6.2</b>	<b>7.6</b>	<b>5.6</b>	<b>5.5</b>	<b>5.5</b>

<sup>a</sup> For details on these estimates and how they were compiled see U.S. EPA 2019.

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

## Land Area

The land area included in the U.S. EPA (2019) report of GHG emissions and removals includes lands directly influenced by human intervention. Direct intervention occurs mostly in areas accessible to human activity and includes altering or maintaining the condition of the land 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. Forest Inventory and Analysis data from each of the conterminous 48 states and Alaska comprise an estimated 273 million hectares of forest land that are considered managed and are included in this report along with an additional 10 million hectares of non-forest land converted to forest land. Some differences exist in forest land area estimates in the latest update to the Resources Planning Act Assessment (Oswalt et al. 2019) and the forest land area estimates included in U.S. EPA (2019) report, which are based on the annual FIA data through 2017 for all states (USDA Forest Service 2018). This difference is due, in large part, to the separation of land categories and the managed land definition used in the U.S. EPA (2019) report. Sufficient annual inventory data are not yet available for Hawaii but estimates of these areas are included in Oswalt et al. (2019). While Hawaii and U.S. Territories have relatively small areas of forest land and thus may not substantially influence the overall C budget for forest land, these regions will be added to the forest C 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 (2019) report since they are not explicitly inventoried (i.e., they are classified as an agroforestry system) 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” and “land converted to grassland” categories and is not explicitly separated in the U.S. EPA (2019) report as a subcategory of grasslands. Combined, forest land and woodland area accounts for more than 304 million hectares (Table 4).

**Table 4.—Annual estimates of forest land and woodland area (1000 ha).**

Land Area Category <sup>a</sup>	1990	1995	2000	2005	2010	2015	2016	2017	2018
Forest land remaining forest land	269,959	270,720	271,530	271,883	272,609	273,346	273,494	273,623	273,791
Non-forest land converted to forest land	10,089	10,140	10,194	10,249	10,301	10,341	10,341	10,341	10,341
Woodlands remaining woodlands	20,576	20,314	19,779	18,925	17,684	16,282	16,015	15,749	15,483
Non-woodlands converted to woodlands	5,942	5,849	5,656	5,342	4,880	4,456	4,456	4,456	4,456
<b>Total Area</b>	<b>306,566</b>	<b>307,023</b>	<b>307,160</b>	<b>306,399</b>	<b>305,474</b>	<b>304,425</b>	<b>304,307</b>	<b>304,170</b>	<b>304,072</b>

<sup>a</sup> For details on these estimates and how they were compiled see U.S. EPA 2019.

Notes: Totals may not sum due to independent rounding.

## Planned Improvements

Planned improvements can be broadly assigned to the following categories: development of a robust estimation and reporting system, individual C 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, and disease) and human (e.g., harvesting) disturbances are implicitly included in the report given the design of the annual NFI, but not explicitly estimated. In addition to integrating auxiliary information into the estimation framework, alternative estimators are also being evaluated which 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. Finally, estimates of emissions and removals from woodlands were compiled for the reporting period but were not included in the U.S. EPA (2019) report. Preliminary estimates suggest that in 2017, “Woodlands remaining woodlands” emitted 3.0 MMT CO<sub>2</sub> eq., “Woodlands converted to non-woodlands” emitted 11.6 MMT CO<sub>2</sub> eq., and “Non-woodlands converted to woodlands” was a small sink at 0.5 MMT CO<sub>2</sub> eq. Emissions and removals from woodlands will be incorporated in future U.S. EPA reports.

### Box 2: 2019 Highlights

There were several improvements made in the compilation of the forest land, HWPs, and urban trees in settlements in the U.S. EPA (2019) report.

- Included, for the first time, more than 24.5 million hectares of managed forest land in interior Alaska.
- Replaced the regional approach for C estimation in the western United States with the state-level method used in the eastern United States so C stocks and stock changes are now estimated consistently for the entire 1990 to 2017 time series in all states with remeasurements in the NFI.
- Consistent estimation nationally resolved unbalanced area estimates which may have resulted in over or underestimates in C stock changes, particularly soil C, in past reports.
- Incorporated forest stand-level fuel estimates as well as combustion factors related to fire severity classifications in the compilation of fire emissions estimates.
- Settlement land area was used with percentage tree cover in developed land as a proxy for percentage tree cover in settlement area. This improved alignment with other estimates in the settlements category.

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