Princeton's Net-Zero America Study

Annex P: Past and Prospective Changes in the Net CO_2 Flux of U.S. Forests

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Abstract

U.S. forests and forest products remove CO_2 from the atmosphere at a rate of about -600 Tg CO_2 per year. Other land-based components of the carbon cycle also remove CO_2, such that the total land sink including aquatic ecosystems is about -1,300 Tg CO_2 per year. Projections indicate that the forest sector will continue to remove CO_2 through 2050, but at a much lower level, about 300 Tg CO_2 per year primarily because of continued deforestation, forests growing older and slower, increasing disturbances, and increasing harvest. Yet, to reach net zero emissions by 2050 will require a forest sector CO_2 sink of about -800 Tg CO_2 per year, leaving a gap of -500 Tg CO_2 per year. To sustain or increase the forest C sink above current levels, a variety of activities have the technical potential to add between 500 and 1500 Tg CO_2 per year, though the actual potential is lower than this range because of uncertainties in estimates, barriers to adoption of different management practices, and remoteness of areas having potential. This wide range allows policy makers and programs to select among different activities to achieve the GHG reductions needed to sustain or increase the forest C sink. The main forest sector activities include increased reforestation, improved forest management, increased retention of carbon in harvested wood, avoided deforestation, and increased use of waste wood for bioenergy. The potential of these activities varies significantly by region and state. Enhancements to monitoring programs would be necessary to ensure that goals would be met.

1. Recent inventory and trends

The U.S. greenhouse gas inventory indicates that, on balance and considering all factors, U.S. forests and forest products remove CO_2 from the atmosphere at a rate of about -600 Tg CO_2 per year [1,2]. Besides forests, other land-based components of the carbon cycle also remove CO_2, such that the total land sink including aquatic ecosystems is about -1,300 Tg CO_2 per year [3] (Figure 1).

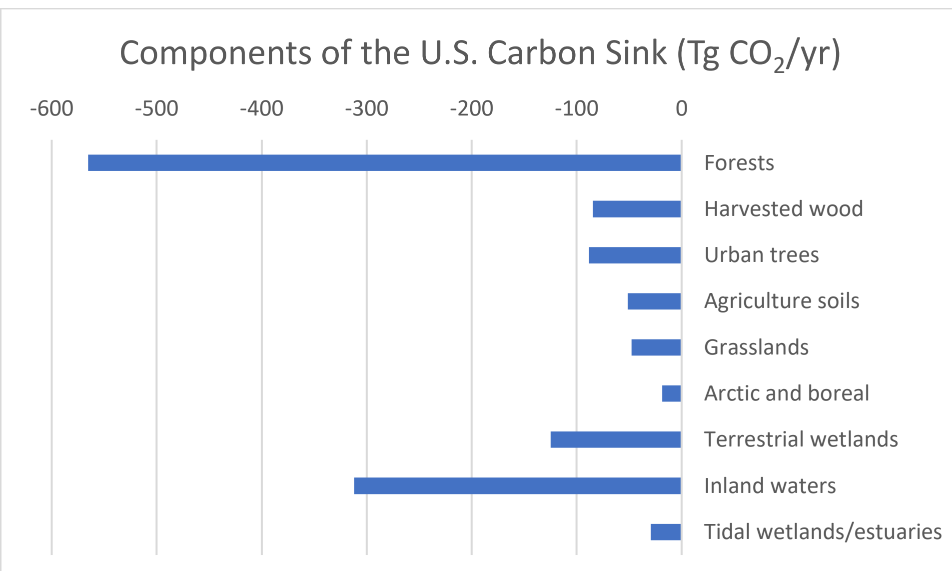

Figure 1. Components of the U.S. carbon sink, average from 2004-2013 (from [3]). Negative number denotes net removal of CO_2 from the atmosphere.

The net removal of CO_2 is the balance of emissions from harvesting and other disturbances, and removals from forest growth and additions to the harvested wood pool (table 1). Net ecosystem exchange includes both net forest growth and net emissions from natural disturbances such as wildfire and insects.

Table 1. Net emissions of CO_2 for forest lands of the U.S. by emission or removal category, average from 2000 to 2014, $TgCO_2yr^{-1}$ (Domke et al. 2018).

Emission or removal category	***Net flux[1]***
Net ecosystem exchange for forest remaining forest	-980
Emissions from forest area loss	84
Removals from forest area gain	-84
Emissions from forest harvest[2]	415
Additions to wood products[3]	-84
Net forest sector-atmosphere exchange	-649

[1]Negative number denotes net removal (land sink). "Removal" in this report refers to removal of CO_2 from the atmosphere, not removal of trees from the forest for wood products.
[2]Emissions from forest harvest represents the loss of carbon from forest ecosystems as a result of harvesting. Does not include fossil fuel emissions associated with harvesting operations and transport.
[3]Additions to wood products represent the change in the stock of carbon in wood products in use and in solid waste disposal sites, from past and current harvests.

Trends since 1990 show relatively little change through 2017 according to statistics reported by the Environmental Protection Agency, U.S. greenhouse gas inventory (Figure 2). The net change for the U.S. fluctuates around -600 $TgCO_2$ per year – some of the variability is caused by changes in methods. The carbon sink for the reference year of 2005 is estimated to be -632 $TgCO_2$ per year for the forest sector, with uncertainty estimated as ± 270 $TgCO_2$ per year. One of the noticeable trends is an increase in emissions from wildfire, though net additions to the dead wood pool were stable.

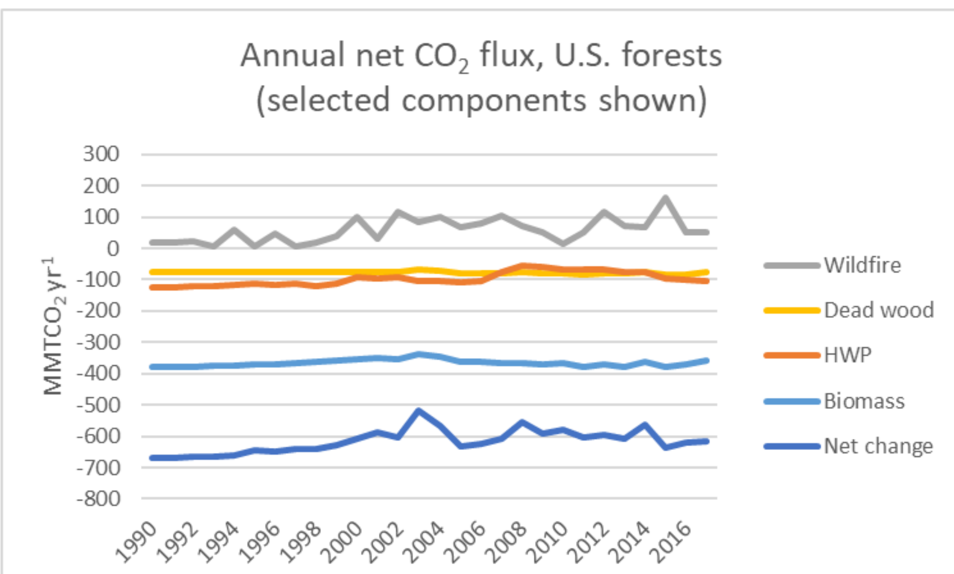

Figure 2. Annual net CO_2 flux from U.S. forests, 1990-2017, showing selected components that are included in the net change (from [1]).

There are indications that the trends shown in the EPA GHG inventory do not accurately reflect some important changes that are evident in other data. This is partially because the land inventories underlaying the estimates are lagging indicators of trends due to the sampling cycle, which ranges from 5 to 10 years and therefore is, on average, 5 or so years behind the current year's actual data. An exception is wildfire which is tracked separately based on remote sensing data, though the emission estimates from wildfire are included in the net ecosystem data based on field observations. This time lag causes the GHG inventory to delay accounting for the full effects of natural disturbances and harvesting. Also, the accounting scheme in the EPA GHG follows IPCC guidelines regarding land-use changes, which are tracked in the change category for 20 years which makes it difficult to identify annual changes and impacts on forests[1].

Natural disturbance statistics indicate increasing impacts over the last several decades, particularly from wildfire and insects (Figure 3). The major outbreak of western bark beetles affected millions of acres from 2000-2010, though this outbreak has subsided and has likely run its course since many areas of host trees have been killed. Impacts on carbon flux will be felt for decades as dead trees slowly release their stored carbon, and as the affected forests grow new biomass.

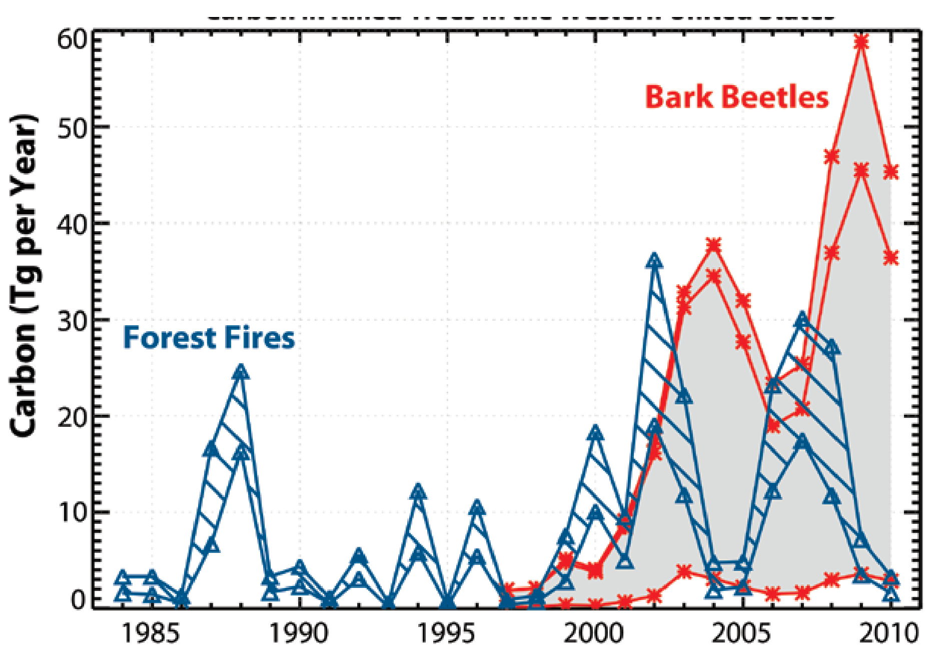

Figure 3. Teragrams of carbon in Western U.S. trees killed by disturbances. The impacts of major bark beetle disturbances (1997 to 2010; red lines represent upper, middle, and lower estimates; gray shading indicates range between upper and lower estimates) and forest fires (1984 to 2010); blue lines represent moderate and moderate plus high-severity burned areas; hatching indicates range between moderate and moderate plus high-severity burned areas) are shown. (Figure source: copied from [2]; redrawn from [4]).

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[1] Lands are treated as remaining in the same category (e.g., Cropland Remaining Cropland) if a land-use change has not occurred in the last 20 years. Otherwise, the land is classified in a land-use change category based on the current use and most recent use before conversion to the current use (e.g., Cropland Converted to Forest Land). Land classified as a land-use change remains in the change category for 20 years before being re-classified in the new category.

The increasing area of wildfire has been linked to increasing temperature and drought. When the weather is hot, dry, and windy, an ignition can start a wildfire regardless of how the vegetation has been managed. Extended drought has caused the fire season to last most of the year in many regions, and caused fires to burn hotter and over larger areas. Besides climate change, decades of fire suppression have caused a buildup of fuel in many forests of the Western U.S., yet research has been inconclusive regarding the link between fuel buildup and increasing wildfires. One way that fire suppression has increased the risk of wildfire is by causing massive insect outbreaks that are more severe because of higher vegetation density, coupled with warmer winters that allow insect populations to thrive. Insect-killed trees eventually fall and create the ladder fuels that make wildfires more severe.

Climate studies have documented that a warming Arctic and reduction of sea-ice cover may contribute to hotter and dryer conditions in the West, as have natural fluctuations in Pacific Ocean temperature patterns. The most recent National Climate Assessment illustrated how climate change has already doubled the area of forest burned in the Western U.S. [5] (Figure 4).

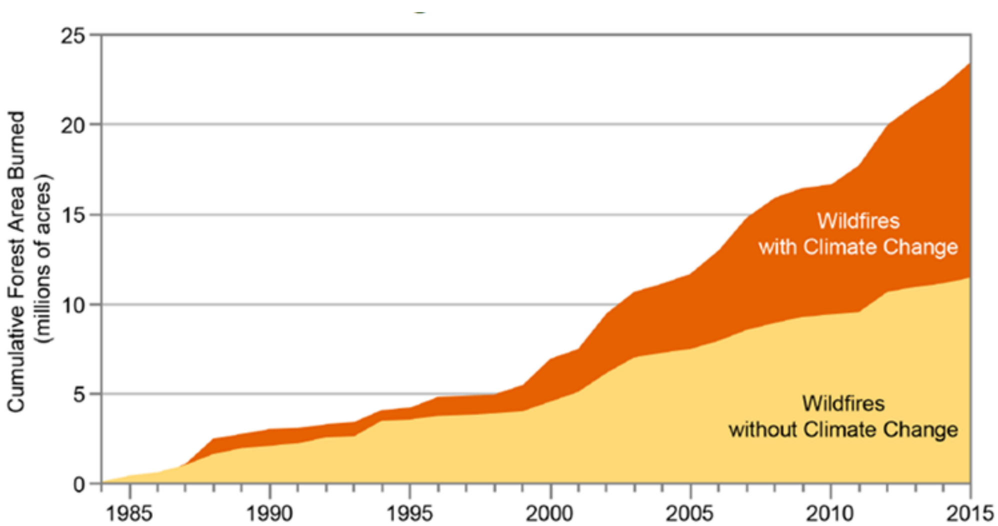

Figure 4. How climate change has increased area burned in the U.S. (from [5]).

In addition to the significant effects of natural disturbances, land-use change is a constant driver of forest changes. Deforestation[2] affects about 355,000 ha of forest land annually [6], mostly in the South and Pacific Coast regions according to that report, but recent estimates indicate more activity in the North and Rocky Mountain regions (see tables 2-5). But deforestation has been more than offset by increases in forest area from reforestation, so that the net change in forest area has been a gain in U.S. forest land of about 117,000 ha per year [1] between 2008 and 2017, largely converted from grasslands and croplands in the North and Rocky Mountain regions. The most recent data available from the National Resources Inventory (private land only) indicates that from 2012-2015, 570,000 ha were transferred from forest to non-forest land use/cover, and 920,000 ha from non-forest to forest, for a net gain in forest land of 350,000 ha or 117,000 ha per

[2] Defined as a change in land use, not necessarily a change in land cover.

year [7]. According to U.S. Forest Service data [2], the effect of land-use change on net emissions is about zero (table 1) which reflects the GHG balance between higher emissions per hectare over a very short time from deforestation, compared with a lower rate of removals over many decades from afforestation/reforestation.

It is very likely that natural disturbances and land-use change will continue to have very significant effects on the carbon balance of U.S. forests, but whether these effects will increase or decrease is difficult to predict. Based on attribution studies [8,9,10], it is likely that environmental factors including longer growing seasons and increasing concentration of CO_2 in the atmosphere are mitigating the emissions from increasing disturbances. The prospective effects of these and other factors are explored in the next section.

2. Projections of the U.S. forest sink

2.1 National projections

According to projections by USDA for the 2015 Resources Planning Act (RPA) assessment update, the forest sector[3] as depicted by the national greenhouse gas inventory (NGHGI) will continue to remove CO_2 through 2060, but at a much lower level (Figure 5). Instead of removing 600 teragrams of CO_2 annually, the sink is projected to decline by 2/3 to level off at about 200 Tg annually (300 Tg not counting land-use change) by 2060. The actual projected C sink for the future reference year is -195 Tg annually for the reference case, but see later discussion about some alternate scenarios. The main drivers of this projected decline based on the modeling approach are:

- Continuing deforestation mainly to developed land use (driven by population increase)
- Reduced afforestation as land transfers from agriculture to forest cease
- Forests growing older and slower
- Increasing harvest of wood for bioenergy
- Continuing natural disturbances

[3] The forest sector includes forest remaining forest, forest converted to non-forest, non-forest converted to forest, and harvested wood products.

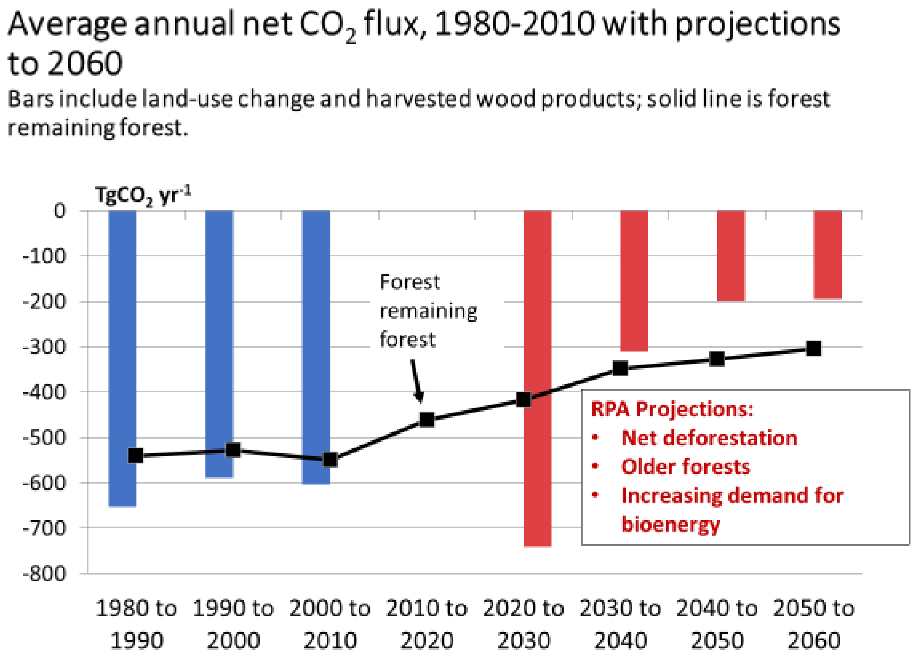

Figure 5. Average annual net CO_2 flux, 1980-2010 with projections to 2060 for the USDA reference case. Estimates represented by bars include land-use change and C in harvested wood, consistent with accounting used in the national greenhouse gas inventory [11]. Estimates represented by black line pertain only to forest remaining forest. Negative number denotes net removal (land sink).

Decomposing the effects of these different factors reveals the magnitude of the underlying causes of the projected decline (Figure 6). Land-use change, when separated from other factors, is the dominant driver of the projected decline in net CO_2 flux [11]. In the last decade or so, increases in forest area have contributed about 40% of the net CO_2 sink in forests based on inventories of C stocks. But in the projected reference case, forest area gains are expected to decline to zero while deforestation continues at historical levels; thus, net CO_2 emissions from land-use change stabilize at about 300 Tg annually beginning around 2040 [11]. Meanwhile, the CO_2 sink in forest remaining forest declines by about 37% as forests age and grow slower, according to the expected decline in net ecosystem production (NEP) that is embedded in the inventory data for different age classes[4]. The projected growth decline is accompanied by continuing current levels of disturbance from harvesting and natural causes especially fire, insects, and weather, all of which contribute to the projected decline in NEP. Because of increasing demand for wood products, the carbon sequestered in harvested wood and discarded wood products in solid waste disposal sites increases to about 150 Tg CO_2 annually, leading some analysts to conclude that the future CO_2 sink in U.S. forests will be primarily in regions where there is the most timber harvesting and as a result, the largest areas of young forests [11].

[4] However, there is reason to consider that the NEP of older forests does not decline as rapidly as depicted by the inventory data, which is interpreted as a “chronosequence” which has some inherent assumptions about substituting space for time.

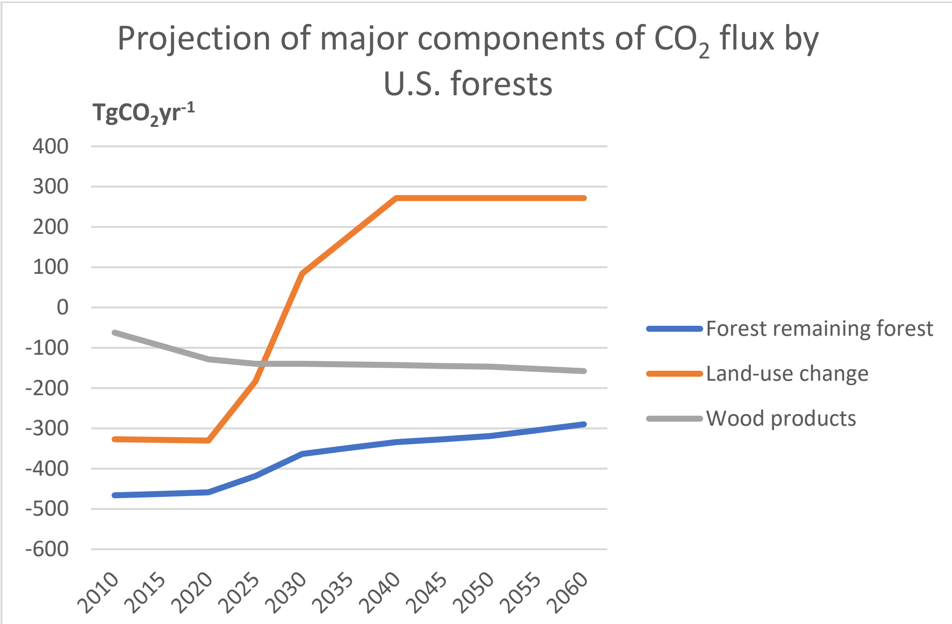

Figure 6. Projection of major components of CO_2 flux by U.S. forests, reference case [11]. Negative number denotes net removal (land sink).

One of the main drivers of increasing harvest is the projected demand for wood for bioenergy, which roughly doubles from 2010 to 2060 (Figure 7). Even with projected doubling, wood for energy accounts for only about 17% of all projected wood harvest in the U.S. Most of the projected increase comes from increased recovery of logging residues and higher amounts of mill residues associated with higher levels of harvest for pulpwood and sawtimber [12]. The impact on the carbon sink for the reference case has not been estimated, but based on the proportion of harvest for fuelwood compared with other products, the effect would be to reduce the potential CO_2 sink by about 70 Tg annually as of the reference year 2005, and about twice that for 2050.

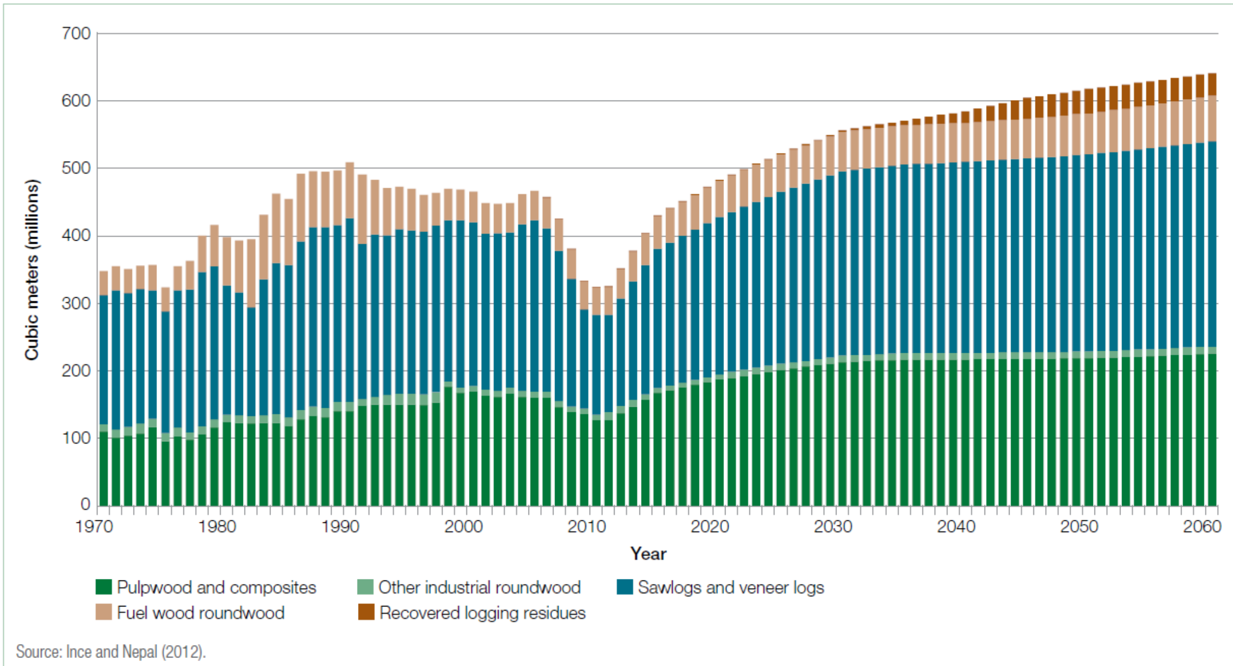

Figure 7. U.S. historical annual timber harvest volumes, 1970 to 2011, with projections to 2060. From [12] as depicted in [11]).

Besides the reference case, USDA projections were made for two alternate scenarios mainly reflecting different levels of land-use change for developed uses. The high scenario assumed that forest area continues to increase at current rates until 2020, after which forest area decreases by about 200,000 ha per year) to about 270 million ha. The low scenario assumed that forest area continues to increase at current levels through 2030, and then levels off at about 285 million ha. These two scenarios bracket the reference case regarding land-use, and highlight one of the primary causes of uncertainty in these future projections (Figure 8). Under the high development scenario, most of the CO_2 sink in forest remaining forest would be offset by increased emissions from deforestation, whereas under the low development scenario, the projected forest sector C sink would nearly double to about 300 Tg CO_2 annually, or half of the current level.

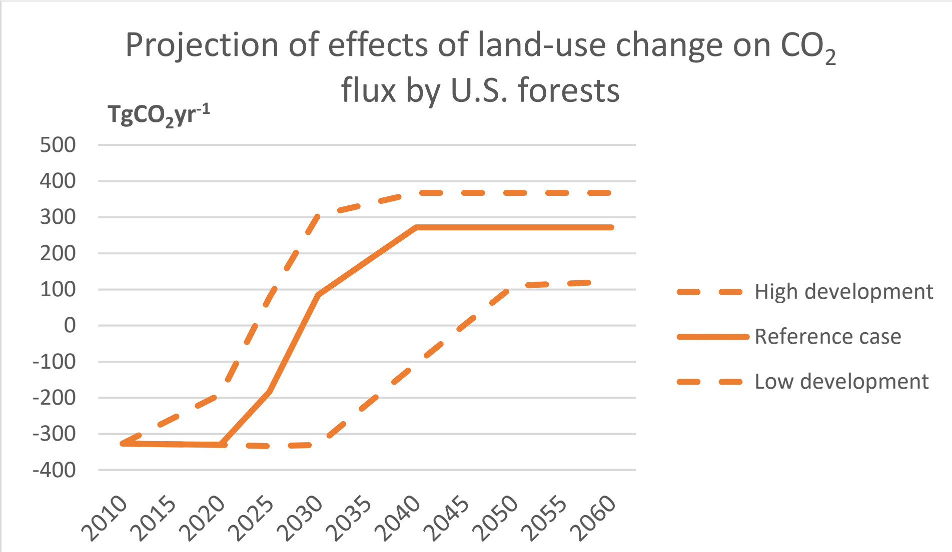

Figure 8. Projected effects of land-use change on CO_2 flux by U.S. forests for the reference case and two scenarios [11]. Estimates are composed of both emissions to the atmosphere and transfers to non-forest land-use classes. Negative number denotes net removal (land sink).

In contrast to the USDA projections, the recent State of the Carbon Cycle Report (SOCCR2) interprets the results of the NGHGI and RPA projections differently, and includes some alternate approaches to estimating the future CO_2 sink for U.S. forests [2]. Gross emissions from timber harvest are clearly shown as more than 400 Tg CO_2 annually (table 1) accounting for the largest single source of emissions from forest land. Although at first glance this might imply that stopping timber harvest would yield an immediate and large addition to the C sink, it cannot be separated from the closely related effects on the age-class distribution and associated higher C accumulation rates for many young, managed forests especially in the South and Pacific Northwest. The report identified the need to better understand the effects of changes in atmospheric chemistry and climate on current and future CO_2 flux, though some studies (see below) have attempted to assess these effects using ecosystem process models. Atmospheric enrichment from CO_2 and nitrogen deposition could increase biomass growth by 0% to 2% annually according to several studies [13,14,15]; yet, the effects of climate change are probably mixed depending on their exact nature and how natural disturbances are affected [16,17]. SOCCR2 reported that using simulations from a nine-member ensemble of coupled carbon-climate models, the potential effects of environmental and other factors by the end of the century ranged from a much larger sink than present of up to 1,500 Tg CO_2 annually, to a net source of 600 Tg CO_2 annually [18].

One modeling study [10] that is compatible with the RPA modeling approach assessed the relative contributions of disturbance and non-disturbance factors on the future forest CO_2 sink over the same projection period. Results can be directly compared for forest remaining forest, and show that accounting for environmental factors (increasing CO_2, N deposition, and climate variability) resulted in an average of 58% more CO_2 removal compared with accounting only for forest disturbance and aging effects. This is close to the estimated global CO_2 fertilization effect [10], and would result in a projected net CO_2 sink for the U.S. forest sector of -422 Tg CO_2 compared with the -176 Tg CO_2 indicated by the baseline projection of the RPA assessment.

2.2 Regional projections

Regional trends (Figure 8) reflect differences in the relative impacts of the major components of the forest sector C budget [11,20] (Tables 2 through 5). State-level estimates disaggregated from these regional projections are shown in appendix C.

Figure 8. Regions used in USDA projections of the forest sector.

Table 2. Projections of the net CO_2 flux for the forest sector, by major component, Northern Region, 2005 -2060 (Tg CO_2). Estimates from [11]. Negative number = sink or transfer to forest from other land use.

Year	*Forest remaining forest*	*Land-use change transfers*	*Harvested wood products*	*Total forest sector change in stocks*	*Total forest land area (million ha)*
2005	-151.3	-142.4	-22.8	-316.4	72.8
2010	-155.8	-149.5	-13.8	-319.1	73.6
2015	-156.4	-152.3	-21.1	-329.9	74.4
2020	-154.9	-152.3	-28.4	-335.7	75.3
2025	-153.0	-99.1	-30.9	-282.9	76.0
2030	-149.9	27.0	-30.9	-153.8	76.1
2035	-145.6	109.1	-31.3	-67.8	75.9
2040	-141.3	123.5	-31.7	-49.4	75.7
2045	-136.8	123.5	-32.1	-45.4	75.5
2050	-132.1	123.5	-32.5	-41.1	75.3
2055	-127.9	123.5	-33.7	-38.1	75.0
2060	-124.2	123.5	-34.9	-35.6	74.8

Table 3. Projections of the net CO_2 flux for the forest sector, by major component, Southern Region, 2005 -2060 (Tg CO_2). Estimates from [11]. Negative number = sink or transfer to forest from other land use.

Year	*Forest remaining forest*	*Land-use change transfers*	*Harvested wood products*	*Total forest sector change in stocks*	*Total forest land area (million ha)*
2005	-196.2	-18.4	-57.4	-272.0	103.1
2010	-236.1	-24.1	-34.8	-295.0	103.6
2015	-224.5	-25.2	-53.3	-303.0	104.1
2020	-216.4	-25.2	-71.7	-313.4	104.7
2025	-200.6	6.9	-77.9	-271.5	105.1
2030	-188.9	58.3	-77.9	-208.4	105.2
2035	-180.1	99.2	-78.9	-159.8	105.1
2040	-166.0	108.9	-79.9	-137.0	104.9
2045	-156.6	108.9	-80.9	-128.6	104.8
2050	-153.1	108.9	-82.0	-126.1	104.6
2055	-142.3	108.9	-85.0	-118.5	104.5
2060	-138.9	108.9	-88.1	-118.1	104.3

Table 4. Projections of the net CO_2 flux for the forest sector, by major component, Rocky Mountain Region, 2005 -2060 (Tg CO_2). Estimates from [11]. Negative number = sink or transfer to forest from other land use.

Year	*Forest remaining forest*	*Land-use change transfers*	*Harvested wood products*	*Total forest sector change in stocks*	*Total forest land area (million ha)*
2005	-35.5	-144.8	-3.4	-183.7	54.1
2010	-27.0	-144.8	-2.1	-173.9	54.9
2015	-24.1	-144.8	-3.2	-172.1	55.6
2020	-30.3	-144.9	-4.2	-179.4	56.4
2025	-3.5	-87.9	-4.6	-96.0	56.8
2030	26.2	-0.2	-4.6	21.4	56.8
2035	12.1	34.6	-4.7	42.0	56.6
2040	11.7	38.7	-4.7	45.7	56.4
2045	7.4	38.7	-4.8	41.4	56.2
2050	7.5	38.8	-4.8	41.4	56.0
2055	8.1	38.7	-5.0	41.8	55.8
2060	9.2	38.8	-5.2	42.7	55.6

Table 5. Projections of the net CO_2 flux for the forest sector, by major component, Pacific Coast Region, 2005 -2060 (Tg CO_2). Estimates from [11]. Negative number = sink or transfer to forest from other land use.

Year	*Forest remaining forest*	*Land-use change transfers*	*Harvested wood products*	*Total forest sector change in stocks*	*Total forest land area (million ha)*
2005	-49.2	-8.9	-19.2	-77.3	38.6
2010	-55.8	-8.9	-11.7	-76.4	38.5
2015	-75.0	-8.9	-17.9	-101.7	38.6
2020	-55.8	-8.9	-24.0	-88.7	38.6
2025	-60.5	-4.4	-26.1	-91.0	38.6
2030	-51.7	1.2	-26.1	-76.6	38.6
2035	-54.8	2.4	-26.5	-78.8	38.6
2040	-39.7	2.4	-26.8	-64.1	38.6
2045	-43.0	2.4	-27.1	-67.7	38.6
2050	-43.1	2.4	-27.5	-68.1	38.6
2055	-46.5	2.4	-28.5	-72.6	38.6
2060	-36.3	2.4	-29.5	-63.4	38.6

In the Northern region, the effects of land-use change closely follow the national trend, switching the forest sector from a significant sink to almost no sink over the projection period (Table 2). Losses and transfers of C because of projected deforestation completely offset the persistent CO_2 sink in the forest remaining forest category. Projected biomass stock in the North is expected to increase through 2030 by about 4%, then decrease by 2% by 2050 [21]. In addition to loss of forest land, demand for timber to support a growing bioenergy market is expected to play an increasingly significant role in the future.

In the South, deforestation has a similar but less pronounced effect, allowing the forest sector to remain a small sink through the projection period (Table 3). Sequestration in forest remaining forest is projected to decline slowly but still at a magnitude much greater than the loss of C from land-use transfers [20]. Increasing C stocks from forest growth are significantly greater than losses from disturbances (including harvesting) since forests recover very rapidly in this region, though there is a gradual slowing of growth projected as forest age [22].

In the Rocky Mountains, in addition to the strong land-use change effect, forest carbon suffers significant losses from forest aging and natural disturbances, so that the forest sector becomes a small net source of CO_2 to the atmosphere beginning as soon as 2025 (Table 4). Recent disturbance rates are high relative to historical levels, and it is expected to take decades for recovering forests to reach their productive capacity. Coupled with undisturbed forests that are getting old, forests of the Rocky Mountains are expected to remain a carbon source for at least several decades [20].

In the Pacific Coast region, land-use change has only a very small effect, allowing the forest sector there to remain a small sink through the projection period (Table 5). Declines in forest area are expected to diminish substantially in the future, while aging forests coupled with natural disturbances and harvesting result in slow but steady net growth [20]. However, in this and other regions, changing environmental conditions could have a significant effect on growth. For example, [23] analyzed the projected effect of warming and increasing CO_2 in Oregon, and found a 32−68% increase in net carbon uptake by 2100, overshadowing increased carbon emissions from projected increases in fire activity and other forest disturbance factors.

2.3 Summary and conclusions – the U.S. Forest CO_2 Sink

There is good consensus from different studies that the CO_2 land sink in the U.S. is about -600 Tg annually, mostly in the forest sector, which offsets about 13% of GHG emissions from other sectors. However, there is significant uncertainty about the persistence of this sink at the current level. Estimates that are compatible with commonly accepted accounting rules and guidelines, and with the most comprehensive U.S. forest assessments, suggest that the carbon sink as of 2060 will likely decline to between -52 and -588 Tg CO_2 annually, depending on the impact of several factors. Land-use change seems to be the most prospectively influential, ranging from estimated emissions plus transfers of 121 to 367 Tg CO_2 annually. Besides this, the impact of environmental factors, including increasing atmospheric CO_2, N deposition, and climate variability could increase the national average CO_2 sink by as much as 246 Tg CO_2 annually (but with significant regional variability). The future occurrence and severity of natural disturbances is largely unknown but potentially significant – in these projections, natural disturbances were assumed to be constant at recent levels. Finally, changing demand for timber products, especially wood biomass for pellets, could have an effect on the magnitude of future harvests.

Considering all influencing factors and estimates of uncertainties, the past and future carbon sink in in the U.S. forest sector is shown in table 6.

Table 6. Summary estimates of the past and projected forest carbon sink with range of values based on quantitative (for 2005) and qualitative (2030 and 2050) uncertainty methods, for selected years (Tg CO_2). Fluxes from land-use change and harvested wood products not included. Projected ranges reflect the uncertainty of the quantitative estimates for 2005, plus future scenarios of environmental impacts (increasing CO_2, N deposition and climate change) and natural disturbances.

Year	***Low estimate***	***Reference case***	***High estimate***
2005	-330	-600	-870
2030	-200	-400	-600
2050	-100	-300	-500

In this section, no consideration was given to implementation of policies to mitigate climate change, which could alter the projections considerably. In the next section, the potential impact of mitigation activities is explored in depth.

3. Technical mitigation potential for the forest sector

The National Academy of Sciences study "*Negative Emissions Technologies and Reliable Sequestration*" [24] assessed mitigation potential for the forest sector of the U.S. and globally. The range of estimates for the U.S. in that consensus report are shown in table 7. The total mitigation potential for all activities combined ranged from 0.45 to 1.6 Pg CO_2 per year including reducing deforestation which was not considered a negative emissions technology in that report. This range is similar to that published in a more recent study led by the Nature Conservancy (TNC) [25] that estimated a range of 0.9 to 1.6 Pg CO_2 for the U.S. Land constraints were similar in both studies, though the specific details of the mix of practices were slightly different, and more weight was given in the NAS study to traditionally low rates of adoption by land managers (hence the lower bound is lower in the NAS study). These differences are addressed later in this section where a new set of estimates is presented. Generally, the estimates in table 7 are at the low end of most published estimates because the NAS committee gave significant weight to constraints such as availability of land for afforestation, conflicts with water supply, and inability to reach the millions of forest landowners to influence management practices. Land area required for the low estimate of reforestation was estimated to be between 3 and 4 million ha, and for the high estimate, between 16 and 20 million ha. Improved forest management would require changes on 11-19 million ha of existing forest for the low estimate, and 70-90 million hectares for the high estimate. The report noted that the cost of meaningful levels of forestry mitigation were low compared to most other mitigation options at less than $50 per ton of CO_2.

Table 7. Estimates of potential negative emissions from forestry activities in the U.S., $PgCO_2/y$ [24].

Activity	*Low estimate*	*High estimate*	*Area needed (million ha)*
Reforestation[1]	0.15	0.4	3-20
Improve forest management	0.1	0.2	11-90
Increase retention of C in harvested wood (frontier technology)	0.1	0.7	
Reduce deforestation[2]	0.1	0.3	5-15
Total all activities	0.45	1.6	

[1]Here we use the term "reforestation" to describe conversion of land from non-forest to forest on areas that were once forest, excluding areas with temporary loss of forest cover because of harvesting or natural disturbance.
[2]Not included in NAS report, but estimated here to present a more complete set of the forest sector options.

The study did not include emissions reductions from avoided deforestation which were noted as potentially very significant and rapidly achieved, nor did it go into specific forest management activities within the broad category of "improved forest management". The report identified several categories of modified forest management that could result in increased sequestration: accelerated regeneration of non-stocked forest after disturbance which increases carbon removal in the near term; restoring degraded forests to healthier and more productive conditions that maintain removal capacity; and extending the rotation length (age of forest at harvest) which maintains removal capacity, avoids emissions associated with wood harvest, and directs more biomass into long-lived wood products that store harvested carbon.

3.1 Reforestation[5]

The area of forest land in the U.S. has been increasing at about 0.4% annually in recent years, and now total about 310 million ha. This increase reflects a greater area of reforestation (307,000 ha/yr) than deforestation (190,000 ha/yr), based on data for nonfederal lands only [7]. There are significant regional differences, with larger changes taking place in the Northern and Rocky Mountain Regions compared in the Southern and Western Regions. Although statistics about the gross changes representing all forest land are not published in Forest Service reports (only the net changes are reported), the National Resources Inventory (NRI) reports detailed land-use transition estimates for non-federal lands by State, and these estimates comprise a large proportion of the areas that are changing categories because of land management. According to the most recent NRI, about 67% of the new forest land came from pastureland and rangeland categories, and an additional 17% came from Conservation Reserve Program (CRP) lands.

Estimating the potential to remove CO_2 by reforesting land requires identifying the area of land that could be available for conversion from non-forest land use, above and beyond the projected baseline area of reforestation. As described earlier, the projected baseline for land-use change represents a decline to a very low level of reforestation compared with the current 307,000 per year, so we could assume an upper limit to the area available for additional reforestation to be the land that is considered "marginal" for food production and having low value for biodiversity. Unfortunately, the concept of "marginal" land is poorly defined, and most analyses defer to information based on actual land management decisions to identify potential reforestation land areas.

Two sources of such information are the periodic NRI which takes account of land enrolled in set-aside programs such as the Conservation Reserve Program (CRP), and the periodic survey of major land uses in the U.S. conducted by the Economic Research Service which includes a specific category of land designated as "idle", which is mostly land enrolled in CRP and similar programs, and is an indicator of land that could be considered marginal. According to the NRI, CRP land remaining in the CRP program averaged 307,000 ha/yr between 2012 and 2015. In this same period, 824,000 ha/yr were transferred from CRP to cropland and pasture use, and 52,000 ha/yr were transferred to forest and presumably will not return to food production. With carbon price incentives, it is likely that some additional CRP land would be converted to forest. Another estimate according to the Economic Research Service indicates that the area of idle cropland over the last decade or so has averaged about 16 million ha/yr [26] (Figure 9). This is about half of the peak area enrolled in acreage-reduction programs in the 1980's. Here we use the estimate of annual average cropland that is idle in recent years (16 million ha/yr) as an estimate of the maximum cropland area that could be reforested without impacting food supply, and half this (8 million ha/yr) as the low end of the range which represents the area of idle cropland from the 1970s. We consider these estimates to be "additional" compared with a baseline that is close to 0 since most idled cropland is temporarily converted to non-forest cover

[5] We adopt the IPCC definition: "Reforestation" is the direct human-induced conversion of non-forested land to forested land through planting, seeding and/or the human-induced promotion of natural seed sources, on land that was forested but that has been converted to nonforested land.

rather than forest cover. This range is significantly higher than the 5.1 million ha/yr estimated by TNC [25].

In addition to the areas of idle cropland, areas of marginal pasture use and possibly areas currently devoted to corn ethanol production could be converted to forest. To estimate the area of marginal pasture (and other marginal lands) potentially available for reforestation, the TNC [25] developed a novel mapping approach. Beginning with a map of historical forest occurrence, they applied a series of filters to remove areas that were already forested or had other higher priority uses, mainly developed land, areas needed for food and fiber production, and biodiversity lands. They estimated an area of 1.3 million ha could be reforested without impacting livestock production, though they also include a higher estimate of 17.5 million ha that would require significant shifting of diet away from meat consumption.

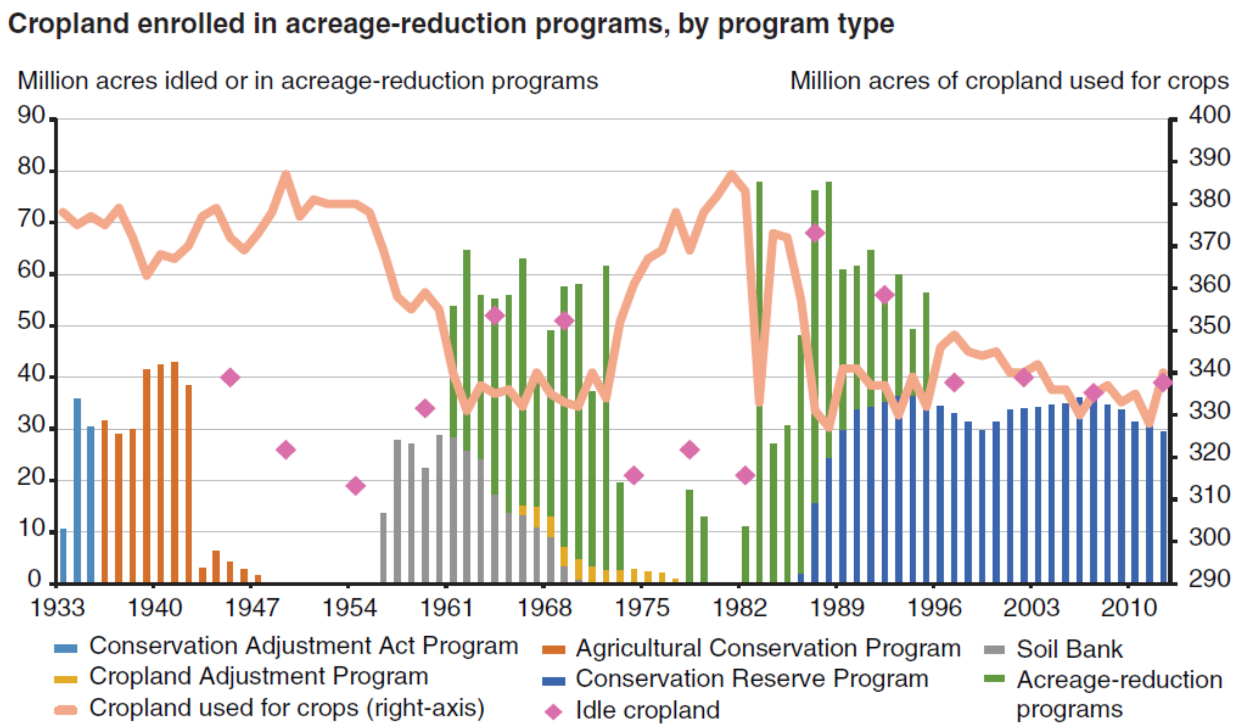

Figure 9. Cropland enrolled in acreage-reduction programs, by program type. Note that units are in acres not hectares (from [26]).

All told, estimates of the total land area available for reforestation are 62.9 million ha, or 79.0 million ha with the higher area of potential pasture conversion [11]. Considering other uncertainties, the range of estimates they used was from 34 to 94 million ha. These estimates include a substantial area of temporarily deforested forest land, which we include later in the category of forest management since this potential "reforestation" actually occurs on land that would be considered "forest remaining forest" in the U.S. GHG inventory.

Here we use a tighter range of area estimates that include a larger area of idle cropland, and exclude temporarily deforested forest land. Table 8 summarizes the area estimates we use for potential reforestation of non-forest land. The middle of the range of total area is 21.4 million ha, which has an uncertainty of about ±9.8 million ha (95% confidence interval) based on the range of published estimates reported by TNC [25].

Table 8. Estimated area and annual CO_2 removal from potential reforestation of non-forest areas.

Non-forest land use	*Low estimate ($TgCO_2/y$)*	*High estimate ($TgCO_2/y$)*	*Low estimate (million ha)*	*High estimate (million ha)*
Cropland	121	242	8.0	16.0
Pasture	20	264	1.3	17.5
Total	141	506	9.3	33.5

We did not consider here that the area of corn ethanol production could be instead converted to producing forest biomass. But because of the incentives currently in place to encourage the ethanol industry, we simply note that this land is another potential source of land for planting trees or other crops for bioenergy feedstock. This will be addressed later in the bioenergy section of this report.

To estimate removal potential, TNC [25] calculated an average sequestration rate for the U.S. of 1.33 Mg C/ha/yr based on estimates previously reported by the Forest Service [27]. These estimates represent the average annual sequestration rate over the first 20 years of stand establishment for fully stocked stands, are based on forest inventory data, and are specific to forest type and region. The estimate is a weighted average over the areas identified by TNC which as noted above, represents a different area than this report since we excluded forest remaining forest and included more cropland. Also, the TNC estimate deducted half of the sequestration rate for conifer forests to account for the albedo effect, which we think is an inappropriate deduction given that we are using GHGs as the main indicator in this report, not some other measure associated with warming, which is based on unsettled science of assessing albedo and other biophysical effects of land cover on climate.

Based on these considerations, we recalculated an average sequestration rate for U.S. forests by querying the national forest inventory database and selecting forest plots of age 0-10 and 30-40 (to target the 2020-2050 time period); selecting all forest plots vs. a subset of fully stocked and higher productivity plots; and estimating the average C stock for the two age groups. We subtracted the two estimates by age group to arrive at average annual sequestration rates ranging from a low of 1.85 ± 0.04 to a high of 4.11 ± 0.08 MgC/ha/yr[6]. The low estimate includes areas that are poorly stocked or overstocked with trees, and average site productivity across all forest lands. This estimate is probably too low since it is based on forest areas rather than crop and pasture areas that would be targeted for reforestation and that tend to have higher productivity. The high estimate includes only forest lands that are well stocked with trees and have an average productivity of at least 85 cubic feet/ac/yr, which more realistically represents the areas that are likely to be reforested. We used this latter estimate to calculate potential CO_2 removal from reforestation.

[6]Uncertainty represents the sampling error only, and not the bias associated with incorrect weighting of the estimated sequestration.

Combining the low and high estimates of area with the higher sequestration rate, we estimate that the potential CO_2 removal from reforestation is from 141 to 506 $TgCO_2$ per year. This is similar to the estimates of 150 to 400 $TgCO_2$ per year estimated by the NAS study, and 90-777 $TgCO_2$ per year reported by TNC [25]. Relative to the previous estimates, these new estimates involve much less land area because they only pertain to cropland and pasture while excluding forest remaining forest, and the estimates use higher average rates of sequestration on these lands because of their higher productivity and our decision to focus on GHGs and not deduct for warming potential.

3.2 Improve forest management

The extent of opportunities and GHG reduction from forest management activities is among the least well quantified mitigation activities of the forest sector. This is because of the many different types of forest management practices occurring in highly diverse ecological and economic circumstances, estimates that are small in comparison to reforestation and other activities, the large areas involved, and the difficulty of estimating how many of the millions of forest land owners might participate.

Here we partition improving forest management into 4 mutually exclusive categories as depicted in table 9. We are focused on forest land remaining forest, excluding urban trees and other "trees outside forests". Forests older than 100 y are excluded because of their high C stocks, relative scarcity, and biodiversity values.

Table 9. Forest management activities and their characteristics.

Activity	***Age range***	***Stocking %[1]***	***Description***
Accelerate regeneration	n/a	<10	Regeneration of nonstocked forests is often lagging and can be accelerated by seeding, tree planting, and/or competing vegetation control.
Restore productivity of degraded forests	20-100	Between 10 and 60; and >100	Silvicultural treatments may be applied to forests that are either under- or over-stocked in order to improve productivity commensurate with inherent site productivity.
Extend rotation lengths	20-100	60 to 100	Allowing forests to grow older before harvesting timber delays emissions of stored carbon from harvest operations.
Improve productivity of plantations	All	All	Silvicultural techniques, tree breeding, and genetic improvements can increase the growth rates of plantation species.

[1]An indicator of the stocking by trees relative to that considered "normal" for the site and species. Inventory categories are: nonstocked = 0-10; poorly stocked = 10-35; medium stocked = 35-60; fully stocked = 60-100; overstocked = >100. Here we use the term "understocked" to represent poorly stocked + medium stocked.

Accelerate regeneration

A recent study [28] identified 8 million ha of nonstocked forests in the U.S., with the largest areas located in the Rocky Mountain and South Central regions. Most of this land is nonstocked following natural or human disturbances – fire is the most common disturbance (62% of total area) that is followed by poor regeneration. Much of the nonstocked area will not regenerate quickly without assistance by seeding, planting, competing vegetation control, or prevention of grazing. Some of the nonstocked forest area may no longer be capable of supporting forest because of changing climate conditions, and some may regenerate to adequate stocking levels without assistance. Estimates of the extent of these conditions are not currently available. Overall, this study [28] estimated a potential additional C sequestration for accelerated regeneration of 48.9 Tg CO_2/yr, which may be considered a technical potential. Since some areas are too remote for practical assisted regeneration, and not all landowners would participate, we assume that half of this estimate is a lower bound of potential, about 24.5 Tg CO_2/yr.

Restore productivity of degraded forests

Here we define degraded forests in terms of stocking compared with that considered "normal", following the approach taken by the Forest Service [29]. We also restricted stand age to the middle ages that represent most forest land in the U.S. and avoid the youngest and oldest forests that may not be ideal for restoring productivity because of other management considerations. For the analysis, forests that are between 20 and 100 years old and have stocking between 10 and 60% are defined as "understocked", and those that have stocking greater than 100% are considered "overstocked" (table 9). The stocking of understocked forests may be increased by planting trees in areas lacking them or by removing non-tree vegetation that is preventing natural regeneration. The stocking of overstocked forests may be decreased by removing trees that are in poor health yet still alive and of low productivity. In both cases, the amount of increased productivity from approaching a normal stocking level represents an annual gain in carbon sequestration as a result of the management activities. As described here, these activities are simplifications of forest restoration practices, which in fact may be much more complex and diverse due to ecological conditions and land management objectives. Practices may involve changes in species composition, using prescribed fire to control understory vegetation or maintain fire-resistant species, harvesting species that are not suitable for the site, preventing disturbances such as grazing, and soil amendments.

For the purpose of this analysis, we do not distinguish among the many possible management practices and ecosystems, but simply calculate the productivity gains that are possible from returning understocked or overstocked forests to a normal stocking range of 60-100%. The net gain is calculated from the FIA database as the difference between the estimated net ecosystem productivity (NEP) of over- or under-stocked sample plots and those having a normal stocking range.

Results indicate that the maximum potential mitigation benefit from increasing the stocking of understocked forests could be as high as 170 TgCO_2/yr on 100 million ha. As with accelerated regeneration, a large proportion of this area would be too remote for assisted stocking control, and some areas would increase stocking naturally, so that a lower bound estimate is more like 1/3 of the total potential, or 57 TgCO_2/yr on 33 million ha. The potential mitigation benefit from decreasing the stocking of overstocked forests could be as high as 10 TgCO_2/yr on 8 million ha. Similarly, a lower bound on this estimate is more like 1/3 of the total potential, or 3 TgCO_2/yr on 2.7 million ha.

Extend rotation length

One popular option for changing forest management is to extend the rotation length, or the age at which a stand of trees is harvested. This approach has two benefits: delaying the net emissions from the ecosystem from harvesting, and allowing trees to grow larger which often means that more of the harvest wood products are longer lived (and higher value), which reduces emissions from the harvested wood carbon pool. Middle-aged stands that are approaching harvestable size would be the target of this activity.

The TNC study [25] performed an extensive analysis of extending harvest rotations of private forests by 25 or more years, and of intensively managed plantations by 5 to 20 years. They estimated a maximum mitigation potential of 267 Tg CO_2/yr with a range from 232-302 TgCO_2/yr. We adopt these estimates here, but note that the impact on timber supply and the private sector would be very significant and that this would very likely reduce participation by private companies and individuals. Also, any reduction in timber supply within the U.S. would be at least partially offset by imports or by other building materials especially concrete, steel, and aluminum, all of which have significantly higher emission than comparable wood products. This "substitution effect" was not calculated as part of these estimates. For these reasons, we use only half of the estimated lower bound here, or 116 TgCO_2, as a more likely yet still ambitious estimate.

Improve productivity of plantations

There are about 20 million ha of forest plantations in the U.S., mainly in the South and Pacific Northwest [30]. Forest plantations are more intensively managed than forests of natural origin, and planted tree species and genotypes, mostly conifers, have been selected for traits such as fast growth and resistance to pests. History has shown that it is possible to significantly increase plantation productivity. Over the past 50 years in the South, productivity of pine plantations has been nearly 3 times that of natural pine forests because of silvicultural practices such as site preparation, weeding, and fertilization, and use of genetically improved planting stock [31]. Additional gains from genetic engineering is also possible but has not been practiced widely. There are significant constraints on achievable productivity increases such as inherent site quality associated with climate, soil, and topographic characteristics. Plus, evidence from the South indicates that even with the best management practices, plantations rarely reach their theoretical maximum productivity because of various biotic and abiotic factors [31].

Here we make a modest assumption that forest plantation productivity could be increased by an average of 30% over a decade, which is well within the effect of historical observations. Currently. The average productivity of forest plantations in the U.S. (all C pools combined) is estimated to be $2.47 \pm .07$ tons C/ha/y based on measurements at a chronosequence of more than 12,000 inventory plots. A 30% increase would raise this to 3.21 tons C/ha/y. Applied to almost 21 million ha of existing forest plantation, the total gain in annual CO_2 sequestration would be 56.9 Tg CO_2/yr. Considering the likelihood of incomplete adoption of techniques to improve productivity, a reasonable lower bound could be half of this amount or 28.5 Tg CO_2/yr.

Increase stocking of trees outside forests

Increasing stocking of trees outside forests is possible on many areas of land that has tree cover or could have more tree cover, but do not qualify as "forest" according to most land class definitions including that of FIA. Typically, if the land has another use that is primary, such as urban (or "settlement"), cropland, or grazing land, that land will be classified in an appropriate non-forest category. Recent estimates of the opportunities for increasing the stocking of trees outside forests are few, but the TNC included estimates for two categories of land where stocking and C sequestration of trees outside could be increased: urban land and windbreaks. Estimates of the area of these lands where tree stocking could be increased range from 3.0 to 5.7 million ha, and the potential additional C sequestration ranges from 21 to 60 Tg CO_2/yr. Inclusion of other nonforest land categories or practices such as more agroforestry options could increase these estimates.

3.3 Summary of forest management opportunities

Based on the previous analyses, improved forest management could result in increased C sequestration of about 250 to 644 Tg CO_2/y (Table 10). These estimates are significantly higher than reported in the NAS negative emissions study, which indicated only 100-200 Tg CO_2/y would be feasible. The main reasons are much higher estimates for extending rotations from the TNC study [25] and the inclusion of improved productivity of plantations and increased stocking of trees outside forests, which were not explicitly considered in the NAS study. Extending rotation lengths and improving productivity of degraded forests have the greatest potential. Since these practices could be applied to existing forest land, competition for land needed for food production is not a factor affecting adoption of these approaches; however, the large area of land that would need improved management and the diverse ownership means that adoption rates would be less than needed to attain the high estimate. There could also be impacts on biodiversity, though these would likely be very modest since treatment opportunities would mostly be applied to existing forests with stand ages in the middle-aged range, or to plantations that are already considered to be monocultures.

An important caveat to this analysis is that the estimates represent expected results after an initial period of ramping up that would have a lower rate of increase during the activity initiation period, which could be 10 or more years. However, by 2030 or so, treatments could be applied and results achieved over the following 20 or 30 years before increases in CO_2 removal begin to fade, or before treated forests would have a higher likelihood of becoming affected by timber harvest or other disturbances. Although some of the activities in table 10 are related, they are essentially mutually exclusive.

Table 10. Summary of forest management opportunities to increase C sequestration (Tg CO_2/y).

Activity	Low estimate	High estimate	Low area (Mha)	High area (Mha)
Accelerate regeneration	24.5	48.9	4.0	8.0
Restore productivity of degraded forests	60.0	178.0	35.7	108.0
Extend rotation lengths[1]	116.0	302.0	59.0	154.0
Improve productivity of plantations	28.5	56.5	10.5	21.0
Increase stocking of trees outside forests	21.0	60.0	3.0	5.7
Total	250.0	644.4	112.2	296.7[2]

[1]Some of this area overlaps with areas of other activities, particularly restoring productivity of degraded forests. However, the two activities can be independently implemented on the same areas, so this would only affect the area estimates and not the C sequestration estimates.
[2]This is nearly the total area of U.S. forests (310 Mha).

3.4 Increase retention of C in harvested wood

The NAS study of CDR considered "Increased Use and Preservation of Harvested Wood Products" to be a "frontier technology" in the forest sector since it has not been studied extensively nor has it been applied in small-scale studies. The main climate benefit of increasing the use of harvested wood products has typically been described as emissions reductions from the substitution of wood products for materials such as concrete and steel that require more fossil fuels for production [32,33]. However, increasing the preservation of harvested wood could also be a significant CDR approach. One study [34] proposed harvesting live trees and other biomass from managed forests and burying the logs in trenches or otherwise storing them to prevent the carbon from being released. Improving the preservation of wood products from existing harvest operations, and potentially increasing harvest with high levels of product preservation, could be viable approaches to increasing CDR.

Most (about 75%) of the biomass removed from forests for timber products is emitted during the production process and initial years of use [35]. After the end of their useful life, wood products are typically deposited in landfills that are often designed for relatively rapid decomposition, or subject to other fates such as deposit in dumps that emit their stored C [36]. If most (up to 80%) of wood products and associated wood wastes from current harvests were placed in a landfill designed for slow decomposition, then this would create an additional sink of 100 to 300 Tg CO_2/yr in the US which could be extended indefinitely as long as such landfills continued to be constructed. Preservation of currently harvested wood plus increasing harvest of secondary forests to use all available growth (sustainable harvest) has the capacity to remove a total of 100 to 700 Tg CO_2 annually in the U.S. This could be accomplished without involving protected or intact forests, or affecting food supply or biological diversity. However, increasing wood harvest would conflict with the forest management activity of increasing the rotation length, so these two are not mutually exclusive, and so increasing harvest is not included in the summary table 10. However, in application, having both as alternatives would increase the likelihood of adoption since they would comport differently with other objective, mainly timber production and preservation of land and existing C stocks. These estimates are more or less in line with another study [37], which estimated that the global potential of green-tree burial was between 1.0 and 3.0 Pg CO_2 per year, with the lower end of this range representing roughly doubling the current global harvest and affecting about 800,000 hectares of forest land. They excluded agricultural land, protected areas, inaccessible forests, and wood used for other purposes such as timber and paper. To date, this proposed approach has not been tested though the technology is relatively simple and easily applied.

A related approach involving wood products would be to shift the product mix to more durable and long-lived products such as lumber, plywood, or mass timber, and away from short-lived products such as pulp. Besides increasing the time before release of the stored C (in the absence of increasing retention as described above), longer-lived wood products have substantial benefits from substitution for other types of similar products. Although the benefits of shifting product mix have not been well quantified for the U.S., a few studies indicate the magnitude of the potential. A recent study [38] estimated that the potential gain (including displacement of other products) from a 10% shift of products from pulp to sawtimber at two U.S. landscapes increased retention of C plus displacement of other products that totaled about 10 TgC over 40 years. Scaled up to represent the level of all harvest in the U.S. (about 13 billion cu. ft.) yields an approximate mitigation benefit of about 15 TgC per year.

3.5 Avoid deforestation

The TNC [25] estimated that deforestation from 2000 to 2010 of an average annual area of 380,000 ha emitted about 14 TgC per year from loss of above-ground biomass, accounting for the proportion of harvested biomass retained in wood products. Their area estimate was derived from the North American Forest Dynamics data set by eliminating all temporary losses of forest cover and concentrating on those areas that were converted to another land use after loss of forest canopy. The area estimate compares well with one other published estimate of 355,000 ha for about the same time period [6]. However, the estimated emissions from deforestation are significantly lower than other estimates, particularly one assessment [2] (84 TgC per year) which closely follows the methods used in the U.S. EPA GHG inventory and accounts for all C pools, not just biomass; estimates a higher proportion of biomass loss from deforestation; adjusts for transfers of C from forest to other land uses (the stored C is not emitted); and includes only the CO_2 that is emitted to the atmosphere. Here, we use these two estimates to represent the lower and upper bounds of the past impact of deforestation, and consider that it is technically feasible to completely halt deforestation in the U.S., though it is not very likely given the strong pressures to convert forest land to other uses particularly nears expanding urban centers, and because land-use decision are typically made at smaller jurisdiction scales by many different actors.

4. The potential supply of woody biomass from U.S. forests

Availability of biomass feedstock is a critical issue when assessing the potential role of BECCS to mitigate climate change, and a very wide range of values are available in the literature. High uncertainties associated with land availability, energy crop yields, and the future availability of waste, forest wood, and residues from forestry and agriculture are the main reasons for this wide range of values [39] (Slade et al. 2014).

Sources of biomass from forests include logging residues, whole-tree harvests, and other wood wastes (mainly sawmill and urban wood waste). Currently, 44% of biomass feedstock comes from forests, 332 Tg/y of biomass (Table 11). This is very close to the economically feasible quantity, yet only 40% of the technically feasible quantity. Future sources from forests do not exceed the current technical or economically feasible quantities, assuming that no new forests are established specifically for producing biomass feedstock.

Table 11. Estimated annual dry biomass potential and equivalent CO_2 flux (Tg/y) (reproduced from [24]. The CO_2 fluxes summarized here assume that the total carbon content of the biomass is sequestered.

Source	Current Use	2017				2040			
		Technical Potential		Economically Feasible		Technical Potential		Economically Feasible	
	Biomass	Biomass	CO_2 Flux	Biomass	CO_2 Flux	Biomass	CO_2 Flux	Biomass	CO_2 Flux
Agricultural Byproducts	**130**	**154**	**269**	**125**	**218**	**219**	**382**	**195**	**339**
Agricultural residues	—	106	185	94	164	171	298	161	280
Agricultural wastes	—	48	84	31	54	48	84	34	59
Energy Crops	**0.087**	**503**	**875**	**—**	**—**	**503**	**875**	**373**	**649**
Switchgrass	—	—	—	—	—	—	—	146	254
Miscanthus	—	—	—	—	—	—	—	145	253
Biomass sorghum	—	—	—	—	—	—	—	17	30
Energy cane	—	—	—	—	—	—	—	0	0
Non-coppice	—	—	—	—	—	—	—	41	71
Coppice	—	—	—	—	—	—	—	24	41
Forestry	**132**	**332**	**609**	**124**	**228**	**332**	**609**	**122**	**225**
Logging residues	—	43	78	16	30	43	78	19	35
Whole-tree	—	143	263	64	117	143	263	55	102
Other wood wastes	—	146	268	44	82	146	268	48	88
Organic Waste	**36**	**259**	**240**	**259**	**240**	**309**	**286**	**309**	**286**
Municipal solid waste	30	203	166	203	166	242	198	242	198
Construction & demolition	—	46	68	46	68	54	81	54	81
Sewage & wastewater	6	10	6	10	6	12	7	12	7
Total	**298**	**1248**	**1993**	**508**	**686**	**1363**	**2152**	**999**	**1499**

Source: Based on [40,41].

On forest land, annual biomass production exceeds current harvest by about 70% [42] or 225 million dry tons per year. Some of this could be harvested for biofuel, although this would reduce the forest carbon stock and sink strength, and therefore the CDR benefit would be correspondingly reduced unless emissions from combustion were fully captured. But on forest land that is currently harvested, there is a significant amount of logging residues that is not currently utilized, and this is readily available for increasing biofuel supply. As described in part 2 of this report, economic projections indicate a steady increase of bioenergy from forests, including significant increases in both roundwood harvest and utilization of logging residues.

Assuming that the total C content of woody biomass is captured and stored, and that there are no GHG emissions associated with harvesting, transporting, and process the biomass for fuel, the range of CO_2 removal from the atmosphere is between 228 (economically feasible) and 609 (technically feasible) $TgCO_2$/y (table 11). Note that increasing the use of live wood for bioenergy is not mutually exclusive of other forestry activities; however, increasing the utilization of wood waste is mostly independent of other activities. If only considering the increased use of logging residues and other wood waste, then the estimated additional sequestration from woody biomass would be between 112 and 346 $TgCO_2$/y (table 11)[7]. Without carbon capture and storage, many studies have concluded that increasing the harvesting of live trees for bioenergy results in higher emissions; net emissions reductions without CCS can be achieved in a few years only if waste wood that would otherwise quickly lose its stored C to the atmosphere is burned in place of a fossil fuel source, assuming that transportation emissions are low [38,43,44].

One of the more promising and potentially productive options would be to grow energy crops on land that is considered “marginally productive” for crops. There is a significant amount of marginal land that could be converted to energy crops without affecting production of other commodities. There is no generally accepted definition of marginal land (it is an economic decision that varies over time) nor it’s extent, but a good indicator is the amount of farmland enrolled annually in the Conservation Reserve Program, which typically exceeded 8 million ha annually before the program expired [45]. However, productivity of woody crops is typically less than other crop types, indicating that if land is converted to bioenergy production, the other crop types would be favored over trees. Furthermore, annual or perennial non-woody crop types can be genetically engineered to increase productivity, and the projected amounts of biomass available from non-woody crops (Table 12) include annual increases in productivity.

[7] Recent increases in the amount of mortality from western wildfires, insects, and drought may have increased the availability of “other wood wastes”.

Table 12: Productivity of selected bioenergy crops by region (metric tons/ha)[1]. Reproduced from [24].

Crop Type/Species	Northeast	Southeast	Delta	Corn Belt	Lake States	Plains States
Perennial grasses	9.0–16.8	7.8–21.3	6.7–15.7	9.0–15.7	1.8–11.2	4.5–14.6
Woody crops	11.4	11.2–12.3	—	7.8–13.4	7.8–13.4	7.8–13.4
Switchgrass	10.3–16.4	10.5–20.8	13.7–21.3	12.3–19.5	6.0–7.4	3.8–19.9
Poplar	9.9–13.2	9.0–14.8	10.5–14.6	10.3–15.0	8.3–13.0	5.8–12.5
Willow	8.5–16.4	8.5–16.8	10.8–12.5	8.7–18.4	8.3–15.9	3.1–13.9
Miscanthus	14.3–20.4	13.0–19.3	16.1–23.1	17.7–25.1	11.9–23.5	8.5–25.1

[1]From [40,41]

The availability of biomass for fuel is unevenly distributed across the U.S. A study led by the Department of Energy [46] developed maps of used and available biomass (excluding live trees) – these maps were slightly updated and made available online [47]. Figure 10 shows the spatial distribution of solid biomass resources. The associated state-level data is available [46]. Additional maps are reproduced in Appendix B to this report.

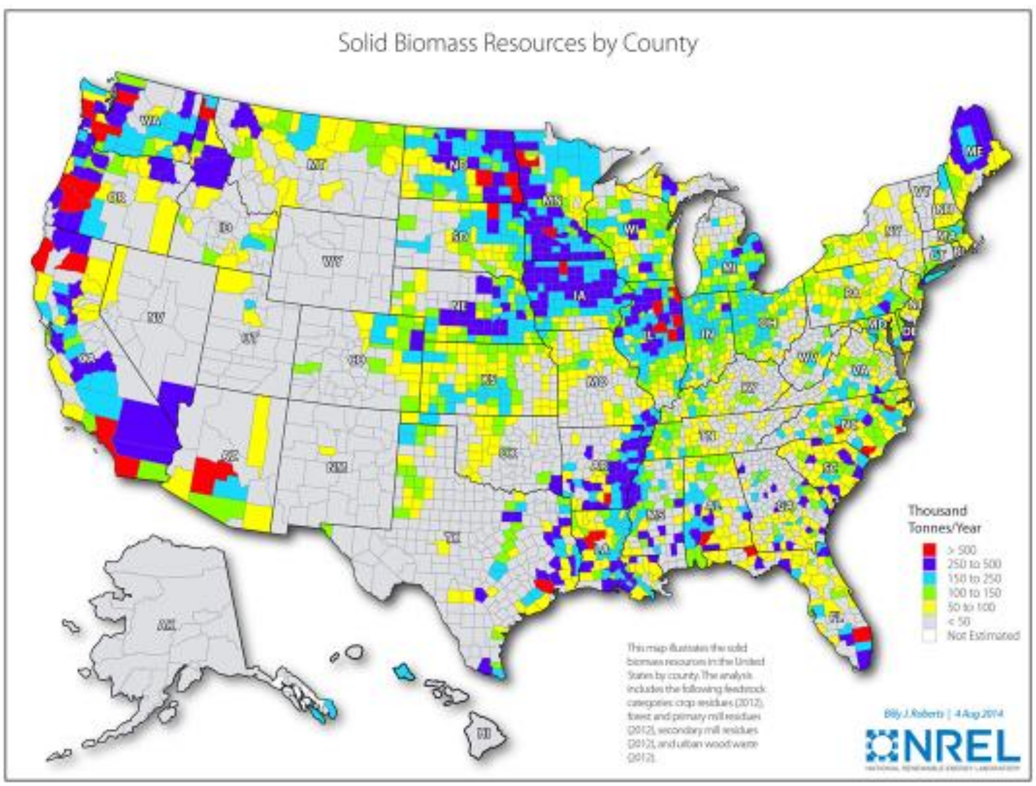

Figure 10. Solid biomass resources by county. Includes crop residues, forest and mill residues, and urban wood waste.

5. Estimates of mitigation potential for different categories of activities at the state level

National-scale estimates were partitioned to states based on area statistics that represent qualifying conditions for each activity. This partitioning approximates the technical potential for each activity for each state, without considering many state and local factors that would influence rates of adoption. Forest management practices are very diverse, depending on site characteristics such as climate, soils, and forest types; the economic and policy context; and willingness of land managers to adopt practices.

Table 13 ranks each state according to total mitigation potential. Large states and states with large areas of forest and forest management rank highest – southern and pacific coast states tend to have the greatest total forest mitigation potential.

Table 13. Total mitigation potential by state, ranked from highest to lowest ($TgCO_2$/year). Estimates represent the middle of the range of technical potential for all activities, which totals 1,254.7 $TgCO_2$/year nationally. Some activities are not mutually exclusive. A detailed table showing all activities by state is in Appendix D.

Texas	107.93	Pennsylvania	22.73
Washington	72.50	Kentucky	21.02
Georgia	61.30	New Mexico	19.15
Oregon	56.83	Iowa	17.46
Alabama	56.66	Ohio	17.41
Mississippi	45.98	North Dakota	16.13
North Carolina	43.35	Illinois	15.22
Arkansas	40.59	West Virginia	15.05
South Carolina	38.08	Utah	12.69
Montana	37.04	Nebraska	11.75
Louisiana	35.32	Arizona	11.17
Missouri	34.88	Indiana	10.69
Colorado	34.16	South Dakota	9.67
California	34.05	Wyoming	9.13
Florida	32.43	Alaska	7.13
Minnesota	30.13	Nevada	6.96
Virginia	29.74	New Hampshire	6.31
Kansas	29.13	Vermont	5.55
Michigan	28.92	Maryland	4.08
Oklahoma	28.71	Massachusetts	3.48
Maine	26.71	New Jersey	2.40
Wisconsin	26.14	Connecticut	2.25
Tennessee	25.18	Hawaii	1.00
New York	24.71	Delaware	0.74
Idaho	24.58	Rhode Island	0.44

Table 14 ranks each state according to the proportion of managed land that would be involved with implementing forest mitigation activities. The ranking is significantly different than that shown in table 12, since the proportion of managed land, particularly forest land, is more important than the total size of each state. As a result, northern states rank much higher on an area basis.

Table 14. Proportion of managed land[1] that would be involved with forest mitigation activities, ranked by state from highest to lowest. Estimates represent the middle of the range of technical potential for all activities except for increasing retention of harvested biomass and increasing woody biomass for BECCS. Some activities are not mutually exclusive. The national average is .329 involving 237 million hectares of managed land. A detailed table showing all activities by state is in Appendix D.

Maine	0.706	Nevada	0.410
Alabama	0.693	Maryland	0.409
New Hampshire	0.676	Kentucky	0.400
South Carolina	0.658	Hawaii	0.394
Georgia	0.648	Idaho	0.377
Vermont	0.642	California	0.354
Mississippi	0.615	Delaware	0.343
Virginia	0.596	Missouri	0.341
West Virginia	0.593	Minnesota	0.336
Louisiana	0.568	Colorado	0.323
North Carolina	0.567	Ohio	0.283
Massachusetts	0.561	New Mexico	0.277
Rhode Island	0.557	Arizona	0.259
Connecticut	0.544	Texas	0.258
New York	0.535	Oklahoma	0.257
Oregon	0.524	Montana	0.225
Washington	0.518	Indiana	0.213
Arkansas	0.501	Illinois	0.173
Florida	0.493	Wyoming	0.163
Michigan	0.491	Iowa	0.140
Pennsylvania	0.489	Kansas	0.129
Utah	0.474	North Dakota	0.086
New Jersey	0.435	Nebraska	0.063
Tennessee	0.434	Alaska	0.060
Wisconsin	0.417	South Dakota	0.060

[1]"Managed land" in this table includes all areas of forest land[30]; non-federal areas of cropland, CRP land, pastureland, and rangeland [7]; and settlement land [1].

6. Enhanced monitoring of results, building on existing federal and state programs

Existing federal and state programs provide a solid foundation for monitoring the trend in the land sink, focused on the "managed" ecosystems as depicted by the U.S. GHG inventory. Despite limitations, this foundation of monitoring is also the basis for formulating mitigation policies and programs, and so data will be directly relevant to assessing the impacts of policies and programs in the future. The two principal land monitoring programs are housed in USDA: the Forest Inventory and Analysis (FIA) program of the U.S. Forest Service, and the National Resources Inventory (NRI) of the National Resources Conservation Service.

There are significant limitations of these two programs that limit their ability to perform the desired monitoring of mitigation activities:

- FIA and NRI are independently implemented using different sampling approaches and timing of data collection, and the NRI only monitors non-federal lands.
- Data typically lags the current year by 5 to 10 years, which delays detection of changes due to disturbances and land-use change.
- Although trends in many variables are readily detectable, attributing the observed changes to specific causes is limited to those causes that can be observed in the field or by remote sensing.
- Even if specific causes are identified, it is difficult to associate them with the "additional" carbon dioxide removal that could result from mitigation activities.
- Factoring out effects of environmental causes of change such as increasing CO_2 concentration and climate change is challenging.

Nonetheless, the foundation of land monitoring by USDA can be augmented with other existing federal programs of NASA and USGS, which emphasize remote sensing and modeling. Remote sensing provides timely detection of changes in forest canopy, which if combined with other spatial datasets can lead to greatly improved attribution of these changes to specific causes, such as types of natural disturbances, harvesting, and land-use change. The main limitation of remote sensing is that it detects biophysical changes in land cover, but not land use, which is the common target of mitigation and the basis of the nation's GHG inventory.

By combining the land and space monitoring systems, and judicious use of ecosystem and carbon accounting models, effective monitoring of changes in carbon stocks and attributing them to specific causes is possible and has been demonstrated to work. For example, some studies [10,18] were able to identify trends and separate effects of management, disturbance and environment on carbon stocks. Carbon accounting models such as CBM-CFS3 developed in Canada are very useful for integrating different sources of information, attributing effects to causes, and adhering to international accounting standards as recommended by the IPCC [48].

In a larger global context, it would be highly desirable to have an effective, operational global monitoring system that can detect changes in land-carbon stocks and attribute those changes to causes. This is important not only to keep track of progress toward implementing global programs such as envisioned by the Paris Agreement, but also to detect leakage for activities such as reducing timber harvesting or deforestation that can induce effects elsewhere that could offset the gains from the mitigation activities in the U.S.

The NAS study on carbon dioxide removal (CDR) recommended enhancements to land monitoring. On private and public forestlands, the USFS should develop a plan to monitor recommended C stock enhancing activities, conduct statistical sampling of total ecosystem carbon stored in a subset of projects, and develop local "climate impact factors" that also account for biophysical effects. It is time consuming and expensive to directly measure the effects of many small projects on net GHG emissions; therefore, approaches that could achieve accurate average estimates for aggregates of projects (based on remote sensing and validated expansion factors) are needed to reduce transaction costs. Additional needs are to use the monitoring system to attribute observed changes in CDR to management activities vs. increasing CO_2 or climate change. Monitoring leakage could require a new LiDAR satellite dedicated to mapping global forestry activities. Knowledge and monitoring of lateral transfers of C from land to inland waters are lacking and are not currently detected by remote sensing or operational field inventories.

There is a substantial existing capacity in remote sensing and field monitoring on which to build the additional needs described here. For example, the USFS FIA program is funded at approximately $70 million per year, collects continuous field data on status and trends of U.S. forests, and collaborates with NASA on developing methods to integrate remote sensing data with field data. Internationally, the status of monitoring is highly variable, with many countries lacking field measurements and capacity to implement monitoring programs. However, there is a significant international aid effort to improve capacity in forest monitoring at the country scale, as well as advancing research on global monitoring capability using satellites. The research cost for the U.S. only is approximately $1.0 million/yr for 3 years for system development and continuous operation would cost approximately $4.0 million per year to staff a small office to analyze data, coordinate field checks, and develop reports. A significant contribution to improving international forest monitoring and reporting, including detection of leakage worldwide, would require about 10 to 20 times the amount needed in the U.S.

7. Summary of technical mitigation potential

We estimate a technical mitigation potential for the forest sector of about 500 to 1500 TgCO_2 per year, excluding BECCS and increased retention of harvested biomass (table 15). Figure 11 summarizes the forestry activities and potential additional net removal of CO_2 in more detail. The estimates are very close to the estimates used in the NAS report (plus avoided deforestation and within the forest management category, inclusion of trees outside forests), though the mix of activities and estimated annual increases in sequestration for the different activities have been updated and are not 100% consistent among these or other studies. The area estimated for improving forest management in this study is significantly larger than most. These results point to several significant challenges for estimating the mitigation potential for the forest sector:

- Lack of common definitions of terms and selection of activities
- Accounting differences, particularly which C pools are included and in at least one case, inclusion of a non-GHG albedo effect
- Uncertainty of estimated per-hectare increases in net C uptake
- Different interpretations of constraints and barriers to implementation

Nonetheless, even the low estimate of 617 TgCO_2 per year (total forest sector plus BECCS/waste wood) indicates that there is significant potential for the forest sector to contribute to reducing net GHG emissions and increasing the expected future C sink, potentially reversing the projected decline and possibly increasing the sink (Figure 12). With the potential for achieving higher additional increases and including opportunities on agricultural lands (described in a separate report), there is flexibility for policies and programs to select a mix of activities at various levels that could achieve the needed additional 500 TgCO_2 per year for the land sink to contribute effectively to the goal of net zero GHG emissions by 2050.

Table 15. Summary of forest sector opportunities to increase C sequestration (Tg CO_2/y)

Activities	***Low estimate***	***High estimate***	***Low area (Mha)***	***High area (Mha)***
Increase reforestation	141.0	506.0	9.3	33.5
Improve forest management[1]	250.0	644.4	112.2	296.7
Increase retention of C in harvested wood	100.0	300.0	n/a	n/a
Avoid deforestation[2]	14.0	84.0	10.7	11.4
Total forest sector	**505.0**	**1534.4**	**132.2**	**341.6**
Other forestry-related activities				
Increase harvest with increased retention[3]	100.0	700.0	n/a	n/a
BECCS/waste wood[4]	112.0	346.0	n/a	n/a
BECCS/live biomass[5]	116.0	263.0	n/a	n/a

[1]Includes increasing stocking of trees outside forests. More than one management activity may be applied to the same forest area (see table 10). Since the can be independently implemented on the same areas, this would only affect the area estimates and not the C sequestration estimates.
[2]Avoid deforestation area is annual amount accumulated over 30 years.
[3]Increasing harvest combined with increasing retention is excluded from the forest sector total because it is not mutually exclusive with other forest management activities, particularly extending rotation lengths and BECCS/live biomass. However, it is a viable activity that could be important in timber-producing regions.
[4]Use of waste wood (forest and mill residues) for BECCS is tracked in energy- and industrial-system modeling, so is not included in the forest sector total.
[5]Use of live biomass for BECCS is excluded from the forest sector total because it is not mutually exclusive with other forest mitigation activities, particularly extending rotation lengths and increasing harvest with increased retention.

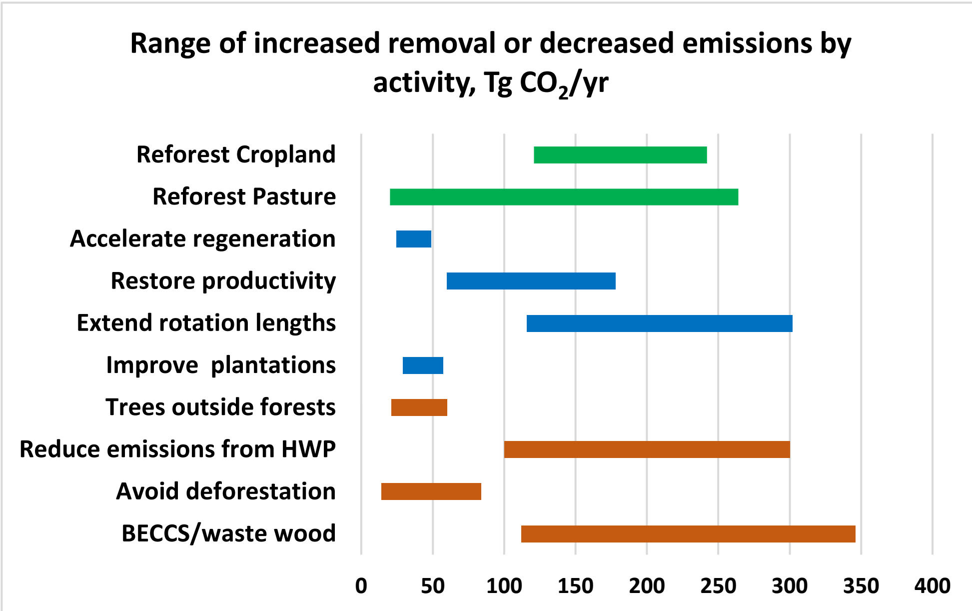

Figure 11. Range of increased removal or decreased emissions by selected activities, Tg CO_2/yr. Green bars represent reforestation and blue bars represent detailed forest management activities. All activities are mutually exclusive (except perhaps restoring productivity and extending rotation lengths, but these can be independently implemented on the same area). See table 15 for alternate activities.

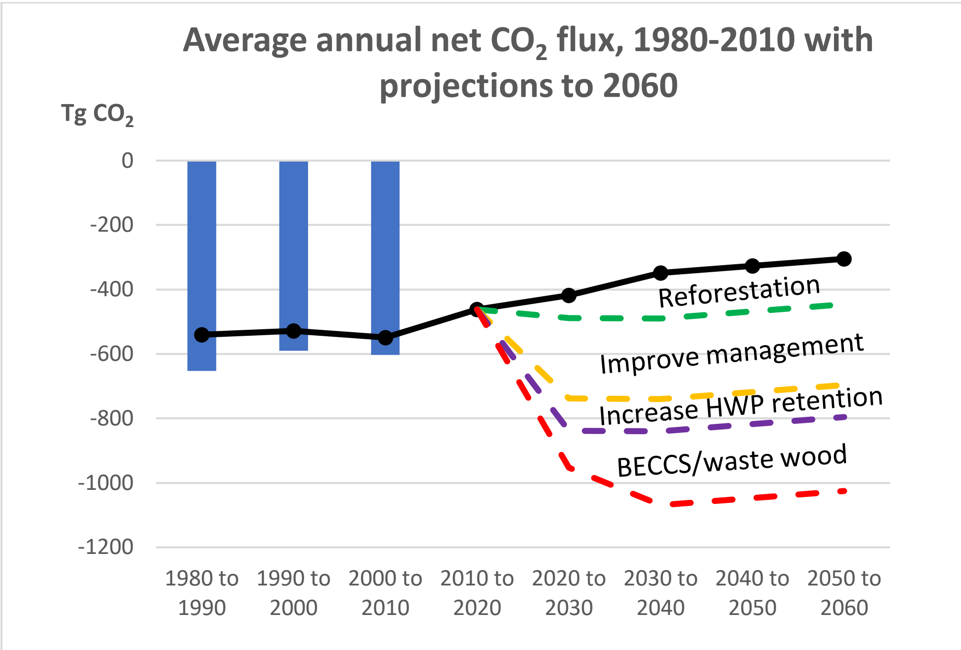

Figure 12. Average annual net CO_2 flux, 1980-2010, with projections to 2060 for a baseline of forest remaining forest plus selected additional activities (dashed lines). The low end of the range of impacts is shown, with a 10-year ramp-up period (20 years for reforestation and BECCS/waste wood). Reforestation and improve management include all activities in tables 7 and 9, respectively. Baseline does not include effects of land-use change, and activities do not include avoided deforestation.

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Appendix A – Summary of methods for GHG inventory and projections

National Greenhouse Gas Inventory

Methods for the forest sector of the national greenhouse gas inventory are described in great detail in the U.S. EPA GHG inventory reports [1]. Methods for carbon accounting based on the national forest inventory (FIA) are described Forest Service reports [2]. Most of the following text is copied directly from these government reports.

The Forest Carbon Accounting Framework (FCAF) is fundamentally driven by the annual forest inventory system conducted by the Forest Inventory and Analysis program of the U.S. Forest Service. The FIA program is considered to be the National Forest Inventory (NFI) for the United States, so these terms are used interchangeably. The FCAF system is comprised of a forest dynamics module and a land use dynamics module. The forest dynamics module assesses forest sequestration, forest aging, and disturbance effects (i.e., disturbances such as wind, fire, and floods identified by foresters on inventory plots). The land use dynamics module assesses carbon stock transfers associated with afforestation and deforestation. Both modules are developed from land use area statistics and carbon stock change or carbon stock transfer by age class. The required inputs are estimated from more than 625,000 forest and nonforest observations in the FIA national database. Model predictions for before or after the annual inventory period are constructed from the FCAF system using the annual observations. This modeling framework includes opportunities for user-defined scenarios to evaluate the impacts of land use change and disturbance rates on future carbon stocks and stock changes. The accounting system is flexible and can incorporate emerging inventory data (e.g., remeasured western plots and Alaskan lichen biomass), future image-based change estimation information, data from trends in burn severity, and process model output (i.e., inform future forest carbon densities or land use dynamics).

USDA/RPA Projections

Methods for projecting forest conditions in the U.S. including CO_2 flux are described in detail by Wear and others [3]. The following summary is copied from this government report.

The Forest Assessment System forecasts forest conditions by modeling the effects of changing climate, market-driven timber harvesting/management, and land use changes along with changes driven by disturbance and successional transitions in forest conditions. The future of these driving forces is defined through a set of scenarios that contain alternative projections of economic, climate, and population futures. The primary objective of the Forest Dynamics Model is to forecast change in the forest inventories measured by the Forest Inventory and Analysis (FIA) Program of the Forest Service, U.S. Department of Agriculture. Thousands of plots comprise the FIA inventories, and the Forest Dynamics Model forecasts development of each observed forest plot in the inventories. Historical FIA plot data provide the information foundation for building forecast models, and results are expanded to broader scales using the area frame design of the forest survey. These methods generate full inventory datasets for each time step of the forecast. To model and forecast changes in forest conditions, the Forest Assessment System forecasts the condition of each plot in the forest inventory in response to multiple vectors of change. Each plot record contains a set of measured and associated variables combined with an expansion factor that describes the area (portion of the sampled population of forests) that each plot represents. In all regions however, the basic structure of the modeling approach is defined by three modules. The modeling starts with an algorithm that clusters similar plots according

to a set of independent variables (the partitioning module). These partitions of plots define the groupings of plots for the imputation module and also define which variables are the state variables that need to be forecasted within the transition module. Changes in key state variables for each forest plot are forecasted in response to projected forest aging, climate conditions, and human use choices (the transition module). After forecasting the state variables, a historical plot record with comparable conditions is selected to represent the simulated plot in the future inventory (the imputation module) based on clusters chosen in the partitioning module.

Integrated Terrestrial Ecosystem Carbon Model

Methods for projecting forest conditions in the U.S. using the Integrated Terrestrial Ecosystem Carbon Model (InTEC) are described in detail in literature and government reports [4,5]. The following summary is copied from the government report [5].

InTEC is a process-based biogeochemical model driven by monthly climate data, vegetation parameters, and forest disturbance information to estimate annual forest C and fluxes in C pools at regional and local scales. InTEC relies on empirical FIA datasets containing variables such as stand age, dominance forest (or forest dominance) type, and net growth, resulting in a hybrid approach which combines a process-based biogeochemical model as well as empirical models. Specifically the FIA-based stand age, dominance (or forest) types, and net primary productivity (NPP)-stand age relationships determine when stands were initially disturbed and depending on dominance forest (or forest dominance) type, how the productivity changes with stand age over time. The C dynamics of a forest region are a function of multiple factors including disturbance, stand age, climate, and atmospheric composition. These are grouped into disturbance and non-disturbance factors. Disturbance factors include primarily fire, harvest, insects, and forest stand age or time since stand-replacing disturbance, which can include disturbances that are not specifically identified or occurred prior to the satellite-based disturbance maps (pre-1990) such as windstorms or diseases. Non-disturbance factors include climate (temperature and precipitation), atmospheric CO_2 concentration, and nitrogen (N) deposition. The time since disturbance influences the rate and accumulation of biomass and C during regrowth after disturbance. Nitrogen deposition and atmospheric CO_2 concentrations influence photosynthesis, respiration, and other variables in the model that determine C production. The InTEC model integrates the effects of non-disturbance and disturbance factors since the initial modeling year. The historical C dynamics are estimated progressively through a mechanistic aggregation of disturbance and non-disturbance factors.

<u>Appendix A – References</u>

[1] U.S. Environmental Protection Agency. 2019. Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2017. EPA 430-R-19-001

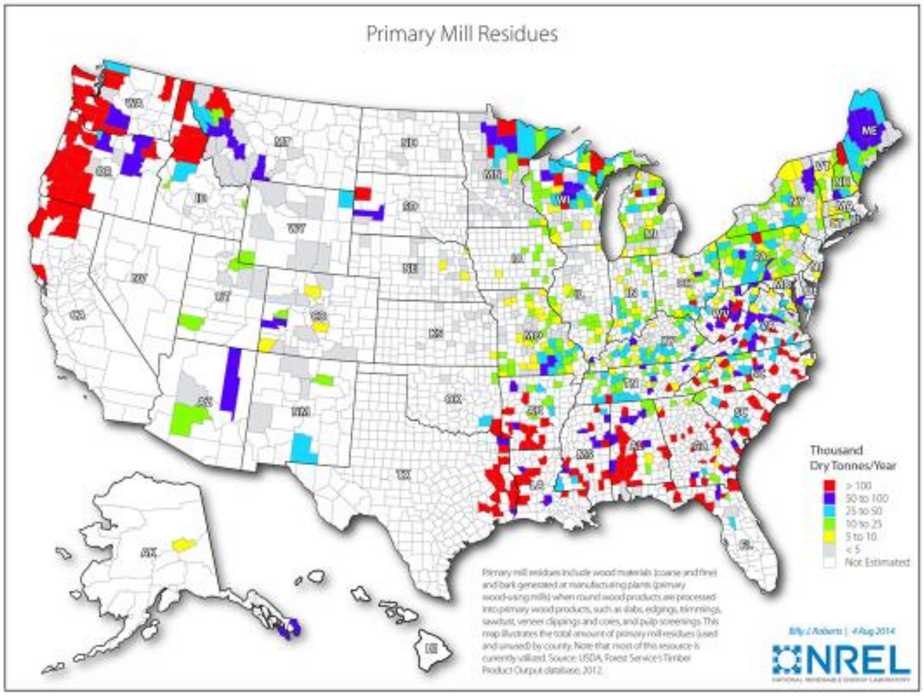
[2] Woodall, C.W.; Coulston, J.W.; Domke, G.M. [et al.]. 2015. The U.S. forest carbon accounting framework: stocks and stock change, 1990–2016. Gen. Tech. Rep. NRS-154. Newtown Square, PA: U.S. Department of Agriculture, Forest Service, Northern Research Station. 49 p.

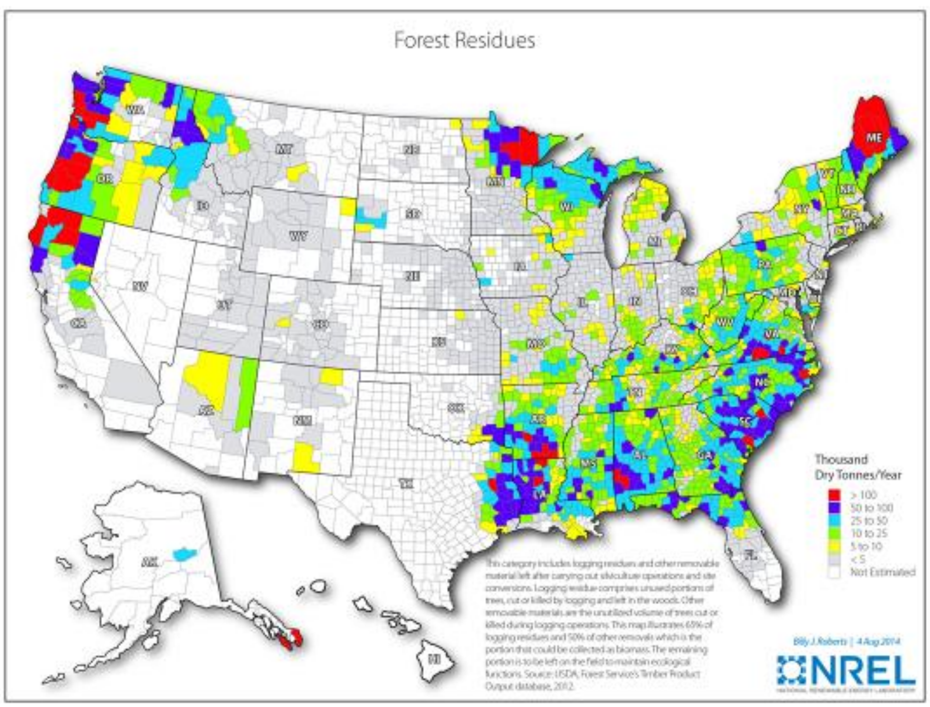
[3] Wear, D.N.; Huggett, R.; Li, R. [et al.]. 2013. Forecasts of forest conditions in U.S. regions under future scenarios: a technical document supporting the Forest Service 2010 RPA Assessment. Gen. Tech. Rep. GTR-SRS-170. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station. 101 p.

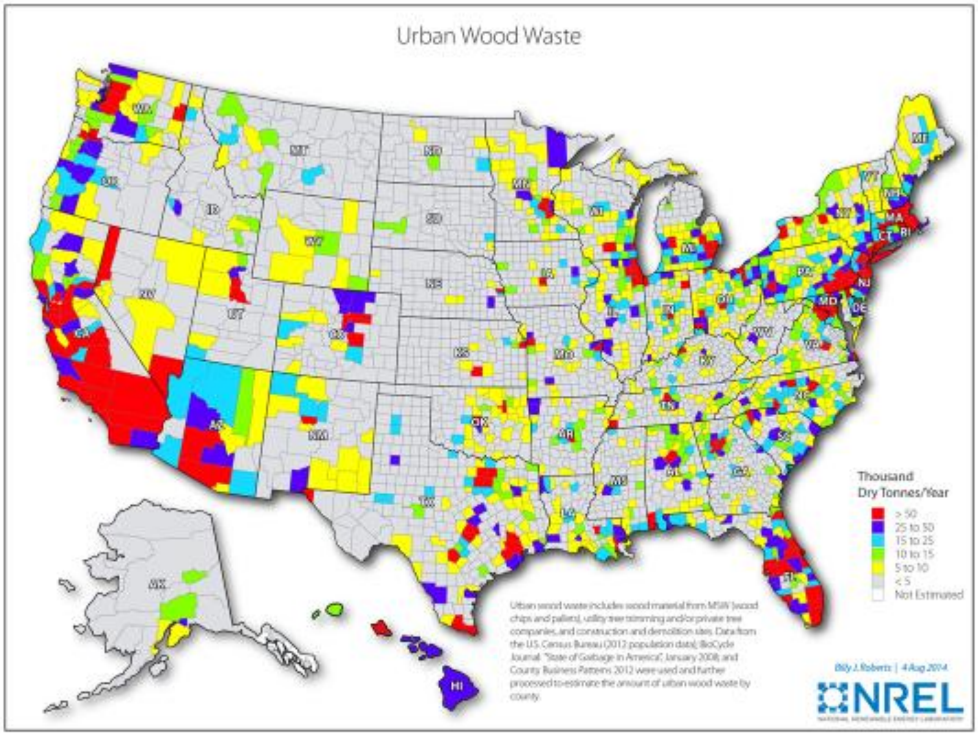
[4] Chen, J. M., Chen, W. & Cihlar, J. 2000. Integrated terrestrial ecosystem carbon-budget model based on changes in disturbance, climate, and atmospheric chemistry. Ecological Modelling, 135: 55-79.

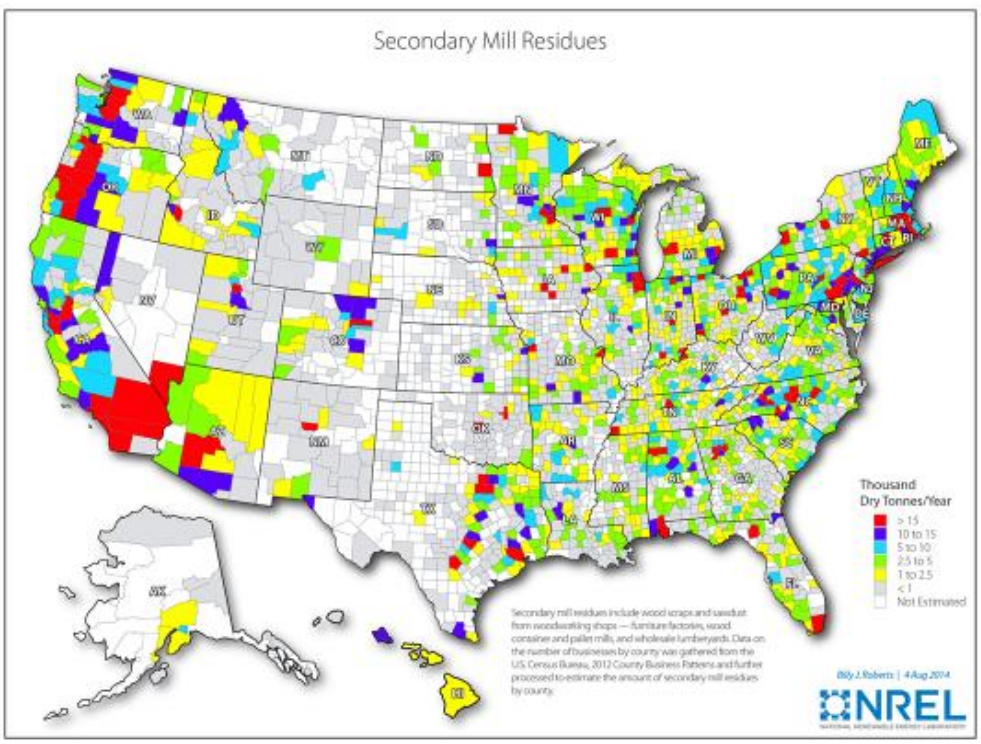
[5] Birdsey, Richard; Dugan, Alexa; Healey, Sean; Dante-Wood, Karen; Zhang, Fangmin; Chen, Jing. 2019. Assessment of the influence of disturbance, management activities, and environmental factors on carbon stocks of United States National Forests. Gen. Tech. Rep. RMRS-GTR-402. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station. 116 pages plus appendices.

Appendix B. Maps of biomass resource for bioenergy (excluding live biomass). From NREL web site: https://www.nrel.gov/gis/biomass.html






Urban Wood Waste
Thousand Dry Tonnes/Year
> 50
25 to 50
15 to 25
10 to 15
5 to 10
< 5
Not Estimated
Urban wood waste includes wood material from MSW (wood chips and pallets), utility tree trimming and/or private tree companies, and construction and demolition sites. Data from the U.S. Census Bureau (2012 population data); BioCycle Journal: "State of Garbage in America", January 2008; and County Business Patterns 2012 were used and further processed to estimate the amount of urban wood waste by county.
Billy J. Roberts | 4 Aug 2014


Secondary Mill Residues
Thousand Dry Tonnes/Year
> 15
10 to 15
5 to 10
2.5 to 5
1 to 2.5
< 1
Not Estimated
Secondary mill residues include wood scraps and sawdust from woodworking shops — furniture factories, wood container and pallet mills, and wholesale lumberyards. Data on the number of businesses by county was gathered from the U.S. Census Bureau, 2012 County Business Patterns and further processed to estimate the amount of secondary mill residues by county.
Billy J. Roberts | 4 Aug 2014

Appendix C. Historical estimates and projections of the CO_2 balance of forests, by State.

Two tables are included here: table C-1 includes the carbon balance of forest remaining forest plus harvested wood products and landfills, and table C-2 includes only the carbon balance of forest remaining forest (similar to table 6 in the main body of this report). Estimates were downscaled from national and regional estimates using state-specific forest area and harvesting data. Estimates are not 100% consistent with those presented earlier based on the EPA greenhouse gas inventory since the approach to extrapolating the underlying inventory data was different. In these tables, the inventory data were assigned to reporting years using the Carbon Calculation Tool (CCT) [1], whereas the EPA GHG estimates were assigned to reporting years using a different hindcasting/forecasting approach with the same inventory data [2].

NOTE: since this analysis was done, new state-level data has become available [3]. However, it was decided to retain the CCT estimates for consistency since it was used in conjunction with other calculations in this report, including the projections. Readers interested in specific states may wish to replace the historical data reported here with the updated historical estimates.

Table C-1. Historical estimates and projections of the CO_2 balance of forests remaining forests and harvested wood products, by State (Tg $CO_2 yr^{-1}$). Negative number indicates net removal of CO2 from the atmosphere (i.e. a carbon sink).

	Historical data (average annual)			Projections (selected years)	
State	1990-1999	2000-2009	2010-2017	2030	2050
Alabama	-51.2	-33.6	-63.0	-28.0	-25.1
Alaska	-0.6	-0.5	-0.5	-31.5	-26.3
Arizona	38.4	33.4	7.5	2.1	0.5
Arkansas	-33.7	-25.1	-26.0	-20.9	-18.5
California	-19.7	-17.7	-15.5	-10.6	-9.5
Colorado	5.1	5.7	6.2	3.9	1.0
Connecticut	-2.2	-1.5	-10.3	-1.7	-1.6
Delaware	0.4	-0.4	-0.7	-0.4	-0.4
Florida	-8.7	-23.4	-27.1	-17.5	-15.2
Georgia	-34.2	-27.1	-18.0	-30.5	-27.5
Hawaii	0.0	0.0	0.0	-0.4	-0.3
Idaho	-10.1	-11.7	-23.1	1.9	-1.3
Illinois	-8.8	-16.6	-11.5	-5.0	-4.6
Indiana	-9.4	-14.3	-7.0	-5.1	-4.7
Iowa	-15.4	-13.6	3.4	-2.9	-2.6
Kansas	-13.5	-16.2	-6.9	0.2	-0.2
Kentucky	-15.2	-17.2	-14.9	-11.7	-10.0
Louisiana	-16.0	-29.5	-35.4	-17.6	-15.7
Maine	-25.1	-15.6	-9.3	-20.6	-19.2
Maryland	0.3	-3.7	-4.6	-2.6	-2.4
Massachusetts	-2.2	-3.5	-5.0	-2.9	-2.6
Michigan	-14.8	-32.2	-38.7	-21.4	-19.7
Minnesota	10.9	-32.1	-34.5	-17.4	-15.9

Mississippi	-43.2	-40.8	-37.1	-22.0	-19.6
Missouri	-22.3	-36.1	-5.1	-15.0	-13.6
Montana	-60.4	-38.3	-14.3	4.0	0.3
Nebraska	-7.6	-9.6	-0.3	0.1	-0.1
Nevada	-12.8	-16.5	0.5	1.5	0.4
New Hampshire	-5.3	-6.3	0.6	-5.2	-4.8
New Jersey	-7.0	-1.2	0.5	-1.8	-1.6
New Mexico	2.4	5.4	-11.8	3.3	0.9
New York	-62.4	-43.5	-11.7	-19.1	-17.5
North Carolina	2.8	-23.8	-35.8	-22.6	-20.2
North Dakota	-2.1	-1.9	-1.2	0.1	0.0
Ohio	-21.9	-20.0	-0.4	-9.4	-8.7
Oklahoma	-8.7	-6.4	-4.4	-10.0	-8.3
Oregon	-115.2	-19.5	-39.7	-16.4	-15.6
Pennsylvania	-25.8	-30.2	-34.5	-17.6	-16.2
Rhode Island	-0.2	-0.7	-1.0	-0.3	-0.3
South Carolina	-19.4	-29.3	-14.5	-18.0	-16.5
South Dakota	-0.6	-5.6	-2.9	0.1	-0.2
Tennessee	-49.9	-19.6	-10.1	-13.8	-12.0
Texas	-17.3	-11.9	-17.8	-37.5	-31.8
Utah	-46.8	-24.3	-0.7	2.4	0.7
Vermont	-10.7	-5.3	3.8	-4.7	-4.3
Virginia	-14.5	-19.1	-44.5	-16.7	-14.6
Washington	-38.1	-35.5	-35.3	-19.0	-18.8
West Virginia	-9.2	-30.2	-6.4	-12.7	-11.7
Wisconsin	-12.5	-28.1	-26.6	-18.0	-16.5
Wyoming	-19.0	23.7	28.9	1.8	0.4
TOTAL U.S.	-853.7	-770.7	-656.9	-506.8	-471.8

Table C-2. Historical estimates and projections of the CO_2 balance of forests remaining forest, by State (Tg $CO_2 yr^{-1}$). Negative number indicates net removal of CO2 from the atmosphere (i.e. a carbon sink).

	Historical data (average annual)			Projections (selected years)	
State	1990-1999	2000-2009	2010-2017	2030	2050
Alabama	-51.2	-33.6	-63.0	-28.0	-25.1
Alaska	-0.6	-0.5	-0.5	-31.5	-26.3
Arizona	38.4	33.4	7.5	2.1	0.5
Arkansas	-33.7	-25.1	-26.0	-20.9	-18.5
California	-19.7	-17.7	-15.5	-10.6	-9.5
Colorado	5.1	5.7	6.2	3.9	1.0
Connecticut	-2.2	-1.5	-10.3	-1.7	-1.6
Delaware	0.4	-0.4	-0.7	-0.4	-0.4
Florida	-8.7	-23.4	-27.1	-17.5	-15.2
Georgia	-34.2	-27.1	-18.0	-30.5	-27.5

Hawaii	0.0	0.0	0.0	-0.4	-0.3
Idaho	-10.1	-11.7	-23.1	1.9	-1.3
Illinois	-8.8	-16.6	-11.5	-5.0	-4.6
Indiana	-9.4	-14.3	-7.0	-5.1	-4.7
Iowa	-15.4	-13.6	3.4	-2.9	-2.6
Kansas	-13.5	-16.2	-6.9	0.2	-0.2
Kentucky	-15.2	-17.2	-14.9	-11.7	-10.0
Louisiana	-16.0	-29.5	-35.4	-17.6	-15.7
Maine	-25.1	-15.6	-9.3	-20.6	-19.2
Maryland	0.3	-3.7	-4.6	-2.6	-2.4
Massachusetts	-2.2	-3.5	-5.0	-2.9	-2.6
Michigan	-14.8	-32.2	-38.7	-21.4	-19.7
Minnesota	10.9	-32.1	-34.5	-17.4	-15.9
Mississippi	-43.2	-40.8	-37.1	-22.0	-19.6
Missouri	-22.3	-36.1	-5.1	-15.0	-13.6
Montana	-60.4	-38.3	-14.3	4.0	0.3
Nebraska	-7.6	-9.6	-0.3	0.1	-0.1
Nevada	-12.8	-16.5	0.5	1.5	0.4
New Hampshire	-5.3	-6.3	0.6	-5.2	-4.8
New Jersey	-7.0	-1.2	0.5	-1.8	-1.6
New Mexico	2.4	5.4	-11.8	3.3	0.9
New York	-62.4	-43.5	-11.7	-19.1	-17.5
North Carolina	2.8	-23.8	-35.8	-22.6	-20.2
North Dakota	-2.1	-1.9	-1.2	0.1	0.0
Ohio	-21.9	-20.0	-0.4	-9.4	-8.7
Oklahoma	-8.7	-6.4	-4.4	-10.0	-8.3
Oregon	-115.2	-19.5	-39.7	-16.4	-15.6
Pennsylvania	-25.8	-30.2	-34.5	-17.6	-16.2
Rhode Island	-0.2	-0.7	-1.0	-0.3	-0.3
South Carolina	-19.4	-29.3	-14.5	-18.0	-16.5
South Dakota	-0.6	-5.6	-2.9	0.1	-0.2
Tennessee	-49.9	-19.6	-10.1	-13.8	-12.0
Texas	-17.3	-11.9	-17.8	-37.5	-31.8
Utah	-46.8	-24.3	-0.7	2.4	0.7
Vermont	-10.7	-5.3	3.8	-4.7	-4.3
Virginia	-14.5	-19.1	-44.5	-16.7	-14.6
Washington	-38.1	-35.5	-35.3	-19.0	-18.8
West Virginia	-9.2	-30.2	-6.4	-12.7	-11.7
Wisconsin	-12.5	-28.1	-26.6	-18.0	-16.5
Wyoming	-19.0	23.7	28.9	1.8	0.4
TOTAL U.S.	-853.7	-770.7	-656.9	-506.8	-471.8

Appendix C references

[1] Smith, J.E., L.S. Heath, and M.C. Nichols (2007) U.S. forest carbon calculation tool user's guide: forestland carbon stocks and net annual stock change. General Technical Report NRS-13. U.S. Department of Agriculture, Forest Service, Northern Research Station, Newtown Square, PA.

[2] Woodall, C.W., Coulston, J.W., Domke, G.M., Walters, B.F., Wear, D.N., Smith, J.E., Anderson, H.-E., Clough, B.J., Cohen, W.B., Griffith, D.M., Hagan, S.C., Hanou, I.S.; Nichols, M.C., Perry, C.H., Russell, M.B., Westfall, J.A., Wilson, B.T. (2015) The U.S. Forest Carbon Accounting Framework: Stocks and Stock change 1990-2016. Gen. Tech. Rep. NRS-154. Newtown Square, PA: U.S. Department of Agriculture, Forest Service, Northern Research Station. 49 pp.

[3] Domke, Grant M.; Walters, Brian F.; Nowak, David J.; Smith, James, E.; Ogle, Stephen M.; Coulston, J.W.; Wirth, T.C. 2020. Greenhouse gas emissions and removals from forest land, woodlands, and urban trees in the United States, 1990-2018. Resource Update FS-227. Madison, WI: U.S. Department of Agriculture, Forest Service, Northern Research Station. 5 p. https://doi.org/10.2737/FS-RU-227

Appendix D. Details of technical mitigation potential by state.

Tables D-1 to D-3. Technical mitigation potential of various forest-related activities, by state ($TgCO_2$/yr). Estimates in table D-1 represent the middle of the range of technical potential described in tables 8, 10, and 15 of the main body of this report. Estimates in table D-2 and D-3 represent the low and high ends of the range of technical potential, respectively. The national estimates were downscaled to states according to areas associated with different activities within each state or to volume of wood harvested annually in each state.

(tables D1 to D3 shown on following pages)

Table D-1. Mitigation potential of forest-related activities, middle of range.

Total U.S. potential partitioned to States (middle of range)					(TgCO$_2$/yr)						
	Reforest cropland[1]	Reforest pasture[2]	Accelerate regeneration[3]	Restore productivity[4]	Extend rotation length[5]	Improve plantations[6]	Increase trees outside forests[7]	Increase retention of HWP[8]	Avoid deforestation[9]	BECCS/woody biomass (waste only)[10]	All activities (not counting overlap)
Alabama	2.29	3.77	0.26	3.72	8.01	4.59	0.40	14.97	1.11	17.55	56.66
Alaska	0.00	0.00	0.45	2.10	3.53	0.00	0.00	0.48	0.00	0.56	7.13
Arizona	0.00	0.05	1.35	3.34	4.86	0.00	0.28	0.10	1.08	0.11	11.17
Arkansas	0.81	6.20	0.27	3.10	6.39	2.27	0.76	9.22	0.78	10.81	40.59
California	0.22	1.49	2.81	5.24	9.37	0.97	1.36	4.38	3.07	5.13	34.05
Colorado	18.68	1.74	1.22	4.09	6.39	0.02	0.86	0.12	0.91	0.14	34.16
Connecticut	0.00	0.12	0.04	0.22	0.80	0.01	0.10	0.24	0.45	0.28	2.25
Delaware	0.00	0.05	0.01	0.05	0.14	0.02	0.06	0.14	0.12	0.16	0.74
Florida	0.35	4.35	1.00	3.20	4.29	2.83	0.66	6.20	2.29	7.27	32.43
Georgia	1.42	3.05	0.59	3.96	8.31	4.81	0.68	16.98	1.61	19.91	61.30
Hawaii	0.00	0.11	0.09	0.21	0.54	0.04	0.01	0.00	0.00	0.00	1.00
Idaho	4.46	1.66	3.32	4.52	3.22	0.22	0.55	2.84	0.46	3.33	24.58
Illinois	4.07	2.60	0.07	0.83	1.68	0.08	2.35	0.91	1.57	1.07	15.22
Indiana	0.95	2.06	0.06	0.86	1.49	0.13	1.35	1.22	1.14	1.43	10.69
Iowa	7.86	3.80	0.10	0.55	0.76	0.03	2.40	0.49	0.90	0.57	17.46
Kansas	20.08	3.57	0.11	0.45	0.68	0.03	2.43	0.36	0.99	0.42	29.13
Kentucky	1.06	5.49	0.07	2.14	3.92	0.04	0.65	3.11	0.90	3.65	21.02
Louisiana	1.00	3.00	0.29	2.53	4.87	2.88	0.57	8.92	0.81	10.46	35.32
Maine	0.30	0.20	0.08	2.37	7.33	0.23	0.09	7.27	0.31	8.53	26.71
Maryland	0.05	0.48	0.03	0.37	0.92	0.10	0.24	0.58	0.64	0.68	4.08
Massachusetts	0.00	0.17	0.03	0.37	1.35	0.00	0.14	0.35	0.67	0.40	3.48
Michigan	0.71	2.56	0.30	3.03	7.63	0.90	1.02	5.04	1.81	5.91	28.92
Minnesota	6.05	4.47	0.36	2.89	5.89	0.59	2.03	3.11	1.09	3.65	30.13
Mississippi	4.89	3.53	0.56	3.36	5.80	3.81	0.55	10.47	0.75	12.27	45.98
Missouri	7.99	11.34	0.12	2.47	5.36	0.11	1.52	2.14	1.33	2.51	34.88
Montana	13.62	5.25	3.24	5.05	5.08	0.09	1.43	1.26	0.55	1.48	37.04
Nebraska	5.89	2.25	0.19	0.29	0.30	0.03	1.83	0.19	0.55	0.22	11.75
Nevada	0.00	0.32	1.19	1.67	3.25	0.00	0.13	0.00	0.40	0.00	6.96
New Hampshire	0.00	0.11	0.03	0.58	2.13	0.01	0.06	1.43	0.27	1.68	6.31
New Jersey	0.00	0.17	0.05	0.32	0.67	0.01	0.18	0.11	0.76	0.13	2.40
New Mexico	4.02	0.65	2.43	4.26	6.70	0.01	0.25	0.07	0.67	0.08	19.15
New York	0.20	2.97	0.29	2.35	8.21	0.45	0.72	3.64	1.61	4.27	24.71
North Carolina	0.43	2.31	0.28	2.64	7.49	1.91	0.77	11.85	1.79	13.90	43.35
North Dakota	10.04	2.84	0.03	0.13	0.29	0.02	2.26	0.03	0.48	0.03	16.13
Ohio	0.87	2.48	0.14	1.38	2.38	0.16	1.30	3.17	1.83	3.71	17.41
Oklahoma	7.30	10.30	0.71	2.22	3.21	0.48	0.93	1.18	0.98	1.39	28.71
Oregon	4.92	2.03	2.30	5.36	7.63	4.28	0.45	13.40	0.74	15.71	56.83
Pennsylvania	0.14	2.22	0.22	2.59	6.07	0.33	0.76	3.96	1.81	4.64	22.73
Rhode Island	0.00	0.03	0.01	0.04	0.17	0.00	0.02	0.04	0.10	0.04	0.44
South Carolina	0.61	1.30	0.24	1.83	5.06	2.08	0.36	11.80	0.96	13.84	38.08
South Dakota	3.43	2.55	0.28	0.44	0.21	0.03	1.63	0.30	0.45	0.35	9.67
Tennessee	1.14	5.16	0.09	2.56	4.00	0.44	0.63	4.56	1.27	5.34	25.18
Texas	28.95	21.25	6.70	12.97	10.41	1.96	2.76	8.75	3.92	10.26	107.93
Utah	1.78	0.71	1.06	3.11	5.26	0.01	0.22	0.02	0.49	0.02	12.69
Vermont	0.00	0.39	0.01	0.49	2.18	0.02	0.08	1.02	0.17	1.20	5.55
Virginia	0.22	3.33	0.19	2.24	6.49	1.69	0.47	6.37	1.25	7.47	29.74
Washington	11.24	1.33	1.63	3.71	6.57	3.04	0.73	19.86	1.11	23.29	72.50
West Virginia	0.00	1.68	0.08	1.84	4.42	0.05	0.13	2.96	0.42	3.47	15.05
Wisconsin	1.67	3.49	0.29	2.82	5.62	0.68	1.11	4.24	1.23	4.97	26.14
Wyoming	1.78	1.03	1.46	2.17	1.67	0.02	0.26	0.16	0.40	0.19	9.13
TOTAL U.S.	181.50	142.00	36.70	119.00	209.00	42.50	40.50	200.00	49.00	234.50	1254.70

[1]Based on area of CRP land

[2]Based on area of pasture (not + rangeland?)

[3]Based on area of nonstocked forest land

[4]Based on area of understocked + overstocked forest land

[5]Based on area of fully stocked forest land

[6]Based on area of plantations

[7]Based on settlement + cropland area

[8]Based on quantity of removals (harvest)

[9]Based on settlement area

[10]Based on quantity of removals (harvest)

Table D-2. Mitigation potential of forest-related activities, low end of range.

Total U.S. potential partitioned to States (low end of range)					($TgCO_2$/yr)						
State	Reforest cropland[1]	Reforest pasture[2]	Accelerate regeneration[3]	Restore productivity[4]	Extend rotation length[5]	Improve plantations[6]	Increase trees outside forests[7]	Increase retention of HWP[8]	Avoid deforestation[9]	BECCS/woody biomass (waste only)[10]	All activities (not counting overlap)
Alabama	1.52	0.53	0.17	1.87	4.45	3.13	0.21	7.48	0.32	8.38	28.07
Alaska	0.00	0.00	0.30	1.06	1.96	0.00	0.00	0.24	0.00	0.27	3.83
Arizona	0.00	0.01	0.90	1.68	2.70	0.00	0.14	0.05	0.31	0.05	5.84
Arkansas	0.54	0.87	0.18	1.57	3.54	1.55	0.39	4.61	0.22	5.16	18.63
California	0.14	0.21	1.88	2.64	5.20	0.66	0.71	2.19	0.88	2.45	16.96
Colorado	12.45	0.25	0.81	2.06	3.55	0.01	0.45	0.06	0.26	0.07	19.96
Connecticut	0.00	0.02	0.03	0.11	0.44	0.01	0.05	0.12	0.13	0.13	1.04
Delaware	0.00	0.01	0.00	0.03	0.08	0.01	0.03	0.07	0.03	0.08	0.34
Florida	0.23	0.61	0.67	1.61	2.38	1.93	0.34	3.10	0.65	3.47	15.00
Georgia	0.94	0.43	0.39	2.00	4.61	3.28	0.35	8.49	0.46	9.51	30.46
Hawaii	0.00	0.02	0.06	0.11	0.30	0.03	0.00	0.00	0.00	0.00	0.51
Idaho	2.98	0.23	2.22	2.28	1.79	0.15	0.28	1.42	0.13	1.59	13.07
Illinois	2.72	0.37	0.05	0.42	0.93	0.06	1.22	0.45	0.45	0.51	7.16
Indiana	0.63	0.29	0.04	0.43	0.83	0.09	0.70	0.61	0.33	0.68	4.63
Iowa	5.24	0.54	0.07	0.28	0.42	0.02	1.24	0.24	0.26	0.27	8.58
Kansas	13.39	0.50	0.07	0.23	0.38	0.02	1.26	0.18	0.28	0.20	16.52
Kentucky	0.70	0.77	0.05	1.08	2.18	0.02	0.34	1.55	0.26	1.74	8.70
Louisiana	0.67	0.42	0.19	1.27	2.70	1.96	0.30	4.46	0.23	5.00	17.21
Maine	0.20	0.03	0.05	1.20	4.07	0.16	0.05	3.64	0.09	4.07	13.55
Maryland	0.03	0.07	0.02	0.18	0.51	0.07	0.12	0.29	0.18	0.32	1.80
Massachusetts	0.00	0.02	0.02	0.19	0.75	0.00	0.07	0.17	0.19	0.19	1.61
Michigan	0.47	0.36	0.20	1.53	4.24	0.61	0.53	2.52	0.52	2.82	13.81
Minnesota	4.03	0.63	0.24	1.46	3.27	0.40	1.05	1.56	0.31	1.74	14.69
Mississippi	3.26	0.50	0.37	1.69	3.22	2.60	0.28	5.23	0.21	5.86	23.23
Missouri	5.33	1.60	0.08	1.24	2.97	0.08	0.79	1.07	0.38	1.20	14.74
Montana	9.08	0.74	2.16	2.54	2.82	0.06	0.74	0.63	0.16	0.71	19.64
Nebraska	3.93	0.32	0.12	0.15	0.16	0.02	0.95	0.09	0.16	0.11	6.01
Nevada	0.00	0.04	0.79	0.84	1.81	0.00	0.07	0.00	0.12	0.00	3.67
New Hampshire	0.00	0.02	0.02	0.29	1.18	0.01	0.03	0.72	0.08	0.80	3.14
New Jersey	0.00	0.02	0.03	0.16	0.37	0.00	0.09	0.06	0.22	0.06	1.03
New Mexico	2.68	0.09	1.62	2.15	3.72	0.01	0.13	0.03	0.19	0.04	10.66
New York	0.14	0.42	0.19	1.18	4.55	0.31	0.38	1.82	0.46	2.04	11.49
North Carolina	0.28	0.33	0.19	1.33	4.16	1.30	0.40	5.93	0.51	6.64	21.05
North Dakota	6.69	0.40	0.02	0.06	0.16	0.01	1.17	0.01	0.14	0.02	8.68
Ohio	0.58	0.35	0.09	0.70	1.32	0.11	0.67	1.58	0.52	1.77	7.70
Oklahoma	4.87	1.45	0.48	1.12	1.78	0.33	0.48	0.59	0.28	0.66	12.04
Oregon	3.28	0.29	1.54	2.70	4.23	2.92	0.23	6.70	0.21	7.50	29.61
Pennsylvania	0.09	0.31	0.15	1.31	3.37	0.22	0.39	1.98	0.52	2.22	10.56
Rhode Island	0.00	0.00	0.00	0.02	0.09	0.00	0.01	0.02	0.03	0.02	0.20
South Carolina	0.41	0.18	0.16	0.92	2.81	1.42	0.19	5.90	0.27	6.61	18.87
South Dakota	2.29	0.36	0.19	0.22	0.12	0.02	0.85	0.15	0.13	0.17	4.48
Tennessee	0.76	0.73	0.06	1.29	2.22	0.30	0.32	2.28	0.36	2.55	10.87
Texas	19.30	2.99	4.47	6.54	5.78	1.33	1.43	4.38	1.12	4.90	52.25
Utah	1.19	0.10	0.71	1.57	2.92	0.01	0.12	0.01	0.14	0.01	6.77
Vermont	0.00	0.05	0.01	0.25	1.21	0.01	0.04	0.51	0.05	0.57	2.70
Virginia	0.15	0.47	0.13	1.13	3.60	1.15	0.25	3.19	0.36	3.57	13.99
Washington	7.49	0.19	1.09	1.87	3.65	2.08	0.38	9.93	0.32	11.12	38.10
West Virginia	0.00	0.24	0.05	0.93	2.45	0.03	0.07	1.48	0.12	1.66	7.03
Wisconsin	1.12	0.49	0.20	1.42	3.12	0.46	0.58	2.12	0.35	2.38	12.24
Wyoming	1.19	0.14	0.98	1.09	0.92	0.01	0.13	0.08	0.12	0.09	4.76
TOTAL U.S.	121.00	20.00	24.50	60.00	116.00	29.00	21.00	100.00	14.00	112.00	617.50

[1]Based on area of CRP land

[2]Based on area of pasture (not + rangeland?)

[3]Based on area of nonstocked forest land

[4]Based on area of understocked + overstocked forest land

[5]Based on area of fully stocked forest land

[6]Based on area of plantations

[7]Based on settlement + cropland area

[8]Based on quantity of removals (harvest)

[9]Based on settlement area

[10]Based on quantity of removals (harvest)

Table D-3. Mitigation potential of forest-related activities, high end of range.

Total U.S. potential partitioned to States (high end of range)					($TgCO_2$/yr)						
State	Reforest cropland[1]	Reforest pasture[2]	Accelerate regeneration[3]	Restore productivity[4]	Extend rotation length[5]	Improve plantations[6]	Increase trees outside forests[7]	Increase retention of HWP[8]	Avoid deforestation[9]	BECCS/woody biomass (waste only)[10]	All activities (not counting overlap)
Alabama	3.05	7.01	0.34	5.56	11.58	6.16	0.59	22.45	1.90	25.89	84.53
Alaska	0.00	0.00	0.60	3.14	5.11	0.00	0.00	0.72	0.00	0.83	10.40
Arizona	0.00	0.10	1.80	4.99	7.02	0.00	0.41	0.14	1.86	0.17	16.48
Arkansas	1.08	11.53	0.36	4.64	9.23	3.04	1.12	13.83	1.33	15.95	62.10
California	0.29	2.78	3.75	7.84	13.54	1.30	2.02	6.57	5.25	7.58	50.92
Colorado	24.90	3.24	1.62	6.12	9.23	0.03	1.27	0.17	1.56	0.20	48.35
Connecticut	0.00	0.22	0.05	0.32	1.16	0.01	0.14	0.36	0.77	0.42	3.46
Delaware	0.01	0.09	0.01	0.08	0.20	0.03	0.08	0.21	0.21	0.24	1.14
Florida	0.46	8.10	1.33	4.78	6.20	3.79	0.98	9.30	3.92	10.73	49.59
Georgia	1.89	5.67	0.78	5.92	12.00	6.45	1.00	25.47	2.76	29.37	91.31
Hawaii	0.00	0.21	0.12	0.32	0.78	0.06	0.01	0.00	0.00	0.00	1.49
Idaho	5.95	3.08	4.42	6.76	4.66	0.29	0.81	4.26	0.79	4.91	35.94
Illinois	5.43	4.83	0.10	1.24	2.43	0.11	3.48	1.36	2.69	1.57	23.23
Indiana	1.26	3.82	0.08	1.28	2.16	0.17	2.01	1.83	1.95	2.12	16.68
Iowa	10.48	7.07	0.13	0.82	1.09	0.04	3.56	0.73	1.53	0.84	26.31
Kansas	26.77	6.65	0.15	0.67	0.98	0.04	3.61	0.54	1.70	0.62	41.73
Kentucky	1.41	10.21	0.10	3.20	5.67	0.05	0.97	4.66	1.54	5.38	33.18
Louisiana	1.34	5.57	0.39	3.78	7.04	3.86	0.85	13.38	1.39	15.43	53.02
Maine	0.40	0.37	0.11	3.55	10.59	0.31	0.13	10.91	0.54	12.58	39.49
Maryland	0.06	0.89	0.04	0.55	1.33	0.14	0.36	0.86	1.10	1.00	6.32
Massachusetts	0.00	0.31	0.04	0.55	1.96	0.00	0.21	0.52	1.15	0.60	5.32
Michigan	0.94	4.76	0.40	4.54	11.03	1.21	1.51	7.56	3.11	8.72	43.78
Minnesota	8.07	8.31	0.48	4.32	8.51	0.79	3.01	4.67	1.87	5.38	45.41
Mississippi	6.52	6.56	0.75	5.02	8.38	5.11	0.81	15.70	1.28	18.11	68.23
Missouri	10.66	21.08	0.16	3.69	7.74	0.15	2.25	3.21	2.27	3.70	54.92
Montana	18.16	9.76	4.32	7.55	7.34	0.12	2.11	1.89	0.95	2.18	54.38
Nebraska	7.86	4.19	0.25	0.43	0.43	0.05	2.72	0.28	0.95	0.33	17.47
Nevada	0.00	0.59	1.58	2.49	4.70	0.00	0.19	0.00	0.69	0.01	10.26
New Hampshire	0.00	0.21	0.03	0.87	3.08	0.02	0.09	2.15	0.47	2.48	9.39
New Jersey	0.00	0.31	0.07	0.48	0.97	0.01	0.27	0.17	1.31	0.20	3.77
New Mexico	5.36	1.22	3.24	6.38	9.68	0.01	0.37	0.10	1.16	0.12	27.63
New York	0.27	5.52	0.38	3.51	11.86	0.60	1.07	5.46	2.75	6.30	37.74
North Carolina	0.57	4.29	0.37	3.95	10.83	2.56	1.13	17.78	3.06	20.50	65.04
North Dakota	13.39	5.27	0.04	0.19	0.41	0.02	3.34	0.04	0.82	0.05	23.58
Ohio	1.17	4.61	0.18	2.07	3.43	0.22	1.92	4.75	3.13	5.48	26.95
Oklahoma	9.73	19.15	0.95	3.32	4.64	0.65	1.38	1.77	1.69	2.05	45.33
Oregon	6.56	3.78	3.07	8.02	11.03	5.75	0.66	20.10	1.27	23.18	83.41
Pennsylvania	0.19	4.12	0.29	3.88	8.78	0.44	1.12	5.94	3.10	6.85	34.70
Rhode Island	0.00	0.05	0.01	0.06	0.25	0.00	0.03	0.05	0.17	0.06	0.68
South Carolina	0.81	2.42	0.31	2.74	7.31	2.79	0.53	17.71	1.65	20.42	56.70
South Dakota	4.57	4.75	0.38	0.66	0.30	0.04	2.41	0.44	0.77	0.51	14.84
Tennessee	1.53	9.59	0.12	3.82	5.78	0.59	0.93	6.83	2.18	7.88	39.25
Texas	38.61	39.51	8.93	19.40	15.04	2.62	4.08	13.13	6.72	15.14	163.18
Utah	2.38	1.33	1.41	4.65	7.60	0.01	0.33	0.03	0.84	0.03	18.61
Vermont	0.00	0.72	0.01	0.73	3.15	0.03	0.11	1.53	0.29	1.77	8.35
Virginia	0.30	6.19	0.25	3.35	9.38	2.27	0.70	9.56	2.15	11.03	45.18
Washington	14.98	2.48	2.17	5.55	9.49	4.08	1.08	29.79	1.90	34.36	105.88
West Virginia	0.00	3.11	0.11	2.75	6.39	0.06	0.20	4.44	0.72	5.12	22.91
Wisconsin	2.23	6.50	0.39	4.22	8.13	0.91	1.65	6.36	2.10	7.34	39.83
Wyoming	2.38	1.91	1.95	3.24	2.41	0.03	0.38	0.24	0.69	0.28	13.50
TOTAL U.S.	242.00	264.00	48.90	178.00	302.00	57.00	60.00	300.00	84.00	346.00	1881.90

[1]Based on area of CRP land

[2]Based on area of pasture (not + rangeland?)

[3]Based on area of nonstocked forest land

[4]Based on area of understocked + overstocked forest land

[5]Based on area of fully stocked forest land

[6]Based on area of plantations

[7]Based on settlement + cropland area

[8]Based on quantity of removals (harvest)

[9]Based on settlement area

[10]Based on quantity of removals (harvest)

Tables D-4 to D-6. Land areas associated with different forest-related activities whose technical potential is shown in tables D-1 to D-3. The land areas in table D-4 represent the area required to implement each activity at the middle of the range of technical potential, by state. Estimates in table D-5 and D-6 represent the low and high ends of the range of technical potential, respectively. Land areas are based on the area of ”managed land” which includes all areas of forest land [1]; non-federal areas of cropland, CRP land, pastureland, and rangeland [2]; and settlement land [3].

(tables are shown on following pages)

Table D-4. Land areas associated with forest-related activities, middle of range.

Total U.S. potential partitioned to States -- AREA (middle of range)						(1,000,000 hectares)						
	Reforest cropland[1]	Reforest pasture[2]	Accelerate regeneration[3]	Restore productivity[4]	Extend rotation length[5]	Improve plantations[6]	Increase trees outside forests[7]	Increase retention of HWP[8]	Avoid deforestation[9]	BECCS/woody biomass (waste only)[10]	Total area impacted (over 30 years)	All activities per managed hectare
Alabama	0.15	0.25	0.04	2.24	4.08	1.71	0.04		8.32		8.8	0.693
Alaska	0.00	0.00	0.07	1.27	1.80	0.00	0.00		0.00		3.1	0.060
Arizona	0.00	0.00	0.22	2.02	2.48	0.00	0.03		8.13		5.0	0.259
Arkansas	0.05	0.41	0.04	1.88	3.25	0.84	0.08		5.84		6.7	0.501
California	0.01	0.10	0.46	3.17	4.78	0.36	0.15		22.99		9.7	0.354
Colorado	1.23	0.12	0.20	2.47	3.26	0.01	0.09		6.82		7.6	0.323
Connecticut	0.00	0.01	0.01	0.13	0.41	0.00	0.01		3.36		0.7	0.544
Delaware	0.00	0.00	0.00	0.03	0.07	0.01	0.01		0.90		0.1	0.343
Florida	0.02	0.29	0.16	1.93	2.18	1.05	0.07		17.16		6.2	0.493
Georgia	0.09	0.20	0.10	2.39	4.23	1.79	0.07		12.09		9.2	0.648
Hawaii	0.00	0.01	0.01	0.13	0.27	0.02	0.00		0.00		0.4	0.394
Idaho	0.30	0.11	0.54	2.73	1.64	0.08	0.06		3.47		5.6	0.377
Illinois	0.27	0.17	0.01	0.50	0.86	0.03	0.25		11.78		2.4	0.173
Indiana	0.06	0.14	0.01	0.52	0.76	0.05	0.15		8.54		1.9	0.213
Iowa	0.52	0.25	0.02	0.33	0.39	0.01	0.26		6.71		2.0	0.140
Kansas	1.33	0.24	0.02	0.27	0.35	0.01	0.26		7.44		2.7	0.129
Kentucky	0.07	0.36	0.01	1.29	2.00	0.01	0.07		6.72		4.0	0.400
Louisiana	0.07	0.20	0.05	1.53	2.48	1.07	0.06		6.07		5.6	0.568
Maine	0.02	0.01	0.01	1.43	3.73	0.09	0.01		2.35		5.4	0.706
Maryland	0.00	0.03	0.00	0.22	0.47	0.04	0.03		4.81		0.9	0.409
Massachusetts	0.00	0.01	0.00	0.22	0.69	0.00	0.02		5.01		1.1	0.561
Michigan	0.05	0.17	0.05	1.83	3.89	0.34	0.11		13.59		6.8	0.491
Minnesota	0.40	0.30	0.06	1.74	3.00	0.22	0.22		8.18		6.2	0.336
Mississippi	0.32	0.23	0.09	2.03	2.95	1.42	0.06		5.59		7.3	0.615
Missouri	0.53	0.75	0.02	1.49	2.73	0.04	0.16		9.95		6.0	0.341
Montana	0.90	0.35	0.53	3.05	2.59	0.03	0.15		4.16		7.7	0.225
Nebraska	0.39	0.15	0.03	0.17	0.15	0.01	0.20		4.14		1.2	0.063
Nevada	0.00	0.02	0.19	1.01	1.66	0.00	0.01		3.02		3.0	0.410
New Hampshire	0.00	0.01	0.00	0.35	1.09	0.00	0.01		2.06		1.5	0.676
New Jersey	0.00	0.01	0.01	0.19	0.34	0.00	0.02		5.71		0.7	0.435
New Mexico	0.27	0.04	0.40	2.58	3.41	0.00	0.03		5.06		6.9	0.277
New York	0.01	0.20	0.05	1.42	4.18	0.17	0.08		12.04		6.5	0.535
North Carolina	0.03	0.15	0.05	1.59	3.82	0.71	0.08		13.39		6.8	0.567
North Dakota	0.66	0.19	0.00	0.08	0.15	0.01	0.24		3.59		1.4	0.086
Ohio	0.06	0.16	0.02	0.84	1.21	0.06	0.14		13.70		2.9	0.283
Oklahoma	0.48	0.68	0.12	1.34	1.64	0.18	0.10		7.38		4.8	0.257
Oregon	0.33	0.13	0.38	3.24	3.89	1.59	0.05		5.54		9.8	0.524
Pennsylvania	0.01	0.15	0.04	1.57	3.10	0.12	0.08		13.58		5.5	0.489
Rhode Island	0.00	0.00	0.00	0.03	0.09	0.00	0.00		0.72		0.1	0.557
South Carolina	0.04	0.09	0.04	1.10	2.58	0.77	0.04		7.20		4.9	0.658
South Dakota	0.23	0.17	0.05	0.27	0.11	0.01	0.18		3.37		1.1	0.060
Tennessee	0.08	0.34	0.01	1.54	2.04	0.16	0.07		9.53		4.5	0.434
Texas	1.91	1.41	1.10	7.84	5.30	0.73	0.30		29.39		19.5	0.258
Utah	0.12	0.05	0.17	1.88	2.68	0.00	0.02		3.66		5.0	0.474
Vermont	0.00	0.03	0.00	0.30	1.11	0.01	0.01		1.27		1.5	0.642
Virginia	0.01	0.22	0.03	1.35	3.31	0.63	0.05		9.40		5.9	0.596
Washington	0.74	0.09	0.27	2.24	3.35	1.13	0.08		8.33		8.1	0.518
West Virginia	0.00	0.11	0.01	1.11	2.25	0.02	0.01		3.17		3.6	0.593
Wisconsin	0.11	0.23	0.05	1.70	2.87	0.25	0.12		9.20		5.6	0.417
Wyoming	0.12	0.07	0.24	1.31	0.85	0.01	0.03		3.03		2.7	0.163
TOTAL U.S.	12.00	9.40	6.00	71.90	106.50	15.80	4.35		367.50		237.0	0.329

[1]Based on area of CRP land

[2]Based on area of pasture (not + rangeland?)

[3]Based on area of nonstocked forest land

[4]Based on area of understocked + overstocked forest land

[5]Based on area of fully stocked forest land

[6]Based on area of plantations

[7]Based on settlement + cropland area

[8]Based on harvest volume not area

[9]Based on settlement area

[10]Based on Based on harvest volume not area

Table D-5. Land areas associated with forest-related activities, low end of range.

Total U.S. potential partitioned to States (low end of range)					($TgCO_2$/yr)						
State	Reforest cropland[1]	Reforest pasture[2]	Accelerate regeneration[3]	Restore productivity[4]	Extend rotation length[5]	Improve plantations[6]	Increase trees outside forests[7]	Increase retention of HWP[8]	Avoid deforestation[9]	BECCS/woody biomass (waste only)[10]	All activities (not counting overlap)
Alabama	1.52	0.53	0.17	1.87	4.45	3.13	0.21	7.48	0.32	8.38	28.07
Alaska	0.00	0.00	0.30	1.06	1.96	0.00	0.00	0.24	0.00	0.27	3.83
Arizona	0.00	0.01	0.90	1.68	2.70	0.00	0.14	0.05	0.31	0.05	5.84
Arkansas	0.54	0.87	0.18	1.57	3.54	1.55	0.39	4.61	0.22	5.16	18.63
California	0.14	0.21	1.88	2.64	5.20	0.66	0.71	2.19	0.88	2.45	16.96
Colorado	12.45	0.25	0.81	2.06	3.55	0.01	0.45	0.06	0.26	0.07	19.96
Connecticut	0.00	0.02	0.03	0.11	0.44	0.01	0.05	0.12	0.13	0.13	1.04
Delaware	0.00	0.01	0.00	0.03	0.08	0.01	0.03	0.07	0.03	0.08	0.34
Florida	0.23	0.61	0.67	1.61	2.38	1.93	0.34	3.10	0.65	3.47	15.00
Georgia	0.94	0.43	0.39	2.00	4.61	3.28	0.35	8.49	0.46	9.51	30.46
Hawaii	0.00	0.02	0.06	0.11	0.30	0.03	0.00	0.00	0.00	0.00	0.51
Idaho	2.98	0.23	2.22	2.28	1.79	0.15	0.28	1.42	0.13	1.59	13.07
Illinois	2.72	0.37	0.05	0.42	0.93	0.06	1.22	0.45	0.45	0.51	7.16
Indiana	0.63	0.29	0.04	0.43	0.83	0.09	0.70	0.61	0.33	0.68	4.63
Iowa	5.24	0.54	0.07	0.28	0.42	0.02	1.24	0.24	0.26	0.27	8.58
Kansas	13.39	0.50	0.07	0.23	0.38	0.02	1.26	0.18	0.28	0.20	16.52
Kentucky	0.70	0.77	0.05	1.08	2.18	0.02	0.34	1.55	0.26	1.74	8.70
Louisiana	0.67	0.42	0.19	1.27	2.70	1.96	0.30	4.46	0.23	5.00	17.21
Maine	0.20	0.03	0.05	1.20	4.07	0.16	0.05	3.64	0.09	4.07	13.55
Maryland	0.03	0.07	0.02	0.18	0.51	0.07	0.12	0.29	0.18	0.32	1.80
Massachusetts	0.00	0.02	0.02	0.19	0.75	0.00	0.07	0.17	0.19	0.19	1.61
Michigan	0.47	0.36	0.20	1.53	4.24	0.61	0.53	2.52	0.52	2.82	13.81
Minnesota	4.03	0.63	0.24	1.46	3.27	0.40	1.05	1.56	0.31	1.74	14.69
Mississippi	3.26	0.50	0.37	1.69	3.22	2.60	0.28	5.23	0.21	5.86	23.23
Missouri	5.33	1.60	0.08	1.24	2.97	0.08	0.79	1.07	0.38	1.20	14.74
Montana	9.08	0.74	2.16	2.54	2.82	0.06	0.74	0.63	0.16	0.71	19.64
Nebraska	3.93	0.32	0.12	0.15	0.16	0.02	0.95	0.09	0.16	0.11	6.01
Nevada	0.00	0.04	0.79	0.84	1.81	0.00	0.07	0.00	0.12	0.00	3.67
New Hampshire	0.00	0.02	0.02	0.29	1.18	0.01	0.03	0.72	0.08	0.80	3.14
New Jersey	0.00	0.02	0.03	0.16	0.37	0.00	0.09	0.06	0.22	0.06	1.03
New Mexico	2.68	0.09	1.62	2.15	3.72	0.01	0.13	0.03	0.19	0.04	10.66
New York	0.14	0.42	0.19	1.18	4.55	0.31	0.38	1.82	0.46	2.04	11.49
North Carolina	0.28	0.33	0.19	1.33	4.16	1.30	0.40	5.93	0.51	6.64	21.05
North Dakota	6.69	0.40	0.02	0.06	0.16	0.01	1.17	0.01	0.14	0.02	8.68
Ohio	0.58	0.35	0.09	0.70	1.32	0.11	0.67	1.58	0.52	1.77	7.70
Oklahoma	4.87	1.45	0.48	1.12	1.78	0.33	0.48	0.59	0.28	0.66	12.04
Oregon	3.28	0.29	1.54	2.70	4.23	2.92	0.23	6.70	0.21	7.50	29.61
Pennsylvania	0.09	0.31	0.15	1.31	3.37	0.22	0.39	1.98	0.52	2.22	10.56
Rhode Island	0.00	0.00	0.00	0.02	0.09	0.00	0.01	0.02	0.03	0.02	0.20
South Carolina	0.41	0.18	0.16	0.92	2.81	1.42	0.19	5.90	0.27	6.61	18.87
South Dakota	2.29	0.36	0.19	0.22	0.12	0.02	0.85	0.15	0.13	0.17	4.48
Tennessee	0.76	0.73	0.06	1.29	2.22	0.30	0.32	2.28	0.36	2.55	10.87
Texas	19.30	2.99	4.47	6.54	5.78	1.33	1.43	4.38	1.12	4.90	52.25
Utah	1.19	0.10	0.71	1.57	2.92	0.01	0.12	0.01	0.14	0.01	6.77
Vermont	0.00	0.05	0.01	0.25	1.21	0.01	0.04	0.51	0.05	0.57	2.70
Virginia	0.15	0.47	0.13	1.13	3.60	1.15	0.25	3.19	0.36	3.57	13.99
Washington	7.49	0.19	1.09	1.87	3.65	2.08	0.38	9.93	0.32	11.12	38.10
West Virginia	0.00	0.24	0.05	0.93	2.45	0.03	0.07	1.48	0.12	1.66	7.03
Wisconsin	1.12	0.49	0.20	1.42	3.12	0.46	0.58	2.12	0.35	2.38	12.24
Wyoming	1.19	0.14	0.98	1.09	0.92	0.01	0.13	0.08	0.12	0.09	4.76
TOTAL U.S.	121.00	20.00	24.50	60.00	116.00	29.00	21.00	100.00	14.00	112.00	617.50

[1]Based on area of CRP land
[2]Based on area of pasture (not + rangeland?)
[3]Based on area of nonstocked forest land
[4]Based on area of understocked + overstocked forest land
[5]Based on area of fully stocked forest land
[6]Based on area of plantations
[7]Based on settlement + cropland area
[8]Based on quantity of removals (harvest)
[9]Based on settlement area
[10]Based on quantity of removals (harvest)

Table D-6. Land areas associated with forest-related activities, high end of range.

Total U.S. potential partitioned to States -- AREA (High end of range)						(1,000,000 hectares)						
	Reforest cropland[1]	Reforest pasture[2]	Accelerate regeneration[3]	Restore productivity[4]	Extend rotation length[5]	Improve plantations[6]	Increase trees outside forests[7]	Increase retention of HWP[8]	Avoid deforestation[9] (1000 ha/yr)	BECCS/woody biomass (waste only)[10]	Total area impacted (over 30 years)	All activities per managed hectare
Alaska	0.00	0.00	0.10	1.04	2.60	0.00	0.00		0.00		3.7	0.072
Arizona	0.00	0.00	0.29	1.65	3.58	0.00	0.04		8.38		5.8	0.302
Arkansas	0.07	0.33	0.06	1.54	4.71	1.12	0.11		6.02		8.1	0.603
California	0.02	0.08	0.61	2.60	6.91	0.48	0.19		23.72		11.6	0.423
Colorado	1.65	0.09	0.27	2.03	4.71	0.01	0.12		7.04		9.1	0.387
Connecticut	0.00	0.01	0.01	0.11	0.59	0.00	0.01		3.47		0.8	0.679
Delaware	0.00	0.00	0.00	0.03	0.10	0.01	0.01		0.93		0.2	0.416
Florida	0.03	0.23	0.22	1.58	3.16	1.40	0.09		17.71		7.2	0.573
Georgia	0.12	0.16	0.13	1.96	6.12	2.38	0.10		12.48		11.3	0.795
Hawaii	0.00	0.01	0.02	0.11	0.40	0.02	0.00		0.00		0.5	0.490
Idaho	0.39	0.09	0.72	2.24	2.38	0.11	0.08		3.58		6.1	0.414
Illinois	0.36	0.14	0.02	0.41	1.24	0.04	0.33		12.15		2.9	0.205
Indiana	0.08	0.11	0.01	0.43	1.10	0.06	0.19		8.81		2.2	0.247
Iowa	0.69	0.20	0.02	0.27	0.56	0.01	0.34		6.92		2.3	0.163
Kansas	1.77	0.19	0.02	0.22	0.50	0.02	0.34		7.67		3.3	0.158
Kentucky	0.09	0.29	0.02	1.06	2.89	0.02	0.09		6.94		4.7	0.465
Louisiana	0.09	0.16	0.06	1.25	3.59	1.42	0.08		6.26		6.8	0.690
Maine	0.03	0.01	0.02	1.18	5.40	0.11	0.01		2.43		6.8	0.896
Maryland	0.00	0.03	0.01	0.18	0.68	0.05	0.03		4.97		1.1	0.492
Massachusetts	0.00	0.01	0.01	0.18	1.00	0.00	0.02		5.17		1.4	0.702
Michigan	0.06	0.14	0.07	1.50	5.62	0.45	0.14		14.02		8.4	0.602
Minnesota	0.53	0.24	0.08	1.43	4.34	0.29	0.29		8.44		7.4	0.404
Mississippi	0.43	0.19	0.12	1.66	4.27	1.88	0.08		5.77		8.8	0.744
Missouri	0.70	0.60	0.03	1.22	3.95	0.06	0.21		10.26		7.1	0.401
Montana	1.20	0.28	0.71	2.50	3.74	0.05	0.20		4.29		8.8	0.256
Nebraska	0.52	0.12	0.04	0.14	0.22	0.02	0.26		4.28		1.4	0.074
Nevada	0.00	0.02	0.26	0.83	2.40	0.00	0.02		3.12		3.6	0.496
New Hampshire	0.00	0.01	0.01	0.29	1.57	0.01	0.01		2.12		1.9	0.866
New Jersey	0.00	0.01	0.01	0.16	0.49	0.00	0.03		5.89		0.9	0.511
New Mexico	0.35	0.03	0.53	2.11	4.94	0.00	0.03		5.22		8.2	0.328
New York	0.02	0.16	0.06	1.16	6.05	0.22	0.10		12.42		8.1	0.674
North Carolina	0.04	0.12	0.06	1.31	5.52	0.94	0.11		13.81		8.5	0.707
North Dakota	0.89	0.15	0.01	0.06	0.21	0.01	0.32		3.71		1.8	0.105
Ohio	0.08	0.13	0.03	0.69	1.75	0.08	0.18		14.13		3.4	0.327
Oklahoma	0.64	0.54	0.16	1.10	2.37	0.24	0.13		7.61		5.4	0.292
Oregon	0.43	0.11	0.50	2.66	5.62	2.12	0.06		5.72		11.7	0.626
Pennsylvania	0.01	0.12	0.05	1.28	4.48	0.16	0.11		14.01		6.6	0.593
Rhode Island	0.00	0.00	0.00	0.02	0.13	0.00	0.00		0.75		0.2	0.699
South Carolina	0.05	0.07	0.05	0.91	3.73	1.03	0.05		7.43		6.1	0.825
South Dakota	0.30	0.13	0.06	0.22	0.15	0.02	0.23		3.48		1.2	0.066
Tennessee	0.10	0.27	0.02	1.27	2.95	0.22	0.09		9.83		5.2	0.499
Texas	2.55	1.12	1.46	6.43	7.67	0.97	0.39		30.32		21.5	0.285
Utah	0.16	0.04	0.23	1.54	3.88	0.00	0.03		3.78		6.0	0.564
Vermont	0.00	0.02	0.00	0.24	1.61	0.01	0.01		1.31		1.9	0.834
Virginia	0.02	0.18	0.04	1.11	4.79	0.83	0.07		9.70		7.3	0.741
Washington	0.99	0.07	0.36	1.84	4.84	1.50	0.10		8.59		10.0	0.633
West Virginia	0.00	0.09	0.02	0.91	3.26	0.02	0.02		3.27		4.4	0.724
Wisconsin	0.15	0.18	0.06	1.40	4.14	0.34	0.16		9.50		6.7	0.500
Wyoming	0.16	0.05	0.32	1.07	1.23	0.01	0.04		3.12		3.0	0.179
TOTAL U.S.	16.00	7.50	8.00	59.00	154.00	21.00	5.70		379.10		282.6	0.392

[1]Based on area of CRP land

[2]Based on area of pasture (not + rangeland?)

[3]Based on area of nonstocked forest land

[4]Based on area of understocked + overstocked forest land

[5]Based on area of fully stocked forest land

[6]Based on area of plantations

[7]Based on settlement + cropland area

[8]Based on harvest volume not area

[9]Based on settlement area

[10]Based on Based on harvest volume not area

Appendix D references

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