**USDA Integrated Projections for Agriculture and Forest Sector Land Use, Land-Use Change, and GHG Emissions and Removals:**

 **2015 to 2060**

**January 19, 2016**

**Introduction**

In 2014, USDA established a formal process for developing short-, medium-, and long-term projections regarding land use, land-use change, GHG emissions, and CO2 removals for the U.S. agriculture and forestry sectors. This document describes the methods, data, and assumptions used to construct the 2015 projections, which cover the period 2015–2060. The projections serve several Departmental and U.S. government needs.

U.S. reporting obligations under the United Nations Framework Convention on Climate Change (UNFCCC) include both a Climate Action Report (CAR) every four years and a Biennial Report (BR) every two years. Both documents include projections of GHG emissions and removals from the agriculture and forestry sectors. The CAR and BR reporting requirements mean that USDA will need to develop projections of land use and emissions/removals for the agriculture and forestry sectors at least once every two years. The projections described in this document are used in the 2nd Biennial Report, which the U.S. Department of State submitted to the UNFCCC in January of 2016.

U.S. forests currently store enough additional carbon each year to offset about 12 percent of gross U.S. GHG emissions (USEPA 2015). To formulate sound GHG mitigation strategies that can preserve and grow the forest sink requires an informed assessment of how forest carbon sequestration may evolve over the next few decades under current and alternative agricultural and forest policy scenarios.

The projections described in this document were developed by an interagency USDA team consisting of analysts from the Forest Service, the Economic Research Service, and the Office of the Chief Economist. In constructing the projections, the USDA team used a composite methodology that combined information and insights obtained from: 1) forest and agricultural sector models used by USDA’s Forest Service and Economic Research Service; 2) current and historical data on GHG emissions, CO2 removals, population growth, and urbanization; 3) recent assessments of current U.S. forest conditions and the trends that are likely to affect future conditions over the next several decades; 4) recent projections of population growth, economic growth, and commodity market conditions developed by other Executive Branch agencies; and 5) judgment-based analysis. The result is a set of land use and GHG emissions projections for the forest and agricultural sectors that are internally consistent and, generally consistent with a wide set of U.S. government data products and projections (see Box 1).

|  |
| --- |
| **BOX 1: U.S. government data products, projections, and reports used as inputs to construct land use and GHG emissions projections from 2015-2060 for the forestry and agriculture sectors.*** USDA Agricultural Projections to 2024: <http://www.usda.gov/oce/commodity/projections/index.htm>
* 2010 Resources Planning Act (RPA) Assessment: <http://www.fs.fed.us/research/rpa/>
* U.S. Environmental Protection Agency; Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990–2013: <http://www.epa.gov/climatechange/ghgemissions/usinventoryreport.html>
* 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. Rept. NRS-154. U.S. Department of Agriculture Forest Service, Northern Research Station. 49 p.
* U.S. Department of Energy, Energy Information Energy Information Agency: *2015Annual Energy Outlook:* <http://www.eia.gov/forecasts/aeo/>

U.S. Department of Commerce, Census Bureau, Population Division: Projections of the Population and Components of Change for the United States: 2015 to 2060 (NP2014-T1). Release Date: December 2014.* USDA Economic Research Service: Major Uses of Land in the United States, 2007: <http://www.ers.usda.gov/publications/eib-economic-information-bulletin/eib89.aspx#.U9poVKPnK-U>
* USDA Forest Service Forest Inventory and Analysis data: <http://www.fia.fs.fed.us/tools-data/>
* USDA Natural Resources Conservation Service: National Resources Inventory <http://www.nrcs.usda.gov/wps/portal/nrcs/main/national/technical/nra/nri/>)
* United Nations projections of world population growth: United Nations. 2015. Department of Economic and Social Affairs, Population Division. <http://esa.un.org/unpd/wpp/DVD/>
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The 2015 USDA projections include a Reference Scenario, a High Emissions Scenario, and a Low Emissions Scenario. The Reference Scenario was constructed to evaluate how land use and GHG emissions paths in the agriculture and forestry sectors might evolve over the next few decades assuming a continuation of current conditions and/or trends in key factors that could affect long-run changes in the markets for agricultural and forest products, and current agricultural and forest sector policies. The Low- and High Emissions Scenarios incorporate variations in the rate of U.S. population growth and the demand for land for developed uses. The assumptions for the Reference Scenario and the variations are described in the next section. For each scenario, the full set of projections includes:

1. The area of U.S. land in
	1. Forest uses
	2. Cropland

Disaggregated to identify planted acres and harvest acres in corn, wheat, soybeans, cotton, and other principal crops.

* 1. Developed Uses
	2. Other non-federal rural land (primarily grasslands)
1. GHG emissions and removals
	1. Net carbon flux from U.S. Forests

Disaggregated to identify the flux related to land in forest remaining forest and land transitioning into (or out of) forest

* 1. Carbon sequestered in harvest wood products (HWP)
	2. GHG emissions from U.S. crop and livestock production systems.
	3. Carbon sequestered in urban forests
1. Agricultural production – crops
	1. Corn: Million bushels and Bushels per acre
	2. Wheat: Million bushels and Bushels per acre
	3. Soybean: Million bushels and Bushels per acre
	4. Cotton: Bales and pounds per acre
2. Agricultural production – livestock
	1. Beef cattle: 1,000 head and million pounds
	2. Dairy cattle: 1,000 head and billion pounds
	3. Hogs: 1,000 head and million pounds
	4. Poultry: million pounds

**Reference Scenario**

The reference scenario was developed to evaluate the likely trajectory of carbon stocks and flux in agriculture and forests based on the continuation of historical trends in population growth, economic growth, and land use change. The Reference Scenario includes all policies in place at the time of the analysis and assumes these policies are maintained over the projection period.

**Socioeconomic Assumptions**

***Population Trends***

Alternative projections of domestic and global population growth were taken, or developed, from population projections produced by the U.S. Census Bureau (USBC) and the United Nations (UN). Each year USBC projects U.S. population over the next several decades; the UN does the same by country and for the world in aggregate. The U.S. population projection for the Reference Scenario is the 2014 projection from the U.S. Census Bureau (USCB 2014) as shown in Table 1. The same population projection was used in the 2015 USDA Baseline (USDA 2015) and in the 2015 Annual Energy Outlook (AEO) Reference Case (USDOE 2015). World population growth through 2060 in the Reference Scenario is assumed to follow the U.N’s 2014 central projection.

The UN population projections also include high and low population growth scenarios. In these projections the U.S. population in 2060 is, respectively, 5.14 percent higher and 5.31 percent lower than in the UN central projection. These percentage changes are applied to the USBC projection to develop the U.S. population growth paths in USDA High- and Low- emissions scenarios.

**Table 1**. U.S. population projections for the Reference, Low, and High Scenarios, 2015-2060.

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Year** | **Reference Scenario1** | **Reference Scenario** | **Low Scenario** | **High Scenario** |
|  | **(000s)** | **Percent Change** | **(000s)** | **Percent Change** |
| 2015 | 321,369 |  | 320,555 | 322,155 |
| 2020 | 334,503 | 4.09% | 332,324 | 336,620 |
| 2025 | 347,335 | 3.84% | 343,269 | 351,116 |
| 2030 | 359,402 | 3.47% | 353,364 | 365,081 |
| 2035 | 370,338 | 3.04% | 362,116 | 378,115 |
| 2040 | 380,219 | 2.67% | 369,611 | 390,029 |
| 2045 | 389,394 | 2.41% | 376,505 | 401,660 |
| 2050 | 398,328 | 2.29% | 382,753 | 413,265 |
| 2055 | 407,412 | 2.28% | 388,793 | 425,216 |
| 2060 | 416,795 | 2.30% | 394,663 | 438,218 |

1USCB 2014

***Economic Trends***

The 2015 USDA Baseline assumes U.S. GDP grows 2.6 percent annually from 2016-2024 (USDA 2015). Projections for the agricultural sector from 2024 to 2060 assume the same annual rate of GDP growth. The 2015 Annual Energy Outlook Reference Case assumes an annual growth rate of 2.4 percent for 2012-2040. Projections for the forest sector adopted the 2015 AEO U.S. GDP growth rate of 2.4 percent per year for 2015 through 2030; from 2030 to 2060 GDP growth varied on a per capita basis.

Global GDP growth is critical to evaluating trade impacts on forest product markets, which influence the amount of carbon stored in harvested wood products (HWPs). Global GDP growth rates in this analysis were based on country specific growth rates in the Global Forest Products Model (GFPM).

***Housing starts***

Housing starts are a key variable for projecting forest product consumption and production and the carbon sequestered in HWPs. Housing starts in the 2015 AEO Reference Case reach almost 1.7 million per year by 2020 and remain between 1.6 and 1.7 million through 2040. This level of housing starts is high compared to FS estimates. The FS used a housing starts model estimated on quarterly data that is tied to GDP per capita and population growth rates to estimate the housing starts.

Housing starts were projected for the Reference, Low, and High Scenario using the different rates of population growth from 2015 to 2060 described previously (Figure 1). GDP growth was assumed constant at 2.4 percent throughout, implying that variation in GDP per capita growth rates is caused only by changes in population. Figure 1 indicates a rapid achievement of long-run equilibrium projected total (single plus multifamily) housing start levels. For the Reference Scenario annual total housing starts range from 1.07 to 1.11 and average 1.08 million between 2015 and 2060. In the Low Scenario, they range from 1.08 to 1.16 and average 1.11 million, while in the High Scenario they range from 1.10 to 1.19 million and average 1.14 million.

**Figure 1.** Historical total U.S. housing starts and projections to 2060 under Reference, Low, and High Scenarios.



In the FS housing starts model used for this projection, quarterly housing starts were expressed as a function of seasonal dummies, one-quarter lagged housing starts, changes in GDP per capita, total U.S. population, the 30-year fixed rate mortgage interest rate, the all-commodity producer price index deflated national hourly average construction wage, the all-commodity consumer price index based inflation, and the one-quarter lag of the GDP deflator adjusted S&P/Case-Shiller U.S. National Home Price Index.

All three projections assumed the following about the period 2015 to 2060: (a) zero real (all-commodity producer price index deflated) changes in hourly construction wages, which is consistent with historical data from 1990 to 2014; (b) no change in average national mortgage rates (i.e., rates are held constant throughout the projection); and (c) no change in consumer price inflation (i.e., the rate of inflation is held constant). In the projections, a reduced-form house price model, similar to the reduced-form housing starts model, projects housing prices to 2060 and hence contributes the lagged first-differenced housing price in the housing starts projection.

Projected housing starts are depicted and simulated in the analyses based on stability of driving variables besides population. In reality, future starts will vary according to variations of driving variables. It is beyond the scope of this study to simulate the entire probability density of these ranges and hence the carbon implications of these variations.

**Land Use Trends**

Land use change is a critical variable in projecting trends in carbon emissions and sequestration in the land sector. Therefore, the Low and High Scenarios, based on variation in population growth and rate of developed land growth, were developed to explore the sensitivity of carbon storage and flux to varying assumptions about land use change relative to the Reference Scenario. The National Resource Inventory (NRI) definitions and data provided the historical patterns of change for the U.S. nonfederal land base. The total area of the federal land base is assumed to remain constant over the projection period.

***Developed Land Trends***

Figure 2 shows the NRI-based changes in developed land area from 1982 to 2010. Over this period developed land consistently increased but at varying rates. Since development is linked to population change, we calculated the developed land acres per additional person in the U.S. population over different intervals in the NRI time series to compare rates of change over time. Changes in those rates could be a result of overall change in development, but may also reflect the density of development over time.

**Figure 2**. Trends in acreage of NRI-defined developed lands from 1982-2007.



Source: USDA 2013.

Table 2 presents the change in developed acres per additional person for multiple time frames from the NRI. The first column of rates of change is based on 5-year increments (3-years for 2007-2010). Most noticeable are the decline in the rate since 2002, and the decline in 2007-2010 that likely reflects the 2007-2009 economic recession.

**Table 2**. Acres per person added to the U.S. population across multiple time scales, 1982-2010, for the conterminous United States.

|  |  |  |  |
| --- | --- | --- | --- |
| **Year** | **U.S. Population (millions)** | **Developed Land (million acres)** | **Acres/ person added** |
| 2010 | 309.35 | 113.3 | 0.271 | 0.387 | 0.474 | 0.532 |
| 2007 | 301.23 | 111.1 | 0.456 |   |   |   |
| 2002 | 287.63 | 104.9 | 0.601 | 0.636 |   |   |
| 1997 | 272.65 | 95.9 | 0.669 |   | 0.586 |   |
| 1992 | 256.51 | 85.1 | 0.506 | 0.531 |   |   |
| 1987 | 242.29 | 77.9 | 0.564 |   |   |   |
| 1982 | 231.66 | 71.9 |   |   |   |   |

Source: USDA 2013; USCB 2014

The Reference Scenario assumes that the slowing of development rates in the last decade will continue in the future, so the rate of change between 2002 and 2010 (0.387 acres/additional person) was applied to the projected population change. This lower rate of development also reflects an assumption that future urbanization will occur within already developed areas rather than entirely through conversion of other rural land uses. The Low Scenario reflects the most recent development rate (0.271 acres/additional person) with slower population growth and a denser development pattern than seen in longer term historical trends. The High Scenario reflects development rates over the entire time frame of the NRI (0.532 acres/additional person) that accommodates more extensive development patterns consistent with the historical patterns of the 1980s and 1990s (Table 3). Table 4 shows the trend and projection in total developed land use in the conterminous United States.

**Table 3**. Population (in 1,000 people) and developed land (in 1,000 acres) projections for the Reference, Low, and High Scenarios, 2015-2060, for the conterminous United States.

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| **Year** | **Population Reference**  | **Developed Land Change Reference**  | **Population Low** | **Developed Land Change Low** | **Population High** | **Developed Land Change High**  |
| 2015 | 321,369 |  | 320,555 |  | 322,155 |  |
| 2020 | 334,503 | 5,082.86 | 332,324 | 3,189.40 | 336,620 | 7,709.85 |
| 2025 | 347,335 | 4,965.98 | 343,269 | 2,966.10 | 351,116 | 7,726.37 |
| 2030 | 359,402 | 4,669.93 | 353,364 | 2,735.75 | 365,081 | 7,443.35 |
| 2035 | 370,338 | 4,232.23 | 362,116 | 2,371.79 | 378,115 | 6,947.12 |
| 2040 | 380,219 | 3,823.95 | 369,611 | 2,031.15 | 390,029 | 6,350.16 |
| 2045 | 389,394 | 3,550.73 | 376,505 | 1,868.27 | 401,660 | 6,199.32 |
| 2050 | 398,328 | 3,457.46 | 382,753 | 1,693.21 | 413,265 | 6,185.47 |
| 2055 | 407,412 | 3,515.51 | 388,793 | 1,636.84 | 425,216 | 6,369.88 |
| 2060 | 416,795 | 3,631.22 | 394,663 | 1,590.77 | 438,218 | 6,930.07 |
| **Sum** |  | 36,929.86 |  | 20,083.27 |  | 61,861.58 |
| **Per Year** |  | 802.82 |  | 436.59 |  | 1,344.82 |

**Table 4**. Developed land area under the Reference, High, and Low Scenarios, 2010-2060, for the conterminous United States.

|  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
|  | **2010** | **2015** | **2020** | **2025** | **2030** | **2040** | **2050** | **2060** |
| **Scenario** |  | *Thousand acres* |
| Reference | 113,300 |  118,400  | 123,500 | 128,400 |  133,100 | 141,200 | 148,200 | 155,300 |
| Low | 113,341 |  116,500  |  119,700  | 122,600  | 125,400  |  129,800  | 133,300  | 136,600  |
| High | 113,341 |  121,000  |  128,700  |  136,400  |  143,900  |  157,200  |  169,600  |  182,900  |

*Cropland Trends*

Projections of planted cropland are presented in Table 5 for the Reference, Low, and High Scenarios. Each projection is based on an extension of the USDA Baseline beyond its official projection period (ending in 2024) out to 2060 under three alternative assumptions regarding U.S. and global population growth rates. Projections are developed separately for corn, soybeans, wheat, and upland cotton using the following procedure:

1. Generate commodity specific projections of domestic demand and exports based on population and income assumptions and the relation of each demand to those factors in the last 5 years of the 10-year USDA Baseline (USDA 2015).
2. Given projections of total use (i.e., domestic demand plus exports), assume production is equal to use (with adjustments for imports and stock changes).
3. Derive harvested acreage in each year based on total production and commodity specific yield assumptions.
4. Derive planted acreage from harvested acreage.

Acreage for four other crop categories –other feed grains, rice, harvested hay, and other principal crops - are assumed to remain constant at current levels through 2060. With the exception of harvested hay, commodities have been, and are projected to remain, small in planted and total production relative to crops described above. In addition, for all four of these crops, total acreage and production have varied within very narrow ranges historically.

The projections of planted acres reflect the summation of the projections of the acres planted to each of the eight crop categories described above. Since corn, soybeans, wheat, and cotton have unique GHG intensities per acre of production, year to year changes in the projections of acres planted to these crops are reflected in the projection of emissions from “soil management.”

Finally, between now and 2060 it is almost certain—that some land now in crop production will be converted to developed uses. As the second highest valued use of land, however, our projections assume that any such land will be replaced by some mix of lands now in the other cropland and pasture/range categories (for example CRP and other idle uses). We also assume that any net additions to cropland will come from these other agricultural land categories. In general then, we assume that, at least through 2060, it will not be cost effective to shift lands now in forest uses to crop production. Similarly, in the Low Scenario, we assume all acres removed from crop production are shifted to pasture, range, or idle cropland use. For the agricultural sector then, the key projection is the quantity of land in crop production.

**Table 5**. Planted cropland under the Reference, High, and Low Scenarios, 2010-2060, for the conterminous United States.

|  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
|  |  |  |  |  |  |  |  |  |
|  | **2010** | **2015** | **2020** | **2025** | **2030** | **2040** | **2050** | **2060** |
| **Scenario** |   | *thousand acres* |
| Reference | 313,900 | 322,900 |  314,400  |  314,100  |  313,900  |  313,200  |  312,700  |  313,300  |
| Low | 313,900 | 322,254 | 313,771  |  312,100  |  311,200  | 308,800 | 306,500 | 304,900 |
| High | 313,900 | 323,546 |  315,029  |  315,900  |  316,500  | 317,500 | 318,800 | 321,700 |

***Forest Land Trends***

The Forest Service’s Forest Inventory and Analysis (FIA) program is the basis for estimates of forest land on all ownerships of the United States. Future forest area depends on a number of factors including development, the demand for cultivated cropland, and the disposition of other forms of agricultural land. While long run projections indicate an eventual net decline in forest land in response to these factors (Wear 2011) inventoried forest area has recently trended upward. Greenhouse gas inventories and the forest inventories upon which they are based have shown increasing forest area since the first NGHGI in 1990. According to the preliminary 2016 forest GHG inventory numbers (Woodall et al. 2015), forest area grew by about one million acres per year over the period 2005 to 2015.

Table 6 presents the projections of forest land area under the Reference, Low, and High Scenarios. In the Reference Scenario we assume that forest area continues to accumulate at its current rate through 2025, increase at a decreasing rate to reach a maximum in 2030, and then slowly decline through 2060. The Low Scenario assumes that forest area will continue to accumulate at its current rate through 2030, increase at a decreasing rate through 2050, and stabilize between 2050 and 2060. For the High Scenario we assume that forest area will continue to accumulate at current levels until 2020, increase at a decreasing rate until 2025, and then decline through 2060.

**Table 6**. Forest land under the Reference, High, and Low Scenarios, 2010-2060, for the conterminous United States and coastal Alaska.

|  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
|  |  |  |  |  |  |  |  |  |
|  | **2010** | **2015** | **2020** | **2025** | **2030** | **2040** | **2050** | **2060** |
| **Scenario** |   | *thousand acres* |
| Reference  | 671,610 | 676,795 | 682,122 | 687,541 | 689,583 | 687,310 | 684,410 | 681,509 |
| Low  | 671,610 | 676,795 | 682,122 | 687,451 | 692,780 | 700,773 | 703,437 | 703,437 |
| High  | 671,610 | 676,795 | 682,122 | 684,254 | 683,188 | 678,188 | 673,188 | 668,188 |

***Summary of land use projections***

Table 7 summarizes the land use trends and projections for developed land, planted cropland, and forest land for the Reference, High, and Low Scenarios. Develop land and planted cropland area includes only the conterminous United States; forest land also includes coastal Alaska forest land that is included in the forest NGHGI.

**Table 7**. Land use projections under the Reference, High, and Low Scenarios, 2010-2060, for the conterminous United States.

|  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
|  |  |  |  |  |  |  |  |  |
|  | **2010** | **2015** | **2020** | **2025** | **2030** | **2040** | **2050** | **2060** |
| **Scenario** |   | *thousand acres* |
| **Reference Scenario** |  |  |  |  |  |  |  |
| Developed land | 113,300 |  118,400  | 123,500 | 128,400 |  133,100 | 141,200 | 148,200 | 155,300 |  |
| Planted cropland | 313,900 | 322,900 | 314,400 | 314,100 | 313,900 |  313,200  |  312,700 | 313,300 |
| Forest land1 | 671,610 | 676,795 | 682,122 | 687,541 | 689,583 | 687,310 | 684,410 | 681,509 |
|  |  |  |  |  |  |  |  |  |
| **Low Scenario** |  |  |  |  |  |  |  |  |
| Developed land | 113,341 |  116,500  |  119,700  | 122,600  | 125,400  |  129,800  | 133,300  | 136,600  |
| Planted cropland | 313,900 | 322,254 | 313,771  |  312,100  |  311,200  | 308,800 | 306,500 | 304,900 |
| Forest land1  | 671,610 | 676,795 | 682,122 | 687,451 | 692,780 | 700,773 | 703,437 | 703,437 |
|  |  |  |  |  |  |  |  |  |
| **High Scenario** |  |  |  |  |  |  |  |  |
| Developed land | 113,341 |  121,000  |  128,700  |  136,400  |  143,900  |  157,200  |  169,600  |  182,900  |
| Planted cropland | 313,900 | 323,546 |  315,029  |  315,900  |  316,500  | 317,500 | 318,800 | 321,700 |
| Forest land1  | 671,610 | 676,795 | 682,122 | 684,254 | 683,188 | 678,188 | 673,188 | 668,188 |
| 1 Forest land includes coastal Alaska.  |
|  |  |  |  |  |  |  |  |  |
|  |  |  |  |  |  |  |  |  |

**GHG Emissions in the Agriculture and Forestry Sector**

**Agriculture Sector**

Projections of emissions from agricultural sources are presented in Table 8. The projections were developed using historical emissions data contained in the 2015 National Greenhouse Gas Inventory (NGHGI) (USEPA 2015), commodity specific emissions data contained in the 2011 edition of the USDA Agriculture and Forestry Greenhouse Gas Inventory (USDA 2011), historical data related to commodity production available from various USDA sources, projections (through 2024) of U.S. commodity production and input use contained in the 2015 edition of the USDA 10-Year Agricultural Baseline (USDA 2015), and three scenarios that extend the USDA Baseline to 2060 described below.

While aggregated to fewer categories, the emissions shown in Table 8 for historical years (i.e., 2005, 2010, and 2013), align exactly with emissions shown in Table 5.1 of the 2015 NGHGI (USEPA 2015). In Table 8, emissions from “agricultural soil management” include the N2O emissions reported for the same category in the NGHGI Table 5-1 plus the CH4 emissions reported for “rice cultivation”. Similarly, the category “manure management emissions” in Table 8 reflect the sum of emissions reported for the CH4 and N2O manure management categories in the NGHGI table.

**Table 8**. GHG emissions from U.S. agriculture, 2005-2013, and projections through 2060 for the Reference, Low, and High Scenarios (Tg CO2 eq.).

|  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
|  |  |  |  |  |  |  |  |  |  |  |
| **Reference Scenario** |  | **2005** | **2010** | **2013** | **2020** | **2025** | **2030** | **2040** | **2050** | **2060** |
|  Soil Management  | 252.8 | 275.8 | 272.5 | 262.4 | 262.3 | 262.4 | 262.4 | 262.5 | 262.9 |
|  Enteric Fermentation | 168.9 | 171.1 | 164.5 | 173.0 | 175.3 | 175.8 | 176.2 | 176.3 | 177.3 |
|  Manure Management | 72.7 | 78 | 78.7 | 79.9 | 80.6 | 81.5 | 83.1 | 84.8 | 87.2 |
|  Building Blocks |  | 0 | 0 | 0 | -11.4 | -25.7 | -25.7 | -25.7 | -25.7 | -25.7 |
|  Total Emissions  |  | 494.4 | 524.9 | 515.7 | 503.9 | 492.5 | 494.0 | 496.0 | 497.8 | 501.7 |
|  |  |  |  |  |  |  |  |  |  |  |
| **Low Scenario** | **2005** | **2010** | **2013** | **2020** | **2025** | **2030** | **2040** | **2050** | **2060** |
|  Soil Management  | 252.8 | 275.8 | 272.5 | 260.4 | 261.8 | 261.7 | 261.2 | 260.9 | 260.7 |
|  Enteric Fermentation | 168.9 | 171.1 | 164.5 | 171.7 | 172.7 | 172.4 | 170.7 | 168.6 | 166.9 |
|  Manure Management | 72.7 | 78 | 78.7 | 78.9 | 79.4 | 79.7 | 80.2 | 80.7 | 81.5 |
|  Building Blocks |  | 0 | 0 | 0 | -11.4 | -25.7 | -25.7 | -25.7 | -25.7 | -25.7 |
|  Total Emissions  |  | 494.4 | 524.9 | 515.7 | 499.6 | 488.2 | 488.1 | 486.4 | 484.4 | 483.5 |
|  |  |  |  |  |  |  |  |  |  |  |
| **High Scenario** | **2005** | **2010** | **2013** | **2020** | **2025** | **2030** | **2040** | **2050** | **2060** |
|  Soil Management  | 252.8 | 275.8 | 272.5 | 261.5 | 262.8 | 263.1 | 263.5 | 264.1 | 265.1 |
|  Enteric Fermentation | 168.9 | 171.1 | 164.5 | 176.8 | 177.8 | 179.1 | 181.6 | 184.0 | 187.9 |
|  Manure Management | 72.7 | 78 | 78.7 | 81.3 | 81.7 | 83.1 | 85.9 | 88.9 | 93.0 |
|  Building Blocks |  | 0 | 0 | 0 | -11.4 | -25.7 | -25.7 | -25.7 | -25.7 | -25.7 |
|  Total Emissions |  | 494.4 | 524.9 | 515.7 | 508.2 | 496.6 | 499.6 | 505.3 | 511.3 | 520.3 |
|  |  |  |  |  |  |  |  |  |  |  |

Projected emissions to 2060 assume that for each livestock and crop commodity, emissions per production unit remain constant from the present to 2060. This means the projections take as given the current mix of farm and climate policies relevant to the farm sector and the current mix of production practices and technologies used on U.S. farms. For crop commodities (namely corn, soybeans, wheat, cotton, other feed grains, rice, hay, and other principal crops) the production unit is acres planted. For livestock commodities (namely dairy, beef, swine, and poultry) the production unit is number of animals.

By allocating total agricultural emissions in a given year to production of the commodities described above in that same year, one can derive a set of commodity specific relationships linking emissions to production. For the projections shown in Table 8, such relationships were derived using the following process.

1. Allocate the total emissions in a given source category reported in the NGHGI (e.g., enteric fermentation) to the commodities that account for those emissions (dairy, beef, and other livestock),
2. For each commodity (e.g. dairy), align the total source emissions with the units of production (i.e., number of head),
3. Compute GHG emissions per unit of production (e.g. CH4 per head).

The set of relationships between commodity production and GHG emissions developed using the above process can be applied to any set of projections of future commodity production to develop internally consistent projections of future emissions from agricultural sources. In Table 8, emissions projections are presented for three extensions of the 2015 USDA Baseline. The USDA Baseline projects commodity production, consumption, trade, input use, and other variables through 2024. The USDA Baseline was extended through 2060 under alternative assumptions about U.S. and global population growth rates described in the Assumptions Section. U.S. and global population growth rates were chosen as the drivers distinguishing the three scenarios because they have been, and are expected to continue to be, the most important determinants of the aggregate demand for - and thus, production of - U.S. agricultural commodities.

Finally, USDA has initiated a comprehensive strategy to support farmers, ranchers, and forest land owners in responding to climate change. The strategy includes ten “building blocks” that promote the voluntary adoption of greenhouse gas (GHG) mitigating technologies and practices in the context of working production systems. USDA expects actions taken under the building blocks to mitigate over 120 million metric tons of CO2 equivalents per year by 2025. The mitigation to be achieved under the “livestock partnerships” and the “nitrogen stewardship” building blocks are reflected in Table 2 assuming the combined goal of 25.7 Tg CO2 eq. in 2025 is achieved in equal annual increment increases beginning in 2017. Because mitigation goals have not been established for the Building Blocks for the post 2025 period, we assume the 2025 goal is maintained through 2060.

***Non-forest Land Use Carbon Agricultural Soil Carbon flux***

As input to the 2nd Biennial Report, the USDA Projections Team developed projections through 2030 for the carbon fluxes related to agricultural soils management, expansion of urban forests, and the burial of yard trimmings and food wasted in landfills. These projections, are presented in Table 9. The projections are largely based on means and trends observable in corresponding data for these flux categories for the period 2009-2013, which are available in Table 6-1 of the 2015 NGHGI (USEPA 2015). As can be seen in that source, these flux categories have been relatively constant in recent years: agricultural soils show a small but steady downward trend, urban forests show a small but steady upward trend, yard trim and food waste shows no clear trend.

**Table 9**. GHG emissions from non-forest land use categories, 2005-2013, and projections through 2030 for the Reference Scenario (Tg CO2 eq).

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
|  |  | **2005** | **2010** | **2013** | **2020** | **2025** | **2030** |
| **Ag Soil Carbon** | -13.0 | -6.9 | -4 | -12.2 | -23.8 | -23.8 |
|  *Cropland remaining cropland* | *-28* | *-25.9* | *-23.4* | *-21.9* | *-21.9* | *-21.9* |
|  *Land converted to cropland* | *19.8* | *16.2* | *16.1* | *16.2* | *16.2* | *16.2* |
|  *Grassland remaining grassland* | *4.2* | *11.7* | *12.1* | *11.7* | *11.7* | *11.7* |
|  *Land converted to grassland* | *-9* | *-8.9* | *-8.8* | *-8.9* | *-8.9* | *-8.9* |
|  *Building Blocks* | *0* | *0* | *0* | *-9.3* | *-20.9* | *-20.9* |
| **Urban Forests** | -80.5 | -86.1 | -89.5 | -97.5 | -103.2 | -108.9 |
|  *Building Blocks* | *0* | *0* | *0* | *-0.01* | *-0.02* | *-0.02* |
|  |  |  |  |  |  |  |  |
| **Yard Trim & Food Waste** | -12.0 | -13.6 | -12.8 | -13.2 | -13.2 | -13.2 |

Given the historical data, the flux associated with the category “urban forests” is projected to increase through 2030 at the same average annual rate it has increased between 2009 and 2013 (1.13 Tg CO2 eq.). The flux associated with the category “yard trim and food waste” is projected to remain constant through 2030 at its mean annual rate over the period 2009 to 2013 (13.2 Tg CO2 eq.).

The category “agricultural soils” in Table 9 is further disaggregated in five sub-categories. The first four - cropland remaining cropland, land converted to cropland, grassland remaining grassland, and land converted to grass – correspond exactly to categories Table 6-1 of the 2015 NGHGI (USEPA 2015). The historical data available in the 2015 NGHGI show very little fluctuation over the period 2009-2013 and no clear trend is evident for the latter three categories. For each of these sub-categories, the carbon flux is projected to remain constant through 2060 at the annual mean level observed over the period 2009-2013.

For the sub-category “cropland remaining cropland” there is a small but steady decline in the magnitude of the annual flux between 2009 and 2013. This decrease, totaling about 4.1 Tg CO2 eq., is largely related to farmers withdrawing 6.9 million acres out of the Conservation Reserve Program (CRP) over this period and returning it to crop production. Under the Agricultural Act of 2014, the CRP is capped at 24 million acres, which it must reach by 2017. Therefore, between now and 2017 land enrolled in the CRP must decline by another 2.8 million acres. Assuming this will all be land now in grassland uses, the associated reduction in soil carbon is estimated to be 1.5 Tg CO2 eq. annually. Further assuming the CRP will remain at its statutory cap between 2017 and 2030 the projected annual flux for “croplands remaining croplands” declines to 21.9 Tg CO2 eq. (i.e., 23.4 – 1.5) in 2018 and remains constant at that level through 2030.

As in Table 8, the category “Building Blocks” reflects the GHG mitigation goal of the relevant USDA Building Blocks – specifically “soil health,” which has a mitigation goal of 20.9 Tg CO2 eq by 2025. In Table 9, this goal is achieved in equal annual increment increases starting in 2017.

The projections shown in table 9 augment the Reference Scenario to present a more complete land-use emissions picture - at least through 2030. Given the limited data that underlie these projections, however, there is little statistical basis for developing separate variations to augment the Low- and High-emissions scenarios or to extend the Reference Scenario projections (i.e., those in Table 9) to 2060.

**Forest Sector**

U.S. forests have provided a carbon sink for more than twenty years. The National Greenhouse Gas Inventory (NGHGI, U.S. EPA 2015) estimated the rate of change in the forest carbon inventory at -211.5 teragrams per year (Tg/yr) in 2013. This rate of carbon accumulation reflects both the net effects of forest dynamics, including forest growth, mortality, disturbances, and harvests, and transfers associated with land use changes to and from forest land.

Data from the USDA Forest Inventory and Analysis (FIA) program are the basis for the NGHGI and the projections. The FIA program relies on a rotating panel statistical design with a sampling intensity of one 674.5 m2 ground plot per 6,000 acres of land and water area. A five-panel design (20 percent of the field plots typically measured each year) is used in eastern United States and a ten-panel design (10 percent of the field plots) is used in the western United States. From the measurements taken on the field plots carbon values are predicted for eight pools (down dead wood, forest floor, live trees above ground, live trees below ground, standing dead wood, soil organic carbon, understory vegetation above ground, and understory vegetation ground) using the models described by Smith et al. (2013).

We used the preliminary forest carbon inventory for the 2016 NGHGI that is based on the U.S. Forest Carbon Accounting Framework (FCAF) for the forest carbon projections (Woodall et al. 2015). Since the results presented in this document are based on the updated forest carbon baseline they do not match numbers reported in the most recent NGHGI (EPA 2015). The FCAF is a comprehensive approach to using the annual Forest Inventory and Analysis (FIA) data to improve historical forest carbon data and to seamlessly model future forest carbon. Projections are based on recent measured changes in forest inventory, new estimates of forest soil organic carbon, and projections of land use changes consistent with the USDA scenarios. We also separated changes in forest carbon associated with change in the total area of forests from changes associated with forest growth.

The new framework directly addresses questions regarding disturbance and land use effects using all available inventory information. These changes improve the consistency of historical estimates and respond to the latest international scientific guidelines for carbon accounting and projections (UNFCCC 2013). The annual inventory system measures disturbances and carbon stocks on all forest plots while identifying land use and change on all plots, regardless of presence of forest, and serves as the foundation of the accounting system. Older, periodic inventories with their inconsistent field protocols and sample designs have been removed from the accounting system per recommendation from the United Nations Framework Convention on Climate Change (UNFCCC) expert review team (Woodall 2012). A modeling approach now moves the annual inventory system from the start of the annual system in the early 2000s back to 1990 and forward through time to provide carbon estimates and projections that satisfy UNFCCC requirements and future commitments.

The FCAF system is comprised of a forest dynamics module and a land use dynamics module. The land use dynamics module assesses carbon stock transfers associated with afforestation and deforestation. The forest dynamics module estimates changes in carbon density within forests in response to aging, growth, harvesting, and natural disturbances. Forward and backward projections are conducted at fine scales (plot level in the East and State or sub-State in the West) and aggregated to report on regional and national carbon stock dynamics (see Wear and Coulson in press for details).

The forest carbon pool in the NGHGI combines two IPCC land use categories—“Forest land remaining forest land” and “ land becoming forest land”—using an inventory change model to derive the rate of carbon accumulation (see Chapter 6, USEPA 2015; UNFCCC 2013). As a result, measured changes in forest carbon inventory are not equivalent to carbon sequestered by forests. Figure 3 shows a simple description of carbon transfers associated with land use changes between forests, developed land, and all other rural land. Isolating the carbon sequestered by forests (CFF alone) requires accounting for the land use transfers.

 Figure 3. Diagram of carbon change within and between land uses.



CFF = carbon accumulation in forests remaining forests

CFO = carbon transferred with land use change from forest to other land uses

CFD = carbon transferred with land use change from forest to developed land

COO = carbon accumulation in others land uses remaining in other land uses

COF = carbon transferred with land use change from other land uses to forest

COD = carbon transferred with land use change from other land uses to developed land

CDD = carbon accumulation in developed land remaining developed

Table 10 summarizes the projections of changes in forest carbon from 2015-2060 in the categories described above in teragrams of CO2 equivalent for the Reference Scenario. The table is broken into three segments. The first segment displays the average annual change in forest carbon using the current NGHGI definitions (CFF+COF-CFO-CFD) plus the carbon sequestered in wood products. The second segment displays the average annual change in carbon for forest remaining forest, CFF (actual carbon sequestered from the atmosphere) plus carbon stored in wood products. The final segment displays the carbon associated with land use transfers, which is the difference between the two totals.

**Table 10.** Projections of average annual change in NGHGI forest sector carbon, average annual change in forests remaining forests, and average annual change in carbon in land use transfers, 2005-2060 for the Reference Scenario (teragrams of CO2 equivalent per year).

|  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
|   | 2005 | 2010 | 2020 | 2025 | 2030 | 2040 | 2050 | 2060 |
| *Average annual change in forest carbon - NGHGI definitions* |
| Change in forest carbon\* | -731 | -793 | -788 | -601 | -278 | -62 | -47 | -17 |
| Wood products carbon | -103 | -62 | -128 | -139 | -139 | -141 | -148 | -156 |
| Total forest carbon sequestration | -834 | -855 | -916 | -741 | -417 | -203 | -195 | -173 |
| *Average annual change in forest sector carbon - forests remaining forests*  |
| Carbon sequestered | -417 | -466 | -457 | -417 | -364 | -335 | -320 | -290 |
| Wood products carbon | -103 | -62 | -128 | -139 | -139 | -141 | -148 | -156 |
| Total forest carbon sequestered | -520 | -529 | -585 |  -556 | -503 | -476 | -469 | -446 |
| *Average annual change in carbon associated with land transfers to and from the forest sector* |
| Land use carbon transfer | -314 | -327 | -331 | -184 | 86 | 273 | 273 | 273 |
| Building Blocks | 0 | 0 | -5 | -11 | -11 | -11 | -11 | -11 |
| Total with Building Blocks | -834 | -855 | -921 | -752 | -428 | -214 | -206 | -184 |

\*Change in forest carbon = carbon sequestered in forests remaining forests + carbon associated with land transfers to and from the forest sector.

Totals may not sum due to independent rounding

The Reference Scenario results in Table 10 and Figure 4 show a generally a stable trend in forest carbon through 2020 and then a slow decline in the rate of sequestration that reflects a slowing accumulation rate due mainly to forest aging. Between 2025 and 2030, the rate of sequestration declines even though total forest area increases. While net sequestration remains positive, the land use transfer carbon for that period becomes an emission source after 2025 because the carbon density of area transitions from forest to other land uses exceeds the carbon density of transitions into forests. Carbon stored in HWPs increases significantly between 2010 and 2020 as a result of recovery in forest product use, and then continues to gradually increase through 2060.

**Figure 4** – Trend in annual carbon flux for total forest carbon, land use carbon transfers, and forests remaining forest, 2005-2015, and projections to 2060 under the Reference Scenario (Tg CO2 eq.).



Three USDA building blocks – stewardship of federal forests, private forest growth and retention, and promotion of wood products - encompass a wide variety of voluntary actions private and public owners of forest land and producers and consumers of forest products can undertake to sequester additional carbon in forest systems and harvested wood products. The 2025 GHG mitigation goals for these building blocks are, respectively, 0.03, 4.8, and 5.9 Tg CO2 eq. Table 11 presents projections for GHG mitigation associated with the three forest sector building blocks assuming each mitigation goal is attained in equal annual increases over the period 2017 – 2025, after which they remain constant through 2030. Projections were not made past 2030. The totals in Table 11 are also shown in the final rows of Table 10.

|  |
| --- |
| **Table 11**: Projections of additional carbon sequestered from forest sector USDA Building Blocks (average annual Tg CO2 eq.). |
|  |  | 2005 | 2010 | 2013 | 2020 | 2025 | 2030 |
| Carbon in Forests | 0 | 0 | 0 | -2.11 | -4.83 | -4.83 |
|  *Private Forests* | *0* | *0* | *0* | *-2.10* | *-4.80* | *-4.80* |  |
|  *Public Forests* | *0* | *0* | *0* | *-0.01* | *-0.03* | *-0.03* |
| Harvested Wood Products  | 0 | 0 | 0 | -2.60 | -5.90 | -5.90 |
| Total Forest Building Blocks | 0 | 0 | 0 | -4.71 | -10.73 | -10.73 |
|   |  |  |  |  |  |  |  |

Projections of forest carbon under Low and High Scenarios provide information on the sensitivity of the results of the Reference Scenario to varying assumptions about land use change. Projections of carbon in HWPs do not vary across the scenarios. The Low Scenario (Table 13) assumes that forest land continues to accumulate at recent historical rates until 2030, increase at a slower rate until 2040 and then stabilize through 2060. As a result, total forest carbon remains stable through 2030, and then tapers off from 2030 to 2060. Conversely, the High Scenario (Table 13) assumes forest land begins to decline between 2025 and 2030 and continues to decline through 2060, resulting in a sharp decline in forest carbon after 2020 as a result of land use carbon transfers. While the carbon sequestered in forests remaining forests declines gradually through 2060, the forest sector becomes a net emitter by 2040 using the current NGHGI definition.

**Table 12**. Historical and projections of average annual change in NGHGI forest carbon, carbon sequestered, land use carbon transferred, and wood products carbon, 2005-2060 for the Low Scenario (Tg CO2 eq.).

|  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
|   | 2005 | 2010 | 2020 | 2025 | 2030 | 2040 | 2050 | 2060 |
| *Average annual change in forest carbon - NGHGI definitions* |  |  |  |  |  |
| Change in forest carbon\* | -731 | -793 | -792 | -784 | -774 | -502 | -253 | -228 |
| Wood products carbon | -103 | -62 | -128 | -139 | -139 | -141 | -148 | -156 |
| Total forest sector carbon  | -834 | -855 | -920 | -907 | -893 | -643 | -401 | -384 |
| *Average annual change in forest sector carbon - forests remaining forests* |  |  |  |
| Carbon sequestered | -417 | -466 | -461 | -452 | -443 | -396 | -364 | -347 |
| Wood products carbon | -103 | -62 | -128 | -139 | -139 | -141 | -148 | -156 |
| Total carbon sequestered | -520 | -529 | -588 | -592 | -582 | -537 | -512 | -503 |
| *Average annual change in carbon associated with land transfers to and from the forest sector* |  |  |
| Land use carbon transfer | -314 | -327 | -331 | -331 | -331 | -106 | 111 | 119 |
| Building Blocks | 0 | 0 | -5 | -11 | -11 | -11 | -11 | -11 |
| Total with Building Blocks | -834 | -855 | -925 | -918 | -904 | -654 | -412 | -395 |

**Table 13**. Historical and projections of average annual change in NGHGI forest carbon, carbon sequestered, land use carbon transferred, and wood products carbon, 2005-2060 for the High Scenario (Tg CO2 eq.).

|  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
|   | 2005 | 2010 | 2020 | 2025 | 2030 | 2040 | 2050 | 2060 |
| *Average annual change in forest carbon - NGHGI definitions* |  |  |
| Change in forest carbon\* | -731 | -793 | -615 | -313 | -51 | 47 | 83 | 105 |
| Wood products carbon | -103 | -62 | -128 | -139 | -139 | -141 | -148 | -156 |
| Total forest sector carbon  | -834 | -855 | -743 | -452 | -190 | -94 | -65 | -51 |
| *Average annual change in forest sector carbon - forests remaining forests* |  |  |  |
| Carbon sequestered | -417 | -466 | -427 | -388 | -355 | -318 | -282 | -261 |
| Wood products carbon | -103 | -62 | -128 | -139 | -139 | -141 | -148 | -156 |
| Total carbon sequestered | -520 | -529 | -554 | -527 | -494 | -459 | -430 | -417 |
| *Average annual change in carbon associated with land transfers to and from the forest sector* |  |
| Land use carbon transfer | -314 | -327 | -188 | 75 | 303 | 366 | 366 | 366 |
| Building Blocks | 0 | 0 | -5 | -11 | -11 | -11 | -11 | -11 |
| Total with Building Blocks | -834 | -855 | -748 | -463 | -201 | -105 | -76 | -62 |

***Forest Carbon (1990-2015)***

In the United States, forest carbon increased from 86,064 teragrams (Tg) of carbon in 1990 to 91,262 Tg carbon in 2016. The rate of change in recent years is about 0.23 percent of the stock and is estimated at 222 Tg carbon per yearbetween 2010 and 2015. This reflects both the accumulation of forest area (averaging +1.03 million acres/year between 1990 and 2015 and +1.06 million acres/year between 2010 and 2015) and forest growth in forests remaining forests. Land use transfers of carbon resulting from forest area expansion accounts for about -90 Tg carbon per year (2010-2015) or about 41 percent of total forest carbon sequestration in the NGHGI. Forest growth therefore yielded a net sequestration from the atmosphere of -132 Tg carbon per year over this period. Recent increases in carbon accumulation rates for forests correspond with harvest reductions from the economic contraction of 2007.

Forest carbon stocks are highest in the two eastern RPA regions where in 2015 the South and North[[1]](#footnote-1) Regions constituted 31 and 30 percent of carbon stocks respectively. The Rocky Mountain and Pacific Coast Regions in the West constitute 20 and 18 percent respectively. Annual change in carbon stocks is also greatest in the eastern regions (-84 Tg carbon per yearand -68 Tg carbon per year for the North and South respectively) when compared to the Rocky Mountain (-46 Tg carbon per year) and Pacific Coast regions (-23 Tg carbon per year). Eastern regions account for an even greater proportion of net forest carbon sequestration from the atmosphere, roughly 80 percent, with 33 and 47 percent attributable to the North and South respectively.

Temporal patterns of forest carbon dynamics also differ by region. In the North, South, and Pacific Coast Regions, net sequestration trended up between 1990 and 2015, with largest gains in the last half of the period for the South. In the Rocky Mountain Region, sequestration declined, likely reflecting the effects of forest aging and disturbances including wildfire. Transfers of carbon associated with land use were high in the North (roughly equivalent to the rate of sequestration) and in the Rocky Mountain Regions (nearly twice as high as the rate of sequestration) but low relative to sequestration in the Pacific Coast and the South Regions.

***Forest Carbon Projections (2016-2060)***

Projections of forest carbon derived from models that account for land use changes, forest disturbances, forest aging/growth, and harvesting were applied to the ground-based FIA forest inventories. We projected forest carbon changes using a forest carbon dynamics model for 2015-2060 (Wear and Coulston in press) to address the USDA scenarios described previously, and to be consistent with the new forest inventory, especially the substantially revised estimates of forest soil organic carbon. Projections of carbon stored in wood products are based on harvests projected by the U.S. Forest Products Model (Ince et al. 2010) coupled with the HWP carbon inventory model used for the 2010 RPA Assessment (USDA Forest Service 2012a) but reflect projections of population, economic growth, and housing starts consistent with the USDA scenarios. None of these projections include the potential effects of productivity enhancement from accumulation of atmospheric CO2 or nitrogen deposition or productivity implications of changing climate conditions nor do they include new policy initiatives.

We constructed projection models to be consistent with the format of the NGHGI system and using the same data sets in each region of the United States. Differences between sampling rates (number of plots per year) and the availability of repeated observations in the eastern and western regions led to different modeling approaches. In the East where the inventory cycle is five years, re-measured plots supported explicit transition measurements (aging, disturbance, harvesting) for individual inventory plots based on observed changes over the most recent past and allowed for direct extrapolation. In the West where the inventory cycle is at least ten years, forest transitions were modeled using inventory aggregates along with aging and disturbance rates applied to carbon density distributions drawn from the most recent inventories. Projections were developed at the subregional scale in the East and at State and sub-State levels in the West (methods are described in Wear and Coulston [in press]).

A transition matrix specified the aging of forests and rate at which disturbances (including harvests) lead to replacement of forests. Disturbance rates, aging rates, and existing areal age distributions of forests were estimated for each State from the plots in its most recent inventory . At each time step the forest area by age class was multiplied by the carbon density by age class to define the total forest carbon inventory for the State. Without the complete land use transition matrix available in the West, we had to approximate land use carbon transfers using the net area change observations and soil carbon densities. Regional results were defined by aggregating across all States in the Region. Details on projection algorithms are found in Wear and Coulston (in press).

Results (Table 14) reflect the land use assumptions for the Reference Scenario and show a decline in the rate of forest carbon change from 216 Tg/yr in 2010 to 4.5 Tg/yr in 2037. However, the amount of carbon sequestered by forests decreases by a much smaller amount, from 127 Tg/yr in 2010 to 79 Tg/yr in 2060. The carbon transferred with land use change, the difference between change in the forest carbon and the carbon sequestered, declines as a direct result of the land use change assumptions of the Reference Scenario.[[2]](#footnote-2)

**Table 14**. Projections of change in forest carbon, carbon sequestration, and land use carbon transfers based on the Forest Transition Model, 2010-2060 (Tg CO2eq).

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Projection year(Report year) | Forest area1 | Change in Forest carbon | Carbon sequestered | Land Use carbon transfer |
|  | *thousand acres* | *----------------------Teragrams per year------------------------* |
| 2010 | 668,325 | -793 | -466 | -327 |
| 2020 | 679,179 | -788 | -457 | -331 |
| 2030 | 683,555 | -278 | -364 | -86 |
| 2040 | 680,924 | -62 | -335 | 273 |
| 2050 | 678,034 | -47 | -320 | 273 |
| 2060 | 675,014 | -17 | -290 | 273 |

1 Forest area does not include interior Alaska

Source: Wear and Coulston 2014

To complete a full accounting of carbon dynamics in the U.S. forest sector requires a final adjustment to account for carbon transfers from forests to durable wood products. The stock adjustment approach to evaluating change in forest carbon implicitly treats removals due to harvesting as an atmospheric emission. We need to account for how harvested wood products (HWP) stores and emits this carbon over time. These harvested materials accrue at a rate determined by conversion to end products and also the decay of products over time according to product class. The HWP pool therefore represents a separate and complex inventory with a variety of factors influencing accumulation in the pool and depreciation of the pool (eventual emissions to the atmosphere). An important element of the HWP is the transfer of wood products in use to landfills and we account for storage in these two separate major categories.

These linked models for estimated carbon stored in HWPs were run using the assumptions of the USDA scenarios with outputs being especially sensitive to projections of population, income, and associated estimates of housing starts. Wood products carbon varies across the projection period as shown in Figure 5 (in Tg carbon).

Harvested wood products carbon declined somewhat between 1990 and 2000, fell precipitously to historically low values in 2005 and recovered to 1990s values in 2015. These dynamics are explained by changes in the wood products in use category and reflect the historic nadir of housing construction observed in the mid-2000s. In contrast, storage in landfilled wood remained fairly constant throughout the historic period. Projections reflect a recovery of the housing market with growth and then stabilization of wood products carbon combined with a steady increase in landfilled wood products carbon through the projection period. Total HWP carbon is projected to accumulate at a rate of 43 Tg/year in 2060, 19 percent higher than the rate of 36 Tg/year observed in 1990.

**Figure 6**. Estimates of U.S. historical and projected carbon stored in wood decomposed into components for wood products in use (wood products) and wood products stored in landfills (landfilled wood) for the Reference scenario, 1990-2060 (teragrams carbon).



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1. The eastern plains states of North Dakota, South Dakota, Kansas, and Nebraska are included in the RPA North Region in these analyses. [↑](#footnote-ref-1)
2. [↑](#footnote-ref-2)