6. Land Use, Land-Use Change, and Forestry

This chapter provides an assessment of the net greenhouse gas flux resulting from the use and conversion of land-use categories in the United States.[1] The Intergovernmental Panel on Climate Change *2006 Guidelines for National Greenhouse Gas Inventories* (IPCC 2006) recommends reporting fluxes according to changes within and conversions between certain land-use types termed: Forest Land, Cropland, Grassland, Settlements, Wetlands (as well as Other Land). The greenhouse gas flux from *Forest Land Remaining Forest Land* is reported using estimates of changes in forest ecosystem carbon (C) stocks, harvested wood pools, non-carbon dioxide (non-CO_2) emissions from forest fires, and the application of synthetic fertilizers to forest soils. Only fluxes for C stock changes from mineral soils are included for *Land Converted to Forest Land*. Fluxes are reported for four agricultural land use/land-use change categories: *Cropland Remaining Cropland*, *Land Converted to Cropland*, *Grassland Remaining Grassland*, and *Land Converted to Grassland*. The reported greenhouse gas fluxes from these agricultural lands include changes in organic C stocks in mineral and organic soils due to land use and management, emissions of CO_2 due to the application of crushed limestone and dolomite to managed land (i.e., soil liming), urea fertilization and the change in aboveground biomass C stocks for *Forest Land Converted to Cropland* and *Forest Land Converted to Grassland*.[2] Fluxes from *Wetlands Remaining Wetlands* include CO_2, methane (CH_4) and nitrous oxide (N_2O) emissions from managed peatlands; estimates for *Land Converted to Wetlands* are currently not available. Fluxes resulting from *Settlements Remaining Settlements* include those from urban trees and application of nitrogen fertilizer to soils; fluxes from *Land Converted to Settlements* are currently not available. Landfilled yard trimmings and food scraps are accounted for separately under *Other*.

Land use, land-use change, and forestry (LULUCF) activities in 2014 resulted in a net increase in C stocks (i.e., net CO_2 removals) of 787.0 MMT CO_2 Eq. (214.6 MMT C).[3] This represents an offset of approximately 11.5 percent of total (i.e., gross) greenhouse gas emissions in 2014. Emissions from land use, land-use change, and forestry activities in 2014 are 24.6 MMT CO_2 Eq. and represent 0.4 percent of total greenhouse gas emissions.[4]

Total C sequestration in the LULUCF sector increased by approximately 4.5 percent between 1990 and 2014. This increase was primarily due to an increase in the rate of net C accumulation in forest and urban tree C stocks.[5] Net C accumulation in *Forest Land Remaining Forest Land* and *Settlements Remaining Settlements* increased, while net C

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[1] The term “flux” is used to describe the net emissions of greenhouse gases accounting for both the emissions of CO_2 to and the removals of CO_2 from the atmosphere. Removal of CO_2 from the atmosphere is also referred to as “carbon sequestration”.

[2] Direct and indirect emissions of N_2O from inputs of N to cropland and grassland soils are included in the Agriculture Chapter.

[3] Net CO_2 flux is the net C stock change from the following categories: *Forest Land Remaining Forest Land, Land Converted to Forest Land, Cropland Remaining Cropland, Land Converted to Cropland, Grassland Remaining Grassland, Land Converted to Grassland, Settlements Remaining Settlements,* and *Other.*

[4] LULUCF emissions include the CO_2, CH_4, and N_2O emissions reported for Non-CO_2 Emissions from Forest Fires, N_2O Fluxes from Forest Soils, CO_2 Emissions from Liming, CO_2 Emissions from Urea Fertilization, Peatlands Remaining Peatlands, and N_2O Fluxes from Settlement Soils.

[5] Carbon sequestration estimates are net figures. The C stock in a given pool fluctuates due to both gains and losses. When losses exceed gains, the C stock decreases, and the pool acts as a source. When gains exceed losses, the C stock increases, and the pool acts as a sink; also referred to as net C sequestration or removal.

accumulation in *Land Converted to Forest Land, Cropland Remaining Cropland, Grassland Remaining Grassland*, and *Landfilled Yard Trimmings and Food Scraps* slowed over this period. Emissions from *Land Converted to Cropland* and *Wetlands Remaining Wetlands* decreased, while emissions from *Land Converted to Grassland* increased. Net C stock change from LULUCF is summarized in Table 6-1.

Table 6-1: Net C Stock Change from Land Use, Land-Use Change, and Forestry (MMT CO_2 Eq.)

Gas/Land-Use Category	1990	2005	2010	2011	2012	2013	2014
Forest Land Remaining Forest Land	**(723.5)**	**(691.9)**	**(742.0)**	**(736.7)**	**(735.8)**	**(739.1)**	**(742.3)**
Changes in Forest Carbon Stock[a]	(723.5)	(691.9)	(742.0)	(736.7)	(735.8)	(739.1)	(742.3)
Land Converted to Forest Land	**(0.7)**	**(0.8)**	**(0.4)**	**(0.4)**	**(0.4)**	**(0.3)**	**(0.3)**
Changes in Forest Carbon Stock	(0.7)	(0.8)	(0.4)	(0.4)	(0.4)	(0.3)	(0.3)
Cropland Remaining Cropland	**(34.3)**	**(14.1)**	**1.8**	**(12.5)**	**(11.2)**	**(9.3)**	**(8.4)**
Changes in Agricultural Carbon Stock[b]	(34.3)	(14.1)	1.8	(12.5)	(11.2)	(9.3)	(8.4)
Land Converted to Cropland	**65.7**	**32.2**	**23.7**	**21.6**	**22.0**	**22.1**	**22.1**
Changes in Agricultural Carbon Stock[b]	65.7	32.2	23.7	21.6	22.0	22.1	22.1
Grassland Remaining Grassland	**(12.9)**	**(3.3)**	**(7.3)**	**3.1**	**3.6**	**3.8**	**3.8**
Changes in Agricultural Carbon Stock[b]	(12.9)	(3.3)	(7.3)	3.1	3.6	3.8	3.8
Land Converted to Grassland	**39.1**	**43.1**	**39.3**	**39.9**	**40.4**	**40.4**	**40.4**
Changes in Agricultural Carbon Stock[b]	39.1	43.1	39.3	39.9	40.4	40.4	40.4
Settlements Remaining Settlements	**(60.4)**	**(80.5)**	**(86.1)**	**(87.3)**	**(88.4)**	**(89.5)**	**(90.6)**
Changes in Carbon Stocks in Urban Trees	(60.4)	(80.5)	(86.1)	(87.3)	(88.4)	(89.5)	(90.6)
Other	**(26.0)**	**(11.4)**	**(13.2)**	**(12.7)**	**(12.2)**	**(11.7)**	**(11.6)**
Landfilled Yard Trimmings and Food Scraps	(26.0)	(11.4)	(13.2)	(12.7)	(12.2)	(11.7)	(11.6)
LULUCF Total Net Flux	**(753.0)**	**(726.7)**	**(784.3)**	**(784.9)**	**(782.0)**	**(783.7)**	**(787.0)**

[a] Includes the effects of net additions to stocks of carbon stored in forest ecosystem pools and harvested wood products.
[b] Estimates include C stock changes in all pools.
Notes: Totals may not sum due to independent rounding. Parentheses indicate net sequestration.

Emissions from LULUCF activities are shown in Table 6-2. Liming and urea fertilization in 2014 resulted in CO_2 emissions of 8.7 MMT CO_2 Eq. (8,653 kt of CO_2). Lands undergoing peat extraction (i.e., *Peatlands Remaining Peatlands*) resulted in CO_2 emissions of 0.8 MMT CO_2 Eq. (842 kt of CO_2), CH_4 emissions of less than 0.05 MMT CO_2 Eq., and N_2O emissions of less than 0.05 MMT CO_2 Eq. The application of synthetic fertilizers to forest soils in 2014 resulted in N_2O emissions of 0.5 MMT CO_2 Eq. (2 kt of N_2O). Nitrous oxide emissions from fertilizer application to forest soils have increased by 455 percent since 1990, but still account for a relatively small portion of overall emissions. Additionally, N_2O emissions from fertilizer application to settlement soils in 2014 accounted for 2.4 MMT CO_2 Eq. (8 kt of N_2O). This represents an increase of 78 percent since 1990. Forest fires in 2014 resulted in CH_4 emissions of 7.3 MMT CO_2 Eq. (294 kt of N_2O), and N_2O emissions of 4.8 MMT CO_2 Eq. (16 kt of N_2O). Emissions and removals from LULUCF are summarized in Table 6-3 by land-use and category, and Table 6-4 and Table 6-5 by gas in MMT CO_2 Eq. and kt, respectively.

Table 6-2: Emissions from Land Use, Land-Use Change, and Forestry by Gas (MMT CO_2 Eq.)

Gas/Land-Use Category	1990	2005	2010	2011	2012	2013	2014
CO_2	**8.1**	**9.0**	**9.6**	**8.9**	**11.0**	**9.0**	**9.5**
Cropland Remaining Cropland: CO_2 Emissions from Urea Fertilization	2.4	3.5	3.8	4.1	4.2	4.3	4.5
Cropland Remaining Cropland: CO_2 Emissions from Liming	4.7	4.3	4.8	3.9	6.0	3.9	4.1
Wetlands Remaining Wetlands: Peatlands Remaining Peatlands	1.1	1.1	1.0	0.9	0.8	0.8	0.8
CH_4	**3.3**	**9.9**	**3.3**	**6.6**	**11.1**	**7.3**	**7.4**
Forest Land Remaining Forest Land: Non-CO_2 Emissions from Forest Fires	3.3	9.9	3.3	6.6	11.1	7.3	7.3
Wetlands Remaining Wetlands: Peatlands Remaining Peatlands	+	+	+	+	+	+	+
N_2O	**3.6**	**9.3**	**5.0**	**7.3**	**10.3**	**7.7**	**7.7**
Forest Land Remaining Forest Land:	2.2	6.5	2.2	4.4	7.3	4.8	4.8

Non-CO_2 Emissions from Forest Fires							
Settlements Remaining Settlements:							
N_2O Fluxes from Settlement Soils[a]	1.4	2.3	2.4	2.5	2.5	2.4	2.4
Forest Land Remaining Forest Land:							
N_2O Fluxes from Forest Soils[b]	0.1	0.5	0.5	0.5	0.5	0.5	0.5
Wetlands Remaining Wetlands:							
Peatlands Remaining Peatlands	+	+	+	+	+	+	+
LULUCF Emissions	**15.0**	**28.2**	**17.8**	**22.9**	**32.3**	**24.1**	**24.6**

+ Does not exceed 0.05 MMT CO_2 Eq.

[a] Estimates include emissions from N fertilizer additions on both *Settlements Remaining Settlements* and *Land Converted to Settlements.*

[b] Estimates include emissions from N fertilizer additions on both *Forest Land Remaining Forest Land* and *Land Converted to Forest Land*.

Note: Totals may not sum due to independent rounding.

Table 6-3: Emissions and Removals (Net Flux) from Land Use, Land-Use Change, and Forestry by Land Use and Land-Use Change Category (MMT CO_2 Eq.)

Land-Use Category	1990	2005	2010	2011	2012	2013	2014
Forest Land Remaining Forest Land	**(718.0)**	**(675.0)**	**(736.2)**	**(725.2)**	**(717.1)**	**(726.5)**	**(729.7)**
Changes in Forest Carbon Stock[a]	(723.5)	(691.9)	(742.0)	(736.7)	(735.8)	(739.1)	(742.3)
Non-CO_2 Emissions from Forest Fires	5.4	16.5	5.4	11.0	18.3	12.2	12.2
N_2O Fluxes from Forest Soils[b]	0.1	0.5	0.5	0.5	0.5	0.5	0.5
Land Converted to Forest Land	**(0.7)**	**(0.8)**	**(0.4)**	**(0.4)**	**(0.4)**	**(0.3)**	**(0.3)**
Changes in Forest Carbon Stock	(0.7)	(0.8)	(0.4)	(0.4)	(0.4)	(0.3)	(0.3)
Cropland Remaining Cropland	**(27.2)**	**(6.3)**	**10.3**	**(4.5)**	**(1.0)**	**(1.0)**	**0.2**
Changes in Agricultural Carbon Stock[c]	(34.3)	(14.1)	1.8	(12.5)	(11.2)	(9.3)	(8.4)
CO_2 Emissions from Liming	4.7	4.3	4.8	3.9	6.0	3.9	4.1
CO_2 Emissions from Urea Fertilization	2.4	3.5	3.8	4.1	4.2	4.3	4.5
Land Converted to Cropland	**65.7**	**32.2**	**23.7**	**21.6**	**22.0**	**22.1**	**22.1**
Changes in Agricultural Carbon Stock[c]	65.7	32.2	23.7	21.6	22.0	22.1	22.1
Grassland Remaining Grassland	**(12.9)**	**(3.3)**	**(7.3)**	**3.1**	**3.6**	**3.8**	**3.8**
Changes in Agricultural Carbon Stock[c]	(12.9)	(3.3)	(7.3)	3.1	3.6	3.8	3.8
Land Converted to Grassland	**39.1**	**43.1**	**39.3**	**39.9**	**40.4**	**40.4**	**40.4**
Changes in Agricultural Carbon Stock[c]	39.1	43.1	39.3	39.9	40.4	40.4	40.4
Wetlands Remaining Wetlands	**1.1**	**1.1**	**1.0**	**0.9**	**0.8**	**0.8**	**0.8**
Peatlands Remaining Peatlands	1.1	1.1	1.0	0.9	0.8	0.8	0.8
Settlements Remaining Settlements	**(59.0)**	**(78.2)**	**(83.8)**	**(84.8)**	**(85.8)**	**(87.1)**	**(88.2)**
Changes in Carbon Stocks in Urban Trees	(60.4)	(80.5)	(86.1)	(87.3)	(88.4)	(89.5)	(90.6)
N_2O Fluxes from Settlement Soils[d]	1.4	2.3	2.4	2.5	2.5	2.4	2.4
Other	**(26.0)**	**(11.4)**	**(13.2)**	**(12.7)**	**(12.2)**	**(11.7)**	**(11.6)**
Landfilled Yard Trimmings and Food Scraps	(26.0)	(11.4)	(13.2)	(12.7)	(12.2)	(11.7)	(11.6)
LULUCF Emissions[e]	**15.0**	**28.2**	**17.8**	**22.9**	**32.3**	**24.1**	**24.6**
LULUCF Total Net Flux[f]	**(753.0)**	**(726.7)**	**(784.3)**	**(784.9)**	**(782.0)**	**(783.7)**	**(787.0)**
LULUCF Sector Total[g]	**(738.0)**	**(698.5)**	**(766.4)**	**(762.0)**	**(749.7)**	**(759.6)**	**(762.5)**

+ Does not exceed 0.05 MMT CO_2 Eq.

[a] Includes the effects of net additions to stocks of carbon stored in forest ecosystem pools and harvested wood products.

[b] Estimates include emissions from N fertilizer additions on both *Forest Land Remaining Forest Land* and *Land Converted to Forest Land*.

[c] Estimates include C stock changes in all pools.

[d] Estimates include emissions from N fertilizer additions on both *Settlements Remaining Settlements* and *Land Converted to Settlements.*

[e] LULUCF emissions include the CO_2, CH_4, and N_2O emissions reported for Non-CO_2 Emissions from Forest Fires, N_2O Fluxes from Forest Soils, CO_2 Emissions from Liming, CO_2 Emissions from Urea Fertilization, Peatlands Remaining Peatlands, and N_2O Fluxes from Settlement Soils.

[f] LULUCF Total Net Flux includes any C sequestration gains and losses from all land use and land use conversion categories.

[g] The LULUCF Sector Total is the net sum of all emissions (i.e., sources) of greenhouse gases to the atmosphere plus removals of CO_2 (i.e., sinks or negative emissions) from the atmosphere.

Notes: Totals may not sum due to independent rounding. Parentheses indicate net sequestration.

Table 6-4: Emissions and Removals (Net Flux) from Land Use, Land-Use Change, and Forestry by Gas (MMT CO_2 Eq.)

Gas/Land-Use Category	1990	2005	2010	2011	2012	2013	2014
Net CO_2 Flux[a]	**(753.0)**	**(726.7)**	**(784.3)**	**(784.9)**	**(782.0)**	**(783.7)**	**(787.0)**
Forest Land Remaining Forest Land[b]	(723.5)	(691.9)	(742.0)	(736.7)	(735.8)	(739.1)	(742.3)
Land Converted to Forest Land	(0.7)	(0.8)	(0.4)	(0.4)	(0.4)	(0.3)	(0.3)
Cropland Remaining Cropland	(34.3)	(14.1)	1.8	(12.5)	(11.2)	(9.3)	(8.4)
Land Converted to Cropland	65.7	32.2	23.7	21.6	22.0	22.1	22.1
Grassland Remaining Grassland	(12.9)	(3.3)	(7.3)	3.1	3.6	3.8	3.8
Land Converted to Grassland	39.1	43.1	39.3	39.9	40.4	40.4	40.4
Settlements Remaining Settlements	(60.4)	(80.5)	(86.1)	(87.3)	(88.4)	(89.5)	(90.6)
Other: Landfilled Yard Trimmings and Food Scraps	(26.0)	(11.4)	(13.2)	(12.7)	(12.2)	(11.7)	(11.6)
CO_2	**8.1**	**9.0**	**9.6**	**8.9**	**11.0**	**9.0**	**9.5**
Cropland Remaining Cropland: CO_2 Emissions from Urea Fertilization	2.4	3.5	3.8	4.1	4.2	4.3	4.5
Cropland Remaining Cropland: CO_2 Emissions from Liming	4.7	4.3	4.8	3.9	6.0	3.9	4.1
Wetlands Remaining Wetlands: Peatlands Remaining Peatlands	1.1	1.1	1.0	0.9	0.8	0.8	0.8
CH_4	**3.3**	**9.9**	**3.3**	**6.6**	**11.1**	**7.3**	**7.4**
Forest Land Remaining Forest Land: Non-CO_2 Emissions from Forest Fires	3.3	9.9	3.3	6.6	11.1	7.3	7.3
Wetlands Remaining Wetlands: Peatlands Remaining Peatlands	+	+	+	+	+	+	+
N_2O	**3.6**	**9.3**	**5.0**	**7.3**	**10.3**	**7.7**	**7.7**
Forest Land Remaining Forest Land: Non-CO_2 Emissions from Forest Fires	2.2	6.5	2.2	4.4	7.3	4.8	4.8
Settlements Remaining Settlements: N_2O Fluxes from Settlement Soils[c]	1.4	2.3	2.4	2.5	2.5	2.4	2.4
Forest Land Remaining Forest Land: N_2O Fluxes from Forest Soils[d]	0.1	0.5	0.5	0.5	0.5	0.5	0.5
Wetlands Remaining Wetlands: Peatlands Remaining Peatlands	+	+	+	+	+	+	+
LULUCF Emissions[e]	**15.0**	**28.2**	**17.8**	**22.9**	**32.3**	**24.1**	**24.6**
LULUCF Total Net Flux[a]	**(753.0)**	**(726.7)**	**(784.3)**	**(784.9)**	**(782.0)**	**(783.7)**	**(787.0)**
LULUCF Sector Total[f]	**(738.0)**	**(698.5)**	**(766.4)**	**(762.0)**	**(749.7)**	**(759.6)**	**(762.5)**

+ Does not exceed 0.05 MMT CO_2 Eq.

[a] Net CO_2 flux is the net C stock change from the following categories: *Forest Land Remaining Forest Land*, *Land Converted to Forest Land*, *Cropland Remaining Cropland*, *Land Converted to Cropland*, *Grassland Remaining Grassland*, *Land Converted to Grassland*, *Settlements Remaining Settlements*, and *Other*.

[b] Includes the effects of net additions to stocks of carbon stored in forest ecosystem pools and harvested wood products.

[c] Estimates include emissions from N fertilizer additions on both *Settlements Remaining Settlements* and *Land Converted to Settlements.*

[d] Estimates include emissions from N fertilizer additions on both *Forest Land Remaining Forest Land* and *Land Converted to Forest Land*.

[e] LULUCF emissions include the CO_2, CH_4, and N_2O emissions reported for Non-CO_2 Emissions from Forest Fires, N_2O Fluxes from Forest Soils, CO_2 Emissions from Liming, CO_2 Emissions from Urea Fertilization, Peatlands Remaining Peatlands, and N_2O Fluxes from Settlement Soils.

[f] The LULUCF Sector Total is the net sum of all emissions (i.e., sources) of greenhouse gases to the atmosphere plus removals of CO_2 (i.e., sinks or negative emissions) from the atmosphere.

Notes: Totals may not sum due to independent rounding. Parentheses indicate net sequestration.

Table 6-5: Emissions and Removals (Flux) from Land Use, Land-Use Change, and Forestry by Gas (kt)

Gas/Land-Use Category	1990		2005		2010	2011	2012	2013	2014
Net CO_2 Flux[a]	**(752,993)**		**(726,692)**		**(784,268)**	**(784,882)**	**(782,024)**	**(783,680)**	**(787,045)**
Forest Land Remaining Forest Land[b]	(723,536)		(691,873)		(742,040)	(736,690)	(735,837)	(739,112)	(742,328)
Land Converted to Forest Land	(677)		(819)		(374)	(372)	(352)	(350)	(349)
Cropland Remaining Cropland	(34,326)		(14,116)		1,787	(12,484)	(11,179)	(9,273)	(8,428)
Land Converted to Cropland	65,710		32,168		23,695	21,601	22,048	22,097	22,104
Grassland Remaining Grassland	(12,865)		(3,254)		(7,315)	3,112	3,552	3,769	3,772
Land Converted to Grassland	39,083		43,087		39,308	39,859	40,358	40,380	40,383
Settlements Remaining Settlements	(60,408)		(80,523)		(86,129)	(87,250)	(88,372)	(89,493)	(90,614)
Other: Landfilled Yard Trimmings and Food Scraps	(25,975)		(11,360)		(13,200)	(12,659)	(12,242)	(11,698)	(11,585)
CO_2	**8,139**		**8,955**		**9,584**	**8,898**	**11,015**	**9,021**	**9,495**
Cropland Remaining Cropland: CO_2 Emissions from Urea Fertilization	2,417		3,504		3,778	4,099	4,225	4,342	4,514
Cropland Remaining Cropland: CO_2 Emissions from Liming	4,667		4,349		4,784	3,873	5,978	3,909	4,139
Wetlands Remaining Wetlands: Peatlands Remaining Peatlands	1,055		1,101		1,022	926	812	770	842
CH_4	**131**		**397**		**131**	**265**	**443**	**294**	**294**
Forest Land Remaining Forest Land: Non-CO_2 Emissions from Forest Fires	131		397		131	265	443	294	294
Wetlands Remaining Wetlands: Peatlands Remaining Peatlands	+		+		+	+	+	+	+
N_2O	**12**		**31**		**17**	**25**	**34**	**26**	**26**
Forest Land Remaining Forest Land: Non-CO_2 Emissions from Forest Fires	7		22		7	15	24	16	16
Settlements Remaining Settlements: N_2O Fluxes from Settlement Soils[c]	5		8		8	8	9	8	8
Forest Land Remaining Forest Land: N_2O Fluxes from Forest Soils[d]	+		2		2	2	2	2	2
Wetlands Remaining Wetlands: Peatlands Remaining Peatlands	+		+		+	+	+	+	+

+ Does not exceed 0.5 kt

[a] Net CO_2 flux is the net C stock change from the following categories: *Forest Land Remaining Forest Land*, *Land Converted to Forest Land*, *Cropland Remaining Cropland*, *Land Converted to Cropland*, *Grassland Remaining Grassland*, *Land Converted to Grassland*, *Settlements Remaining Settlements*, and *Other*.

[b] Includes the effects of net additions to stocks of carbon stored in forest ecosystem pools and harvested wood products.

[c] Estimates include emissions from N fertilizer additions on both *Settlements Remaining Settlements* and *Land Converted to Settlements*.

[d] Estimates include emissions from N fertilizer additions on both *Forest Land Remaining Forest Land* and *Land Converted to Forest Land*.

Box 6-1: Methodological Approach for Estimating and Reporting U.S. Emissions and Sinks

In following the UNFCCC requirement under Article 4.1 to develop and submit national greenhouse gas emissions inventories, the gross emissions total presented in this report for the United States excludes emissions and sinks from LULUCF. The net emissions total presented in this report for the United States includes emissions and sinks from LULUCF. All emissions and sinks estimates are calculated using internationally-accepted methods provided by the IPCC.[6] Additionally, the calculated emissions and sinks in a given year for the United States are presented in a common manner in line with the UNFCCC reporting guidelines for the reporting of inventories under this international agreement.[7] The use of consistent methods to calculate emissions and sinks by all nations providing their inventories to the UNFCCC ensures that these reports are comparable. In this regard, U.S. emissions and sinks reported in this Inventory report are comparable to emissions and sinks reported by other countries. The manner that emissions and sinks are provided in this Inventory is one of many ways U.S. emissions and sinks could be examined; this Inventory report presents emissions and sinks in a common format consistent with how countries are to report inventories under the UNFCCC. The report itself follows this standardized format, and provides an explanation of the IPCC methods used to calculate emissions and sinks, and the manner in which those calculations are conducted.

6.1 Representation of the U.S. Land Base

A national land-use categorization system that is consistent and complete, both temporally and spatially, is needed in order to assess land use and land-use change status and the associated greenhouse gas fluxes over the Inventory time series. This system should be consistent with IPCC (2006), such that all countries reporting on national greenhouse gas fluxes to the UNFCCC should: (1) describe the methods and definitions used to determine areas of managed and unmanaged lands in the country (Table 6-6), (2) describe and apply a consistent set of definitions for land-use categories over the entire national land base and time series (i.e., such that increases in the land areas within particular land-use categories are balanced by decreases in the land areas of other categories unless the national land base is changing) (Table 6-7), and (3) account for greenhouse gas fluxes on all managed lands. The IPCC (2006, Vol. IV, Chapter 1) considers all anthropogenic greenhouse gas emissions and removals associated with land use and management to occur on managed land, and all emissions and removals on managed land should be reported based on this guidance (see IPCC 2010 for further discussion). Consequently, managed land serves as a proxy for anthropogenic emissions and removals. This proxy is intended to provide a practical framework for conducting an inventory, even though some of the greenhouse gas emissions and removals on managed land are influenced by natural processes that may or may not be interacting with the anthropogenic drivers. Guidelines for factoring out natural emissions and removals may be developed in the future, but currently the managed land proxy is considered the most practical approach for conducting an inventory in this sector (IPCC 2010). The implementation of such a system helps to ensure that estimates of greenhouse gas fluxes are as accurate as possible, and does allow for potentially subjective decisions in regards to subdividing natural and anthropogenic driven emissions. This section of the Inventory has been developed in order to comply with this guidance.

Three databases are used to track land management in the United States and are used as the basis to classify U.S. land area into the thirty-six IPCC land-use and land-use change categories (Table 6-7) (IPCC 2006). The primary databases are the U.S. Department of Agriculture (USDA) National Resources Inventory (NRI)[8] and the USDA Forest Service (USFS) Forest Inventory and Analysis (FIA)[9] Database. The Multi-Resolution Land Characteristics Consortium (MRLC) National Land Cover Dataset (NLCD)[10] is also used to identify land uses in regions that were not included in the NRI or FIA.

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[6] See <http://www.ipcc-nggip.iges.or.jp/public/index.html>.

[7] See <http://unfccc.int/resource/docs/2013/cop19/eng/10a03.pdf>.

[8] NRI data is available at <http://www.nrcs.usda.gov/wps/portal/nrcs/site/national/home>.

[9] FIA data is available at <http://www.fia.fs.fed.us/tools-data/default.asp>.

[10] NLCD data is available at <http://www.mrlc.gov/> and MRLC is a consortium of several U.S. government agencies.

The total land area included in the U.S. Inventory is 936 million hectares across the 50 states.[11] Approximately 890 million hectares of this land base is considered managed and 46 million hectares is unmanaged, which has not changed by much over the time series of the Inventory (Table 6-7). In 2014, the United States had a total of 295 million hectares of managed Forest Land (3.2 percent increase since 1990), 164 million hectares of Cropland (6.3 percent decrease since 1990), 321 million hectares of managed Grassland (1.7 percent decrease since 1990), 42 million hectares of managed Wetlands (7.2 percent decrease since 1990), 43 million hectares of Settlements (28 percent increase since 1990), and 25 million hectares of managed Other Land (Table 6-7). Wetlands are not differentiated between managed and unmanaged, and are reported solely as managed. In addition, C stock changes are not currently estimated for the entire land base, which leads to discrepancies between the managed land area data presented here and in the subsequent sections of the Inventory (e.g., *Grassland Remaining Grassland*, interior Alaska).[12] Planned improvements are under development to account for C stock changes on all managed land (e.g., Grasslands and Forest Lands in Alaska) and ensure consistency between the total area of managed land in the land-representation description and the remainder of the Inventory.

Dominant land uses vary by region, largely due to climate patterns, soil types, geology, proximity to coastal regions, and historical settlement patterns, although all land uses occur within each of the 50 states (Table 6-6). Forest Land tends to be more common in the eastern states, mountainous regions of the western United States, and Alaska. Cropland is concentrated in the mid-continent region of the United States, and Grassland is more common in the western United States and Alaska. Wetlands are fairly ubiquitous throughout the United States, though they are more common in the upper Midwest and eastern portions of the country. Settlements are more concentrated along the coastal margins and in the eastern states.

Table 6-6: Managed and Unmanaged Land Area by Land-Use Categories for All 50 States (Thousands of Hectares)

Land-Use Categories	1990	2005	2010	2011	2012	2013	2014
Managed Lands	**890,019**	**890,016**	**890,017**	**890,017**	**890,017**	**890,017**	**890,017**
Forest Land	285,837	292,106	294,175	294,585	294,988	294,988	294,988
Croplands	174,678	166,064	163,745	163,745	163,752	163,752	163,752
Grasslands	326,526	323,239	321,717	321,421	321,118	321,118	321,118
Settlements	33,420	40,450	42,645	42,645	42,648	42,648	42,648
Wetlands	45,361	43,004	42,336	42,223	42,113	42,112	42,113
Other Land	24,197	25,154	25,398	25,398	25,399	25,399	25,399
Unmanaged Lands	**46,211**	**46,214**	**46,213**	**46,213**	**46,213**	**46,213**	**46,213**
Forest Land	9,634	9,634	9,634	9,634	9,634	9,634	9,634
Croplands	0	0	0	0	0	0	0
Grasslands	25,782	25,782	25,782	25,782	25,782	25,782	25,782
Settlements	0	0	0	0	0	0	0
Wetlands	0	0	0	0	0	0	0
Other Land	10,795	10,797	10,797	10,797	10,797	10,797	10,797
Total Land Areas	**936,230**	**936,230**	**936,230**	**936,230**	**936,230**	**936,230**	**936,230**
Forest Land	295,471	301,740	303,810	304,219	304,622	304,622	304,622
Croplands	174,678	166,064	163,745	163,745	163,752	163,752	163,752
Grasslands	352,308	349,021	347,499	347,203	346,900	346,900	346,900
Settlements	33,420	40,450	42,645	42,645	42,648	42,648	42,648
Wetlands	45,361	43,004	42,336	42,223	42,113	42,112	42,113
Other Land	34,992	35,951	36,195	36,195	36,196	36,196	36,196

[11] The current land representation does not include areas from U.S. Territories, but there are planned improvements to include these regions in future reports.

[12] These "managed area" discrepancies also occur in the Common Reporting Format (CRF) tables submitted to the UNFCCC.

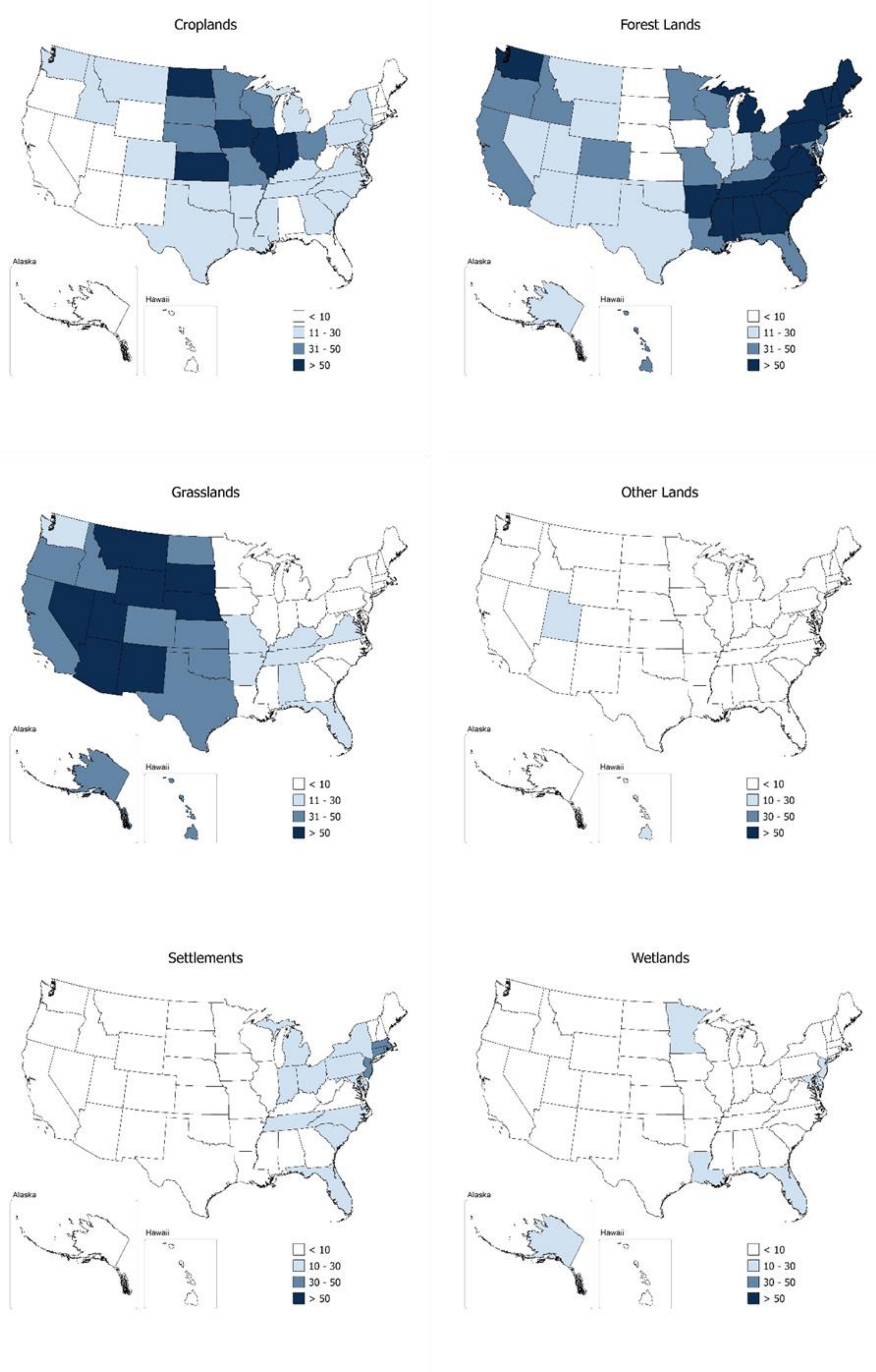
Table 6-7: Land Use and Land-Use Change for the U.S. Managed Land Base for All 50 States (Thousands of Hectares)

Land-Use & Land-Use Change Categories[a]	1990	2005	2010	2011	2012	2013	2014
Total Forest Land	**285,837**	**292,106**	**294,175**	**294,585**	**294,988**	**294,988**	**294,988**
FF	284,642	291,098	293,234	293,644	294,051	294,051	294,051
CF	233	215	189	189	183	183	183
GF	841	635	637	637	638	638	638
WF	20	23	23	23	23	23	23
SF	15	15	16	16	15	15	15
OF	86	120	77	77	77	77	77
Total Cropland	**174,678**	**166,064**	**163,745**	**163,745**	**163,752**	**163,752**	**163,752**
CC	161,960	151,903	152,079	152,079	152,084	152,084	152,084
FC	252	91	48	48	49	49	49
GC	12,066	13,581	11,215	11,215	11,215	11,215	11,215
WC	141	166	114	114	114	114	114
SC	77	78	72	72	72	72	72
OC	182	245	217	217	217	217	217
Total Grassland	**326,526**	**323,239**	**321,717**	**321,421**	**321,118**	**321,118**	**321,118**
GG	316,489	303,987	303,284	302,989	302,687	302,688	302,687
FG	899	1,538	1,481	1,481	1,479	1,479	1,479
CG	8,396	16,335	15,776	15,776	15,776	15,776	15,776
WG	283	437	250	250	250	250	250
SG	53	115	119	119	119	119	119
OG	406	827	806	806	806	806	806
Total Wetlands	**45,361**	**43,004**	**42,336**	**42,223**	**42,113**	**42,112**	**42,113**
WW	44,649	41,785	41,280	41,167	41,056	41,056	41,056
FW	38	41	35	35	35	35	35
CW	214	362	321	321	321	321	321
GW	396	770	661	661	661	661	661
SW	2	1	2	2	2	2	2
OW	63	45	38	38	38	38	38
Total Settlements	**33,420**	**40,450**	**42,645**	**42,645**	**42,648**	**42,648**	**42,648**
SS	30,632	32,188	34,870	34,870	34,870	34,870	34,870
FS	232	339	362	362	365	365	365
CS	1,227	3,530	3,205	3,205	3,205	3,205	3,205
GS	1,268	4,164	3,981	3,981	3,981	3,981	3,981
WS	6	26	24	24	24	24	24
OS	55	201	204	204	204	204	204
Total Other Land	**24,197**	**25,154**	**25,398**	**25,398**	**25,399**	**25,399**	**25,399**
OO	23,162	23,312	23,475	23,475	23,476	23,476	23,476
FO	37	54	61	61	61	61	61
CO	328	706	812	812	812	812	812
GO	531	966	969	969	969	969	969
WO	135	109	70	70	70	70	70
SO	4	7	12	12	12	12	12
Grand Total	**890,019**	**890,016**	**890,017**	**890,017**	**890,017**	**890,017**	**890,017**

[a] The abbreviations are "F" for Forest Land, "C" for Cropland, "G" for Grassland, "W" for Wetlands, "S" for Settlements, and "O" for Other Lands. Lands remaining in the same land-use category are identified with the land-use abbreviation given twice (e.g., "FF" is *Forest Land Remaining Forest Land*), and land-use change categories are identified with the previous land use abbreviation followed by the new land-use abbreviation (e.g., "CF" is *Cropland Converted to Forest Land*).

Note: All land areas reported in this table are considered managed. A planned improvement is underway to deal with an exception for Wetlands, which based on the definitions for the current U.S. Land Representation Assessment includes both managed and unmanaged lands. U.S. Territories have not been classified into land uses and are not included in the U.S. Land Representation Assessment. See the Planned Improvements section for discussion on plans to include territories in future inventories. In addition, C stock changes are not currently estimated for the entire land base, which leads to discrepancies between the managed land area data presented here and in the subsequent sections of the Inventory.

Figure 6-1: Percent of Total Land Area for Each State in the General Land-Use Categories for 2014



Methodology

IPCC Approaches for Representing Land Areas

IPCC (2006) describes three approaches for representing land areas. Approach 1 provides data on the total area for each individual land-use category, but does not provide detailed information on changes of area between categories and is not spatially explicit other than at the national or regional level. With Approach 1, total net conversions between categories can be detected, but not the individual changes (i.e., additions and/or losses) between the land-use categories that led to those net changes. Approach 2 introduces tracking of individual land-use changes between the categories (e.g., Forest Land to Cropland, Cropland to Forest Land, and Grassland to Cropland), using survey samples or other forms of data, but does not provide location data on all parcels of land. Approach 3 extends Approach 2 by providing location data on all parcels of land, such as maps, along with the land-use history. The three approaches are not presented as hierarchical tiers and are not mutually exclusive.

According to IPCC (2006), the approach or mix of approaches selected by an inventory agency should reflect calculation needs and national circumstances. For this analysis, the NRI, FIA, and the NLCD have been combined to provide a complete representation of land use for managed lands. These data sources are described in more detail later in this section. NRI and FIA are Approach 2 data sources that do not provide spatially-explicit representations of land use and land-use conversions, even though land use and land-use conversions are tracked explicitly at the survey locations. NRI and FIA data are aggregated and used to develop a land-use conversion matrix for a political or ecologically-defined region. NLCD is a spatially-explicit time series of land-cover data that is used to inform the classification of land use, and is therefore Approach 3 data. 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*).

Definitions of Land Use in the United States

Managed and Unmanaged Land

The United States definition of managed land is similar to the basic IPCC (2006) definition of managed land, but with some additional elaboration to reflect national circumstances. Based on the following definitions, most lands in the United States are classified as managed:

- *Managed Land*: Land is considered managed if direct human intervention has influenced its condition. Direct intervention occurs mostly in areas accessible to human activity and includes altering or maintaining the condition of the land to produce commercial or non-commercial products or services; to serve as transportation corridors or locations for buildings, landfills, or other developed areas for commercial or non-commercial purposes; to extract resources or facilitate acquisition of resources; or to provide social functions for personal, community, or societal objectives where these areas are readily accessible to society.[13]
- *Unmanaged Land*: All other land is considered unmanaged. Unmanaged land is largely comprised of areas inaccessible to society due to the remoteness of the locations. Though these lands may be influenced

[13] Wetlands are an exception to this general definition, because these lands, as specified by IPCC (2006), are only considered managed if they are created through human activity, such as dam construction, or the water level is artificially altered by human activity. Distinguishing between managed and unmanaged wetlands in the United States is difficult due to limited data availability. Wetlands are not characterized by use within the NRI. Therefore, unless wetlands are managed for cropland or grassland, it is not possible to know if they are artificially created or if the water table is managed based on the use of NRI data. As a result, all Wetlands are reported as managed. See the Planned Improvements section of the Inventory for work being done to refine the Wetland area estimates.

indirectly by human actions such as atmospheric deposition of chemical species produced in industry or CO_2 fertilization, they are not influenced by a direct human intervention.[14]

In addition, land that is previously managed remains in the managed land base for 20 years before re-classifying the land as unmanaged in order to account for legacy effects of management on C stocks.

Land-Use Categories

As with the definition of managed lands, IPCC (2006) provides general non-prescriptive definitions for the six main land-use categories: Forest Land, Cropland, Grassland, Wetlands, Settlements and Other Land. In order to reflect national circumstances, country-specific definitions have been developed, based predominantly on criteria used in the land-use surveys for the United States. Specifically, the definition of Forest Land is based on the FIA definition of forest,[15] while definitions of Cropland, Grassland, and Settlements are based on the NRI.[16] The definitions for Other Land and Wetlands are based on the IPCC (2006) definitions for these categories.

- *Forest Land*: A land-use category that includes areas at least 120 feet (36.6 meters) wide and at least one acre (0.4 hectare) in size with at least 10 percent cover (or equivalent stocking) by live trees including land that formerly had such tree cover and that will be naturally or artificially regenerated. Trees are woody plants having a more or less erect perennial stem(s) capable of achieving at least 3 inches (7.6 centimeters) in diameter at breast height, or 5 inches (12.7 cm) diameter at root collar, and a height of 16.4 feet (5 m) at maturity in situ. Forest Land includes all areas recently having such conditions and currently regenerating or capable of attaining such condition in the near future. Forest Land also includes transition zones, such as areas between forest and non-forest lands that have at least 10 percent cover (or equivalent stocking) with live trees and forest areas adjacent to urban and built-up lands. Unimproved roads and trails, streams, and clearings in forest areas are classified as forest if they are less than 120 feet (36.6 m) wide or an acre (0.4 ha) in size. However, land is not classified as Forest Land if completely surrounded by urban or developed lands, even if the criteria are consistent with the tree area and cover requirements for Forest Land. These areas are classified as Settlements. In addition, Forest Land does not include land that is predominantly under an agricultural land use (Oswalt et al. 2014).
- *Cropland*: A land-use category that includes areas used for the production of adapted crops for harvest; this category includes both cultivated and non-cultivated lands. Cultivated crops include row crops or close-grown crops and also hay or pasture in rotation with cultivated crops. Non-cultivated cropland includes continuous hay, perennial crops (e.g., orchards) and horticultural cropland. Cropland also includes land with agroforestry, such as alley cropping and windbreaks,[17] if the dominant use is crop production, assuming the stand or woodlot does not meet the criteria for Forest Land. Lands in temporary fallow or enrolled in conservation reserve programs (i.e., set-asides[18]) are also classified as Cropland, as long as these areas do not meet the Forest Land criteria. Roads through Cropland, including interstate highways, state highways, other paved roads, gravel roads, dirt roads, and railroads are excluded from Cropland area estimates and are, instead, classified as Settlements.
- *Grassland*: A land-use category on which the plant cover is composed principally of grasses, grass-like plants (i.e., sedges and rushes), forbs, or shrubs suitable for grazing and browsing, and includes both pastures and native rangelands. This includes areas where practices such as clearing, burning, chaining, and/or chemicals are applied to maintain the grass vegetation. Grassland may have three or fewer years of

[14] There are some areas, such as Forest Land and Grassland in Alaska that are classified as unmanaged land due to the remoteness of their location.

[15] See <http://www.fia.fs.fed.us/library/field-guides-methods-proc/docs/2015/Core-FIA-FG-7.pdf>, page 22.

[16] See <http://www.nrcs.usda.gov/wps/portal/nrcs/site/national/home>.

[17] Currently, there is no data source to account for biomass C stock change associated with woody plant growth and losses in alley cropping systems and windbreaks in cropping systems, although these areas are included in the Cropland land base.

[18] A set-aside is cropland that has been taken out of active cropping and converted to some type of vegetative cover, including, for example, native grasses or trees.

hay production[19] that is otherwise pasture or rangelands. Savannas, deserts, and tundra are considered Grassland.[20] Drained wetlands are considered Grassland if the dominant vegetation meets the plant cover criteria for Grassland. Woody plant communities of low forbs and shrubs, such as mesquite, chaparral, mountain shrub, and pinyon-juniper, are also classified as Grassland if they do not meet the criteria for Forest Land. Grassland includes land managed with agroforestry practices, such as silvipasture and windbreaks, if the land is principally grasses, grass-like plants, forbs, and shrubs suitable for grazing and browsing, and assuming the stand or woodlot does not meet the criteria for Forest Land. Roads through Grassland, including interstate highways, state highways, other paved roads, gravel roads, dirt roads, and railroads are excluded from Grassland and are, instead, classified as Settlements.

- *Wetlands*: A land-use category that includes land covered or saturated by water for all or part of the year, in addition to the areas of lakes, reservoirs, and rivers. Managed Wetlands are those where the water level is artificially changed, or were created by human activity. Certain areas that fall under the managed Wetlands definition are included in other land uses based on the IPCC guidance, including Cropland (drained wetlands for crop production and also systems that are flooded for most or just part of the year, such as rice cultivation and cranberry production), Grassland (drained wetlands dominated by grass cover), and Forest Land (including drained or un-drained forested wetlands).
- *Settlements*: A land-use category representing developed areas consisting of units of 0.25 acres (0.1 ha) or more that includes residential, industrial, commercial, and institutional land; construction sites; public administrative sites; railroad yards; cemeteries; airports; golf courses; sanitary landfills; sewage treatment plants; water control structures and spillways; parks within urban and built-up areas; and highways, railroads, and other transportation facilities. Also included are tracts of less than 10 acres (4.05 ha) that may meet the definitions for Forest Land, Cropland, Grassland, or Other Land but are completely surrounded by urban or built-up land, and so are included in the Settlements category. Rural transportation corridors located within other land uses (e.g., Forest Land, Cropland, and Grassland) are also included in Settlements.
- *Other Land*: A land-use category that includes bare soil, rock, ice, and all land areas that do not fall into any of the other five land-use categories, which allows the total of identified land areas to match the managed land base. Following the guidance provided by the IPCC (2006), C stock changes and non-CO_2 emissions are not estimated for Other Lands because these areas are largely devoid of biomass, litter and soil C pools. However, C stock changes and non-CO_2 emissions are estimated for *Land Converted to Other Land* during the first 20 years following conversion to account for legacy effects.

Land-Use Data Sources: Description and Application to U.S. Land Area Classification

U.S. Land-Use Data Sources

The three main sources for land-use data in the United States are the NRI, FIA, and the NLCD (Table 6-8). These data sources are combined to account for land use in all 50 states. FIA and NRI data are used when available for an area because the surveys contain additional information on management, site conditions, crop types, biometric measurements, and other data from which to estimate C stock changes on those lands. If NRI and FIA data are not available for an area, however, then the NLCD product is used to represent the land use.

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[19] Areas with four or more years of continuous hay production are Cropland because the land is typically more intensively managed with cultivation, greater amounts of inputs, and other practices.

[20] *2006 IPCC Guidelines* do not include provisions to separate desert and tundra as land-use categories.

Table 6-8: Data Sources Used to Determine Land Use and Land Area for the Conterminous United States, Hawaii, and Alaska

	NRI	FIA	NLCD
Forest Land			
Conterminous United States			
Non-Federal		•	
Federal		•	
Hawaii			
Non-Federal	•		
Federal			•
Alaska			
Non-Federal			•
Federal			•
Croplands, Grasslands, Other Lands, Settlements, and Wetlands			
Conterminous United States			
Non-Federal	•		
Federal			•
Hawaii			
Non-Federal	•		
Federal			•
Alaska			
Non-Federal			•
Federal			•

National Resources Inventory

For the Inventory, the NRI is the official source of data on all land uses on non-federal lands in the conterminous United States and Hawaii (except Forest Land), and is also used as the resource to determine the total land base for the conterminous United States and Hawaii. The NRI is a statistically-based survey conducted by the USDA Natural Resources Conservation Service and is designed to assess soil, water, and related environmental resources on non-federal lands. The NRI has a stratified multi-stage sampling design, where primary sample units are stratified on the basis of county and township boundaries defined by the United States Public Land Survey (Nusser and Goebel 1997). Within a primary sample unit (typically a 160 acre [64.75 ha] square quarter-section), three sample points are selected according to a restricted randomization procedure. Each point in the survey is assigned an area weight (expansion factor) based on other known areas and land-use information (Nusser and Goebel 1997). The NRI survey utilizes data derived from remote sensing imagery and site visits in order to provide detailed information on land use and management, particularly for Croplands and Grasslands, and is used as the basis to account for C stock changes in agricultural lands (except federal Grasslands). The NRI survey was conducted every 5 years between 1982 and 1997, but shifted to annualized data collection in 1998. The land use between five-year periods from 1982 and 1997 are assumed to be the same for a five-year time period if the land use is the same at the beginning and end of the five-year period. (Note: most of the data has the same land use at the beginning and end of the five-year periods.) If the land use had changed during a five-year period, then the change is assigned at random to one of the five years. For crop histories, years with missing data are estimated based on the sequence of crops grown during years preceding and succeeding a missing year in the NRI history. This gap-filling approach allows for development of a full time series of land-use data for non-federal lands in the conterminous United States and Hawaii. This Inventory incorporates data through 2010 from the NRI. The land use patterns are assumed to remain the same from 2010 through 2014 for this Inventory, but the time series will be updated when new data are released.

Forest Inventory and Analysis

The FIA program, conducted by the USFS, is another statistically-based survey for the conterminous United States, and the official source of data on Forest Land area and management data for the Inventory in this region of the country. FIA engages in a hierarchical system of sampling, with sampling categorized as Phases 1 through 3, in which sample points for phases are subsets of the previous phase. Phase 1 refers to collection of remotely-sensed data (either aerial photographs or satellite imagery) primarily to classify land into forest or non-forest and to identify landscape patterns like fragmentation and urbanization. Phase 2 is the collection of field data on a network of ground plots that enable classification and summarization of area, tree, and other attributes associated with forest-land uses. Phase 3 plots are a subset of Phase 2 plots where data on indicators of forest health are measured. Data from all three phases are also used to estimate C stock changes for Forest Land. Historically, FIA inventory surveys have been conducted periodically, with all plots in a state being measured at a frequency of every five to 14 years. A new national plot design and annual sampling design was introduced by FIA about ten years ago. Most states, though, have only recently been brought into this system. Annualized sampling means that a portion of plots throughout each state is sampled each year, with the goal of measuring all plots once every five years. See Annex 3.13 to see the specific survey data available by state. The most recent year of available data varies state by state (range of most recent data is from 2012 through 2014; see Table A-255).

National Land Cover Dataset

While the NRI survey sample covers the conterminous United States and Hawaii, land use data are only collected on non-federal lands. In addition, FIA only records data for forest land across the land base in the conterminous United States and a portion of Alaska.[21] Consequently, major gaps exist in the land use classification when the datasets are combined, such as federal grassland operated by Bureau of Land Management (BLM), USDA, and National Park Service, as well as Alaska.[22] The NLCD is used as a supplementary database to account for land use on federal lands in the conterminous United States and Hawaii, in addition to federal and non-federal lands in Alaska.

NLCD products provide land-cover for 1992, 2001, 2006, and 2011 in the conterminous United States (Homer et al. 2007), and also for Alaska and Hawaii in 2001. For the conterminous United States, the NLCD data have been further processed to derive Land Cover Change Products for 2001, 2006, and 2011 (Fry et al. 2011, Homer et al. 2007, Jin et al. 2013). A change product is not available for Alaska and Hawaii because the data are only available for one year, i.e., 2001). The NLCD products are based primarily on Landsat Thematic Mapper imagery at a 30 meter resolution, and contain 21 categories of land-cover information, which have been aggregated into the 36 IPCC land-use categories for the conterminous United States and into the 6 IPCC land-use categories for Hawaii and Alaska.

The aggregated maps of IPCC land-use categories were used in combination with the NRI database to represent land use and land-use change for federal lands, as well as federal and non-federal lands in Alaska. Specifically, NRI survey locations designated as federal lands were assigned a land use/land use change category based on the NLCD maps that had been aggregated into the IPCC categories. This analysis addressed shifts in land ownership across years between federal or non-federal classes as represented in the NRI survey (i.e., the ownership is classified for each survey location is the NRI). NLCD is strictly a source of land-cover information, however, and does not provide the necessary site conditions, crop types, and management information from which to estimate C stock changes on those lands. The sources of these additional data are discussed in subsequent sections of the NIR.

Managed Land Designation

Lands are designated as managed in the United States based on the definition provided earlier in this section. In order to apply the definition in an analysis of managed land, the following criteria are used:

- All Croplands and Settlements are designated as managed so only Grassland, Forest Land or Other Lands may be designated as unmanaged land;
- All Forest Lands with active fire protection are considered managed;
- All Grassland is considered managed at a county scale if there are livestock in the county;[23]
- Other areas are considered managed if accessible based on the proximity to roads and other transportation corridors, and/or infrastructure;
- Protected lands maintained for recreational and conservation purposes are considered managed (i.e., managed by public and private organizations);
- Lands with active and/or past resource extraction are considered managed; and

[21] FIA does collect some data on non-forest land use, but these are held in regional databases versus the national database. The status of these data is being investigated.

[22] The FIA and NRI survey programs also do not include U.S. Territories with the exception of non-federal lands in Puerto Rico, which are included in the NRI survey. Furthermore, NLCD does not include coverage for all U.S. Territories.

[23] Assuming all Grasslands are grazed in a county with even very small livestock populations is a conservative assumption about human impacts on Grasslands. Currently, detailed information on grazing at sub-county scales is not available for the United States to make a finer delineation of managed land.

- Lands that were previously managed but subsequently classified as unmanaged remain in the managed land base for 20 years following the conversion to account for legacy effects of management on C stocks.

The analysis of managed lands is conducted using a geographic information system. Lands that are used for crop production or settlements are determined from the NLCD (Fry et al. 2011; Homer et al. 2007; Jin et al. 2013). Forest Lands with active fire management are determined from maps of federal and state management plans from the National Atlas (U.S. Department of Interior 2005) and Alaska Interagency Fire Management Council (1998). It is noteworthy that all forest lands in the conterminous United States have active fire protection, and are therefore designated as managed regardless of accessibility or other criteria. The designation of grasslands as managed is based on livestock population data at the county scale from the USDA National Agricultural Statistics Service (U.S. Department of Agriculture 2014). Accessibility is evaluated based on a 10-km buffer surrounding road and train transportation networks using the ESRI Data and Maps product (ESRI 2008), and a 10-km buffer surrounding settlements using NLCD. Lands maintained for recreational purposes are determined from analysis of the Protected Areas Database (U.S. Geological Survey 2012). The Protected Areas Database includes lands protected from conversion of natural habitats to anthropogenic uses and describes the protection status of these lands. Lands are considered managed that are protected from development if the regulations permit extractive or recreational uses or suppression of natural disturbance. Lands that are protected from development and not accessible to human intervention, including no suppression of disturbances or extraction of resources, are not included in the managed land base. Multiple data sources are used to determine lands with active resource extraction: Alaska Oil and Gas Information System (Alaska Oil and Gas Conservation Commission 2009), Alaska Resource Data File (U.S. Geological Survey 2012), Active Mines and Mineral Processing Plants (U.S. Geological Survey 2005), and Coal Production and Preparation Report (U.S. Energy Information Administration 2011). A buffer of 3,300 and 4,000 meters is established around petroleum extraction and mine locations, respectively, to account for the footprint of operation and impacts of activities on the surrounding landscape. The buffer size is based on visual analysis of approximately 130 petroleum extraction sites and 223 mines. The resulting managed land area is overlaid on the NLCD to estimate the area of managed land by land use for both federal and non-federal lands. The remaining land represents the unmanaged land base. The resulting spatial product is used to identify NRI survey locations that are considered managed and unmanaged for the conterminous United States and Hawaii, in addition to determining which areas in the NLCD for Alaska are included in the managed land base.

Approach for Combining Data Sources

The managed land base in the United States has been classified into the thirty-six IPCC land-use/land-use conversion categories using definitions developed to meet national circumstances, while adhering to IPCC (2006).[24] In practice, the land was initially classified into a variety of land-use categories within the NRI, FIA, and NLCD datasets, and then aggregated into the thirty-six broad land use and land-use change categories identified in IPCC (2006). All three datasets provide information on forest land areas in the conterminous United States, but the area data from FIA serve as the official dataset for estimating Forest Land in the conterminous United States.

Therefore, another step in the analysis is to address the inconsistencies in the representation of the Forest Land among the three databases. NRI and FIA have different criteria for classifying Forest Land in addition to different sampling designs, leading to discrepancies in the resulting estimates of Forest Land area on non-federal land in the conterminous United States. Similarly, there are discrepancies between the NLCD and FIA data for defining and classifying Forest Land on federal lands. Any change in Forest Land Area in the NRI and NLCD also requires a corresponding change in other land use areas because of the dependence between the Forest Land area and the amount of land designated as other land uses, such as the amount of Grassland, Cropland, and Wetlands (i.e., areas for the individual land uses must sum to the total area of the country).

FIA is the main database for forest statistics, and consequently, the NRI and NLCD are adjusted to achieve consistency with FIA estimates of Forest Land in the conterminous United States. Adjustments are made in the *Forest Land Remaining Forest Land*, *Land Converted to Forest Land*, and Forest Land converted to other uses (i.e., Grassland, Cropland and Wetlands). All adjustments are made at the state scale to address the differences in Forest Land definitions and the resulting discrepancies in areas among the land use and land-use change categories. There

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[24] Definitions are provided in the previous section.

are three steps in this process. The first step involves adjustments for *Land Converted to Forest Land* (Grassland, Cropland and Wetlands), followed by adjustments in Forest Land converted to another land use (i.e., Grassland, Cropland and Wetlands), and finally adjustments to *Forest Land Remaining Forest Land*.

In the first step, *Land Converted to Forest Land* in the NRI and NLCD are adjusted to match the state-level estimates in the FIA data for non-federal and federal *Land Converted to Forest Land*, respectively. FIA data do not provide specific land-use categories that are converted to Forest Land, but rather a sum of all *Land Converted to Forest Land*. The NRI and NLCD provide information on specific land use conversions, however, such as *Grassland Converted to Forest Land*. Therefore, adjustments at the state level to NRI and NLCD are made proportional to the amount of land use change into Forest Land for the state, prior to any adjustments. For example, if 50 percent of land use change to Forest Land is associated with *Grassland Converted to Forest Land* in a state according to NRI or NLCD, then half of the discrepancy with FIA data in the area of *Land Converted to Forest Land* is addressed by increasing or decreasing the area in *Grassland Converted to Forest Land*. Moreover, any increase or decrease in *Grassland Converted to Forest Land* in NRI or NLCD is addressed by a corresponding change in the area of *Grassland Remaining Grassland*, so that the total amount of managed area is not changed within an individual state.

In the second step, state-level areas are adjusted in the NRI and NLCD to address discrepancies with FIA data for Forest Land converted to other uses. Similar to *Land Converted to Forest Land*, FIA does not provide information on the specific land-use changes, and so areas associated with Forest Land conversion to other land uses in NRI and NLCD are adjusted proportional to the amount area in each conversion class in these datasets.

In the final step, the area of *Forest Land Remaining Forest Land* in a given state according to the NRI and NLCD is adjusted to match the FIA estimates for non-federal and federal land, respectively. It is assumed that the majority of the discrepancy in *Forest Land Remaining Forest Land* is associated with an under- or over-prediction of *Grassland Remaining Grassland* and *Wetland Remaining Wetland* in the NRI and NLCD. This step also assumes that there are no changes in the land use conversion categories. Therefore, corresponding increases or decreases are made in the area estimates of *Grasslands Remaining Grasslands* and *Wetlands Remaining Wetlands* from the NRI and NLCD, in order to balance the change in *Forest Land Remaining Forest Land* area, and ensure no change in the overall amount of managed land within an individual state. The adjustments are based on the proportion of land within each of these land-use categories at the state level. (i.e., a higher proportion of Grassland led to a larger adjustment in Grassland area).

The modified NRI data are then aggregated to provide the land-use and land-use change data for non-federal lands in the conterminous United States, and the modified NLCD data are aggregated to provide the land use and land-use change data for federal lands. Data for all land uses in Hawaii are based on NRI for non-federal lands and on NLCD for federal lands. Land use data in Alaska are based solely on the NLCD data (Table 6-8). The result is land use and land-use change data for the conterminous United States, Hawaii, and Alaska.[25]

A summary of the details on the approach used to combine data sources for each land use are described below.

- *Forest Land*: Both non-federal and federal forest lands in the conterminous United States and coastal Alaska are covered by FIA. FIA is used as the basis for both Forest Land area data as well as to estimate C stocks and fluxes on Forest Land in the conterminous United States. FIA does have survey plots in coastal Alaska that are used to determine the C stock changes, but the area data for this region are based on the 2001 NLCD. In addition, interior Alaska is not currently surveyed by FIA so forest land in this region are also based on the 2001 NLCD. NRI is being used in the current report to provide Forest Land areas on non-federal lands in Hawaii and NLCD is used for federal lands. FIA data will be collected in Hawaii in the future.

- *Cropland*: Cropland is classified using the NRI, which covers all non-federal lands within 49 states (excluding Alaska), including state and local government-owned land as well as tribal lands. NRI is used as the basis for both Cropland area data as well as to estimate soil C stocks and fluxes on Cropland. NLCD is used to determine Cropland area and soil C stock changes on federal lands in the conterminous United

[25] Only one year of data are currently available for Alaska so there is no information on land-use change for this state.

States and Hawaii. NLCD is also used to determine croplands in Alaska, but C stock changes are not estimated for this region in the current Inventory.

- *Grassland*: Grassland on non-federal lands is classified using the NRI within 49 states (excluding Alaska), including state and local government-owned land as well as tribal lands. NRI is used as the basis for both Grassland area data as well as to estimate soil C stocks and fluxes on Grassland. Grassland area and soil C stock changes are determined using the classification provided in the NLCD for federal land within the conterminous United States. NLCD is also used to estimate the areas of federal and non-federal grasslands in Alaska, and the federal lands in Hawaii, but the current Inventory does not include C stock changes in these areas.
- *Wetlands*: NRI captures wetlands on non-federal lands within 49 states (excluding Alaska), while federal wetlands and wetlands in Alaska are covered by the NLCD.[26]
- *Settlements*: NRI captures non-federal settlement area in 49 states (excluding Alaska). If areas of Forest Land or Grassland under 10 acres (4.05 ha) are contained within settlements or urban areas, they are classified as Settlements (urban) in the NRI database. If these parcels exceed the 10 acre (4.05 ha) threshold and are Grassland, they will be classified as such by NRI. Regardless of size, a forested area is classified as non-forest by FIA if it is located within an urban area. Settlements on federal lands and in Alaska are covered by NLCD.
- *Other Land*: Any land that is not classified into one of the previous five land-use categories, is categorized as Other Land using the NRI for non-federal areas in the conterminous United States and Hawaii and using the NLCD for the federal lands in all regions of the United States and for non-federal lands in Alaska.

Some lands can be classified into one or more categories due to multiple uses that meet the criteria of more than one definition. However, a ranking has been developed for assignment priority in these cases. The ranking process is from highest to lowest priority, in the following manner:

Settlements > *Cropland* > *Forest Land* > *Grassland* > *Wetlands* > *Other Land*

Settlements are given the highest assignment priority because they are extremely heterogeneous with a mosaic of patches that include buildings, infrastructure, and travel corridors, but also open grass areas, forest patches, riparian areas, and gardens. The latter examples could be classified as Grassland, Forest Land, Wetlands, and Cropland, respectively, but when located in close proximity to settlement areas they tend to be managed in a unique manner compared to non-settlement areas. Consequently, these areas are assigned to the Settlements land-use category. Cropland is given the second assignment priority, because cropping practices tend to dominate management activities on areas used to produce food, forage, or fiber. The consequence of this ranking is that crops in rotation with pasture will be classified as Cropland, and land with woody plant cover that is used to produce crops (e.g., orchards) is classified as Cropland, even though these areas may meet the definitions of Grassland or Forest Land, respectively. Similarly, Wetlands are considered Croplands if they are used for crop production, such as rice or cranberries. Forest Land occurs next in the priority assignment because traditional forestry practices tend to be the focus of the management activity in areas with woody plant cover that are not croplands (e.g., orchards) or settlements (e.g., housing subdivisions with significant tree cover). Grassland occurs next in the ranking, while Wetlands then Other Land complete the list.

The assignment priority does not reflect the level of importance for reporting greenhouse gas emissions and removals on managed land, but is intended to classify all areas into a discrete land use. Currently, the IPCC does not make provisions in the guidelines for assigning land to multiple uses. For example, a wetland is classified as Forest Land if the area has sufficient tree cover to meet the stocking and stand size requirements. Similarly, wetlands are classified as Cropland if they are used for crop production, such as rice or cranberries, or as Grassland if they are composed principally of grasses, grass-like plants (i.e., sedges and rushes), forbs, or shrubs suitable for grazing and browsing. Regardless of the classification, emissions from these areas are included in the Inventory if the land is considered managed and presumably impacted by anthropogenic activity in accordance with the guidance provided in IPCC (2006).

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[26] This analysis does not distinguish between managed and unmanaged wetlands, which is a planned improvement for the Inventory.

QA/QC and Verification

The land base derived from the NRI, FIA, and NLCD was compared to the Topologically Integrated Geographic Encoding and Referencing (TIGER) survey (U.S. Census Bureau 2010). The U.S. Census Bureau gathers data on the U.S. population and economy, and has a database of land areas for the country. The land area estimates from the U.S. Census Bureau differ from those provided by the land-use surveys used in the Inventory because of discrepancies in the reporting approach for the Census and the methods used in the NRI, FIA, and NLCD. The area estimates of land-use categories, based on NRI, FIA, and NLCD, are derived from remote sensing data instead of the land survey approach used by the U.S. Census Survey. More importantly, the U.S. Census Survey does not provide a time series of land-use change data or land management information. Consequently, the U.S. Census Survey was not adopted as the official land area estimate for the Inventory. Rather, the NRI, FIA, and NLCD datasets were adopted because these databases provide full coverage of land area and land use for the conterminous United States, Alaska, and Hawaii, in addition to management and other data relevant for the Inventory. Regardless, the total difference between the U.S. Census Survey and the combined NRI, FIA, and NLCD data is about 46 million hectares for the total U.S. land base of about 936 million hectares currently included in the Inventory, or a 5 percent difference. Much of this difference is associated with open waters in coastal regions and the Great Lakes, which is included in the TIGER Survey of the U.S. Census, but not included in the land representation using the NRI, FIA and NLCD. There is only a 0.4 percent difference when open water in coastal regions is removed from the TIGER data.

Recalculations Discussion

In previous years, FIA did not separate Forest Land into land use and land use change categories, reporting all areas as *Forest Land Remaining Forest Land* for the purpose of estimating forest carbon stock changes. In this Inventory, forest carbon stock changes are reported for *Land Converted to Forest*, *Forest Converted to other Land Uses*, in addition to *Forest Land Remaining Forest Land.* As such, adjustments to NRI and NLCD accounted for land use changes associated with Forest Land, which led to minor adjustments to the time series. Other small changes occurred in the areas of Grassland, Wetland, and Cropland due to the modifications to the Forest Land data in FIA and the process of combining the NRI, NLCD and FIA products into a harmonized dataset.

In addition to the changes in the FIA data, a new NRI dataset was incorporated into the current Inventory extending the time series from 2007 to 2010. The NRI program also recalculated the previous time series based on changes to the classification and imputation procedures for filling gaps.

The definition of Grassland also changed so that a land use history that includes three or fewer years within a sequence of grass pasture or rangeland is considered Grassland, rather than converting these areas into Cropland. Land use remains virtually unchanged in these cases with harvesting of the existing grass vegetation, with no impact on carbon stocks. In contrast, longer term adoption of continuous hay tends to change the management to a more intensive set of practices that influences the carbon stocks. This exception is only applied to hay. Any change in land management that involves cultivation of other crops, such as corn, wheat, or soybeans, is still considered a land use change.

The revisions in land representation led to the following changes in land use areas for the managed land base: on average over the time series, Forest Land area decreased by 0.2 percent, Cropland area increased by 3.1 percent, Grassland area increased by 0.7 percent, Wetland area decreased by 0.8 percent, Settlements decreased by 16.6 percent, and Other Lands increased by 5.8 percent.

Planned Improvements

A key planned improvement is to fully incorporate area data by land-use type for U.S. Territories into the Inventory. Fortunately, most of the managed land in the United States is included in the current land-use statistics, but a complete accounting is a key goal for the near future. Preliminary land-use area data for U.S. Territories by land-use category are provided in Box 6-2: Preliminary Estimates of Land Use in U.S. Territories.

Box 6-2: Preliminary Estimates of Land Use in U.S. Territories

Several programs have developed land cover maps for U.S. Territories using remote sensing imagery, including the Gap Analysis Program, Caribbean Land Cover project, National Land Cover Dataset, USFS Pacific Islands Imagery Project, and the National Oceanic and Atmospheric Administration (NOAA) Coastal Change Analysis Program (C-CAP). Land-cover data can be used to inform a land-use classification if there is a time series to evaluate the dominate practices. For example, land that is principally used for timber production with tree cover over most of the time series is classified as forest land even if there are a few years of grass dominance following timber harvest. These products were reviewed and evaluated for use in the national Inventory as a step towards implementing a planned improvement to include U.S. Territories in the land representation for the Inventory. Recommendations are to use the NOAA C-CAP Regional Land Cover Database for the smaller island Territories (U.S. Virgin Islands, Guam, Northern Marianas Islands, and American Samoa) because this program is ongoing and therefore will be continually updated. The C-CAP product does not cover the entire territory of Puerto Rico so the NLCD was used for this area. The final selection of a land-cover product for these territories is still under discussion. Results are presented below (in hectares). The total land area of all U.S. Territories is 1.05 million hectares, representing 0.1 percent of the total land base for the United States.

Table 6-9: Total Land Area (Hectares) by Land-Use Category for U.S. Territories

	Puerto Rico	U.S. Virgin Islands	Guam	Northern Marianas Islands	American Samoa	Total
Cropland	19,712	138	236	289	389	20,764
Forest Land	404,004	13,107	24,650	25,761	15,440	482,962
Grasslands	299,714	12,148	15,449	13,636	1,830	342,777
Other Land	5,502	1,006	1,141	5,186	298	13,133
Settlements	130,330	7,650	11,146	3,637	1,734	154,496
Wetlands	24,525	4,748	1,633	260	87	31,252
Total	**883,788**	**38,796**	**54,255**	**48,769**	**19,777**	**1,045,385**

Additional work will be conducted to reconcile differences in Forest Land estimates between the NRI and FIA. This improvement will include an analysis designed to develop finer scale adjustments at the survey locations. Harmonization is planned at the survey location scale using ancillary data, such as the NLCD, which is expected to better capture the differences in Forest Land classification between the two surveys, as well as the conversions of land to other uses that involve Forest Land.

NLCD data for Alaska were recently released for 2011, and will be used to analyze land use change for this state in the next Inventory. There are also other databases that may need to be reconciled with the NRI and NLCD datasets, particularly for Settlements. Urban area estimates, used to produce C stock and flux estimates from urban trees, are currently based on population data (1990, 2000, and 2010 U.S. Census data). Using the population statistics, "urban clusters" are defined as areas with more than 500 people per square mile. The USFS is currently moving ahead with an Urban Forest Inventory program so that urban forest area estimates will be consistent with FIA forest area estimates outside of urban areas, which would be expected to reduce omissions and overlap of forest area estimates along urban boundary areas.

As adopted by the UNFCCC, new guidance in the *2013 Supplement to the 2006 Guidelines for National Greenhouse Gas Inventories: Wetlands* will be implemented in the Inventory. This will likely have implications for the classification of managed and unmanaged wetlands in the Inventory report. More detailed wetlands datasets will also be evaluated and integrated into the analysis in order to implement the new guidance.

6.2 Forest Land Remaining Forest Land

Changes in Forest Carbon Stocks (IPCC Source Category 4A1)

Delineation of Carbon Pools

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

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

In addition, there are two harvested wood pools to account for when estimating C flux:

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

Forest Carbon Cycle

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

The net change in forest C is not equivalent to the net flux between forests and the atmosphere because timber harvests do not cause an immediate flux of all harvested biomass C to the atmosphere. Instead, harvesting transfers a portion of the C stored in wood to a "product pool." Once in a product pool, the C is emitted over time as CO_2 in the case of decomposition and as CO_2, CH_4, N_2O, CO, NO_x when the wood product combusts. The rate of emission varies considerably among different product pools. For example, if timber is harvested to produce energy, combustion releases C immediately, and these emissions are reported for information purposes in the Energy sector while the harvest (i.e., the associated reduction in forest C stocks) and subsequent combustion are implicitly accounted for under the Land Use, Land-Use Change, and Forestry (LULUCF) sector (i.e., the harvested timber does not enter the HWP pools). Conversely, if timber is harvested and used as lumber in a house, it may be many decades or even centuries before the lumber decays and C is released to the atmosphere. If wood products are disposed of in SWDS, the C contained in the wood may be released many years or decades later, or may be stored almost permanently in the SWDS. These latter fluxes, with the exception of CH_4 from wood in SWDS which is included in the Waste sector, are also accounted for under the LULUCF sector.

Net Change in Carbon Stocks within Forest Land of the United States

This section describes the general method for quantifying the net changes in C stocks in the five forest C pools and two harvested wood pools. The underlying methodology for determining C stock and stock-change relies on data from the Forest Inventory and Analysis (FIA) program within the USDA Forest Service. The annual forest inventory system is implemented across all U.S. forest lands within the conterminous 48 states but excluding interior Alaska, Hawaii, and U.S. Territories at this time. The methods for estimation and monitoring are continuously improved and these improvements are reflected in the C estimates (Woodall et al. 2015a). The net change in C stocks for each pool is estimated, and then the changes in stocks are summed for all pools to estimate total net flux. The focus on C implies that all C-based greenhouse gases are included, and the focus on stock change suggests that specific ecosystem fluxes do not need to be separately itemized in this report. Changes in C stocks from disturbances, such as forest fires or harvesting, are included in the net changes. For instance, an inventory conducted after fire counts only the trees that are left. Therefore, changes in C stocks from natural disturbances, such as wildfires, pest outbreaks, and storms, are accounted for in the forest inventory approach; however, they are highly variable from year to year. The IPCC (2006) recommends estimating changes in C stocks from forest lands according to several land-use types and conversions, specifically *Forest Land Remaining Forest Land* and *Land Converted to Forest Land*, with the former being forest lands that have been forest lands for 20 years or longer and the latter being lands that have been classified as forest lands for less than 20 years. This is the first report to delineate forest C stock changes by these two categories and in order to facilitate this delineation, a different approach to forest C accounting was used this year in the United States (Woodall et al. 2015a).

Forest Area in the United States

Approximately 34 percent of the U.S. land area is estimated to be forested based on the U.S. definition of forest land as provided in the Section 6.1 Representation of the U.S. Land Base. The most recent forest inventories from each of the conterminous 48 states (USDA Forest Service 2014a, 2014b) comprise an estimated 266 million hectares of forest land that are considered managed and are included in this Inventory. An additional 6.2 million hectares of forest land in southeast and south central coastal Alaska are inventoried and are also included here. Some differences exist in forest land defined in Oswalt et al. (2014) and the forest land included in this report, which is based on the USDA Forest Service (2015b) forest inventory. Annual inventory data are not yet available for Hawaii and interior Alaska, but estimates of these areas are included in Oswalt et al. (2014). Updated survey data for central and western forest land in both Oklahoma and Texas have only recently become available, and these forests contribute to overall C stocks reported below. While Hawaii and U.S. Territories have relatively small areas of forest land and thus may not substantially influence the overall C budget, these regions will be added to the forest C estimates as sufficient data become available. Agroforestry systems that meet the definition of forest land are also not currently accounted for in the Inventory since they are not explicitly inventoried by either the FIA program or the Natural Resources Inventory (NRI)[27] of the USDA Natural Resources Conservation Service (Perry et al. 2005).

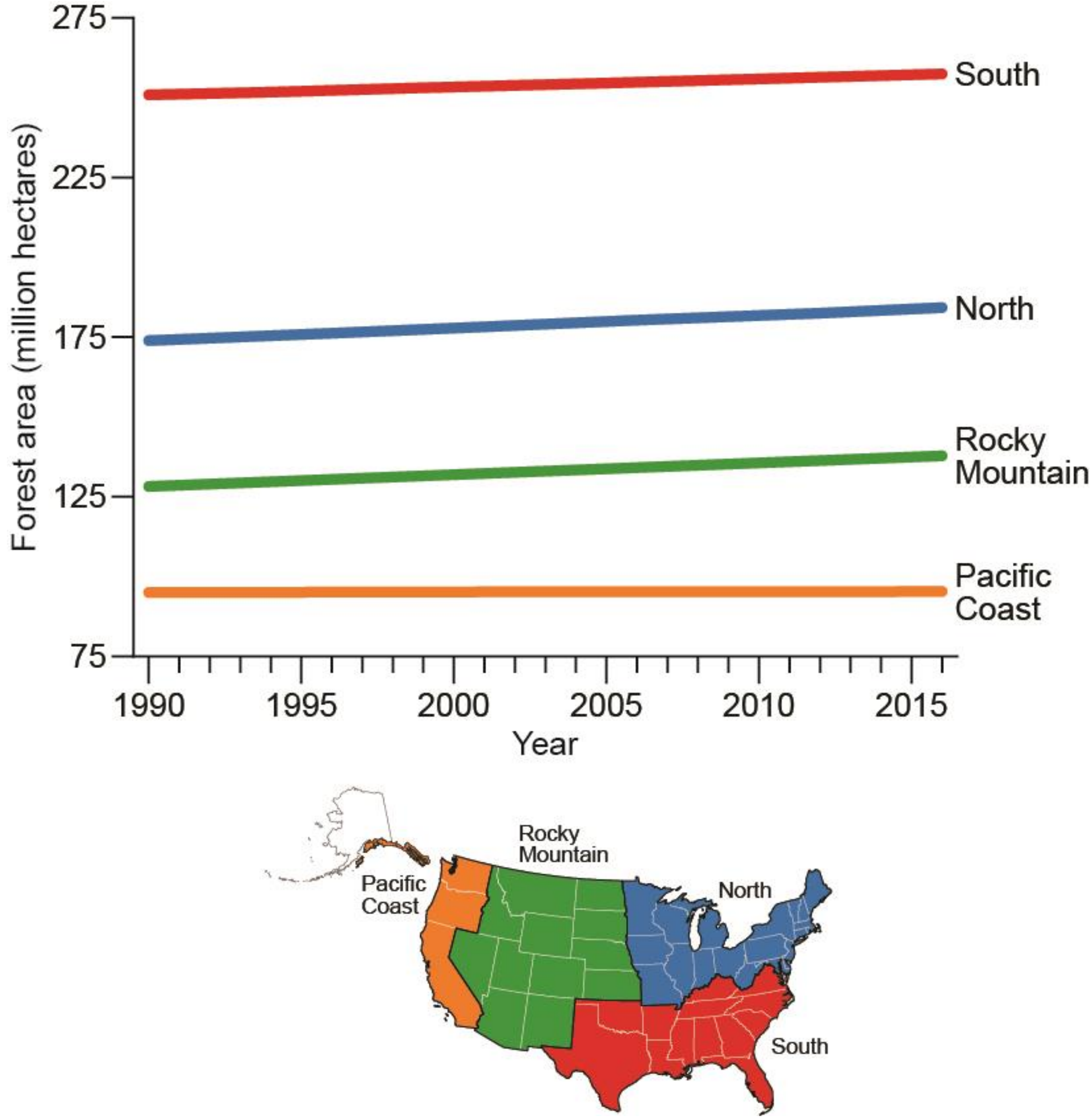
An estimated 77 percent (211 million hectares) of U.S. forests in southeast and southcentral coastal Alaska and the conterminous United States are classified as timberland, meaning they meet minimum levels of productivity and have not been removed from production. Ten percent of southeast and southcentral coastal Alaska forest land and 80 percent of forest land in the conterminous United States are classified as timberland. Of the remaining non-timberland, 30 million hectares are reserved forest lands (withdrawn by law from management for production of wood products) and 69 million hectares are lower productivity forest lands (Oswalt et al. 2014). Historically, the timberlands in the conterminous 48 states have been more frequently or intensively surveyed than forest land not meeting the minimum level of productivity and removed from production.

Since the late 1980s, forest land area in southeast and southcentral coastal Alaska and the conterminous United States has increased by about 14 million hectares (Oswalt et al. 2014) with the southern region of the United States containing the most forest land (Figure 6-2). A substantial portion of this accrued forest land is from the conversion of abandoned croplands to forest (e.g., Woodall et al. 2015b). Current trends in the forest land area in the conterminous U.S. and southeast and south central coastal Alaska represented here show an average annual rate of increase of 0.1 percent. In addition to the increase in forest area, the major influences to the net C flux from forest land across the 1990 to 2014 time series are management activities and the ongoing impacts of previous land-use conversions. These activities affect the net flux of C by altering the amount of C stored in forest ecosystems and also the area converted to forest land. For example, intensified management of forests that leads to an increased rate of

[27] The Natural Resources Inventory of the USDA Natural Resources Conservation Service is described in the Section 6.1—Representation of the U.S. Land Base.

growth of aboveground biomass (and possible changes to the other C pools) may increase the eventual biomass density of the forest, thereby increasing the uptake and storage of C in the aboveground biomass pool.[28] Though harvesting forests removes much of the C in aboveground biomass (and possibly changes C density in other pools), on average, the estimated volume of annual net growth in the conterminous U.S. states is about double the volume of annual removals on timberlands (Oswalt et al. 2014). The net effects of forest management and changes in *Forest Land Remaining Forest Land* are captured in the estimates of C stocks and fluxes presented in this section.

Figure 6-2: Changes in Forest Area by Region for *Forest Land Remaining Forest Land* in the conterminous United States and coastal Alaska (1990-2014, Million Hectares)



Forest Carbon Stocks and Stock Change

In the United States, improved forest management practices, the regeneration of forest areas cleared more than 20 years prior to the reporting year, and timber harvesting and use have resulted in net uptake (i.e., net sequestration) of C each year from 1990 through 2014. The rate of forest clearing in the 17th century following European settlement

[28] The term "biomass density" refers to the mass of live vegetation per unit area. It is usually measured on a dry-weight basis. Dry biomass is assumed to be 50 percent C by weight.

had slowed by the late 19th century. Through the later part of the 20th century many areas of previously forested in the United States were allowed to revert to forests or were actively reforested. The impacts of these land-use changes still influence C fluxes from these forest lands. More recently, the 1970s and 1980s saw a resurgence of federally-sponsored forest management programs (e.g., the Forestry Incentive Program) and soil conservation programs (e.g., the Conservation Reserve Program), which have focused on tree planting, improving timber management activities, combating soil erosion, and converting marginal cropland to forests. In addition to forest regeneration and management, forest harvests have also affected net C fluxes. Because most of the timber harvested from U.S. forest land is used in wood products, and many discarded wood products are disposed of in SWDS rather than by incineration, significant quantities of C in harvested wood are transferred to these long-term storage pools rather than being released rapidly to the atmosphere (Skog 2008). The size of the stocks in these long-term C storage pools has increased during the last century with the question arising as to how long U.S. forest land can remain a net C sink (Coulston et al. 2015; Wear and Coulston 2015). Changes in C stocks in the forest and harvested wood pools associated with *Forest Land Remaining Forest Land* were estimated to account for net sequestration of 742.3 MMT CO_2 Eq. (202.5 MMT C) in 2014 (Table 6-10 and Table 6-11). Overall, estimates of average C density in forest ecosystems (including all pools) remained stable at approximately 0.0003 MMT C ha^{-1} from 1990 to 2014 (Table 6-11 and Table 6-12). The stable forest ecosystem C density when combined with increasing forest area results in net C accumulation over time. Management practices that increase C stocks on forest land, as well as legacy effects of afforestation and reforestation efforts, influence the trends of increased C densities in forests and increased forest land area in the United States (Woodall et al. 2015b). These increases may be influenced in some regions by reductions in C density or forest land area due to natural disturbances (e.g., wildfire, weather, insects/disease). Aboveground live biomass accounted for the majority of net sequestration among all forest ecosystem pools (Figure 6-4).

The estimated net sequestration of C in HWP was 112.3 MMT CO_2 Eq. (30.6 MMT C) in 2014 (Table 6-10 and Table 6-11). The majority of this sequestration, 69.5 MMT CO_2 Eq. (19.0 MMT C) was from wood and paper in SWDS. Products in use accounted for an estimated 42.7 MMT CO_2 Eq. (11.7 MMT C) in 2014.

Table 6-10: Net CO_2 Flux from Forest Pools in *Forest Land Remaining Forest Land* and Harvested Wood Pools. (MMT CO_2 Eq.)

Carbon Pool	1990		2005		2010	2011	2012	2013	2014
Forest	**(598.8)**		**(584.3)**		**(647.2)**	**(637.8)**	**(632.4)**	**(631.2)**	**(630.1)**
Aboveground	(312.4)		(310.3)		(331.2)	(329.4)	(324.6)	(323.5)	(322.5)
Belowground	(66.6)		(65.7)		(69.6)	(69.3)	(68.2)	(67.9)	(67.6)
Dead Wood	(34.8)		(44.0)		(50.2)	(52.9)	(53.7)	(53.9)	(54.2)
Litter	(35.9)		(28.5)		(34.5)	(33.9)	(33.1)	(32.9)	(32.7)
Soil Organic C	(149.2)		(135.8)		(161.7)	(152.4)	(152.8)	(152.9)	(153.1)
Harvested Wood	**(124.7)**		**(107.6)**		**(94.8)**	**(98.9)**	**(103.4)**	**(107.9)**	**(112.3)**
Products in Use	(55.6)		(44.2)		(30.4)	(33.1)	(36.4)	(39.6)	(42.7)
SWDS	(69.1)		(63.4)		(64.5)	(65.8)	(67.1)	(68.3)	(69.5)
Total Net Flux	**(723.5)**		**(691.9)**		**(742.0)**	**(736.7)**	**(735.8)**	**(739.1)**	**(742.3)**

Note: Forest C stocks do not include forest stocks in U.S. Territories, Hawaii, a portion of managed forests in Alaska, or trees on non-forest land (e.g., urban trees, agroforestry systems). Parentheses indicate net C sequestration (i.e., a net removal of C from the atmosphere). Total net flux is an estimate of the actual net flux between the total forest C pool and the atmosphere. Harvested wood estimates are based on results from annual surveys and models. Totals may not sum due to independent rounding.

Table 6-11: Net C Flux from Forest Pools in *Forest Land Remaining Forest Land* and Harvested Wood Pools (MMT C)

Carbon Pool	1990		2005		2010	2011	2012	2013	2014
Forest	**(163.3)**		**(159.3)**		**(176.5)**	**(173.9)**	**(172.5)**	**(172.2)**	**(171.8)**
Aboveground Biomass	(85.2)		(84.6)		(90.3)	(89.8)	(88.5)	(88.2)	(88.0)
Belowground Biomass	(18.2)		(17.9)		(19.0)	(18.9)	(18.6)	(18.5)	(18.4)
Dead Wood	(9.5)		(12.0)		(13.7)	(14.4)	(14.6)	(14.7)	(14.8)
Litter	(9.8)		(7.8)		(9.4)	(9.3)	(9.0)	(9.0)	(8.9)
Soil Organic C	(40.7)		(37.0)		(44.1)	(41.6)	(41.7)	(41.7)	(41.7)

Harvested Wood	**(34.0)**		**(29.3)**		**(25.9)**	**(27.0)**	**(28.2)**	**(29.4)**	**(30.6)**
Products in Use	(15.2)		(12.1)		(8.3)	(9.0)	(9.9)	(10.8)	(11.7)
SWDS	(18.8)		(17.3)		(17.6)	(17.9)	(18.3)	(18.6)	(19.0)
Total Net Flux	**(197.3)**		**(188.7)**		**(202.4)**	**(200.9)**	**(200.7)**	**(201.6)**	**(202.5)**

Note: Forest C stocks do not include forest stocks in U.S. Territories, Hawaii, a portion of managed lands in Alaska, or trees on non-forest land (e.g., urban trees, agroforestry systems). Parentheses indicate net C sequestration (i.e., a net removal of C from the atmosphere). Total net flux is an estimate of the actual net flux between the total forest C pool and the atmosphere. Harvested wood estimates are based on results from annual surveys and models. Totals may not sum due to independent rounding.

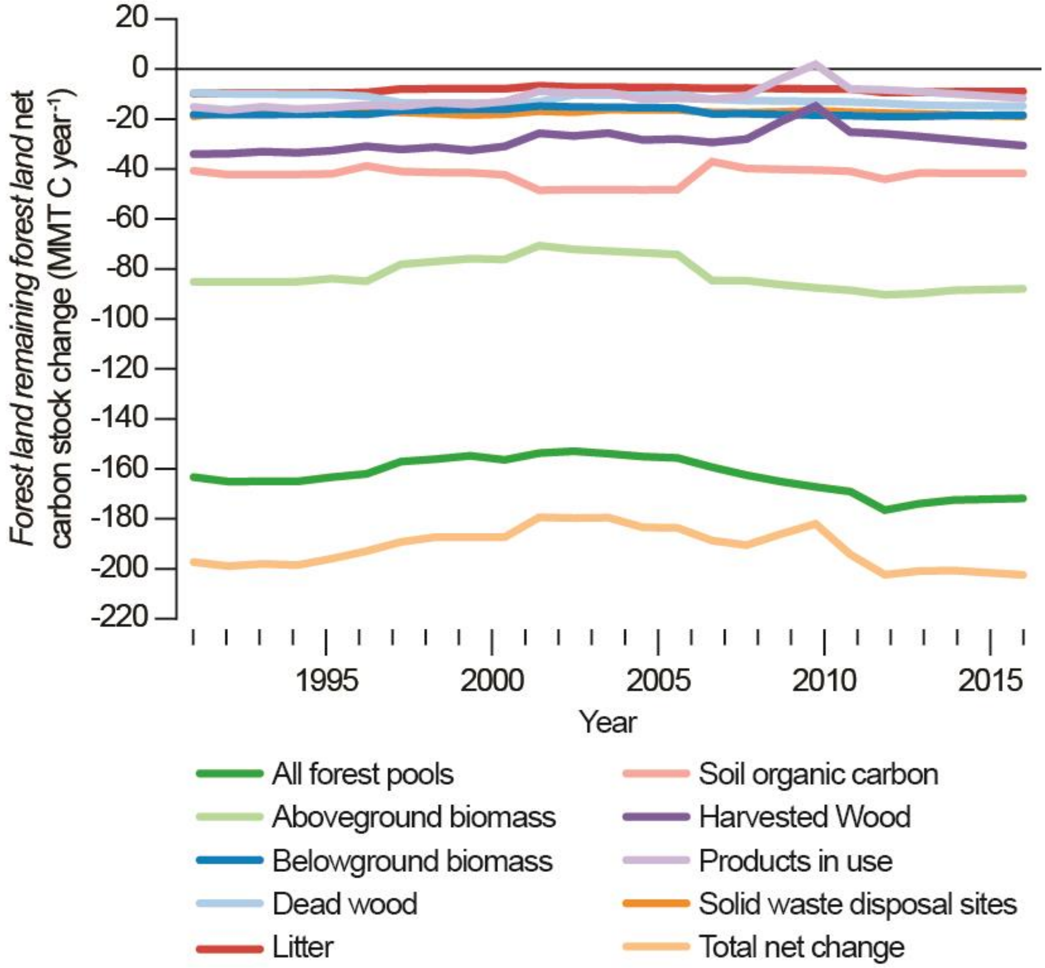
Stock estimates for forest and harvested wood C storage pools are presented in Table 6-12. Together, the estimated aboveground biomass and soil C pools account for a large proportion of total forest C stocks. Note that the forest land area estimates in Table 6-12 do not precisely match those in Section 6.1 Representation of the U.S. Land Base for *Forest Land Remaining Forest Land*. This is because the forest land area estimates in Table 6-12 only include managed forest land in the conterminous 48 states and southeast and south central coastal Alaska (which is the current area encompassed by FIA survey data, approximately 6.2 million ha) while the estimates in Section 6.1 include all managed forest land in Alaska (approximately 28.0 million ha as part of interior Alaska).

Table 6-12: Forest Area (1,000 ha) and C Stocks in *Forest Land Remaining Forest Land* and Harvested Wood Pools (MMT C)

	1990		2005		2010	2011	2012	2013	2014	2015
Forest Area (1000 ha)	*261,796*		*268,029*		*270,065*	*270,462*	*270,871*	*271,871*	*271,719*	*272,158*
Carbon Pools (MMT C)										
Forest	**84,891**		**87,271**		**88,094**	**88,271**	**88,445**	**88,617**	**88,789**	**88,961**
Aboveground Biomass	11,896		13,076		13,508	13,598	13,688	13,777	13,865	13,953
Belowground Biomass	2,442		2,691		2,782	2,801	2,820	2,839	2,857	2,876
Dead Wood	2,404		2,574		2,637	2,651	2,665	2,680	2,695	2,710
Litter	5,833		5,958		5,997	6,006	6,016	6,025	6,034	6,042
Soil Organic C	62,316		62,972		63,170	63,214	63,255	63,297	63,339	63,381
Harvested Wood	**1,897**		**2,356**		**2,474**	**2,500**	**2,527**	**2,555**	**2,584**	**2,615**
Products in Use	1,250		1,449		1,482	1,490	1,499	1,509	1,520	1,531
SWDS	647		906		992	1,010	1,028	1,046	1,065	1,084
Total C Stock	**86,788**		**89,627**		**90,568**	**90,771**	**90,972**	**91,172**	**91,374**	**91,576**

Note: Forest area and C stock estimates include all *Forest Land Remaining Forest Land* in the conterminous 48 states and southeast and south central coastal Alaska (6.2 million ha), which is the current area encompassed by FIA survey data. Forest C stocks do not include forest stocks in U.S. Territories, Hawaii, a large portion of interior Alaska (28.0 million ha), or trees on non-forest land (e.g., urban trees, agroforestry systems). The forest area estimates in this table do not match those Section 6.1 Representation of the U.S. Land Base, which includes all managed forest land in Alaska. Harvested wood product stocks include exports, even if the logs are processed in other countries, and exclude imports. Harvested wood estimates are based on results from annual surveys and models. Totals may not sum due to independent rounding. Inventories are assumed to represent stocks as of January 1 of the Inventory year. Flux is the net annual change in stock. Thus, an estimate of flux for 2014 requires estimates of C stocks for 2014 and 2015.

Figure 6-3: Estimated Net Annual Changes in C Stocks for Major C Pools in Forest Land Remaining Forest Land in the Conterminous U.S. and Coastal Alaska (MMT C year^{-1})



Box 6-3: CO_2 Emissions from Forest Fires

As stated previously, the forest inventory approach implicitly accounts for all C losses due to disturbances such as forest fires, because only C remaining in the forest is estimated. Net C stock change is estimated by subtracting consecutive C stock estimates. A forest fire disturbance removes C from the forest. The inventory data on which net C stock estimates are based already reflect this C loss. Therefore, estimates of net annual changes in C stocks for U.S. forest land already account for CO_2 emissions from forest fires occurring in the conterminous states as well as the portion of managed forest lands in Alaska that are captured in this Inventory. Because it is of interest to quantify the magnitude of CO_2 emissions from fire disturbance, these separate estimates are highlighted here. Note that these CO_2 estimates are based on the same methodology as applied for the non-CO_2 greenhouse gas emissions from forest fires that are also quantified in a separate section below as required by IPCC Guidance and UNFCCC Reporting Requirements.

The IPCC (2006) methodology and a combination of U.S.-specific data on annual area burned and potential fuel availability together with default combustion factors were employed to estimate CO_2 emissions from forest fires. CO_2 emissions for wildfires in the conterminous 48 states and in Alaska as well as prescribed fires in 2014 were estimated to be 92.3 MMT CO_2 year^{-1} (Table 6-13). Most of this quantity is an embedded component of the net annual forest C stock change estimates provided previously (e.g., Table 6-11), but this separate approach to estimate emissions is necessary in order to associate a portion of emissions, including estimates of CH_4 and N_2O, with fire. See the discussion in Annex 3.13 for more details on this methodology. Note that the estimates for Alaska provided in Table 6-13 include all managed forest land in the state and are not limited to the subset with permanent inventory plots on managed lands as specified elsewhere in this chapter (e.g., Table 6-11).

Table 6-13: Estimates of CO_2 (MMT year^{-1}) Emissions from Forest Fires in the Conterminous 48 States and Alaska[a]

Year	CO_2 emitted from Wildfires in the Conterminous 48 States (MMT yr^{-1})	CO_2 emitted from Wildfires in Alaska (MMTyr^{-1})	CO_2 emitted from Prescribed Fires (MMTyr^{-1})	Total CO_2 emitted (MMTyr^{-1})
1990	21.3	19.5	0.2	40.9
2005	42.9	80.7	1.3	124.9
2010	12.2	11.2	18.4	41.7
2011	73.9	3.5	5.9	83.3
2012	133.7	2.7	2.9	139.3
2013	64.7	22.3	5.3	92.3
2014[b]	64.7	22.3	5.3	92.3

[a] These emissions have already been accounted for in the estimates of net annual changes in C stocks, which account for the amount sequestered minus any emissions, including the assumption that combusted wood may continue to decay through time.

[b] The data for 2014 were incomplete when these estimates were summarized; therefore 2013, the most recent available estimate, is applied to 2014.

Methodology and Data Sources

The methodology described herein is consistent with IPCC (2006). Forest ecosystem C stocks and net annual C stock change were determined according to the stock-difference method, which involved applying C estimation factors to annual forest inventories across time to obtain C stocks and then subtracting between the years to obtain the stock change. Harvested wood C estimates were based on factors such as the allocation of wood to various primary and end-use products as well as half-life (the time at which half of the amount placed in use will have been discarded from use) and expected disposition (e.g., product pool, SWDS, combustion). An overview of the different methodologies and data sources used to estimate the C in forest ecosystems or harvested wood products is provided here. See Annex 3.13 for details and additional information related to the methods and data.

Forest Ecosystem Carbon from Forest Inventory

The U.S. used a different accounting approach (Woodall et al. 2015a) for this Inventory than what was used in previous submissions that removes the older, often inconsistent inventory information from the accounting procedures and enables the delineation of forest C accumulation by forest growth, land use change, and natural disturbances such as fire. Development will continue on a system that attributes changes in forest C to disturbances and delineates *Land Converted to Forest Land* from *Forest Land Remaining Forest Land*. As part of this development, C pool science will continue and will be expanded to include C stock transfers from forest land to other land uses, and include techniques to better identify land use change (see the Planned Improvements section below).

Unfortunately, the annual inventory system does not extend into the 1990s, necessitating the adoption of a system to "backcast" the annual C estimates. To facilitate the backcasting of the U.S. annual forest inventory C estimates, the accounting framework used in this Inventory is comprised of a forest dynamics module (age transition matrices) and a land use dynamics module (land area transition matrices). 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 C stock transfers associated with afforestation and deforestation (e.g., Woodall et al. 2015b). Both modules are developed from land use area statistics and C stock change or C stock transfer by age class. The required inputs are estimated from more than 625,000 forest and nonforest observations in the FIA national database (U.S. Forest Service 2015a, b, c). Model predictions for before the annual inventory period are constructed from the accounting framework using the annual observations. The accounting approach used this year is fundamentally driven by the annual forest inventory system conducted by the FIA program (Frayer and Furnival 1999; Bechtold and Patterson 2005; USDA Forest Service 2015d, 2015a). The FIA program relies on a rotating panel statistical design with a sampling intensity of one 674.5 m^2 ground plot per 2,403 ha of land and water area. A five-panel design, with 20 percent of the field plots typically measured each year within a state, is used in the eastern United States and a ten-panel design, with 10 percent of the field plots measured each year within a state, is used in the western United States. The interpenetrating hexagonal design across the U.S. landscape enables the sampling of plots at various intensities in a spatially and temporally unbiased manner. Typically, tree and site attributes are measured with higher sample intensity while other ecosystem attributes such as downed dead wood are sampled during summer months at lower intensities. The first step in incorporating FIA data into the framework was to identify annual inventory datasets by state. Inventories include data collected on permanent inventory plots on forest lands and were organized as separate datasets, each representing a complete inventory, or survey, of an individual state at a specified time. Many of the annual inventories reported for states are represented as "moving window" averages, which mean that a portion—but not all—of the previous year's inventory is updated each year (USDA Forest Service 2015d). Forest C calculations are organized according to these state surveys, and the frequency of surveys varies by state.

Using this FIA data, separate estimates were prepared for the five C storage pools identified by IPCC (2006) and described above. All estimates were based on data collected from the extensive array of permanent, annual forest inventory plots and associated models (e.g., live tree belowground biomass) in the U.S. (USDA Forest Service 2015b, 2015c). Carbon conversion factors were applied at the disaggregated level of each inventory plot and then appropriately expanded to population estimates. Tier 3 methods, as outlined by IPCC (2006), were used for the five reporting pools.

Carbon in Biomass

Live tree C pools include aboveground and belowground (coarse root) biomass of live trees with diameter at breast height (dbh) of at least 2.54 cm at 1.37 m above the forest floor. Separate estimates were made for above- and belowground biomass components. If inventory plots included data on individual trees, tree C was based on Woodall et al. (2011a), which is also known as the component ratio method (CRM), and is a function of volume, species, and diameter. An additional component of foliage, which was not explicitly included in Woodall et al. (2011a), was added to each tree following the same CRM method.

Understory vegetation is a minor component of biomass, which is defined as all biomass of undergrowth plants in a forest, including woody shrubs and trees less than 2.54 cm dbh. For this Inventory, it was assumed that 10 percent of total understory C mass is belowground (Smith et al. 2006). Estimates of C density were based on information in Birdsey (1996) and biomass estimates from Jenkins et al. (2003). Understory biomass represented over one percent of C in biomass, but its contribution rarely exceeded 2 percent of the total.

Carbon in Dead Organic Matter

Dead organic matter was initially calculated as three separate pools—standing dead trees, downed dead wood, and litter—with C stocks estimated from sample data or from models. The standing dead tree C pool includes aboveground and belowground (coarse root) biomass for trees of at least 12.7 cm dbh. Calculations followed the basic method applied to live trees (Woodall et al. 2011a) with additional modifications to account for decay and structural loss (Domke et al. 2011; Harmon et al. 2011). Downed dead wood estimates are based on measurement of a subset of FIA plots for downed dead wood (Domke et al. 2013; Woodall and Monleon 2008; Woodall et al. 2013). Downed dead wood is defined as pieces of dead wood greater than 7.5 cm diameter, at transect intersection, that are not attached to live or standing dead trees. This includes stumps and roots of harvested trees. To facilitate the downscaling of downed dead wood C estimates from the state-wide population estimates to individual plots, downed dead wood models specific to regions and forest types within each region are used. Litter C is the pool of organic C (also known as duff, humus, and fine woody debris) above the mineral soil and includes woody fragments with diameters of up to 7.5 cm. A subset of FIA plots are measured for litter C. A modeling approach, using litter C measurements from FIA plots (Domke et al. 2016) was used to estimate litter C for every FIA plot used in the accounting framework.

Carbon in Forest Soil

Soil organic carbon (SOC) is the largest terrestrial C sink, and management of this pool is a critical component of efforts to mitigate atmospheric C concentrations. SOC also affects essential biological, chemical, and physical soil functions such as nutrient cycling, water retention, and soil structure (Jandl et al. 2014). Much of the SOC on earth is found in forest ecosystems and is thought to be relatively stable. However, there is growing evidence that SOC is sensitive to global change effects, particularly land use histories, resource management, and climate. In the U.S., SOC in forests is monitored the FIA program (O'Neill et al. 2005). In previous C inventory submissions, SOC predictions were based, in part, on a model using the State Soil Geographic (STATSGO) database compiled by the Natural Resources Conservation Service (NRCS) (Amichev and Glabraith 2004). Estimates of forest SOC found in the STATSGO database may be based on expert opinion rather than actual measurements. The FIA program has been consistently measuring soil attributes as part of the annual inventory since 2001 and has amassed an extensive inventory of SOC measurement data on forest land in the conterminous U.S. and coastal Alaska (O'Neill et al. 2005). More than 5,000 profile observations of SOC on forest land from FIA and the International Soil Carbon Monitoring Network were used to develop and implement an approach that enabled the prediction of soil C to a depth of 100 cm from empirical measurements to a depth of 20 cm and included site-, stand-, and climate-specific variables that yield predictions of SOC stocks and stock changes specific to forest land in the United States (Domke et al. In prep). Note that SOC is reported to a depth of 100 cm for Forest Land Remaining Forest Land to remain consistent with past reporting, however for consistency across land-use categories it is reported to a depth of 30 cm in Section 6.3 *Land Converted to Forest Land*.

Harvested Wood Carbon

Estimates of the HWP contribution to forest C sinks and emissions (hereafter called "HWP Contribution") were based on methods described in Skog (2008) using the WOODCARB II model and the U.S. forest products module (Ince et al. 2011). These methods are based on IPCC (2006) guidance for estimating the HWP contribution. IPCC (2006) provides methods that allow for reporting of HWP contribution using one of several different accounting approaches: Production, stock change and atmospheric flow, as well as a default method that assumes there is no change in HWP C stocks (see Annex 3.13 for more details about each approach). The U.S. used the production accounting approach to report HWP Contribution. Under the production approach, C in exported wood was estimated as if it remains in the United States, and C in imported wood was not included in the estimates. Annual estimates of change were calculated by tracking the additions to and removals from the pool of products held in end uses (i.e., products in use such as housing or publications) and the pool of products held in SWDS. Emissions from HWP associated with wood biomass energy are not included in this accounting—a net of zero sequestration and emissions as they are a part of energy accounting (see Chapter 3).

Solidwood products added to pools include lumber and panels. End-use categories for solidwood include single and multifamily housing, alteration and repair of housing, and other end-uses. There is one product category and one end-use category for paper. Additions to and removals from pools were tracked beginning in 1900, with the exception that additions of softwood lumber to housing began in 1800. Solidwood and paper product production and trade data were taken from USDA Forest Service and other sources (Hair and Ulrich 1963; Hair 1958; USDC Bureau of Census 1976; Ulrich 1985, 1989; Steer 1948; AF&PA 2006a, 2006b; Howard 2003, 2007, forthcoming). Estimates for disposal of products reflected the change over time in the fraction of products discarded to SWDS (as opposed to burning or recycling) and the fraction of SWDS that were in sanitary landfills versus dumps.

The annual HWP variables that were used to estimate HWP contribution using the production approach are:

(1) annual change of C in wood and paper products in use in the U.S. and other countries where the wood came from trees harvested in the United States, and

(2) annual change of C in wood and paper products in SWDS in the U.S. and other countries where the wood came from trees harvested in the United States

The sum of these variables yield estimates for HWP contribution under the production accounting approach.

Uncertainty and Time-Series Consistency

A quantitative uncertainty analysis placed bounds on current flux for forest ecosystems through a combination of sample-based and model-based approaches to uncertainty for forest ecosystem CO_2 flux (IPCC Approach 1). A

Monte Carlo Stochastic Simulation of the Methods described above and probabilistic sampling of C conversion factors were used to determine the HWP uncertainty (IPCC Approach 2). See Annex 3.13 for additional information. The 2014 net annual change for forest C stocks was estimated to be between -1,018.4 and -465.7 MMT CO_2 Eq. around a central estimate of -742.3 MMT CO_2 Eq. at a 95 percent confidence level. This includes a range of -905.0 to -355.1 MMT CO_2 Eq. around a central estimate of -630.1 MMT CO_2 Eq. for forest ecosystems and -136.8 to -82.2 MMT CO_2 Eq. around a central estimate of -112.3 for HWP.

Table 6-14: Quantitative Uncertainty Estimates for Net CO_2 Flux from *Forest Land Remaining Forest Land*: Changes in Forest C Stocks (MMT CO_2 Eq. and Percent)

Source	Gas	2014 Flux Estimate (MMT CO_2 Eq.)	Uncertainty Range Relative to Flux Estimate (MMT CO_2 Eq.)		(%)	
			Lower Bound	**Upper Bound**	**Lower Bound**	**Upper Bound**
Forest C Pools[a]	CO_2	(630.1)	(905.0)	(355.1)	-43.6%	43.6%
Harvested Wood Products[b]	CO_2	(112.3)	(136.8)	(82.2)	-21.9%	26.8%
Total Forest	**CO_2**	**(742.3)**	**(1,018.4)**	**(465.7)**	**-37.2%**	**37.3%**

[a] Range of flux estimates predicted through a combination of sample based and model based uncertainty for a 95 percent confidence interval, IPCC Approach 1.

[b] Range of flux estimates predicted by Monte Carlo stochastic simulation for a 95 percent confidence interval, IPCC Approach 2.

Note: Parentheses indicate negative values or net sequestration.

Methodological recalculations were applied to the entire time-series to ensure time-series consistency from 1990 through 2014. Details on the emission trends through time are described in more detail in the Methodology section, above.

QA/QC and Verification

As discussed above, the FIA program has conducted consistent forest surveys based on extensive statistically-based sampling of most of the forest land in the conterminous United States, dating back to 1952. The FIA program includes numerous quality assurance and quality control (QA/QC) procedures, including calibration among field crews, duplicate surveys of some plots, and systematic checking of recorded data. Because of the statistically-based sampling, the large number of survey plots, and the quality of the data, the survey databases developed by the FIA program form a strong foundation for C stock estimates. Field sampling protocols, summary data, and detailed inventory databases are archived and are publicly available on the Internet (USDA Forest Service 2015d).

General quality control procedures were used in performing calculations to estimate C stocks based on survey data. For example, the C datasets, which include inventory variables such as areas and volumes, were compared to standard inventory summaries such as the forest resource statistics of Oswalt et al. (2014) or selected population estimates generated from FIADB 6.0, which are available at an FIA internet site (USDA Forest Service 2015b). Agreement between the C datasets and the original inventories is important to verify accuracy of the data used. Finally, C stock estimates were compared with previous Inventory report estimates to ensure that any differences could be explained by either new data or revised calculation methods (see the Recalculations discussion, below).

Estimates of the HWP variables and the HWP contribution under the production accounting approach use data from U.S. Census and USDA Forest Service surveys of production and trade. Factors to convert wood and paper to units of C are based on estimates by industry and Forest Service published sources. The WOODCARB II model uses estimation methods suggested by IPCC (2006). Estimates of annual C change in solidwood and paper products in use were calibrated to meet two independent criteria. The first criterion is that the WOODCARB II model estimate of C in houses standing in 2001 needs to match an independent estimate of C in housing based on U.S. Census and USDA Forest Service survey data. Meeting the first criterion resulted in an estimated half-life of about 80 years for single family housing built in the 1920s, which is confirmed by other U.S. Census data on housing. The second criterion is that the WOODCARB II model estimate of wood and paper being discarded to SWDS needs to match EPA estimates of discards used in the Waste sector each year over the period 1990 to 2000 (EPA 2006). These criteria help reduce uncertainty in estimates of annual change in C in products in use in the United States and, to a lesser degree, reduce uncertainty in estimates of annual change in C in products made from wood harvested in the United States. In addition, WOODCARB II landfill decay rates have been validated by ensuring that estimates of

CH_4 emissions from landfills based on EPA (2006) data are reasonable in comparison to CH_4 estimates based on WOODCARB II landfill decay rates.

Recalculations Discussion

Forest ecosystem stock and stock-change estimates differ from the previous Inventory report principally due to the adoption of a new accounting framework (Woodall et al. 2015a). The major differences between the framework used this year and past accounting approaches is the sole use of annual FIA data and the back-casting of forest C stocks across the 1990s based on forest C stock density and land use change information obtained from the nationally consistent annual forest inventory coupled with in situ observations of non-tree C pools such as soils, dead wood, and litter. The use of this accounting framework has enabled the creation of the two land use sections for forest C stocks: *Forest Land Remaining Forest Land* and *Land Converted to Forest Land*. In prior submissions (e.g., the 1990 through 2013 Inventory submission), the C stock changes from *Land Converted to Forest Land* were a part of the *Forest Land Remaining Forest Land* section and it was not possible to disaggregate the estimates. A second major change was the adoption of a new approach to estimate forest soil C, the largest C stock in the U.S. For detailed discussion of these new approaches please refer to the Methodology section, Annex 3.13, Domke et al. (In prep), and Woodall et al. (2015a). In addition to these major changes, the refined land representation analysis described in Section 6.1 Representation of the U.S. Land Base which identifies some of the forest land in south central and southeastern coastal Alaska as unmanaged; this is in contrast to past assumptions of "managed" land for these forest lands included in the FIA database. Therefore, the C stock and flux estimates for southeast and south central coastal Alaska, as included here, reflect that adjustment, which effectively reduces the managed forest area by approximately 5 percent.

In addition to the creation of explicit estimates of removals and emissions by *Forest Land Remaining Forest Land* versus *Land Converted to Forest Land*, the accounting framework used this year eliminated the use of periodic data (which may be inconsistent with annual inventory data) which contributed to a data artifact in prior estimates of emissions/removals from 1990 to the present. In the previous Inventory report, there was a reduction in net sequestration from 1995 to 2000 followed by an increase in net sequestration from 2000 to 2004. This artifact of comparing inconsistent inventories of the 1980s through 1990s to the nationally consistent inventories of the 2000s has been removed in this Inventory.

Estimated annual net additions to HWP C stocks increased slightly between 2014 and 2015. Estimated net additions to solidwood products in use slightly increased due to a further recovery of the housing market. Estimated net additions to products in use for 2014 are about 20 percent of the level of net additions to products in use in 2006, i.e., prior to the recession. The decline in net additions to HWP C stocks continued through 2008 from the recent high point in 2005. This is due to sharp declines in U.S. production of solidwood and paper products in 2007 and 2008 primarily due to the decline in housing construction. The low level of gross additions to solidwood and paper products in use in 2007 and 2008 were exceeded by discards from uses. The result is a net reduction in the amount of HWP C that is held in products in use during this time period. For 2008, emissions from landfills exceeded additions to landfills. That said, following the recent recession the net additions to landfills have returned to normal levels. Overall, there were net C additions to HWP in use and in SWDS combined due, in large part, to updated data on products in use from 2010 to the present.

Planned Improvements

Reliable estimates of forest C across the diverse ecosystems of the U.S. require a high level of investment in both annual monitoring and associated analytical techniques. Development of improved monitoring/reporting techniques is a continuous process that occurs simultaneously with annual Inventory submissions. Planned improvements can be broadly assigned to the following categories: development of a robust accounting system, individual C pool estimation, coordination with other land-use categories, and annual inventory data incorporation.

As this is the first report to delineate C change by *Forest Land Remaining Forest Land* and *Land Converted to Forest Land*, there are many improvements necessary. Since the accounting approach used this year operates at the regional scale for the United States, research will occur to leverage auxiliary information (i.e., remotely sensed information) to operate at finer scales in future accounting approaches. As in past submissions, deforestation is implicitly included in the report given the annual forest inventory system but not explicitly estimated. Carbon dioxide, CH_4 and N_2O emissions from forest lands with drained organic soils were not included in this Inventory.

We will apply the latest guidance in the Wetlands Supplement (IPCC 2014) by including CO_2, CH_4 and N_2O emissions from forest lands with drained organic soils in future submissions. The transparency and repeatability of accounting systems will be increased through the dissemination of open source code (e.g., R programming language) in concert with the public availability of the annual forest inventory data (USDA 2015b). Also, several FIA database processes will be institutionalized to increase efficiency and QA/QC in reporting and further improve transparency, consistency, and availability of data used in reporting. Finally, a Tier 1 approach was used to estimate uncertainty associated with C stock changes in the *Forest Land Remaining Forest Land* category in this report. There is research underway investigating more robust approaches to total uncertainty (Woodall et al. 2015a) which will be considered in future Inventory reports.

In the current Inventory, the approach to estimating the soil C pool was refined by incorporating a national inventory of SOC (O'Neil et al. 2005) in combination with auxiliary soil, site, and climate information (Domke et al. In prep). The modeling framework used to estimate downed dead wood within the dead wood C pool will be updated similar to the litter (Domke et al. 2016) and soil C pools (Domke et al. In prep). Finally, components of other pools, such as C in belowground biomass (Russell et al. 2015) and understory vegetation (Russell et al. 2014), are being explored but may require additional investment in field inventories before improvements can be realized with Inventory submissions.

The foundation of forest C accounting is the annual forest inventory system. The ongoing annual surveys by the FIA program are expected to improve the accuracy and precision of forest C estimates as new state surveys become available (USDA Forest Service 2015b), particularly in western states. Hawaii and U.S. Territories will be included when appropriate forest C data are available (as of July 21, 2015, Hawaii is not yet reporting any data from the annualized sampling design). Forest lands in interior Alaska (AK) are not yet included in this report as an annual inventory has never been conducted in this remote region. A pilot study of an efficient method for inventorying forest C stocks in interior AK (Woodall et al. 2015) has been conducted with results still being evaluated. Although an annual forest inventory of interior AK may be implemented in the 2016 field season, alternative methods of estimating C stock change will need to be explored as it may take over a decade to re-measure newly established plots in the 2016 field season. To that end, research is underway to incorporate all FIA plot information (both annual and periodic data) and the Landsat and MODIS time-series (along with other remotely sensed data) in a design-based, model-assisted format for estimating GHG emissions and removals as well as change detection across the entire reporting period and all managed forest land in the United States. Leveraging this auxiliary information will aid not only the interior AK effort but the entire inventory system. In addition to fully inventorying all managed forest land in the United States, the more intensive sampling of fine woody debris, litter, and SOC on a subset of FIA plots continues and will substantially improve resolution of C pools (i.e., greater sample intensity; Westfall et al. 2013) as this information becomes available (Woodall et al. 2011b). Increased sample intensity of some C pools and using annualized sampling data as it becomes available for those states currently not reporting are planned for future submissions. The FIA sampling frame extends beyond the forest land use category (e.g., woodlands and urban areas) with inventory-relevant information for these lands which will likely become increasingly available in coming years.

Non-CO_2 Emissions from Forest Fires

Emissions of non-CO_2 gases from forest fires were estimated using U.S.-specific data for annual area of forest burned and potential fuel availability as well as the default IPCC (2006) emissions and combustion factors applied to the IPCC methodology. Emissions from this source in 2014 were estimated to be 7.3 MMT CO_2 Eq. of CH_4 and 4.8 MMT CO_2 Eq. of N_2O (Table 6-15, kt units available in Table 6-16). The estimates of non-CO_2 emissions from forest fires account for wildfires in the conterminous 48 states and Alaska as well as prescribed fires.

Table 6-15: Estimated Non-CO_2 Emissions from Forest Fires (MMT CO_2 Eq.) for U.S. Forests

Gas	1990		2005		2010	2011	2012	2013	2014[a]
CH_4	3.3		9.9		3.3	6.6	11.1	7.3	7.3
N_2O	2.2		6.5		2.2	4.4	7.3	4.8	4.8
Total	**5.4**		**16.5**		**5.4**	**11.0**	**18.3**	**12.2**	**12.2**

[a] The data for 2014 were incomplete when these estimates were summarized; therefore 2013, the most recent available estimate, is applied to 2014.

Table 6-16: Estimated Non-CO_2 Emissions from Forest Fires (kt) for U.S. Forests

Gas	1990		2005		2010	2011	2012	2013	2014[a]
CH_4	131		397		131	265	443	294	294
N_2O	7		22		7	15	24	16	16
CO	2,792		8,515		2,845	5,683	9,499	6,298	6,298
NO_x	78		239		80	159	266	177	177

[a] The data for 2014 were incomplete when these estimates were summarized; therefore 2013, the most recent available estimate, is applied to 2014.

Methodology

Non-CO_2 emissions from forest fires—specifically for CH_4 and N_2O emissions—were calculated following IPCC (2006) methodology, which included a combination of U.S. specific data on area burned and potential fuel available for combustion along with IPCC default combustion and emission factors. The estimates were calculated according to model 2.27 of IPCC (2006, Volume 4, Chapter 2), which in general terms is:

$$\text{Emissions} = \text{Area burned} \times \text{Fuel available} \times \text{Combustion factor} \times \text{Emission factor} \times 10^{-3}$$

where area burned is based on Monitoring Trends in Burn Severity (MTBS) data summaries (MTBS 2015), fuel estimates are based on current carbon density estimates obtained from the latest FIA data for each state, and combustion and emission factors are from IPCC (2006, Volume 4, Chapter 2). See Annex 3.13 for further details.

Uncertainty and Time-Series Consistency

In order to quantify the uncertainties for non-CO_2 emissions from forest fires calculated as described above, a Monte Carlo (IPCC Approach 2) sampling approach was employed to propagate uncertainty in the model as it was applied for U.S. forest land. See IPCC (2006) and Annex 3.13 for the quantities and assumptions employed to define and propagate uncertainty. The results of the Approach 2 quantitative uncertainty analysis are summarized in Table 6-17.

Table 6-17: Quantitative Uncertainty Estimates of Non-CO_2 Emissions from Forest Fires in *Forest Land Remaining Forest Land* (MMT CO_2 Eq. and Percent)

Source	Gas	2014 Emission Estimate (MMT CO_2 Eq.)	Uncertainty Range Relative to Emission Estimate[a] (MMT CO_2 Eq.)		(%)	
			Lower Bound	Upper Bound	Lower Bound	Upper Bound
Non-CO_2 Emissions from Forest Fires	CH_4	7.3	1.0	20.1	−86%	+174%
Non-CO_2 Emissions from Forest Fires	N_2O	4.8	1.2	12.4	−76%	+157%

[a] Range of flux estimates predicted by Monte Carlo Stochastic Simulation for a 95 percent confidence interval.

Methodological recalculations were applied to the entire time-series to ensure time-series consistency from 1990 through 2014. Details on the emission trends through time are described in more detail in the Methodology section, above.

QA/QC and Verification

Tier 1 and Tier 2 QA/QC activities were conducted consistent with the U.S. QA/QC plan. Source-specific quality control measures for forest fires included checking input data, documentation, and calculations to ensure data were properly handled through the Inventory process. Further, the set of fire emissions estimates using MODIS imagery and post-fire observations developed for Alaska by Veraverbeke et al. (2015) (Table A-16) were used to compare with the estimates of CO_2 and C emissions from forest fires in Alaska (Table 6-13 and A-14). The alternate sources of data for annual areas burned and possible fuel availability were found to be similar to the data in use here. The QA/QC analysis did not reveal any inaccuracies or incorrect input values.

Recalculations Discussion

The current non-CO_2 emissions estimates are based on the calculation described above and in IPCC (2006), which is a very similar approach to the basic calculation of previous Inventory reports. However, some of the data summarized and applied to the calculation are very different for the current Inventory. The use of the MTBS data summaries is the most prominent example. Annual burned areas on managed forest lands were identified according to Ruefenacht et al. (2008) and Ogle et al. (In preparation). The other change with the current Inventory estimates is in the use of the underlying plot level carbon densities based on forest inventory plots. Although the base data are similar to past years, the current uncertainty estimates are based on an assumption that plot-to-plot variability is a greater influence on uncertainty than the uncertainty in the forest-inventory to C conversion factors (as employed for uncertainty in the past). See Annex 3.13 for additional details.

Planned Improvements

Possible future improvements within the context of this same IPCC (2006) methodology are most likely to involve greater specificity by fire or groups of fires and less reliance on wide regional values or IPCC defaults. Spatially relating potential fuel to more localized forest structure is the best example of this. An additional improvement would be combustion factors more locally appropriate for the type, location, and intensity of fire, which are currently unused information provided with the MTBS data summaries. All planned improvements depend on future availability of appropriate U.S.-specific data.

N_2O Fluxes from Forest Soils (IPCC Source Category 4A1)

Of the synthetic nitrogen (N) fertilizers applied to soils in the United States, no more than one percent is applied to forest soils. Application rates are similar to those occurring on cropland soils, but in any given year, only a small proportion of total forested land receives N fertilizer. This is because forests are typically fertilized only twice during their approximately 40-year growth cycle (once at planting and once midway through their life cycle). While the rate of N fertilizer application for the area of forests that receives N fertilizer in any given year is relatively high, the annual application rate is quite low over the entire forestland area.

N additions to soils result in direct and indirect N_2O emissions. Direct emissions occur on-site due to the N additions. Indirect emissions result from fertilizer N that is transformed and transported to another location in a form other than N_2O (ammonia [NH_3] and nitrogen oxide [NO_x] volatilization, nitrogen trioxide [NO_3] leaching and runoff), and later converted into N_2O at the off-site location. The indirect emissions are assigned to forest land because the management activity leading to the emissions occurred in forest land.

Direct N_2O emissions from forest soils in 2014 were 0.3 MMT CO_2 Eq. (1 kt), and the indirect emissions were 0.1 MMT CO_2 Eq. (0.4 kt). Total emissions for 2014 were 0.5 MMT CO_2 Eq. (2 kt) and have increased by 455 percent from 1990 to 2014. Increasing emissions over the time series is a result of greater area of N fertilized pine plantations in the southeastern United States and Douglas-fir timberland in western Washington and Oregon. Total forest soil N_2O emissions are summarized in Table 6-18.

Table 6-18: N_2O Fluxes from Soils in *Forest Land Remaining Forest Land* (MMT CO_2 Eq. and kt N_2O)

	1990	2005	2010	2011	2012	2013	2014
Direct N_2O Fluxes from Soils							
MMT CO_2 Eq.	0.1	0.3	0.3	0.3	0.3	0.3	0.3
kt N_2O	+	1	1	1	1	1	1
Indirect N_2O Fluxes from Soils							
MMT CO_2 Eq.	0.0	0.1	0.1	0.1	0.1	0.1	0.1
kt N_2O	+	+	+	+	+	+	+
Total							
MMT CO_2 Eq.	**0.1**	**0.5**	**0.5**	**0.5**	**0.5**	**0.5**	**0.5**
kt N_2O	**+**	**2**	**2**	**2**	**2**	**2**	**2**

+ Does not exceed 0.05 MMT CO_2 Eq. or 0.5 kt.
Note: Totals may not sum due to independent rounding.

Methodology

The IPCC Tier 1 approach is used to estimate N_2O from soils within *Forest Land Remaining Forest Land*. According to U.S. Forest Service statistics for 1996 (USDA Forest Service 2001), approximately 75 percent of trees planted are for timber, and about 60 percent of national total harvested forest area is in the southeastern United States. Although southeastern pine plantations represent the majority of fertilized forests in the United States, this Inventory also accounted for N fertilizer application to commercial Douglas-fir stands in western Oregon and Washington. For the Southeast, estimates of direct N_2O emissions from fertilizer applications to forests are based on the area of pine plantations receiving fertilizer in the southeastern United States and estimated application rates (Albaugh et al. 2007; Fox et al. 2007). Not accounting for fertilizer applied to non-pine plantations is justified because fertilization is routine for pine forests but rare for hardwoods (Binkley et al. 1995). For each year, the area of pine receiving N fertilizer is multiplied by the weighted average of the reported range of N fertilization rates (121 lbs. N per acre). Area data for pine plantations receiving fertilizer in the Southeast are not available for 2005 through 2014, so data from 2004 are used for these years. For commercial forests in Oregon and Washington, only fertilizer applied to Douglas-fir is addressed in the inventory because the vast majority (approximately 95 percent) of the total fertilizer applied to forests in this region is applied to Douglas-fir (Briggs 2007). Estimates of total Douglas-fir area and the portion of fertilized area are multiplied to obtain annual area estimates of fertilized Douglas-fir stands. Similar to the Southeast, data are not available for 2005 through 2014, so data from 2004 are used for these years. The annual area estimates are multiplied by the typical rate used in this region (200 lbs. N per acre) to estimate total N applied (Briggs 2007), and the total N applied to forests is multiplied by the IPCC (2006) default emission factor of one percent to estimate direct N_2O emissions.

For indirect emissions, the volatilization and leaching/runoff N fractions for forest land are calculated using the IPCC default factors of 10 percent and 30 percent, respectively. The amount of N volatilized is multiplied by the IPCC default factor of one percent for the portion of volatilized N that is converted to N_2O off-site. The amount of N leached/runoff is multiplied by the IPCC default factor of 0.075 percent for the portion of leached/runoff N that is converted to N_2O off-site The resulting estimates are summed to obtain total indirect emissions.

Uncertainty and Time-Series Consistency

The amount of N_2O emitted from forests depends not only on N inputs and fertilized area, but also on a large number of variables, including organic C availability, oxygen gas partial pressure, soil moisture content, pH, temperature, and tree planting/harvesting cycles. The effect of the combined interaction of these variables on N_2O flux is complex and highly uncertain. IPCC (2006) does not incorporate any of these variables into the default methodology, except variation in estimated fertilizer application rates and estimated areas of forested land receiving N fertilizer. All forest soils are treated equivalently under this methodology. Furthermore, only synthetic N fertilizers are captured, so applications of organic N fertilizers are not estimated. However, the total quantity of organic N inputs to soils is included in Section 5.4 Agricultural Soil Management and Section 6.10 Settlements Remaining Settlements.

Uncertainties exist in the fertilization rates, annual area of forest lands receiving fertilizer, and the emission factors. Fertilization rates are assigned a default level[29] of uncertainty at ±50 percent, and area receiving fertilizer is assigned a ±20 percent according to expert knowledge (Binkley 2004). The uncertainty ranges around the 2005 activity data and emission factor input variables are directly applied to the 2014 emission estimates. IPCC (2006) provided estimates for the uncertainty associated with direct and indirect N_2O emission factor for synthetic N fertilizer application to soils.

Uncertainty is quantified using simple error propagation methods (IPCC 2006). The results of the quantitative uncertainty analysis are summarized in Table 6-19. Direct N_2O fluxes from soils in 2014 are estimated to be between 0.1 and 1.1 MMT CO_2 Eq. at a 95 percent confidence level. This indicates a range of 59 percent below and 211 percent above the 2014 emission estimate of 0.3 MMT CO_2 Eq. Indirect N_2O emissions in 2014 are between 0.02 and 0.4 MMT CO_2 Eq., ranging from 86 percent below to 238 percent above the 2014 emission estimate of 0.1 MMT CO_2 Eq.

[29] Uncertainty is unknown for the fertilization rates so a conservative value of ±50 percent is used in the analysis.

Table 6-19: Quantitative Uncertainty Estimates of N_2O Fluxes from Soils in *Forest Land Remaining Forest Land* (MMT CO_2 Eq. and Percent)

Source	Gas	2014 Emission Estimate (MMT CO_2 Eq.)	Uncertainty Range Relative to Emission Estimate (MMT CO_2 Eq.)		(%)	
Forest Land Remaining Forest Land			Lower Bound	Upper Bound	Lower Bound	Upper Bound
Direct N_2O Fluxes from Soils	N_2O	0.3	0.1	1.1	-59%	+211%
Indirect N_2O Fluxes from Soils	N_2O	0.1	+	0.4	-86%	+238%

+ Does not exceed 0.05 MMT CO_2 Eq.

Note: These estimates include direct and indirect N_2O emissions from N fertilizer additions to both *Forest Land Remaining Forest Land* and *Land Converted to Forest Land*.

Methodological recalculations were applied to the entire time series to ensure time-series consistency from 1990 through 2014. Details on the emission trends through time are described in more detail in the Methodology section, above.

QA/QC and Verification

The spreadsheet tab containing fertilizer applied to forests and calculations for N_2O and uncertainty ranges are checked and verified.

Planned Improvements

Additional data will be compiled to update estimates of forest areas receiving N fertilizer as new reports are made available. Another improvement is to further disaggregate emissions by state for southeastern pine plantations and northwestern Douglas-fir forests to estimate soil N_2O emission. This improvement is contingent on the availability of state-level N fertilization data for forest land.

6.3 Land Converted to Forest Land (IPCC Source Category 4A2)

The C stock change estimates for *Land Converted to Forest Land* that are provided in this section include all forest land in an inventory year that had been in another land use(s) during the previous 20 years[30] (USDA NRCS 2009). For example, cropland or grassland converted to forest land during the past 20 years would be reported in this category. Recently-converted lands are in this category for 20 years as recommended in the *2006 IPCC Guidelines* (IPCC 2006). It is also important to note that the accounting framework used this year to develop estimates of C stock change for *Forest Land Remaining Forest Land* and intended to be used for *Land Converted to Forest Land* was not fully developed for this Inventory and therefore only estimates of C stock changes from mineral soils are included in *Land Converted to Forest Land* following Ogle et al (2003, 2006) and IPCC (2006). Carbon stock changes for the other pools (i.e., aboveground and belowground biomass, dead wood, and litter), as recommended for inclusion by IPCC (2006) are not included for the *Land Converted to Forest Land* category in this Inventory, but research is underway to include these IPCC pools in subsequent submissions of the Inventory. This was due, in part, for a need to more thoroughly quantify the length of time that land remains in a conversion category after a change in land use and also because the accounting framework was not fully developed in time to estimate C stocks and

[30] The 2009 USDA National Resources Inventory (NRI) land-use survey points were classified according to land-use history records starting in 1982 when the NRI survey began. Consequently the classifications from 1990 to 2001 were based on less than 20 years.

stock changes for the IPCC pools over the default 20-year conversion period in the *Land Converted to Forest Land* category.

Area of Land Converted to Forest in the United States

The annual conversion of land from other land-use categories (i.e., Cropland, Grassland, Wetlands, Settlements, and Other Lands) to forest land resulted in a fairly continuous net annual accretion of forest land area from 1990 to the present at an approximate rate of 1 million ha year^{-1}. The rate of forest clearing in the 17th century following European settlement had slowed by the late 19th century. Through the later part of the 20th century, many areas of previously converted forested land in the United States were allowed to revert to forests or were actively reforested (Birdsey et al. 2006). The impacts of these land-use changes still influence C fluxes from these forest lands (land-use change legacy effects, Woodall et al. 2015b). More recently, the 1970s and 1980s saw a resurgence of federally-sponsored forest management programs (e.g., the Forestry Incentive Program) and soil conservation programs (e.g., the Conservation Reserve Program), which have focused on tree planting, improving timber management activities, combating soil erosion, and converting marginal cropland to forests. Recent analyses suggest that net accumulation of forest area continues in areas of the United States, in particular the northeastern United States (Woodall et al. 2015b).

The conversion of grassland to forest land resulted in the largest source of soil C sequestration (accounting for approximately 68 percent of the sequestration in the category in 2014), though gains have decreased over the time series which is the result of less conversion into the forest land category in recent years (see Table 6-20). The net flux of C from the mineral soil stock changes in 2014 was -0.3 MMT CO_2 Eq. (-0.1 MMT C) (Table 6-20 and Table 6-21). Note that soil carbon has historically been reported to a depth of 100 cm in the *Forest Land Remaining Forest Land* category (Domke et al. In preparation) while other land-use categories report soil carbon to a depth of 20 or 30 cm. To ensure consistency in the *Land Converted to Forest Land* category where C stock transfers occur between land-use categories, all soil estimates are based on methods from Ogle et al. (2003, 2006) and IPCC (2006).

Table 6-20: Net CO_2 Flux from Soil C Stock Changes in *Land Converted to Forest Land* by Land Use Change Category (MMT CO_2 Eq.)

Soil Type	1990		2005		2010	2011	2012	2013	2014
Cropland Converted to Forest Land									
Mineral Soil	(0.2)		(0.2)		(0.1)	(0.1)	(0.1)	(0.1)	(0.1)
Grassland Converted to Forest Land									
Mineral Soil	(0.4)		(0.5)		(0.3)	(0.2)	(0.2)	(0.2)	(0.2)
Other Land Converted to Forest Land									
Mineral Soil	(0.1)		(0.1)		+	+	+	+	+
Settlements Converted to Forest Land									
Mineral Soil	+		+		+	+	+	+	+
Wetlands Converted to Forest Land									
Mineral Soil	+		+		+	+	+	+	+
Total Mineral Soil Flux	**(0.7)**		**(0.8)**		**(0.4)**	**(0.4)**	**(0.4)**	**(0.3)**	**(0.3)**
Total Soil Flux	**(0.7)**		**(0.8)**		**(0.4)**	**(0.4)**	**(0.4)**	**(0.3)**	**(0.3)**

\+ Absolute value does not exceed 0.05 MMT CO_2 Eq.
Notes: Totals may not sum due to independent rounding. Parentheses indicate net sequestration.

Table 6-21: Net C Flux from Soil C Stock Changes in Land Converted to Forest Land by Land Use Change Category (MMT C)

Soil Type	1990		2005		2010	2011	2012	2013	2014
Cropland Converted to Forest Land									
Mineral Soil	+		(0.1)		+	+	+	+	+
Grassland Converted to Forest Land									
Mineral Soil	(0.1)		(0.1)		(0.1)	(0.1)	(0.1)	(0.1)	(0.1)
Other Land Converted to Forest Land									
Mineral Soil	+		+		+	+	+	+	+
Settlements Converted to Forest Land									

Mineral Soil	+	+	+	+	+	+	+
Wetlands Converted to Forest Land							
Mineral Soil	+	+	+	+	+	+	+
Total Mineral Soil Flux	**(0.2)**	**(0.2)**	**(0.1)**	**(0.1)**	**(0.1)**	**(0.1)**	**(0.1)**
Total Soil Flux	**(0.2)**	**(0.2)**	**(0.1)**	**(0.1)**	**(0.1)**	**(0.1)**	**(0.1)**

+ Absolute value does not exceed 0.05 MMT C.

Notes: Totals may not sum due to independent rounding. Parentheses indicate net sequestration.

Methodology

The following section includes a description of the methodology used to estimate changes in mineral soil C stocks for *Land Converted to Forest Land*. Carbon stock changes for the other pools (i.e., aboveground and belowground biomass, dead wood, and litter), as recommended for inclusion by IPCC (2006) for each land use and land use conversion category are not included in this Inventory. This was due, in part, for a need to more thoroughly quantify the length of time that land remains in a conversion category after a change in land use and also because the accounting framework was not developed in time to estimate C stocks and stock changes for the IPCC pools in the *Land Converted to Forest Land* category over the default 20-year conversion period. Improvements are underway to include all C pool estimates in future inventories.

Mineral Soil Carbon Stock Changes

A Tier 2 method is applied to estimate soil C stock changes for *Land Converted to Forest Land* (Ogle et al. 2003, 2006; IPCC 2006). For this method, land is stratified by climate, soil types, land use, and land management activity, and then assigned reference carbon levels and factors for the forest land and the previous land use. The difference between the stocks is reported as the stock change under the assumption that the change occurs over 20 years. Reference C stocks have been estimated from data in the National Soil Survey Characterization Database (USDA-NRCS 1997), and U.S.-specific stock change factors have been derived from published literature (Ogle et al. 2003, 2006). Land use and land use change patterns are determined from a combination of the Forest Inventory and Analysis Dataset (FIA), the 2010 National Resources Inventory (NRI) (USDA-NRCS 2013), and National Land Cover Dataset (NLCD) (Homer et al. 2007). See Annex 3.12 for more information about this method (Methodology for Estimating N_2O Emissions, CH_4 Emissions and Soil Organic C Stock Changes from Agricultural Soil Management).

Uncertainty and Time-Series Consistency

Uncertainty estimates for mineral soil C stock changes were developed using the same methodologies as described for the Tier 2 component of the mineral soils in *Cropland Remaining Cropland*.

Uncertainty estimates are presented in Table 6-22 for each land conversion category. Uncertainty estimates were obtained using a Monte Carlo approach. Uncertainty estimates were combined using the error propagation model in accordance with IPCC (2006). The combined uncertainty for soil C stocks in *Land Converted to Forest Land* ranged from 70 percent below to 67 percent above the 2014 stock change estimate of -0.3 MMT CO_2 Eq.

Table 6-22: Quantitative Uncertainty Estimates for Mineral Soil C Stock Changes (MMT CO2 Eq. per yr) in 2014 Occurring Within *Land Converted to Forest Land*

Source	2014 Flux Estimate (MMT CO_2 Eq.)	Uncertainty Range Relative to Flux Range[a] (MMT CO_2 Eq.)		(%)	
		Lower Bound	Upper Bound	Lower Bound	Upper Bound
Cropland Converted to Forest Land					
Mineral Soils Tier 2	(0.1)	(0.1)	+	-99%	94%
Grassland Converted to Forest Land					
Mineral Soils Tier 2	(0.2)	(0.5)	+	-99%	94%
Other Lands Converted to Forest Land					
Mineral Soils Tier 2	+	(0.1)	+	-99%	94%

Settlements Converted to Forest Land					
Mineral Soils Tier 2	+	+	+	-99%	94%
Wetlands Converted to Forest Land					
Mineral Soils Tier 2	+	+	+	-99%	94%
Total: Lands Converted to Forest Lands	**(0.3)**	**(0.6)**	**(0.1)**	**-70%**	**67%**

+ Does not exceed 0.05 MMT CO_2 Eq.
[a] Range of flux estimate for 95 percent confidence interval
Note: Parentheses indicate net sequestration.

Uncertainty is also associated with lack of reporting of biomass, litter and dead wood C stock changes in this category. The accumulation of biomass, litter and dead wood in this category may have led to substantial changes in the biomass, litter and dead wood C stocks in some regions of the U.S. These stock changes will be included in future submissions (see Planned Improvements below).

Methodological recalculations were applied to the entire time-series to ensure time-series consistency from 1990 through 2014. Details on the emission trends through time are described in more detail in the Methodology section, above.

QA/QC and Verification

See QA/QC and Verification section under *Cropland Remaining Cropland.*

Recalculations Discussion

This is the first U.S. submission to include a *Land Converted to Forest Land* section containing specific soil C stock change estimates. In prior submissions (e.g., EPA 2015), the C stock changes from *Land Converted to Forest Land* were a part of the *Forest Land Remaining Forest Land* estimates. As such, no recalculations were conducted for this chapter in this year's submission. See the Recalculations section in *Forest Land Remaining Forest Land* for a detailed explanation on overall changes resulting from implementing a different accounting approach in the current Inventory report.

Planned Improvements

A different accounting framework (Woodall et al. 2015a) was used for the forest land category in this report with the specific intent of separating *Forest Land Remaining Forest Land* and *Land Converted to Forest Land*. While this new approach led to improvements (e.g., disaggregation of forest land area between the land-use categories), there are many improvements still necessary to fully incorporate all C pool estimates and all land-use categories over the entire time series. First, research, in coordination with the other land-use categories, into the length of time that forest land remains in the *Land Converted to Forest Land* category will be undertaken and a mechanism to account for emissions and removals for all IPCC pools in this conversion category will be developed. Second, soil carbon has historically been reported to a depth of 100 cm in the *Forest Land Remaining Forest Land* category (Domke et al. In preparation) while other land-use categories (e.g., Grasslands and Croplands) report soil carbon to a depth of 20 or 30 cm. To ensure consistency in the *Land Converted to Forest Land* category where C stock transfers occur between land-use categories, all mineral soil estimates in the *Land Converted to Forest Land* category in this Inventory are based on methods from Ogle et al. (2003, 2006) and IPCC (2006). Methods have recently been developed (Domke et al. In prep) to estimate soil carbon to depths of 20, 30, and 100 cm the in Forest Land category using in situ measurements from the Forest Inventory and Analysis program within the USDA Forest Service and the International Soil Carbon Network. In subsequent Inventories, a common reporting depth will be defined for all land conversion categories and Domke et al. (In preparation) will be used in the *Forest Land Remaining Forest Land* and *Land Converted to Forest Land* categories to ensure consistent accounting across all forest land. Third, only estimates of mineral soil C are included in the *Land Converted to Forest Land* category this year. This led to an incomplete Inventory since the other IPCC pools were not included. In subsequent reports, all IPCC pools will be included in the *Land Converted to Forest Land* category. This will require coordination between land-use categories to ensure incorporation of country-specific or IPCC Tier 1 estimates for all IPCC C pools to ensure complete and consistent accounting between land-use categories.

6.4 Cropland Remaining Cropland (IPCC Source Category 4B1)

Mineral and Organic Soil Carbon Stock Changes

Carbon (C) in cropland ecosystems occurs in biomass, dead organic matter, and soils. However, C storage in cropland biomass and dead organic matter is relatively ephemeral, with the exception of C stored in perennial woody crop biomass, such as citrus groves and apple orchards. Within soils, C is found in organic and inorganic forms of C, but soil organic C (SOC) is the main source and sink for atmospheric CO_2 in most soils. IPCC (2006) recommends reporting changes in SOC stocks due to agricultural land-use and management activities on both mineral and organic soils.[31]

Well-drained mineral soils typically contain from 1 to 6 percent organic C by weight, whereas mineral soils with high water tables for substantial periods during the year may contain significantly more C (NRCS 1999). Conversion of mineral soils from their native state to agricultural land uses can cause up to half of the SOC to be lost to the atmosphere due to enhanced microbial decomposition. The rate and ultimate magnitude of C loss depends on subsequent management practices, climate and soil type (Ogle et al. 2005). Agricultural practices, such as clearing, drainage, tillage, planting, grazing, crop residue management, fertilization, and flooding, can modify both organic matter inputs and decomposition, and thereby result in a net C stock change (Parton et al. 1987; Paustian et al. 1997a; Conant et al. 2001; Ogle et al. 2005). Eventually, the soil can reach a new equilibrium that reflects a balance between C inputs (e.g., decayed plant matter, roots, and organic amendments such as manure and crop residues) and C loss through microbial decomposition of organic matter (Paustian et al. 1997b).

Organic soils, also referred to as *Histosols*, include all soils with more than 12 to 20 percent organic C by weight, depending on clay content (NRCS 1999; Brady and Weil 1999). The organic layer of these soils can be very deep (i.e., several meters), and form under inundated conditions that results in minimal decomposition of plant residues. When organic soils are prepared for crop production, they are drained and tilled, leading to aeration of the soil that accelerates both the decomposition rate and CO_2 emissions.[32] Due to the depth and richness of the organic layers, C loss from drained organic soils can continue over long periods of time, which varies depending on climate and composition (i.e., decomposability) of the organic matter (Armentano and Menges 1986). Due to deeper drainage and more intensive management practices, the use of organic soils for annual crop production (and also settlements) leads to higher C loss rates than drainage of organic soils in grassland or forests (IPCC 2006).

Cropland Remaining Cropland includes all cropland in an Inventory year that has been used as cropland for the previous 20 years according to the 2010 United States Department of Agriculture (USDA) National Resources Inventory (NRI) land-use survey for non-federal lands (USDA-NRCS 2013) and according to the National Land Cover Dataset for federal lands (Homer et al. 2007; Fry et al. 2011; Homer et al. 2015). Cropland includes all land used to produce food and fiber, in addition to forage that is harvested and used as feed (e.g., hay and silage), and cropland that has been enrolled in the Conservation Reserve Program (CRP) (i.e., considered reserve cropland). Cropland in Alaska is not included in the Inventory, but is a relatively small amount of U.S. cropland area (approximately 28,700 hectares). Some miscellaneous croplands are also not included in the Inventory due to limited understanding of greenhouse gas emissions from these management systems (e.g., aquaculture). This leads to a small discrepancy between the total amount of managed area in *Cropland Remaining Cropland* (see Section 6.1 Representation of the U.S. Land Base) and the cropland area included in the Inventory analysis (0.5 to 0.7 million hectares or 0.02 percent of the total cropland areas in the United States between 1990 and 2014). Improvements are underway to include croplands in Alaska and other miscellaneous cropland areas as part of future C inventories.

[31] Carbon dioxide emissions associated with liming are also estimated but are included in a separate section of the report.

[32] Note: N_2O emissions from soils are included in the Agricultural Soil Management section.

Carbon dioxide emissions and removals[33] due to changes in mineral soil C stocks are estimated using a Tier 3 Approach for the majority of annual crops (Ogle et al. 2010). A Tier 2 IPCC method is used for the remaining crops not included in the Tier 3 method (see Methodology section for a list of crops in the Tier 2 and 3 methods) (Ogle et al. 2003, 2006). In addition, a Tier 2 method is used for very gravelly, cobbly, or shaley soils (i.e., classified as soils that have greater than 35 percent of soil volume comprised of gravel, cobbles, or shale) regardless of crop, and for additional changes in mineral soil C stocks that are not addressed with the Tier 3 approach (i.e., change in C stocks after 2010 due to CRP enrollment). Emissions from organic soils are estimated using a Tier 2 IPCC method.

Land-use and land management of mineral soils are the largest contributor to total net C stock change, especially in the early part of the time series (see Table 6-23 and Table 6-24). (Note: Estimates after 2010 are based on NRI data from 2010 and therefore do not fully reflect changes occurring in the latter part of the time series). In 2014, mineral soils are estimated to sequester 36.2 MMT CO_2 Eq. from the atmosphere (9.9 MMT C). This rate of C storage in mineral soils represents about a 42 percent decrease in the rate since the initial reporting year of 1990. CO_2 emissions from organic soils are 27.8 MMT CO_2 Eq. (7.6 MMT C) in 2014, which is a 0.8 percent decrease compared to 1990. In total, United States agricultural soils in *Cropland Remaining Cropland* sequestered approximately 8.4 MMT CO_2 Eq. (2.3 MMT C) in 2014.

Table 6-23: Net CO_2 Flux from Soil C Stock Changes in *Cropland Remaining Cropland* (MMT CO_2 Eq.)

Soil Type	1990		2005		2010	2011	2012	2013	2014
Mineral Soils	(62.3)		(42.8)		(26.0)	(40.3)	(38.9)	(37.0)	(36.2)
Organic Soils	28.0		28.7		27.8	27.8	27.8	27.8	27.8
Total Net Flux	**(34.3)**		**(14.1)**		**1.8**	**(12.5)**	**(11.2)**	**(9.3)**	**(8.4)**

Notes: Estimates after 2010 are based on NRI data from 2010 and therefore may not fully reflect changes occurring in the latter part of the time series. Totals may not sum due to independent rounding. Parentheses indicate net sequestration.

Table 6-24: Net CO_2 Flux from Soil C Stock Changes in *Cropland Remaining Cropland* (MMT C)

Soil Type	1990		2005		2010	2011	2012	2013	2014
Mineral Soils	(17.0)		(11.7)		(7.1)	(11.0)	(10.6)	(10.1)	(9.9)
Organic Soils	7.6		7.8		7.6	7.6	7.6	7.6	7.6
Total Net Flux	**(9.4)**		**(3.8)**		**0.5**	**(3.4)**	**(3.0)**	**(2.5)**	**(2.3)**

Notes: Estimates after 2010 are based on NRI data from 2010 and therefore may not fully reflect changes occurring in the latter part of the time series. Totals may not sum due to independent rounding. Parentheses indicate net sequestration.

The major cause of the reduction in soil C accumulation over the time series (i.e., 2014 is 75 percent less than 1990) is the decline in annual cropland enrolled in the CRP[34] which was initiated in 1985. For example, over 2 million hectares that had been enrolled in the CRP were returned to agricultural production during the last 5 years resulting in a loss of soil C. However, positive increases in C stocks continue on the nearly 10 million hectares of land currently enrolled in the CRP, as well as from intensification of crop production by limiting the use of bare-summer fallow in semi-arid regions, increased hay production, and adoption of conservation tillage (i.e., reduced- and no-till practices).

[33] Note that removals occur through uptake of CO_2 into crop and forage biomass that is later incorporated into soil C pools.

[34] The Conservation Reserve Program (CRP) is a land conservation program administered by the Farm Service Agency (FSA). In exchange for a yearly rental payment, farmers enrolled in the program agree to remove environmentally sensitive land from agricultural production and plant species that will improve environmental health and quality. Contracts for land enrolled in CRP are 10 to 15 years in length. The long-term goal of the program is to re-establish valuable land cover to help improve water quality, prevent soil erosion, and reduce loss of wildlife habitat.

The spatial variability in the 2014 annual C stock changes are displayed in Figure 6-4 and Figure 6-5 for mineral and organic soils, respectively. The highest rates of net C accumulation in mineral soils occurred in the Midwest, which is the region with the largest amounts of conservation tillage, and the next highest rates of C accumulation occur in the South-central and Northwest regions of the United States. The regions with the highest rates of emissions from organic soils occur in the Southeastern Coastal Region (particularly Florida), upper Midwest and Northeast surrounding the Great Lakes, and the Pacific Coast (particularly California), which coincides with the largest concentrations of organic soils in the United States that are used for agricultural production.

Figure 6-4: Total Net Annual CO_2 Flux for Mineral Soils under Agricultural Management within States, 2014, *Cropland Remaining Cropland*

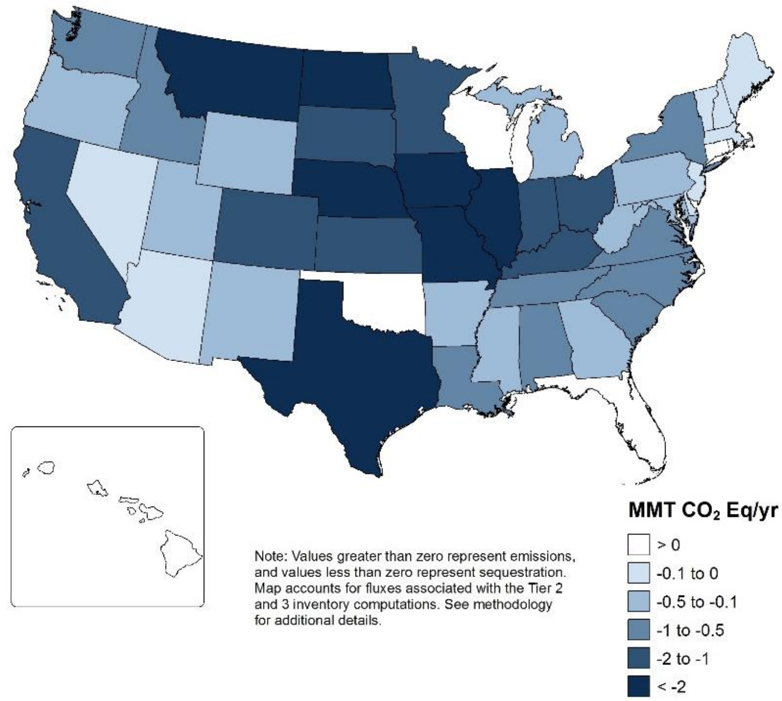
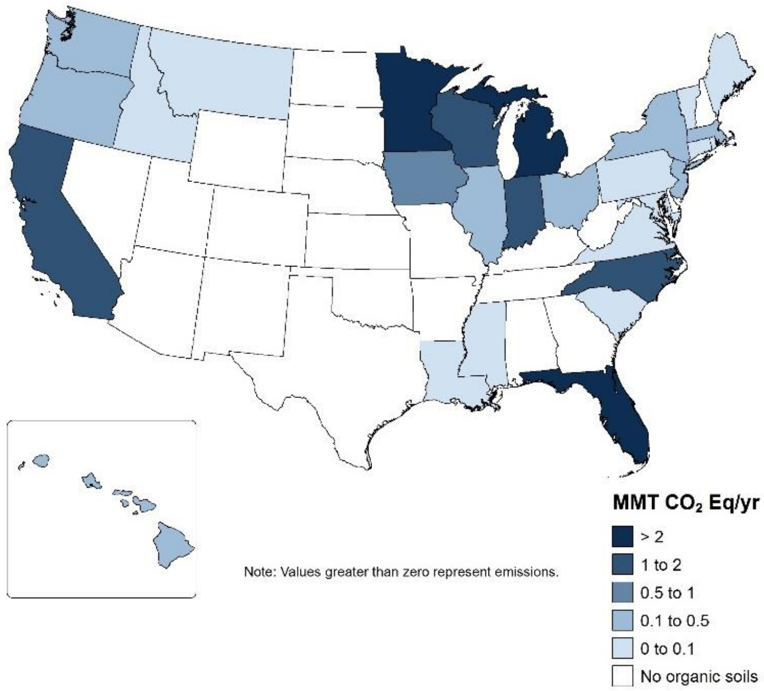


Figure 6-5: Total Net Annual CO_2 Flux for Organic Soils under Agricultural Management within States, 2014, *Cropland Remaining Cropland*



Methodology

The following section includes a description of the methodology used to estimate changes in soil C stocks for *Cropland Remaining Cropland*, including (1) agricultural land-use and management activities on mineral soils; and (2) agricultural land-use and management activities on organic soils.

Soil C stock changes are estimated for *Cropland Remaining Cropland* (as well as agricultural land falling into the IPCC categories *Land Converted to Cropland*, *Grassland Remaining Grassland*, and *Land Converted to Grassland*) according to land-use histories recorded in the USDA NRI survey (USDA-NRCS 2013). The NRI is a statistically-based sample of all non-federal land, and includes approximately 596,787 survey locations in agricultural land for the conterminous United States and Hawaii.[35] Each survey location is associated with an "expansion factor" that allows scaling of C stock changes from NRI survey locations to the entire country (i.e., each expansion factor represents the amount of area with the same land-use/management history as the sample point). Land-use and some management information (e.g., crop type, soil attributes, and irrigation) were collected for each NRI point on a 5-year cycle beginning from 1982 through 1997. For cropland, data had been collected for 4 out of 5 years during each survey cycle (i.e., 1979 through 1982, 1984 through 1987, 1989 through 1992, and 1994 through 1997). In 1998, the NRI program began collecting annual data, and the annual data are currently available through 2012 (USDA-NRCS 2015). However, this Inventory only uses NRI data through 2010 because newer data were not available in time to incorporate the additional years. NRI survey locations are classified as *Cropland Remaining Cropland* in a given year between 1990 and 2010 if the land use had been cropland for a continuous time period of at least 20 years. NRI survey locations are classified according to land-use histories starting in 1979, and consequently the classifications are based on less than 20 years from 1990 to 1998. This may have led to an overestimation of *Cropland Remaining Cropland* in the early part of the time series to the extent that some areas are converted to cropland prior to 1979.

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[35] NRI survey locations are classified as agricultural if under grassland or cropland management between 1990 and 2010.

Mineral Soil Carbon Stock Changes

An IPCC Tier 3 model-based approach (Ogle et al. 2010) is applied to estimate C stock changes for mineral soils on the majority of land that is used to produce annual crops in the United States. These crops include alfalfa hay, barley, corn, cotton, dry beans, grass hay, grass-clover hay, oats, onions, peanuts, potatoes, rice, sorghum, soybeans, sugar beets, sunflowers, tomatoes, and wheat. The model-based approach uses the DAYCENT biogeochemical model (Parton et al. 1998; Del Grosso et al. 2001, 2011) to estimate soil C stock changes and soil nitrous oxide emissions from agricultural soil management. Carbon and N dynamics are linked in plant-soil systems through the biogeochemical processes of microbial decomposition and plant production (McGill and Cole 1981). Coupling the two source categories (i.e., agricultural soil C and N_2O) in a single inventory analysis ensures that there is a consistent treatment of the processes and interactions between C and N cycling in soils.

The remaining crops on mineral soils are estimated using an IPCC Tier 2 method (Ogle et al. 2003), including some vegetables, tobacco, perennial/horticultural crops, and crops that are rotated with these crops. The Tier 2 method is also used for very gravelly, cobbly, or shaley soils (greater than 35 percent by volume), and stock changes on federal croplands are estimated with the Tier 2 method. Mineral SOC stocks are estimated using a Tier 2 method for these areas because the DAYCENT model, which is used for the Tier 3 method, has not been fully tested for estimating C stock changes associated with these crops and rotations, as well as cobbly, gravelly, or shaley soils. In addition, there is insufficient information to simulate croplands on federal lands. The Tier 2 methods is also used to estimate additional stock changes on lands enrolled in CRP after 2010, which is the last year of data in the NRI time series, using aggregated data on CRP enrollment compiled by the USDA Farm Services Agency.

Further elaboration on the methodology and data used to estimate stock changes from mineral soils are described below and in Annex 3.12.

Tier 3 Approach

Mineral SOC stocks and stock changes are estimated using the DAYCENT biogeochemical[36] model (Parton et al. 1998; Del Grosso et al. 2001, 2011), which simulates cycling of C, N and other nutrients in cropland, grassland, forest, and savanna ecosystems. The DAYCENT model utilizes the soil C modeling framework developed in the Century model (Parton et al. 1987, 1988, 1994; Metherell et al. 1993), but has been refined to simulate dynamics at a daily time-step. The modeling approach uses daily weather data as an input, along with information about soil physical properties. Input data on land use and management are specified at a daily resolution and include land-use type, crop/forage type, and management activities (e.g., planting, harvesting, fertilization, manure amendments, tillage, irrigation, residue removal, grazing, and fire). The model simulates net primary productivity (NPP) using the NASA-CASA production algorithm MODIS Enhanced Vegetation Index (EVI) products, MOD13Q1 and MYD13Q1, for most croplands[37] (Potter et al. 1993, 2007). The model also simulates soil temperature, and water dynamics, in addition to turnover, stabilization, and mineralization of soil organic matter C and nutrients (N, P, K, S). This method is more accurate than the Tier 1 and 2 approaches provided by the IPCC (2006) because the simulation model treats changes as continuous over time as opposed to the simplified discrete changes represented in the default method (see Box 6-4 for additional information).

Box 6-4: Tier 3 Approach for Soil C Stocks Compared to Tier 1 or 2 Approaches

A Tier 3 model-based approach is used to estimate soil C stock changes on the majority of agricultural land on mineral soils. This approach results in a more complete and accurate accounting of soil C stock changes and entails several fundamental differences from the IPCC Tier 1 or 2 methods, as described below.

(1) The IPCC Tier 1 and 2 methods are simplified and classify land areas into discrete categories based on highly aggregated information about climate (six regions), soil (seven types), and management (eleven

[36] Biogeochemical cycles are the flow of chemical elements and compounds between living organisms and the physical environment.

[37] NPP is estimated with the NASA-CASA algorithm for most of the cropland that is used to produce major commodity crops in the central United States from 2000 to 2010. Other regions and years prior to 2000 are simulated with a method that incorporates water, temperature and moisture stress on crop production (see Metherell et al. 1993), but does not incorporate the additional information about crop condition provided with remote sensing data.

management systems) in the United States. In contrast, the Tier 3 model incorporates the same variables (i.e., climate, soils, and management systems) with considerably more detail both temporally and spatially, and captures multi-dimensional interactions through the more complex model structure.

(2) The IPCC Tier 1 and 2 methods have a simplified spatial resolution in which data are aggregated to soil types in climate regions, of which there about 30 of combinations in the United States. In contrast, the Tier 3 model simulates soil C dynamics at more than 300,000 individual NRI survey locations in individual fields.

(3) The IPCC Tier 1 and 2 methods use simplified equilibrium step changes for changes in C emissions. In contrast, the Tier 3 approach simulates a continuous time period. More specifically, the DAYCENT model (i.e., daily time-step version of the Century model) simulates soil C dynamics (and CO_2 emissions and uptake) on a daily time step based on C emissions and removals from plant production and decomposition processes. These changes in soil C stocks are influenced by multiple sources that affect primary production and decomposition, including changes in land use and management, weather variability and secondary feedbacks between management activities, climate, and soils.

Historical land-use patterns and irrigation histories are simulated with DAYCENT based on the 2010 USDA NRI survey (USDA-NRCS 2013). Additional sources of activity data are used to supplement the land-use information from the NRI. The Conservation Technology Information Center (CTIC 2004) provided annual data on tillage activity at the county level for the conterminous United States between 1989 and 2004, and these data are adjusted for long-term adoption of no-till agriculture (Towery 2001). Information on fertilizer use and rates by crop type for different regions of the United States are obtained primarily from the USDA Economic Research Service. The data collection program was known as the Cropping Practices Surveys through 1995 (USDA-ERS 1997), and then became the Agricultural Resource Management Surveys (ARMS) (USDA-ERS 2011).[38] Additional data are compiled through other sources particularly the National Agricultural Statistics Service (NASS 1992, 1999, 2004). Frequency and rates of manure application to cropland during 1997 are estimated from data compiled by the USDA Natural Resources Conservation Service (Edmonds et al. 2003), and then adjusted using county-level estimates of manure available for application in other years. Specifically, county-scale ratios of manure available for application to soils in other years relative to 1997 are used to adjust the area amended with manure (see Annex 3.12 for further details). Greater availability of managed manure N relative to 1997 is assumed to increase the area amended with manure, while reduced availability of manure N relative to 1997 is assumed to reduce the amended area. Data on the county-level N available for application are estimated for managed systems based on the total amount of N excreted in manure minus N losses during storage and transport, and include the addition of N from bedding materials. Nitrogen losses include direct N_2O emissions, volatilization of ammonia and NO_x, N runoff and leaching, and the N in poultry manure used as a feed supplement. More information on livestock manure production is available in Section 5.2 - Manure Management and Annex 3.11.

Daily weather data are another input to the model simulations, and these data are based on a 4 kilometer gridded product from the PRISM Climate Group (2015). Soil attributes are obtained from the Soil Survey Geographic Database (SSURGO) (Soil Survey Staff 2015). The C dynamics at each NRI point are simulated 100 times as part of the uncertainty analysis, yielding a total of over 18 million simulation runs for the analysis. Uncertainty in the C stock estimates from DAYCENT associated with parameterization and model algorithms are adjusted using a structural uncertainty estimator accounting for uncertainty in model algorithms and parameter values (Ogle et al. 2007, 2010). Carbon stocks and 95 percent confidence intervals are estimated for each year between 1990 and 2010. C stock changes from 2011 to 2014 are assumed to be similar to 2010 for this Inventory. Future Inventories will be updated with new activity data when the data are made available, and the time series will be recalculated (see Planned Improvements section).

Tier 2 Approach

In the IPCC Tier 2 method, data on climate, soil types, land-use, and land management activity are used to classify land area and apply appropriate stock change factors (Ogle et al. 2003, 2006). Reference C stocks are estimated using the National Soil Survey Characterization Database (NRCS 1997) with cultivated cropland as the reference

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[38] See <http://www.ers.usda.gov/data-products/arms-farm-financial-and-crop-production-practices/arms-data.aspx>.

condition, rather than native vegetation as used in IPCC (2006). Soil measurements under agricultural management are much more common and easily identified in the National Soil Survey Characterization Database (NRCS 1997) than are soils under a native condition, and therefore cultivated cropland provided a more robust sample for estimating the reference condition. U.S.-specific C stock change factors are derived from published literature to determine the impact of management practices on SOC storage (Ogle et al. 2003, Ogle et al. 2006). The factors include changes in tillage, cropping rotations, intensification, and land-use change between cultivated and uncultivated conditions. U.S. factors associated with organic matter amendments are not estimated due to an insufficient number of studies in the United States to analyze the impacts. Instead, factors from IPCC (2006) are used to estimate the effect of those activities.

Climate zones in the United States are classified using mean precipitation and temperature (1950 to 2000) variables from the WorldClim data set (Hijmans et al. 2005) and potential evapotranspiration data from the Consortium for Spatial Information (CGIAR-CSI) (Zomer et al. 2008, 2007) (Figure A-14). IPCC climate zones are then assigned to NRI point locations.

Activity data are primarily based on the historical land-use/management patterns recorded in the 2010 NRI (USDA-NRCS 2013). Each NRI point is classified by land use, soil type, climate region, and management condition. Survey locations on federal lands are included in the NRI, but land use and cropping history are not compiled at these locations in the survey program (i.e., NRI is restricted to data collection on non-federal lands). Land-use patterns at the NRI survey locations on federal lands are based on the National Land Cover Database (NLCD) (Fry et al. 2011; Homer et al. 2007; Homer et al. 2015). Classification of cropland area by tillage practice is based on data from the Conservation Technology Information Center (CTIC 2004; Towery 2001) as described above. Activity data on wetland restoration of Conservation Reserve Program land are obtained from Euliss and Gleason (2002). Manure N amendments over the inventory time period are based on application rates and areas amended with manure N from Edmonds et al. (2003), in addition to the managed manure production data discussed in the methodology subsection for the Tier 3 analysis.

Combining information from these data sources, SOC stocks for mineral soils are estimated 50,000 times for each year in the time series, using a Monte Carlo stochastic simulation approach and probability distribution functions for U.S.-specific stock change factors, reference C stocks, and land-use activity data (Ogle et al. 2002; Ogle et al. 2003; Ogle et al. 2006). The annual C stock changes from 2011 through 2014 for the Tier 2 method is assumed to be similar to 2010 because no additional activity data are available from NRI for these latter years. As with the Tier 3 method, future Inventories will be updated with new activity data when the data are made available, and the time series will be recalculated (see Planned Improvements section).

Additional Mineral C Stock Change

Annual C stock change estimates for mineral soils between 2011 and 2014 are adjusted to account for additional C stock changes associated with gains or losses in soil C after 2010 due to changes in CRP enrollment (USDA-FSA 2014). The change in enrollment relative to 2010 is based on data from USDA-FSA (2014) for 2011 through 2014. The differences in mineral soil areas are multiplied by 0.5 metric tons C per hectare per year to estimate the net effect on soil C stocks. The stock change rate is based on country-specific factors and the IPCC default method (see Annex 3.12 for further discussion).

Organic Soil Carbon Stock Changes

Annual C emissions from drained organic soils in *Cropland Remaining Cropland* are estimated using the Tier 2 method provided in IPCC (2006), with U.S.-specific C loss rates (Ogle et al. 2003) rather than default IPCC rates. The final estimates included a measure of uncertainty as determined from the Monte Carlo Stochastic Simulation with 50,000 iterations. Emissions are based on the annual data for drained organic soils from 1990 to 2010 for *Cropland Remaining Cropland* areas in the 2010 NRI (USDA-NRCS 2013). The annual emissions estimated for 2010 are applied to 2011 through 2014. Future Inventories will be updated with new activity data when the data are made available, and the time series will be recalculated (see Planned Improvements section).

Uncertainty and Time-Series Consistency

Uncertainty associated with the *Cropland Remaining Cropland* land-use category is addressed for changes in agricultural soil C stocks (including both mineral and organic soils). Uncertainty estimates are presented in Table

6-25 for each subsource (mineral soil C stocks and organic soil C stocks) and the method that is used in the Inventory analysis (i.e., Tier 2 and Tier 3). Uncertainty for the Tier 2 and 3 Approaches is derived using a Monte Carlo approach (see Annex 3.12 for further discussion), but the C stock changes from the individual Tier 2 and 3 approaches are combined using the simple error propagation method provided by the IPCC (2006). The combined uncertainty is calculated by taking the square root of the sum of the squares of the standard deviations of the uncertain quantities. The combined uncertainty for soil C stocks in *Cropland Remaining Cropland* ranged from 401 percent below to 414 percent above the 2014 stock change estimate of -8.4 MMT CO_2 Eq.

Table 6-25: Approach 2 Quantitative Uncertainty Estimates for Soil C Stock Changes occurring within *Cropland Remaining Cropland* (MMT CO_2 Eq. and Percent)

Source	2014 Flux Estimate (MMT CO_2 Eq.)	Uncertainty Range Relative to Flux Estimate[a] (MMT CO_2 Eq.)		(%)	
		Lower Bound	Upper Bound	Lower Bound	Upper Bound
Mineral Soil C Stocks: Cropland Remaining Cropland, Tier 3 Inventory Methodology	(36.7)	(69.0)	(4.5)	-88%	+88%
Mineral Soil C Stocks: Cropland Remaining Cropland, Tier 2 Inventory Methodology	(3.2)	(5.2)	(1.5)	-64%	+54%
Mineral Soil C Stocks: Cropland Remaining Cropland (Change in CRP enrollment relative to 2003)	3.7	1.9	5.6	-50%	+50%
Organic Soil C Stocks: Cropland Remaining Cropland, Tier 2 Inventory Methodology	27.8	17.8	41.0	-36%	+48%
Combined Uncertainty for Flux associated with Agricultural Soil Carbon Stock Change in Cropland Remaining Cropland	**(8.4)**	**(42.3)**	**26.5**	**-401%**	**+414%**

[a] Range of C stock change estimates predicted by Monte Carlo Stochastic Simulation for a 95 percent confidence interval.
Notes: Parentheses indicate net sequestration.

Uncertainty is also associated with lack of reporting of agricultural biomass and dead organic matter C stock changes. Biomass C stock changes are likely minor in perennial crops, such as orchards and nut plantations, given the small amount of change in land that is used to produce these commodities in the U.S. In contrast, agroforestry practices, such as shelterbelts, riparian forests and intercropping with trees, may be significantly changing biomass C stocks over the Inventory times series, at least in some regions of the United States, but there are currently no datasets to evaluate the trends. Changes in litter C stocks are also assumed to be negligible in croplands over annual time frames, although there are certainly significant changes at sub-annual time scales across seasons. However, this trend may change in the future, particularly if crop residue becomes a viable feedstock for bioenergy production.

Methodological recalculations were applied to the entire time-series to ensure time-series consistency from 1990 through 2014. Details on the emission trends through time are described in more detail in the Methodology section, above.

QA/QC and Verification

Quality control measures included checking input data, model scripts, and results to ensure data are properly handled throughout the inventory process. Inventory reporting forms and text are reviewed and revised as needed to correct transcription errors. Results from the DAYCENT model are compared to field measurements, and a statistical relationship has been developed to assess uncertainties in the predictive capability of the model. The comparisons included over 80 long-term experiments, representing about 908 combinations of management treatments across all of the sites (see Ogle et al. 2007 and Annex 3.12 for more information). Quality control identified problems with simulation of hydric soils in the equilibrium and base histories, which proceed the simulation of the NRI histories from 1979 to 2010. Hydric soils were draining more quickly than expected in the simulations, and resulted in low values for the carbon stocks at the beginning of the history in 1979. Corrective actions were taken by adjusting the parameters to reduce the drainage rate on hydric soils during the equilibrium and simulate slower decomposition rates with a high water table.

Recalculations Discussion

Methodological recalculations in the current Inventory are associated with the following improvements: 1) incorporation of updated NRI data for 1990 through 2010; 2) inclusion of federal croplands; and 3) improving the simulation of hydric soil. As a result of these improvements, the change in SOC stocks declined by an average of 16.5 MMT CO_2 Eq., which is a 48 percent change in the reported soil C stock changes compared to the previous Inventory. The largest driver of this change is associated with corrective actions taken to more accurately represent the hydric soil condition.

Planned Improvements

Two major planned improvements are underway. The first is to update the time series of land use and management data from the USDA NRI so that it is extended from 2010 through 2012 for both the Tier 2 and 3 methods (USDA-NRCS 2015). Fertilization and tillage activity data will also be updated as part of this improvement. The remote-sensing based data on the Enhanced Vegetation Index will be extended through 2012 in order to use the EVI data to drive crop production in DAYCENT. Overall, this improvement will extend the time series of activity data for the Tier 2 and 3 analyses through 2012.

The second major planned improvement is to analyze C stock changes in Alaska for cropland and managed grassland, using the Tier 2 method for mineral and organic soils that is described earlier in this section. This analysis will initially focus on land use change, which typically has a larger impact on soil C stock changes, but will be further refined over time to incorporate more of the management data.

An improvement is also underway to simulate crop residue burning in the DAYCENT based on the amount of crop residues burned according to the data that is used in the Field Burning of Agricultural Residues source category (Section 5.5). This improvement will more accurately represent the C inputs to the soil that are associated with residue burning. Other improvements are underway to refine the production part of the DAYCENT biogeochemical model. For example, senescence events following grain filling in crops, such as wheat, have been refined based on recent model algorithm development, and will be incorporated into next year's Inventory.

All of these improvements are expected to be completed for the 1990 through 2015 Inventory. However, the time line may be extended if there are insufficient resources to fund all or part of these planned improvements.

CO_2 Emissions from Liming

IPCC (2006) recommends reporting CO_2 emissions from lime additions (in the form of crushed limestone ($CaCO_3$) and dolomite ($CaMg(CO_3)_2$) to soils. Limestone and dolomite are added by land managers to increase soil pH (i.e., to reduce acidification). Carbon dioxide emissions occur as these compounds react with hydrogen ions in soils. The rate and ultimate magnitude of degradation of applied limestone and dolomite depends on the soil conditions, soil type, climate regime, and whether limestone or dolomite is applied. Emissions from liming of soils have fluctuated over the past 24 years, ranging from 3.7 MMT CO_2 Eq. to 6.0 MMT CO_2 Eq. In 2014, liming of soils in the United States resulted in emissions of 4.1 MMT CO_2 Eq. (1.1 MMT C), representing an 11 percent decrease in emissions since 1990 (see Table 6-26 and Table 6-27). The trend is driven by the amount of limestone and dolomite applied to soils over the time period.

Table 6-26: Emissions from Liming (MMT CO_2 Eq.)

Source	1990		2005		2010	2011	2012	2013	2014
Limestone	4.1		3.9		4.3	3.4	4.5	3.6	3.8
Dolomite	0.6		0.4		0.5	0.4	1.5	0.3	0.3
Total[a]	**4.7**		**4.3**		**4.8**	**3.9**	**6.0**	**3.9**	**4.1**

[a] Also includes emissions from liming on *Land Converted to Cropland, Grassland Remaining Grassland, Land Converted to Grassland*, *Settlements Remaining Settlements, Forest Land Remaining Forest Land* and *Land Converted to Forest Land*, as it is not currently possible to apportion the data by land-use category.
Note: Totals may not sum due to independent rounding.

Table 6-27: Emissions from Liming (MMT C)

Source	1990		2005		2010	2011	2012	2013	2014
Limestone	1.1		1.1		1.2	0.9	1.2	1.0	1.0
Dolomite	0.2		0.1		0.1	0.1	0.4	0.1	0.1
Total[a]	**1.3**		**1.2**		**1.3**	**1.1**	**1.6**	**1.1**	**1.1**

[a] Also includes emissions from liming on *Land Converted to Cropland, Grassland Remaining Grassland, Land Converted to Grassland*, and *Settlements Remaining Settlements, Forest Land Remaining Forest Land* and *Land Converted to Forest Land*, as it is not currently possible to apportion the data by land-use category.
Note: Totals may not sum due to independent rounding.

Methodology

Carbon dioxide emissions from application of limestone and dolomite to soils were estimated using a Tier 2 methodology consistent with IPCC (2006). The annual amounts of limestone and dolomite applied (see Table 6-28) were multiplied by CO_2 emission factors from West and McBride (2005). These emission factors (0.059 metric ton C/metric ton limestone, 0.064 metric ton C/metric ton dolomite) are lower than the IPCC default emission factors because they account for the portion of carbonates that are transported from soils through hydrological processes and eventually deposited in ocean basins (West and McBride 2005). This analysis of lime dissolution is based on studies in the Mississippi River basin, where the vast majority of lime application occurs in the United States (West 2008). Moreover, much of the remaining lime application is occurring under similar precipitation regimes, and so the emission factors are considered a reasonable approximation for all lime application in the United States (West 2008).

The annual application rates of limestone and dolomite were derived from estimates and industry statistics provided in the *Minerals Yearbook* and *Mineral Industry Surveys* (Tepordei 1993 through 2006; Willett 2007a, 2007b, 2009, 2010, 2011a, 2011b, 2013a, 2014 and 2015; USGS 2008 through 2015). The U.S. Geological Survey (USGS; U.S. Bureau of Mines prior to 1997) compiled production and use information through surveys of crushed stone manufacturers. However, manufacturers provided different levels of detail in survey responses so the estimates of total crushed limestone and dolomite production and use were divided into three components: (1) production by end-use, as reported by manufacturers (i.e., "specified" production); (2) production reported by manufacturers without end-uses specified (i.e., "unspecified" production); and (3) estimated additional production by manufacturers who did not respond to the survey (i.e., "estimated" production).

Box 6-5: Comparison of the Tier 2 U.S. Inventory Approach and IPCC (2006) Default Approach

Emissions from liming of soils were estimated using a Tier 2 methodology based on emission factors specific to the United States that are lower than the IPCC (2006) emission default factors. Most lime application in the United States occurs in the Mississippi River basin, or in areas that have similar soil and rainfall regimes as the Mississippi River basin. Under these conditions, a significant portion of dissolved agricultural lime leaches through the soil into groundwater. Groundwater moves into channels and is transported to larger rives and eventually the ocean where

$CaCO_3$ precipitates to the ocean floor (West and McBride 2005). The U.S. specific emission factors (0.059 metric ton C/metric ton limestone and 0.064 metric ton C/metric ton dolomite) are about half of the IPCC (2006) emission factors (0.12 metric ton C/metric ton limestone and 0.13 metric ton C/metric ton dolomite). For comparison, the 2014 U.S. emission estimate from liming of soils is 4.1 MMT CO_2 Eq. using the U.S.-specific factors. In contrast, emissions would be estimated at 8.4 MMT CO_2 Eq. using the IPCC (2006) default emission factors.

Data on "specified" limestone and dolomite amounts were used directly in the emission calculation because the end use is provided by the manufactures and can be used to directly determine the amount applied to soils. However, it is not possible to determine directly how much of the limestone and dolomite is applied to soils for manufacturer surveys in the "unspecified" and "estimated" categories. For these categories, the amounts of crushed limestone and dolomite applied to soils were determined by multiplying the percentage of total "specified" limestone and dolomite production applied to soils by the total amounts of "unspecified" and "estimated" limestone and dolomite production. In other words, the proportion of total "unspecified" and "estimated" crushed limestone and dolomite that was applied to soils is proportional to the amount of total "specified" crushed limestone and dolomite that was applied to soils.

In addition, data were not available for 1990, 1992, and 2013 on the fractions of total crushed stone production that were limestone and dolomite, and on the fractions of limestone and dolomite production that were applied to soils. To estimate the 1990 and 1992 data, a set of average fractions were calculated using the 1991 and 1993 data. These average fractions were applied to the quantity of "total crushed stone produced or used" reported for 1990 and 1992 in the 1994 *Minerals Yearbook* (Tepordei 1996). To estimate 2014 data, 2013 fractions were applied to a 2014 estimate of total crushed stone presented in the USGS *Mineral Industry Surveys: Crushed Stone and Sand and Gravel in the First Quarter of 2015* (USGS 2015).

The primary source for limestone and dolomite activity data is the *Minerals Yearbook*, published by the Bureau of Mines through 1994 and by the USGS from 1995 to the present. In 1994, the "Crushed Stone" chapter in the *Minerals Yearbook* began rounding (to the nearest thousand metric tons) quantities for total crushed stone produced or used. It then reported revised (rounded) quantities for each of the years from 1990 to 1993. In order to minimize the inconsistencies in the activity data, these revised production numbers have been used in all of the subsequent calculations.

Emissions from limestone and dolomite are estimated at the state level and summed to obtain the national estimate. The state-level estimates are not reported here, but are available upon request. Also, it is important to note that all emissions from liming are reported in *Cropland Remaining Cropland* because it is not possible to subdivide the data to each land-use category (i.e., *Cropland Remaining Cropland, Land Converted to Cropland, Grassland Remaining Grassland, Land Converted to Grassland, Settlements Remaining Settlements, Forest Land Remaining Forest Land* and *Land Converted to Forest Land*).

Table 6-28: Applied Minerals (MMT)

Mineral	1990		2005		2010	2011	2012	2013	2014
Limestone[a]	19.0		18.1		20.0	15.9	20.8	16.6	17.5
Dolomite[a]	2.4		1.9		1.9	1.9	6.3	1.4	1.5

[a] Data represent amounts applied to *Cropland Remaining Cropland, Land Converted to Cropland, Grassland Remaining Grassland, Land Converted to Grassland, Settlements Remaining Settlements, Forest Land Remaining Forest Land* and *Land Converted to Forest Land,* as it is not currently possible to apportion the data by land-use category.

Uncertainty and Time-Series Consistency

Uncertainty regarding the amount of limestone and dolomite applied to soils was estimated at ±15 percent with normal densities (Tepordei 2003; Willett 2013b). Analysis of the uncertainty associated with the emission factors included the fraction of lime dissolved by nitric acid versus the fraction that reacts with carbonic acid, and the portion of bicarbonate that leaches through the soil and is transported to the ocean. Uncertainty regarding the time associated with leaching and transport was not addressed in this analysis, but is assumed to be a relatively small contributor to the overall uncertainty (West 2005). The probability distribution functions for the fraction of lime dissolved by nitric acid and the portion of bicarbonate that leaches through the soil were represented as smoothed triangular distributions between ranges of zero and 100 percent of the estimates. The uncertainty surrounding these two components largely drives the overall uncertainty. More information on the uncertainty estimates for CO_2 Emissions from Liming is contained within the Uncertainty Annex 7.

A Monte Carlo (Approach 2) uncertainty analysis was applied to estimate the uncertainty in CO_2 emissions from liming. The results of the Approach 2 quantitative uncertainty analysis are summarized in Table 6-29. CO_2 emissions from Liming in 2014 were estimated to be between -0.5 and 7.8 MMT CO_2 Eq. at the 95 percent confidence level. This confidence interval represents a range of 111 percent below to 88 percent above the 2014 emission estimate of 4.1 MMT CO_2 Eq.

Table 6-29: Approach 2 Quantitative Uncertainty Estimates for CO_2 Emissions from Liming (MMT CO_2 Eq. and Percent)

Source	Gas	2014 Emission Estimate (MMT CO_2 Eq.)	Uncertainty Range Relative to Emission Estimate[a] (MMT CO_2 Eq.)		(%)	
			Lower Bound	Upper Bound	Lower Bound	Upper Bound
Liming[b]	CO_2	4.1	(0.5)	7.8	-111%	+88%

[a] Range of emission estimates predicted by Monte Carlo Stochastic Simulation for a 95 percent confidence interval.
[b] Includes emissions from liming on *Land Converted to Cropland, Grassland Remaining Grassland, Land Converted to Grassland, Settlements Remaining Settlements, Forest Land Remaining Forest Land* and *Land Converted to Forest Land*, as it is not possible to subdivide the data by land-use category.

Methodological recalculations were applied to the entire time-series to ensure time-series consistency from 1990 through 2014. Details on the emission trends through time are described in more detail in the Methodology section, above.

QA/QC and Verification

A source-specific QA/QC plan for liming has been developed and implemented, and the quality control effort focused on the Tier 1 procedures for this Inventory. Quality control procedures did uncover a transcription error in the spreadsheets that was corrected.

Recalculations Discussion

Adjustments were made in the current Inventory to improve the results. First, limestone and dolomite application data for 2013 were approximated in the previous Inventory using a ratio of total crushed stone for 2013 relative to 2012 (similar to 2014 in the current Inventory). The estimates for 2013 were updated with the recently published data from USGS (2015). Second, quality control measures uncovered a transcription error in the 2012 activity data that increased the emission estimate by 0.2 MMT CO_2 Eq. related to the previous Inventory. With these revisions in the activity data, the emissions increased by 3.5 percent in 2012 and decreased by 34 percent in 2013 relative to the previous Inventory.

CO_2 Emissions from Urea Fertilization

The use of urea ($CO(NH_2)_2$) as a fertilizer leads to CO_2 emissions through the release of CO_2 that was fixed during the industrial production process. In the presence of water and urease enzymes, urea is converted into ammonium (NH_4^+), hydroxyl ion (OH), and bicarbonate (HCO_3^-). The bicarbonate then evolves into CO_2 and water. Emissions from urea fertilization in the United States totaled 4.5 MMT CO_2 Eq. (1.2 MMT C) in 2014 (Table 6-30 and Table 6-31). Due to an increase in application of urea fertilizers between 1990 and 2014, CO_2 emissions have increased by 87 percent from this management activity.

Table 6-30: CO_2 Emissions from Urea Fertilization (MMT CO_2 Eq.)

Source	1990		2005		2010	2011	2012	2013	2014
Urea Fertilization[a]	2.4		3.5		3.8	4.1	4.2	4.3	4.5

[a] Also includes emissions from urea fertilization on *Land Converted to Cropland, Grassland Remaining Grassland, Land Converted to Grassland, Settlements Remaining Settlements*, *Forest Land Remaining Forest Land* and *Land Converted to Forest Land,* as it is not currently possible to apportion the data by land-use category.

Table 6-31: CO_2 Emissions from Urea Fertilization (MMT C)

Source	1990		2005		2010	2011	2012	2013	2014
Urea Fertilization[a]	0.7		1.0		1.0	1.1	1.2	1.2	1.2

[a] Also includes emissions from urea fertilization on *Land Converted to Cropland, Grassland Remaining Grassland, Land Converted to Grassland, Settlements Remaining Settlements*, *Forest Land Remaining Forest Land* and *Land Converted to Forest Land,* as it is not currently possible to apportion the data by land-use category.

Methodology

Carbon dioxide emissions from the application of urea to agricultural soils were estimated using the IPCC (2006) Tier 1 methodology. The method assumes that all CO_2 fixed during the industrial production process of urea are released after application. The annual amounts of urea applied to croplands (see Table 6-32) were derived from the state-level fertilizer sales data provided in *Commercial Fertilizers* (TVA 1991, 1992, 1993, 1994; AAPFCO 1995 through 2014). These amounts were multiplied by the default IPCC (2006) emission factor (0.20 metric tons of C per metric ton of urea), which is equal to the C content of urea on an atomic weight basis. Because fertilizer sales data are reported in fertilizer years (July previous year through June current year), a calculation was performed to convert the data to calendar years (January through December). According to monthly fertilizer use data (TVA 1992b), 35 percent of total fertilizer used in any fertilizer year is applied between July and December of the previous calendar year, and 65 percent is applied between January and June of the current calendar year. For example, for the 2000 fertilizer year, 35 percent of the fertilizer was applied in July through December 1999, and 65 percent was applied in January through June 2000.

Fertilizer sales data for the 2013 and 2014 fertilizer years (i.e., July 2012 through June 2013 and July 2013 through June 2014) were not available for this Inventory. Therefore, urea application in the 2013 and 2014 fertilizer years were estimated using a linear, least squares trend of consumption over the data from the previous five years (2008 through 2012) at the state level. A trend of five years was chosen as opposed to a longer trend as it best captures the current inter-state and inter-annual variability in consumption. State-level estimates of CO_2 emissions from the application of urea to agricultural soils were summed to estimate total emissions for the entire United States. The fertilizer year data is then converted into calendar year data using the method described above.

Emissions are estimated at the state level and summed to obtain the national estimate. The state-level estimates are not reported here, but are available upon request. Also, it is important to note that all emissions from urea fertilization are reported in *Cropland Remaining Cropland* because it is not currently possible to apportion the emissions to each land-use category (i.e., *Cropland Remaining Cropland, Land Converted to Cropland*, *Grassland Remaining Grassland, Land Converted to Grassland*, *Settlements Remaining Settlements, Forest Land Remaining Forest Land* and *Land Converted to Forest Land*), however, the majority of urea fertilization is likely to have occurred on *Cropland Remaining Cropland*.

Table 6-32: Applied Urea (MMT)

	1990		2005		2010	2011	2012	2013	2014
Urea Fertilizer[a]	3.3		4.8		5.2	5.6	5.8	5.9	6.2

[a] These numbers represent amounts applied to all agricultural land, including *Cropland Remaining Cropland*, *Land Converted to Cropland*, *Grassland Remaining Grassland*, *Land Converted to Grassland*, *Settlements Remaining Settlements*, *Forest Land Remaining Forest Land* and *Land Converted to Forest Land*, as it is not currently possible to apportion the data by land-use category.

Uncertainty and Time-Series Consistency

Uncertainty estimates are presented in Table 6-33 for *Urea Fertilization*. An Approach 2 Monte Carlo analysis was completed. The largest source of uncertainty was the default emission factor, which assumes that 100 percent of the C in $CO(NH_2)_2$ applied to soils is ultimately emitted into the environment as CO_2. This factor does not incorporate the possibility that some of the C may be retained in the soil, and therefore the uncertainty range was set from 0 percent emissions to the maximum emission value of 100 percent using a triangular distribution. In addition, each urea consumption data point has an associated uncertainty. Carbon dioxide emissions from urea fertilization of agricultural soils in 2014 were estimated to be between 2.6 and 4.5 MMT CO_2 Eq. at the 95 percent confidence level. This indicates a range of 42 percent below to 0 percent above the 2014 emission estimate of 4.5 MMT CO_2 Eq.

Table 6-33: Quantitative Uncertainty Estimates for CO_2 Emissions from Urea Fertilization (MMT CO_2 Eq. and Percent)

Source	Gas	2014 Emission Estimate (MMT CO_2 Eq.)	Uncertainty Range Relative to Emission Estimate[a] (MMT CO_2 Eq.)		(%)	
			Lower Bound	Upper Bound	Lower Bound	Upper Bound
Urea Fertilization	CO_2	4.5	2.6	4.5	-42%	0%

[a] Range of emission estimates predicted by Monte Carlo Stochastic Simulation for a 95 percent confidence interval.

There are additional uncertainties that are not quantified in this analysis. Urea for non-fertilizer use, such as aircraft deicing, may be included in consumption totals, but the amount is likely very small. For example, research on aircraft deicing practices is consistent with this assumption based on a 1992 survey that found a known annual usage of approximately 2,000 tons of urea for deicing; this would constitute 0.06 percent of the 1992 consumption of urea (EPA 2000). Similarly, surveys conducted from 2002 to 2005 indicate that total urea use for deicing at U.S. airports is estimated to be 3,740 metric tons per year, or less than 0.07 percent of the fertilizer total for 2007 (Itle 2009). In addition, there is uncertainty surrounding the underlying assumptions behind the calculation that converts fertilizer years to calendar years. These uncertainties are negligible over multiple years, however, because an over- or under-estimated value in one calendar year is addressed with corresponding increase or decrease in the value for the subsequent year.

Methodological recalculations were applied to the entire time-series to ensure time-series consistency from 1990 through 2014. Details on the emission trends through time are described in more detail in the Methodology section, above.

QA/QC and Verification

A source-specific QA/QC plan for Urea Fertilization has been developed and implemented. For this year, the Tier 1 analysis was performed and an error was found in a formula reference to an incorrect cell in the spreadsheets.

Recalculations Discussion

In the current Inventory, the 2013 emission estimate was updated to reflect a correction to the calculations made in the previous Inventory report. Quality control checks uncovered an incorrect spreadsheet cell reference influencing the state-level emission calculations. The 2013 emission estimate increased by 8.3 percent, relative to the previous report, due to this correction.

Planned Improvements

No improvements are planned for this source.

6.5 Land Converted to Cropland (IPCC Source Category 4B2)

Land Converted to Cropland includes all cropland in an Inventory year that had been in another land use(s) during the previous 20 years (USDA-NRCS 2013), and used to produce food or fiber, or forage that is harvested and used as feed (e.g., hay and silage). For example, grassland or forestland converted to cropland during the past 20 years would be reported in this category. Recently-converted lands are retained in this category for 20 years as recommended in the IPCC guidelines (IPCC 2006). This Inventory includes all croplands in the conterminous United States and Hawaii, but does not include a minor amount of *Land Converted to Cropland* in Alaska. Some miscellaneous croplands are also not included in the Inventory due to limited understanding of greenhouse gas dynamics in management systems (e.g., aquaculture) or climate zones (e.g., boreal climates). Consequently there is a discrepancy between the total amount of managed area in *Land Converted to Cropland* (see Section 6.1 Representation of the U.S. Land Base) and the cropland area included in the Inventory. Improvements are underway to include croplands in Alaska and miscellaneous crops in future C inventories.

Land use change can lead to large losses of C to the atmosphere, particularly conversions from forest land (Houghton et al. 1983). Moreover, conversion of forest to another land use (i.e., deforestation) is one of the largest anthropogenic sources of emissions to the atmosphere globally (Schimel 1995), although this source may be declining according to a recent assessment (Tubiello et al. 2015).

The *2006 IPCC Guidelines* recommend reporting changes in biomass, dead organic matter and soil organic carbon (SOC) [39] stocks with land use change. All soil C stock changes are estimated and reported for *Land Converted to Cropland*, but there is limited reporting of other pools in this Inventory. Loss of aboveground biomass C from *Forest Converted to Cropland* is reported but losses from belowground biomass, dead wood and litter pools with forest conversion are not included in this Inventory.[40] In addition, biomass C stock changes are not estimated for other land use conversions (other than Forest Land) to Cropland.[41]

Loss of aboveground woody biomass C from *Forest Converted to Cropland* is the largest contributor to C loss throughout the time series, accounting for approximately 64 percent of the total emissions (Table 6-34 and Table 6-35). *Grassland Converted to Cropland* is the largest source of emissions associated with soil C pools across the time series (accounting for approximately 91 percent of the average loss of soil C), largely because the area of *Grassland Converted to Cropland* is significantly higher than for other land use conversions to cropland, though losses declined over the time series. The net change in total C stocks for 2014 led to CO_2 emissions to the atmosphere of 22.1 MMT CO_2 Eq. (6.0 MMT C), including 11.5 MMT CO_2 Eq. (3.1 MMT C) from biomass C losses, 6.3 MMT CO_2 Eq. (1.7 MMT C) from mineral soils and 4.3 MMT CO_2 Eq. (1.2 MMT C) from drainage and cultivation of organic soils. Emissions in 2014 are 66 percent lower than the emissions in the initial reporting year of 1990, largely due to less conversion of *Forest Land to Cropland*.

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[39] CO_2 emissions associated with liming and urea fertilization are also estimated but included in Section 6.4 *Cropland Remaining Cropland* as it was not possible to separate additions of lime and urea by land use.

[40] A planned improvement is to estimate the losses of carbon from belowground biomass, dead wood and litter with *Forest Converted to Cropland*.

[41] Changes in biomass C stocks are not currently reported for other land use conversions (other than forest land) to cropland, but this is a planned improvement for a future inventory. Note: changes in dead organic matter are assumed to negligible for other land use conversions (i.e., other than forest land) to cropland based on the Tier 1 method in IPCC (2006).

Table 6-34: Net CO_2 Flux from Soil C Stock Changes in *Land Converted to Cropland* by Land Use Change Category (MMT CO_2 Eq.)

	1990	2005	2010	2011	2012	2013	2014
Grassland Converted to Cropland							
Mineral Soils	14.2	9.1	7.9	5.8	5.8	5.9	5.9
Organic Soils	3.2	4.2	3.8	3.8	3.8	3.8	3.8
Forest Converted to Cropland							
Biomass	46.9	17.9	11.0	11.0	11.5	11.5	11.5
Mineral Soils	0.2	0.1	+	+	+	+	+
Organic Soils	0.1	+	+	+	+	+	+
Other Lands Converted Cropland							
Mineral Soils	0.2	0.2	0.2	0.2	0.2	0.2	0.2
Organic Soils	0.1	0.0	0.0	0.0	0.0	0.0	0.0
Settlements Converted Cropland							
Mineral Soils	0.1	+	0.1	0.1	0.1	0.1	0.1
Organic Soils	+	0.1	0.1	0.1	0.1	0.1	0.1
Wetlands Converted Cropland							
Mineral Soils	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Organic Soils	0.6	0.5	0.4	0.4	0.4	0.4	0.4
Total Biomass Flux	**46.9**	**17.9**	**11.0**	**11.0**	**11.5**	**11.5**	**11.5**
Total Mineral Soil Flux	**14.7**	**9.5**	**8.4**	**6.3**	**6.3**	**6.3**	**6.3**
Total Organic Soil Flux	**4.0**	**4.8**	**4.3**	**4.3**	**4.3**	**4.3**	**4.3**
Total Net Flux	**65.7**	**32.2**	**23.7**	**21.6**	**22.0**	**22.1**	**22.1**

+ Does not exceed 0.05 MMT CO_2 Eq.

Notes: Estimates after 2010 are based on NRI data from 2010 and therefore may not fully reflect changes occurring in the latter part of the time series. Totals may not sum due to independent rounding.

Table 6-35: Net CO_2 Flux from Soil C Stock Changes in *Land Converted to Cropland* (MMT C)

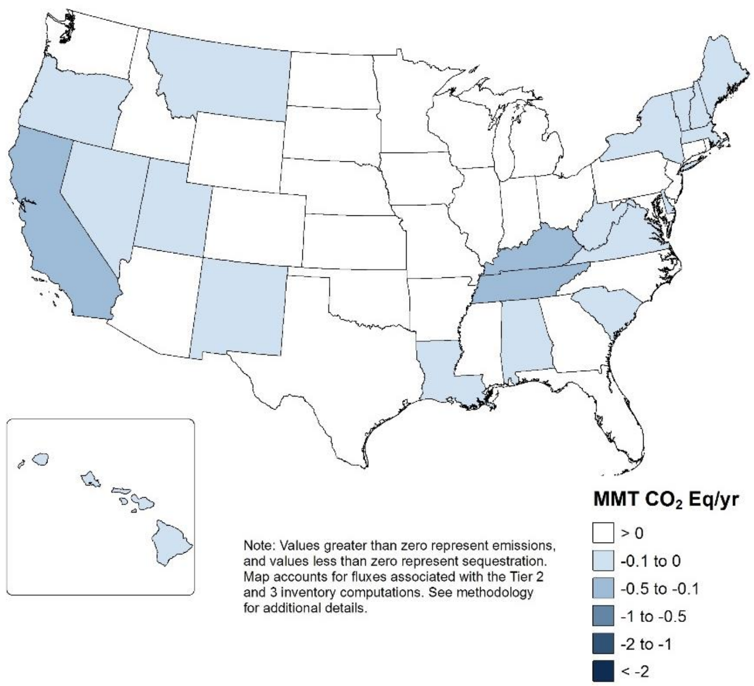
	1990	2005	2010	2011	2012	2013	2014
Grassland Converted to Cropland							
Mineral Soils	3.9	2.5	2.2	1.6	1.6	1.6	1.6
Organic Soils	0.9	1.1	1.0	1.0	1.0	1.0	1.0
Forest Converted to Cropland							
Biomass	12.8	4.9	3.0	3.0	3.1	3.1	3.1
Mineral Soils	0.1	+	+	+	+	+	+
Organic Soils	+	+	+	+	+	+	+
Other Lands Converted Cropland							
Mineral Soils	+	+	+	0.1	0.1	0.1	0.1
Organic Soils	+	0.0	0.0	0.0	0.0	0.0	0.0
Settlements Converted Cropland							
Mineral Soils	+	+	+	+	+	+	+
Organic Soils	+	+	+	+	+	+	+
Wetlands Converted Cropland							
Mineral Soils	+	+	+	+	+	+	+
Organic Soils	0.2	0.1	0.1	0.1	0.1	0.1	0.1
Total Biomass Flux	**12.8**	**4.9**	**3.0**	**3.0**	**3.1**	**3.1**	**3.1**
Total Mineral Soil Flux	**4.0**	**2.6**	**2.3**	**1.7**	**1.7**	**1.7**	**1.7**
Total Organic Soil Flux	**1.1**	**1.3**	**1.2**	**1.2**	**1.2**	**1.2**	**1.2**
Total Net Flux	**17.9**	**8.8**	**6.5**	**5.9**	**6.0**	**6.0**	**6.0**

+ Does not exceed 0.05 MMT C

Notes: Estimates after 2010 are based on NRI data from 2010 and therefore may not fully reflect changes occurring in the latter part of the time series. Totals may not sum due to independent rounding.

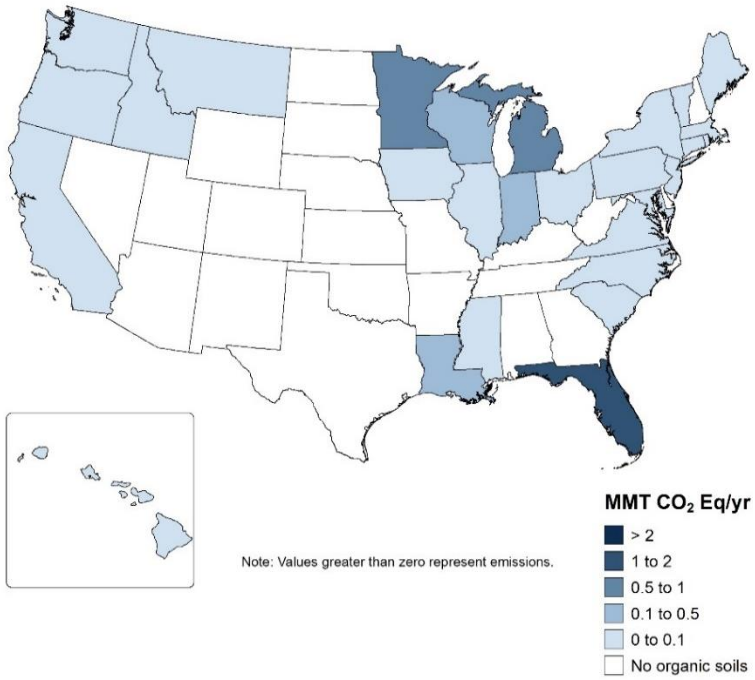
The spatial variability in the 2014 annual C stock changes[42] for mineral soils is displayed in Figure 6-6 and for organic soils in Figure 6-7. In most states, soil C stocks declined for *Land Converted to Cropland*. This is because conversion of grassland and forestland to cropland led to enhanced decomposition of soil organic matter and a net loss of C from the soil pool. There were some exceptions to this generality, with gains in soil C in regions where the cropland is irrigated or land is converted from a grassland into hay production. These types of conversions generally lead to more inputs of fertilizer and/or water, which enhances production and carbon input to the soil. The regions with the highest rates of emissions from organic soils coincide with the largest concentrations of organic soils used for agricultural production, including the Southeastern Coastal Region (particularly Florida), upper Midwest and Northeast surrounding the Great Lakes, and the Pacific Coast.

Figure 6-6: Total Net Annual CO_2 Flux for Mineral Soils under Agricultural Management within States, 2014, *Land Converted to Cropland*



[42] A planned improvement is to include biomass C stock changes in the figures; currently the maps only include the spatial patterns associated with soil C stock changes.

Figure 6-7: Total Net Annual CO_2 Flux for Organic Soils under Agricultural Management within States, 2014, *Land Converted to Cropland*



Methodology

The following section includes a description of the methodology used to estimate changes in C stocks for *Land Converted to Cropland*, including: (1) aboveground biomass from conversion of forest land to cropland; (2) agricultural land-use and management activities on mineral soils; and (3) agricultural land-use and management activities on organic soils. Belowground live biomass and dead organic matter C stock changes are not estimated in the current Inventory for *Land Converted to Cropland*. Further elaboration on the methodologies and data used to estimate stock changes for mineral and organic soils are provided in the *Cropland Remaining Cropland* section and Annex 3.12.

Biomass Carbon Stock Changes

A Tier 2 method is applied to estimate aboveground biomass C stock changes[43] for *Forest Land Converted to Cropland.* For this method, land is stratified by region, forest type, and site productivity and then assigned reference C density estimates for aboveground biomass for the cropland (assumed to be zero since no reference aboveground biomass C density estimates exist) and forest land use. The difference between the stocks is reported as the stock change under the assumption that the change occurred in the year of the conversion. Reference C density estimates for aboveground biomass for the forest land use have been estimated from data in the Forest Inventory and Analysis (FIA) program within the USDA Forest Service (USDA Forest Service 2015). If FIA plots include data on individual trees, aboveground C density estimates are based on Woodall et al. (2011), which is also known as the component ratio method, and is a function of tree volume, species, diameter, and, in some regions, height and site quality. See Annex 3.13 for more information about reference C density estimates for forest land.

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[43] A planned improvement is to estimate the losses of C from belowground biomass, dead wood and litter with *Forest Converted to Cropland*.

Soil Carbon Stock Changes

Soil C stock changes are estimated for *Land Converted to Cropland* according to land-use histories recorded in the 2010 USDA NRI survey for non-federal lands (USDA-NRCS 2013). Land-use and some management information (e.g., crop type, soil attributes, and irrigation) had been collected for each NRI point on a 5-year cycle beginning in 1982. In 1998, the NRI program began collecting annual data, which are currently available through 2012 (USDA-NRCS 2015). However, this Inventory only uses NRI data through 2010 because newer data were not available in time to incorporate the additional years. NRI survey locations are classified as *Land Converted to Cropland* in a given year between 1990 and 2010 if the land use is cropland but had been another use during the previous 20 years. NRI survey locations are classified according to land-use histories starting in 1979, and consequently the classifications are based on less than 20 years from 1990 to 1998, which may have led to an underestimation of *Land Converted to Cropland* in the early part of the time series to the extent that some areas are converted to cropland prior to 1979. For federal lands, the land use history is derived from land cover changes in the National Land Cover Dataset (Homer et al. 2007; Fry et al. 2011; Homer et al. 2015).

Mineral Soil Carbon Stock Changes

An IPCC Tier 3 model-based approach (Ogle et al. 2010) is applied to estimate C stock changes for mineral soils on the majority of land that is used to produce annual crops in the United States. These crops include alfalfa hay, barley, corn, cotton, dry beans, grass hay, grass-clover hay, oats, onions, peanuts, potatoes, rice, sorghum, soybeans, sugar beets, sunflowers, tomatoes, and wheat. Soil C stock changes on the remaining soils are estimated with the IPCC Tier 2 method (Ogle et al. 2003), including land used to produce some vegetables, tobacco, perennial/horticultural crops and crops rotated with these crops; land on very gravelly, cobbly, or shaley soils (greater than 35 percent by volume); and land converted from another land use or federal ownership.[44]

Tier 3 Approach. For the Tier 3 method, mineral SOC stocks and stock changes are estimated using the DAYCENT biogeochemical45 model (Parton et al. 1998; Del Grosso et al. 2001, 2011). The DAYCENT model utilizes the soil C modeling framework developed in the Century model (Parton et al. 1987, 1988, 1994; Metherell et al. 1993), but has been refined to simulate dynamics at a daily time-step. National estimates are obtained by using the model to simulate historical land-use change patterns as recorded in the USDA NRI (USDA-NRCS 2013). Carbon stocks and 95 percent confidence intervals are estimated for each year between 1990 and 2010, but C stock changes from 2010 to 2014 are assumed to be similar to 2010. Future inventories will be updated with new activity data when the data are made available, and the time series will be recalculated (See Planned Improvements section in *Cropland Remaining Cropland*). See the *Cropland Remaining Cropland* section for additional discussion of the Tier 3 methodology for mineral soils.

Tier 2 Approach. For the mineral soils not included in the Tier 3 analysis, SOC stock changes are estimated using a Tier 2 Approach for *Land Converted to Cropland* as described in the Tier 2 Approach for mineral soils in the *Cropland Remaining Cropland* section.

Organic Soil Carbon Stock Changes

Annual C emissions from drained organic soils in *Land Converted to Cropland* are estimated using the Tier 2 method provided in IPCC (2006), with U.S.-specific C loss rates (Ogle et al. 2003) as described in the *Cropland Remaining Cropland* section for organic soils.

Uncertainty and Time-Series Consistency

The uncertainty analysis for aboveground biomass C losses with *Forest Converted to Cropland* is conducted in the same way as the uncertainty assessment for forest ecosystem C flux in the *Forest Land Remaining Forest Land*

[44] Federal land is not a land use, but rather an ownership designation that is treated as grassland for purposes of these calculations. The specific land use on federal lands is not identified in the NRI survey (USDA-NRCS 2013).

[45] Biogeochemical cycles are the flow of chemical elements and compounds between living organisms and the physical environment.

category. Sample and model-based error are combined using simple error propagation methods provided by the IPCC (2006). For additional details see the Uncertainty Analysis in Annex 3.13. Uncertainty analysis for mineral soil C stock changes using the Tier 3 and Tier 2 methodologies are based on a Monte Carlo approach that is described for *Cropland Remaining Cropland*. The uncertainty for annual C emission estimates from drained organic soils in *Land Converted to Cropland* is estimated using a Monte Carlo approach, which is also described in the *Cropland Remaining Cropland* section.

Uncertainty estimates are presented in Table 6-36 for each subsource (i.e., biomass C stocks, mineral soil C stocks and organic soil C stocks) and the method applied in the Inventory analysis (i.e., Tier 2 and Tier 3). Uncertainty estimates from the Tier 2 and 3 approaches are combined using the simple error propagation methods provided by the IPCC (2006), i.e., by taking the square root of the sum of the squares of the standard deviations of the uncertain quantities. The combined uncertainty for total C stocks in *Land Converted to Cropland* ranged from 54 percent below to 52 percent above the 2014 stock change estimate of 22.1 MMT CO_2 Eq.

Table 6-36: Approach 2 Quantitative Uncertainty Estimates for Soil C Stock Changes occurring within *Land Converted to Cropland* (MMT CO_2 Eq. and Percent)

Source	2014 Flux Estimate (MMT CO_2 Eq.)	Uncertainty Range Relative to Flux Estimate[a] (MMT CO_2 Eq.)		(%)	
		Lower Bound	Upper Bound	Lower Bound	Upper Bound
Grassland Converted to Cropland	**9.7**	**(2.2)**	**20.3**	**-123%**	**110%**
Mineral Soil C Stocks: Tier 3	4.5	(5.3)	14.4	-218%	218%
Mineral Soil C Stocks: Tier 2	1.3	(0.1)	2.2	-108%	69%
Organic Soil C Stocks: Tier 2	3.8	10.2	+	-168%	99%
Forests Converted to Cropland	**11.5**	**9.2**	**13.9**	**-21%**	**21%**
Biomass C Stocks	11.5	10.0	12.9	-13%	13%
Mineral Soil C Stocks: Tier 2	+	+	0.1	-111%	71%
Organic Soil C Stocks: Tier 2	+	0.1	0.0	-154%	100%
Other Lands Converted to Cropland	**0.2**	**(+)**	**0.3**	**-112%**	**83%**
Mineral Soil C Stocks: Tier 2	0.2	(+)	0.3	-112%	72%
Organic Soil C Stocks: Tier 2	0.0	0.0	0.1	0%	0%
Settlements Converted to Cropland	**0.1**	**+**	**0.5**	**-71%**	**255%**
Mineral Soil C Stocks: Tier 2	0.1	(+)	0.1	-112%	72%
Organic Soil C Stocks: Tier 2	0.1	0.1	0.4	-91%	454%
Wetlands Converted to Croplands	**0.6**	**0.3**	**4.5**	**-53%**	**694%**
Mineral Soil C Stocks: Tier 2	0.1	+	0.2	-75%	50%
Organic Soil C Stocks: Tier 2	0.4	0.7	4.3	-65%	908%
Total: Land Converted to Cropland	**22.1**	**10.1**	**33.5**	**-54%**	**52%**
Biomass C Stocks	**11.5**	**10.0**	**12.9**	**-13%**	**13%**
Mineral Soil C Stocks: Tier 3	**4.5**	**(5.3)**	**14.4**	**-218%**	**218%**
Mineral Soil C Stocks: Tier 2	**1.7**	**0.3**	**2.7**	**-83%**	**53%**
Organic Soil C Stocks: Tier 2	**4.3**	**(2.1)**	**9.8**	**-148%**	**126%**

+ Absolute value does not exceed 0.05 MMT CO_2 Eq.
[a] Range of C stock change estimates predicted by Monte Carlo Stochastic Simulation for a 95 percent confidence interval.
Notes: Totals may not sum due to independent rounding. Parentheses indicate negative values or net sequestration.

Uncertainty is also associated with lack of reporting of agricultural biomass and litter C stock changes. Biomass C stock changes are likely minor in perennial crops, such as orchards and nut plantations, given the small amount of change in land used to produce these commodities in the United States. In contrast, agroforestry practices, such as shelterbelts, riparian forests and intercropping with trees, may have led to significant changes in biomass C stocks, at least in some regions of the United States. However, there are currently no datasets to evaluate the trends. Changes in dead organic matter C stocks are also assumed to be negligible in croplands over annual time frames, although there are certainly significant changes at sub-annual time scales across seasons. However, this trend may change in the future, particularly if crop residue becomes a viable feedstock for bioenergy production.

Methodological recalculations are applied to the entire time series to ensure time-series consistency from 1990 through 2014. Details on the emission trends through time are described in more detail in the Methodology section, above.

QA/QC and Verification

See the QA/QC and Verification section in *Cropland Remaining Cropland*.

Recalculations Discussion

Methodological recalculations in the current Inventory are associated with the following improvements: 1) incorporation of updated NRI data for 1990 through 2010; 2) inclusion of federal croplands; 3) improving the simulation of hydric soils in DAYCENT, and 4) incorporating the aboveground biomass C stock losses with *Forest Land Converted to Cropland*. As a result of these improvements to the Inventory, *Land Converted to Cropland* have a larger reported loss of C, estimated at 21.0 MMT CO_2 Eq. over the time series. This represents a 100 percent increase in the losses of carbon with *Land Converted to Cropland* compared to the previous Inventory, and is largely driven by reporting aboveground biomass C loss from *Forest Converted to Croplands* in this category instead of *Forest Land Remaining Forest Land* where it was included in the previous Inventory submissions.

Planned Improvements

Soil C stock changes with land use conversion from forest land to cropland are undergoing further evaluation to ensure consistency in the time series. Different methods are used to estimate soil C stock changes in forest land and croplands, and while the areas have been reconciled between these land uses, there has been limited evaluation of the consistency in C stock changes with conversion from forest land to cropland. This planned improvement may not be fully implemented for another year, depending on resource availability.

The impact of *Forest Land Converted to Cropland* on belowground biomass and dead organic matter pools are not estimated in the current Inventory, and so another planned improvement is to estimate changes in C stocks for these pools in the next Inventory. In addition, biomass C stock changes will be estimated for *Grassland Converted to Cropland*, as well as other land use conversions to cropland to the extent that data are available. Additional planned improvements are discussed in the *Cropland Remaining Cropland* section.

6.6 Grassland Remaining Grassland (IPCC Source Category 4C1)

Grassland Remaining Grassland includes all grassland in an Inventory year that had been classified as grassland for the previous 20 years (USDA-NRCS 2013). Grassland includes pasture and rangeland that are primarily, but not exclusively used for livestock grazing. Rangelands are typically extensive areas of native grassland that are not intensively managed, while pastures are typically seeded grassland (possibly following tree removal) that may also have additional management, such as irrigation or interseeding of legumes. This Inventory includes all privately-owned and federal grasslands in the conterminous United States and Hawaii, but does not include approximately 50 million hectares of *Grassland Remaining Grassland* in Alaska. This leads to a discrepancy with the total amount of managed area in *Grassland Remaining Grassland* (see Section 6.1 Representation of the U.S. Land Base) and the grassland area included in the Inventory analysis (IPCC Source Category 4C1—Section 6.6).

Background on agricultural carbon (C) stock changes is provided in Section 6.4, *Cropland Remaining Cropland*, and will only be summarized here. Soils are the largest pool of C in agricultural land, and also have the greatest potential for longer-term storage or release of C. Biomass and dead organic matter C pools are relatively small and ephemeral compared to the soil C pool, with the exception of C stored in tree and shrub biomass that occurs in grasslands. The *2006 IPCC Guidelines* (IPCC 2006) recommend reporting changes in soil organic C (SOC) stocks due to (1) agricultural land-use and management activities on mineral soils, and (2) agricultural land-use and management activities on organic soils.[46]

In *Grassland Remaining Grassland*, there has been considerable variation in soil C stocks between 1990 and 2014. These changes are driven by variability in weather patterns and associated interaction with land management activity. Moreover, changes remain small on a per hectare rate across the time series even in the years with a larger total change in stocks. Land use and management generally increased soil C in mineral soils for *Grassland Remaining Grassland* between 1990 and 2010, after which the trend is reversed to a small decline in soil C. In contrast, organic soils lose a relatively constant amount of C annually from 1990 through 2014. In 2014, soil C stocks decreased by 3.8 MMT CO_2 Eq. (1.0 MMT C), with an uptake of 0.6 MMT CO_2 Eq. (0.2 MMT C) in mineral soils but a loss of 4.3 MMT CO_2 Eq. (1.2 MMT C) from organic soils (Table 6-37 and Table 6-38). The overall trend represents a 129 percent increase in the flux relative to the flux in the initial reporting year of 1990.

Table 6-37: Net CO_2 Flux from Soil C Stock Changes in *Grassland Remaining Grassland* (MMT CO_2 Eq.)

Soil Type	1990		2005		2010	2011	2012	2013	2014
Mineral Soils	(19.0)		(7.7)		(11.7)	(1.2)	(0.8)	(0.6)	(0.6)
Organic Soils	6.1		4.5		4.4	4.4	4.3	4.3	4.3
Total Net Flux	**(12.9)**		**(3.3)**		**(7.3)**	**3.1**	**3.6**	**3.8**	**3.8**

Notes: Estimates after 2010 are based on NRI data from 2010 and therefore may not fully reflect changes occurring in the latter part of the time series. Totals may not sum due to independent rounding. Parentheses indicate net sequestration.

Table 6-38: Net CO_2 Flux from Soil C Stock Changes in *Grassland Remaining Grassland* (MMT C)

Soil Type	1990		2005		2010	2011	2012	2013	2014
Mineral Soils	(5.2)		(2.1)		(3.2)	(0.3)	(0.2)	(0.2)	(0.2)
Organic Soils	1.7		1.2		1.2	1.2	1.2	1.2	1.2
Total Net Flux	**(3.5)**		**(0.9)**		**(2.0)**	**0.8**	**1.0**	**1.0**	**1.0**

Notes: Estimates after 2010 are based on NRI data from 2010 and therefore may not fully reflect changes occurring in the latter part of the time series. Totals may not sum due to independent rounding. Parentheses indicate net sequestration.

The spatial variability in the 2014 annual CO_2 flux associate with mineral soils is displayed in Figure 6-8 and organic soils in Figure 6-9. Although relatively small on a per-hectare basis, grassland soils gained C in several regions during 2014, including most of the Eastern United States and Pacific Coastal Region. For organic soils, the regions with the highest rates of emissions coincide with the largest concentrations of organic soils used for managed grassland, including the Southeastern Coastal Region (particularly Florida), upper Midwest and Northeast, and the Pacific Coast.

[46] CO_2 emissions associated with liming and urea fertilization are also estimated but included in Section 6.4 *Cropland Remaining Cropland*.

Figure 6-8: Total Net Annual CO_2 Flux for Mineral Soils under Agricultural Management within States, 2014, *Grassland Remaining Grassland*

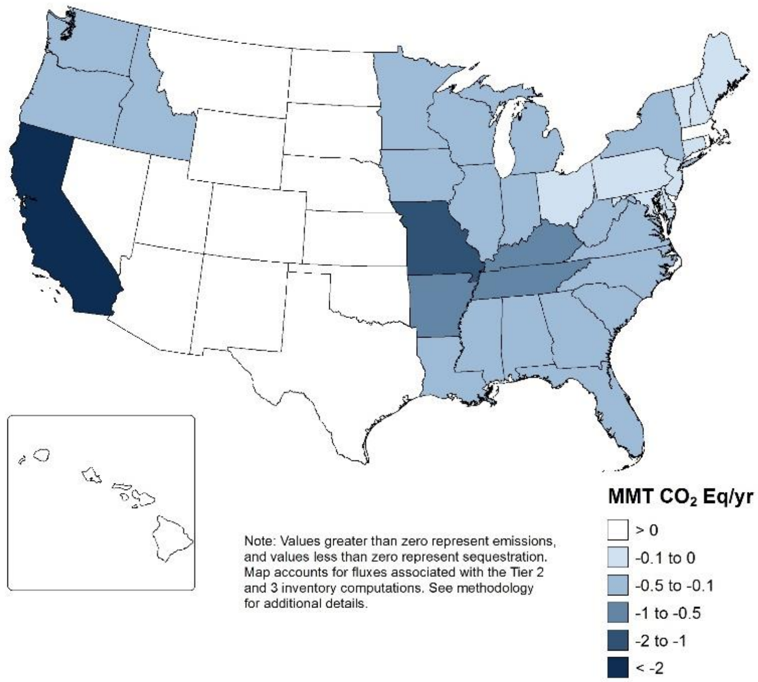
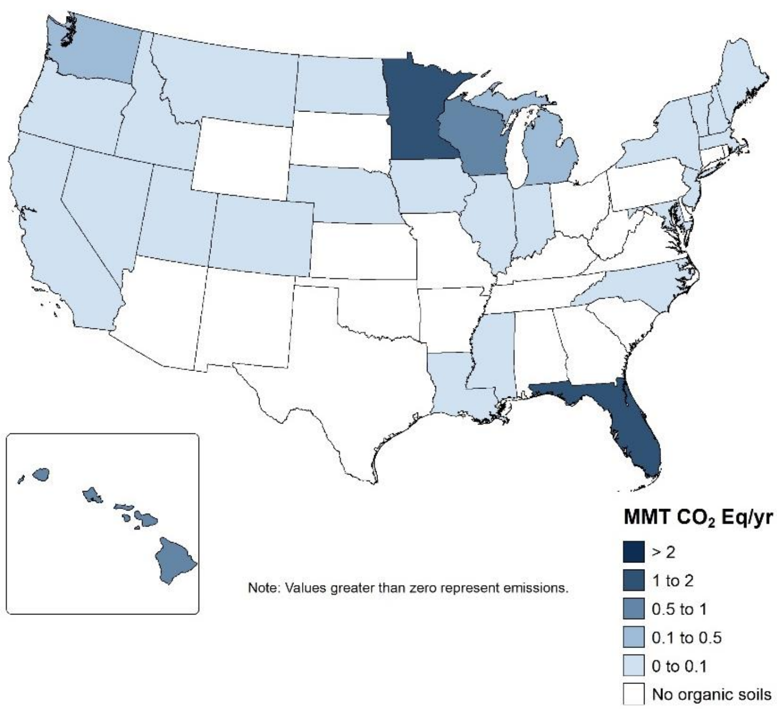


Figure 6-9: Total Net Annual CO_2 Flux for Organic Soils under Agricultural Management within States, 2014, *Grassland Remaining Grassland*



Methodology

The following section includes a brief description of the methodology used to estimate changes in soil C stocks for *Grassland Remaining Grassland*, including: (1) agricultural land-use and management activities on mineral soils; and (2) agricultural land-use and management activities on organic soils. Further elaboration on the methodologies and data used to estimate stock changes from mineral and organic soils are provided in the *Cropland Remaining Cropland* section and Annex 3.12.

Soil C stock changes are estimated for *Grassland Remaining Grassland* on non-federal lands according to land use histories recorded in the 2010 USDA NRI survey (USDA-NRCS 2013). Land-use and some management information (e.g., grass type, soil attributes, and irrigation) were originally collected for each NRI survey location on a 5-year cycle beginning in 1982. In 1998, the NRI program began collecting annual data, and the annual data are currently available through 2012 (USDA-NRCS 2015). However, this Inventory only uses NRI data through 2010 because newer data were not available in time to incorporate the additional years. NRI survey locations are classified as *Grassland Remaining Grassland* in a given year between 1990 and 2010 if the land use had been grassland for 20 years. NRI survey locations are classified according to land-use histories starting in 1979, and consequently the classifications are based on less than 20 years from 1990 to 1998. This may have led to an overestimation of *Grassland Remaining Grassland* in the early part of the time series to the extent that some areas are converted to grassland prior to 1979. For federal lands, the land use history is derived from land cover changes in the National Land Cover Dataset (Homer et al. 2007; Fry et al. 2011; Homer et al. 2015).

Mineral Soil Carbon Stock Changes

An IPCC Tier 3 model-based approach (Ogle et al. 2010) is applied to estimate C stock changes for most mineral soils in *Grassland Remaining Grassland*. The C stock changes for the remaining soils are estimated with an IPCC Tier 2 method (Ogle et al. 2003), including gravelly, cobbly, or shaley soils (greater than 35 percent by volume) and additional stock changes associated with sewage sludge amendments.

Tier 3 Approach

Mineral SOC stocks and stock changes for *Grassland Remaining Grassland* are estimated using the DAYCENT biogeochemical[47] model (Parton et al. 1998; Del Grosso et al. 2001, 2011), as described in *Cropland Remaining Cropland*. The DAYCENT model utilizes the soil C modeling framework developed in the Century model (Parton et al. 1987, 1988, 1994; Metherell et al. 1993), but has been refined to simulate dynamics at a daily time-step. Historical land-use patterns and irrigation histories are simulated with DAYCENT based on the 2010 USDA NRI survey (USDA-NRCS 2013). Frequency and rates of manure application to grassland during 1997 are estimated from data compiled by the USDA Natural Resources Conservation Service (NRCS) (Edmonds, et al. 2003), and then adjusted using county-level estimates of manure available for application in other years. Specifically, county-scale ratios of manure available for application to soils in other years relative to 1997 are used to adjust the area amended with manure (see *Cropland Remaining Cropland* section for further details). Greater availability of managed manure nitrogen (N) relative to 1997 is, thus, assumed to increase the area amended with manure, while reduced availability of manure N relative to 1997 is assumed to reduce the amended area.

The amount of manure produced by each livestock type is calculated for managed and unmanaged waste management systems based on methods described in Section 5.2 - Manure Management and Annex 3.11. Manure N deposition from grazing animals (i.e., PRP manure) is an input to the DAYCENT model (see Annex 3.11), and the remainder is deposited on federal lands (i.e., the amount that is not included in DAYCENT simulations is assumed to be applied on federal grasslands). Carbon stocks and 95 percent confidence intervals are estimated for each year between 1990 and 2010, but C stock changes from 2011 to 2014 are assumed to be similar to 2010 because activity data are not yet available for these years. Future inventories will be updated with new activity data when the data are made available, and the time series will be recalculated. See the *Cropland Remaining Cropland* section for additional discussion of the Tier 3 methodology for mineral soils.

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[47] Biogeochemical cycles are the flow of chemical elements and compounds between living organisms and the physical environment.

Tier 2 Approach

The Tier 2 approach is based on the same methods described in the Tier 2 portion of *Cropland Remaining Cropland* section for mineral soils, with the exception of the land use and management data that are used in the Inventory for federal grasslands. The NRI (USDA-NRCS 2013) provides land use and management histories for all non-federal lands, and is the basis for the Tier 2 analysis for these areas. However, NRI does not provide land use information on federal lands. These data are based on the National Land Cover Database (NLCD) (Fry et al. 2011; Homer et al. 2007; Homer et al. 2015). In addition, the Bureau of Land Management (BLM) manages some of the federal grasslands, and has compiled information on grassland condition through the BLM Rangeland Inventory (BLM 2014). To estimate soil C stock changes from federal grasslands, rangeland conditions in the BLM data are aligned with IPCC grassland management categories of nominal, moderately degraded, and severely degraded in order to apply the appropriate emission factors. Further elaboration on the Tier 2 methodology and data used to estimate C stock changes from mineral soils are described in Annex 3.12.

Additional Mineral C Stock Change Calculations

A Tier 2 method is used to adjust annual C stock change estimates for mineral soils between 1990 and 2014 to account for additional C stock changes associated with sewage sludge amendments. Estimates of the amounts of sewage sludge N applied to agricultural land are derived from national data on sewage sludge generation, disposition, and N content. Although sewage sludge can be added to land managed for other land uses, it is assumed that agricultural amendments only occur in *Grassland Remaining Grassland*. Cropland is not likely to be amended with sewage sludge due to the high metal content and other pollutants in human waste. Total sewage sludge generation data for 1988, 1996, and 1998, in dry mass units, are obtained from EPA (1999) and estimates for 2004 are obtained from an independent national biosolids survey (NEBRA 2007). These values are linearly interpolated to estimate values for the intervening years, and linearly extrapolated to estimate values for years since 2004. N application rates from Kellogg et al. (2000) are used to determine the amount of area receiving sludge amendments. The soil C storage rate is estimated at 0.38 metric tons C per hectare per year for sewage sludge amendments to grassland as described above. The stock change rate is based on country-specific factors and the IPCC default method (see Annex 3.12 for further discussion).

Organic Soil Carbon Stock Changes

Annual C emissions from drained organic soils in *Grassland Remaining Grassland* are estimated using the Tier 2 method provided in IPCC (2006), which utilizes U.S.-specific C loss rates (Ogle et al. 2003) rather than default IPCC rates. For more information, see the *Cropland Remaining Cropland* section for organic soils.

Uncertainty and Time-Series Consistency

Uncertainty analysis for mineral soil C stock changes using the Tier 3 and Tier 2 methodologies are based on a Monte Carlo approach that is described in the *Cropland Remaining Cropland* section. The uncertainty for annual C emission estimates from drained organic soils in *Grassland Remaining Grassland* is estimated using a Monte Carlo approach, which is also described in the *Cropland Remaining Cropland* section.

Uncertainty estimates are presented in Table 6-39 for each subsource (i.e., mineral soil C stocks and organic soil C stocks) and the method applied in the inventory analysis (i.e., Tier 2 and Tier 3). Uncertainty estimates from the Tier 2 and 3 approaches are combined using the simple error propagation methods provided by the IPCC (2006), i.e., by taking the square root of the sum of the squares of the standard deviations of the uncertain quantities. The combined uncertainty for soil C stocks in *Grassland Remaining Grassland* ranges from -1,006 percent below to 1,013 percent above the 2014 stock change estimate of 3.8 MMT CO_2 Eq. The large relative uncertainty is due to the almost zero level of change in soil C for 2014 even though the absolute amount of uncertainty is comparable to other land-use categories in this Inventory.

Table 6-39: Approach 2 Quantitative Uncertainty Estimates for C Stock Changes Occurring Within *Grassland Remaining Grassland* (MMT CO_2 Eq. and Percent)

Source	2014 Flux Estimate (MMT CO_2 Eq.)	Uncertainty Range Relative to Flux Estimate[a] (MMT CO_2 Eq.)		(%)	
		Lower Bound	Upper Bound	Lower Bound	Upper Bound
Mineral Soil C Stocks Grassland Remaining Grassland, Tier 3 Methodology	1.1	(35.8)	38.0	-3,401%	+3,401%
Mineral Soil C Stocks: Grassland Remaining Grassland, Tier 2 Methodology	(0.3)	(8.8)	9.3	-3,307%	+3,680%
Mineral Soil C Stocks: Grassland Remaining Grassland, Tier 2 Methodology (Change in Soil C due to Sewage Sludge Amendments)	(1.4)	(2.1)	(0.7)	-50%	+50%
Organic Soil C Stocks: Grassland Remaining Grassland, Tier 2 Methodology	4.3	2.2	7.2	-49%	+66%
Combined Uncertainty for Flux Associated with Agricultural Soil Carbon Stock Change in Grassland Remaining Grassland	**3.8**	**(34.2)**	**42.0**	**-1,006%**	**+1,013%**

[a] Range of C stock change estimates predicted by Monte Carlo Stochastic Simulation for a 95 percent confidence interval.
Notes: Totals may not sum due to independent rounding. Parentheses indicate negative values.

Uncertainty is also associated with a lack of reporting on biomass and litter C stock changes and non-CO_2 greenhouse gas emissions from grassland fires. Biomass C stock changes may be significant for managed grasslands with woody encroachment despite not having attained enough tree cover to be considered forest lands. This Inventory does not currently include the non-CO_2 greenhouse gas emissions that occur with biomass burning. Grassland burning is not as common in the United States as in other regions of the world, but fires do occur through both natural ignition sources and prescribed burning. Changes in dead organic matter C stocks are assumed to be negligible in grasslands over annual time frames, although there are certainly significant changes at sub-annual time scales across seasons.

Methodological recalculations are applied to the entire time series to ensure time-series consistency from 1990 through 2014. Details on the emission trends through time are described in more detail in the Methodology section, above.

QA/QC and Verification

See the QA/QC and Verification section in *Cropland Remaining Cropland*.

Recalculations Discussion

Methodological recalculations in the current Inventory are associated with the following improvements, including 1) incorporation of updated NRI data for 1990 through 2010; 2) inclusion of federal grasslands in the Tier 2 analysis; and 3) improving the simulation of hydric soils in DAYCENT. As a result of these improvements to the Inventory, SOC stocks increased on average across the time series, equivalent to an uptake of 4.9 MMT CO_2 eq., which is a 20 percent increase in the reported soil C stock changes compared to the previous Inventory.

Planned Improvements

Grasslands in Alaska are not currently included in the Inventory. This is a significant planned improvement and estimates are expected to be available for the 1990 through 2015 Inventory. Another key planned improvement is to estimate biomass C stock changes for grasslands and non-CO_2 greenhouse gas emissions from burning of grasslands. For information about other improvements, see the Planned Improvements section in *Cropland Remaining Cropland*.

6.7 Land Converted to Grassland (IPCC Source Category 4C2)

Land Converted to Grassland includes all grassland in an Inventory year that had been in another land use(s) during the previous 20 years[48] (USDA-NRCS 2013). For example, cropland or forest land converted to grassland during the past 20 years would be reported in this category. Recently-converted lands are retained in this category for 20 years as recommended by IPCC (2006). Grassland includes pasture and rangeland that are used primarily but not exclusively for livestock grazing. Rangelands are typically extensive areas of native grassland that are not intensively managed, while pastures are typically seeded grassland (possibly following tree removal) that may also have additional management, such as irrigation or interseeding of legumes. This Inventory includes all grasslands in the conterminous United States and Hawaii, but does not include *Land Converted to Grassland* in Alaska. Consequently there is a discrepancy between the total amount of managed area for *Land Converted to Grassland* (see Section 6.1 Representation of the U.S. Land Base) and the grassland area included in the inventory analysis (IPCC Source Category 4C2—Section 6.7).

Land-use change can lead to large losses of C to the atmosphere, particularly conversions from forest land (Houghton et al. 1983). Moreover, conversion of forest to another land use (i.e., deforestation) is one of the largest anthropogenic sources of emissions to the atmosphere globally (Schimel 1995), although this source may be declining according to a recent assessment (Tubiello et al. 2015).

IPCC (2006) recommend reporting changes in biomass, dead organic matter, and soil organic C (SOC) stocks due to land use change.[49] All soil C stock changes are estimated and reported for *Land Converted to Grassland*, but there is limited reporting of other pools in this Inventory. Loss of aboveground biomass C from *Forest Converted to Grassland* is reported, but loss of C from belowground biomass, dead wood and litter pools with forest conversion are not included in this Inventory.[50] In addition, biomass C stock changes are not estimated for other land use conversions (other than forest land) to grassland.[51]

Land use and management of mineral soils in *Land Converted to Grassland* led to an increase in soil C stocks between 1990 and 2014 (see Table 6-40 and Table 6-41). The average soil C stock change for mineral soils between 1990 and 2014 sequestered 10.6 MMT CO_2 Eq. from the atmosphere (2.9 MMT C). In contrast, over the same period, drainage of organic soils for grassland management led to CO_2 emissions to the atmosphere of 1.5 MMT CO_2 Eq. (0.4 MMT C). In addition, aboveground woody biomass C losses from *Forest Land Converted to Grasslands* led to CO_2 emissions to the atmosphere of 49.5 MMT CO_2 Eq. (13.5 MMT C) in 2014. The total net C stock change in 2014 for *Land Converted to Grassland* is estimated as a loss of 40.4 MMT CO_2 Eq. (11.0 MMT C), which is a 3 percent increase in emissions compared to the emissions in the initial reporting year of 1990.

Table 6-40: Net CO_2 Flux from Soil and Biomass C Stock Changes for *Land Converted to Grassland* (MMT CO_2 Eq.)

	1990		2005		2010	2011	2012	2013	2014
Cropland Converted to Grassland									
Mineral Soils	(6.9)		(9.7)		(9.1)	(8.6)	(8.6)	(8.6)	(8.6)

[48] NRI survey locations are classified according to land-use histories starting in 1979, and consequently the classifications are based on less than 20 years from 1990 to 2001. This may have led to an underestimation of *Land Converted to Grassland* in the early part of the time series to the extent that some areas are converted to grassland prior to 1979.

[49] CO_2 emissions associated with liming and urea fertilization are also estimated but included in Section 6.4 *Cropland Remaining Cropland*.

[50] A planned improvement is to estimate the losses of carbon from belowground biomass, dead wood and litter with *Forest Converted to Grassland*.

[51] Changes in biomass C stocks are not currently reported for other conversions to grassland (other than forest land), but this is a planned improvement for a future inventory. Note: changes in dead organic matter are assumed to negligible for other land use conversions (i.e., other than forest land) to grassland based on the Tier 1 method in IPCC (2006).

Organic Soils	0.5	1.0	1.1	1.2	1.2	1.2	1.2
Forest Converted to Grassland							
Biomass	47.0	54.3	49.0	49.0	49.5	49.5	49.5
Mineral Soils	(0.5)	(1.0)	(0.8)	(0.8)	(0.8)	(0.8)	(0.8)
Organic Soils	+	+	+	+	+	+	+
Other Lands Converted Grassland							
Mineral Soils	(0.6)	(1.1)	(0.8)	(0.8)	(0.8)	(0.8)	(0.8)
Organic Soils	+	0.0	+	+	+	+	+
Settlements Converted Grassland							
Mineral Soils	(0.1)	(0.2)	(0.1)	(0.1)	(0.1)	(0.1)	(0.1)
Organic Soils	+	+	+	+	+	+	+
Wetlands Converted Grassland							
Mineral Soils	(0.5)	(0.6)	(0.2)	(0.2)	(0.2)	(0.2)	(0.2)
Organic Soils	0.1	0.2	0.3	0.3	0.3	0.3	0.3
Total Biomass Flux	**47.0**	**54.3**	**49.0**	**49.0**	**49.5**	**49.5**	**49.5**
Total Mineral Soil Flux	**(8.6)**	**(12.5)**	**(11.2)**	**(10.6)**	**(10.6)**	**(10.6)**	**(10.6)**
Total Organic Soil Flux	**0.7**	**1.2**	**1.5**	**1.5**	**1.5**	**1.5**	**1.5**
Total Net Flux	**39.1**	**43.1**	**39.3**	**39.9**	**40.4**	**40.4**	**40.4**

+ Does not exceed 0.05 MMT CO_2 Eq.
Notes: Estimates after 2010 are based on NRI data from 2010 and therefore may not fully reflect changes occurring in the latter part of the time series. Totals may not sum due to independent rounding. Parentheses indicate net sequestration.

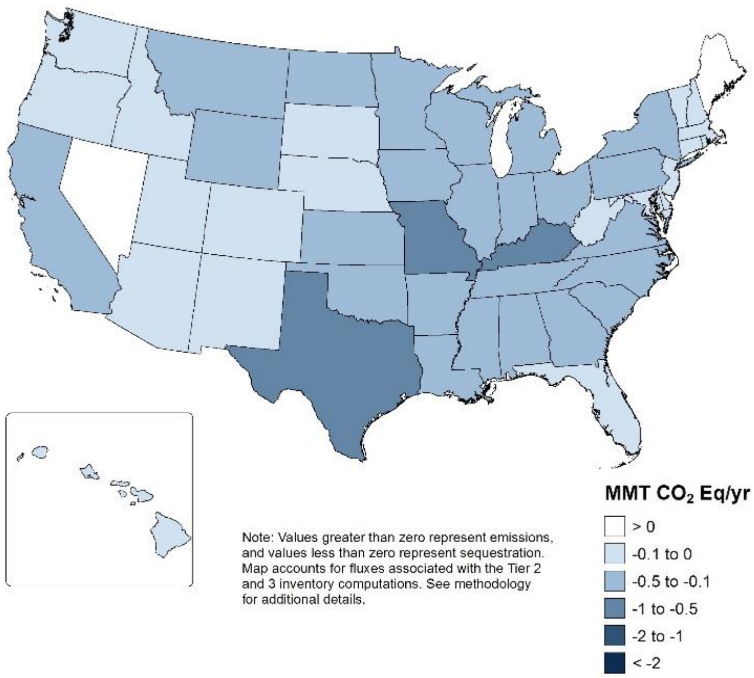
Table 6-41: Net CO_2 Flux from Soil and Biomass C Stock Changes for *Land Converted to Grassland* (MMT C)

	1990	2005	2010	2011	2012	2013	2014
Cropland Converted to Grassland							
Mineral Soils	(1.9)	(2.6)	(2.5)	(2.3)	(2.3)	(2.3)	(2.3)
Organic Soils	0.1	0.3	0.3	0.3	0.3	0.3	0.3
Forest Converted to Grassland							
Biomass	12.8	14.8	13.4	13.4	13.5	13.5	13.5
Mineral Soils	(0.1)	(0.3)	(0.2)	(0.2)	(0.2)	(0.2)	(0.2)
Organic Soils	+	+	+	+	+	+	+
Other Lands Converted Grassland							
Mineral Soils	(0.2)	(0.3)	(0.2)	(0.2)	(0.2)	(0.2)	(0.2)
Organic Soils	+	0.0	+	+	+	+	+
Settlements Converted Grassland							
Mineral Soils	(+)	(+)	(+)	(+)	(+)	(+)	(+)
Organic Soils	+	+	+	+	+	+	+
Wetlands Converted Grassland							
Mineral Soils	(0.1)	(0.2)	(0.1)	(0.1)	(0.1)	(0.1)	(0.1)
Organic Soils	+	0.1	0.1	0.1	0.1	0.1	0.1
Total Biomass Flux	**12.8**	**14.8**	**13.4**	**13.4**	**13.5**	**13.5**	**13.5**
Total Mineral Soil Flux	**(2.3)**	**(3.4)**	**(3.0)**	**(2.9)**	**(2.9)**	**(2.9)**	**(2.9)**
Total Organic Soil Flux	**0.2**	**0.3**	**0.4**	**0.4**	**0.4**	**0.4**	**0.4**
Total Net Flux	**10.7**	**11.8**	**10.7**	**10.9**	**11.0**	**11.0**	**11.0**

+ Does not exceed 0.05 MMT CO_2 Eq.
Notes: Estimates after 2010 are based on NRI data from 2010 and therefore may not fully reflect changes occurring in the latter part of the time series. Totals may not sum due to independent rounding. Parentheses indicate net sequestration.

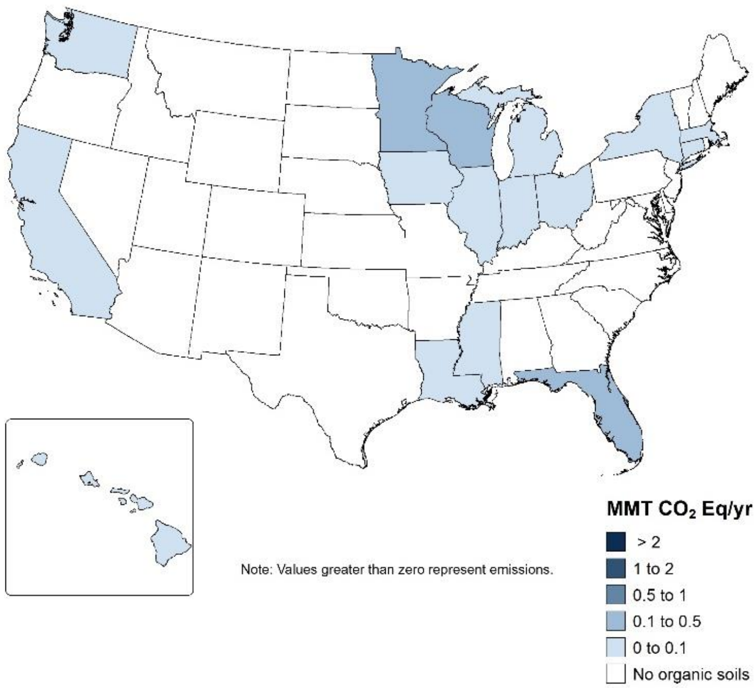
The spatial variability in the 2014 annual flux in CO_2 from mineral soils[52] is displayed in Figure 6-10 and from organic soils in Figure 6-11. Soil C stocks increased in most states for *Land Converted to Grassland*, which is largely driven by conversion of annual cropland into continuous pasture. The largest gains are in Texas, Missouri and Kentucky. For organic soils, the regions with the highest rates of emissions coincide with the largest concentrations of organic soils used for managed grasslands, including Southeastern Coastal Region (particularly Florida), upper Midwest and Northeast surrounding the Great Lakes, and the Pacific Coast.

Figure 6-10: Total Net Annual CO_2 Flux for Mineral Soils under Agricultural Management within States, 2014, *Land Converted to Grassland*



[52] A planned improvement is to include biomass C stock changes in the figures; currently the maps only include the spatial patterns associated with soil C stock changes.

Figure 6-11: Total Net Annual CO_2 Flux for Organic Soils under Agricultural Management within States, 2014, *Land Converted to Grassland*



Methodology

The following section includes a description of the methodology used to estimate changes in biomass and soil C stocks for *Land Converted to Grassland*, including: (1) loss of aboveground biomass C with conversion of forest to grassland; (2) agricultural land-use and management activities on mineral soils; and (3) agricultural land-use and management activities on organic soils. Belowground live biomass and dead organic matter C stock changes associated with conversion of forest land to grassland are not estimated in the current Inventory for *Land Converted to Grassland*.

Biomass Carbon Stock Changes

A Tier 2 method is applied to estimate aboveground biomass C stock changes[53] for *Forest land Converted to Grassland*. For this method, land is stratified by region, forest type, and site productivity and then assigned reference C density estimates for aboveground biomass for the grassland (assumed to be zero since no reference aboveground biomass C density estimates exist) and forest land use. The difference between the stocks is reported as the stock change under the assumption that the change occurred in the year of the conversion. Reference C density estimates for aboveground biomass for the forest land use have been estimated from data in the Forest Inventory and Analysis (FIA) program within the USDA Forest Service (USDA Forest Service 2015). If FIA plots include data on individual trees, aboveground C density estimates are based on Woodall et al. (2011), which is also known as the component ratio method, and is a function of tree volume, species, diameter, and, in some regions, height and site quality. See Annex 3.13 for more information about reference C density estimates for forest land.

[53] A planned improvement is to estimate the losses of C from belowground biomass, dead wood and litter with *Forest Converted to Grassland*.

Soil Carbon Stock Changes

Soil C stock changes are estimated for *Land Converted to Grassland* according to land-use histories recorded in the 2010 USDA NRI survey for non-federal lands (USDA-NRCS 2013). Land use and some management information (e.g., crop type, soil attributes, and irrigation) were originally collected for each NRI survey locations on a 5-year cycle beginning in 1982 In 1998, the NRI Program began collecting annual data, and the annual data are currently available through 2012 (USDA-NRCS 2015). However, this Inventory only uses NRI data through 2010 because newer data were not available in time to incorporate the additional years. NRI survey locations are classified as *Land Converted to Grassland* in a given year between 1990 and 2010 if the land use is grassland but had been classified as another use during the previous 20 years. NRI survey locations are classified according to land-use histories starting in 1979, and consequently the classifications are based on less than 20 years from 1990 to 1998. This may have led to an underestimation of *Land Converted to Grassland* in the early part of the time series to the extent that some areas are converted to grassland prior to 1979. For federal lands, the land use history is derived from land cover changes in the National Land Cover Dataset (Homer et al. 2007; Fry et al. 2011; Homer et al. 2015).

Mineral Soil Carbon Stock Changes

An IPCC Tier 3 model-based approach (Ogle et al. 2010) is applied to estimate C stock changes for *Land Converted to Grassland* on most mineral soils. C stock changes on the remaining soils are estimated with an IPCC Tier 2 approach (Ogle et al. 2003), including prior cropland used to produce vegetables, tobacco, and perennial/horticultural crops; land areas with very gravelly, cobbly, or shaley soils (greater than 35 percent by volume); and land converted to grassland from another land use other than cropland.

Tier 3 Approach. Mineral SOC stocks and stock changes are estimated using the DAYCENT biogeochemical[54] model (Parton et al. 1998; Del Grosso et al. 2001, 2011). The DAYCENT model utilizes the soil C modeling framework developed in the Century model (Parton et al. 1987, 1988, 1994; Metherell et al. 1993), but has been refined to simulate dynamics at a daily time-step. Historical land-use patterns and irrigation histories are simulated with DAYCENT based on the 2010 USDA NRI survey (USDA-NRCS 2013). C stocks and 95 percent confidence intervals are estimated for each year between 1990 and 2010, but C stock changes from 2010 to 2014 are assumed to be similar to 2010. Future inventories will be updated with new activity data when the data are made available, and the time series will be recalculated (See Planned Improvements section in *Cropland Remaining Cropland*). See the *Cropland Remaining Cropland* section and Annex 3.12 for additional discussion of the Tier 3 methodology for mineral soils.

Tier 2 Approach. For the mineral soils not included in the Tier 3 analysis, SOC stock changes are estimated using a Tier 2 Approach for *Land Converted to Grassland* as described in the Tier 2 Approach for mineral soils in the *Grassland Remaining Grassland* section.

Organic Soil Carbon Stock Changes

Annual C emissions from drained organic soils in *Land Converted to Grassland* are estimated using the Tier 2 method provided in IPCC (2006), with U.S.-specific C loss rates (Ogle et al. 2003) as described in the *Cropland Remaining Cropland* section for organic soils.

Uncertainty and Time-Series Consistency

The uncertainty analysis for aboveground biomass C losses with *Forest Converted to Grassland* is conducted in the same way as the uncertainty assessment for forest ecosystem C flux in the *Forest Land Remaining Forest Land* category. Sample and model-based error are combined using simple error propagation methods provided by the IPCC (2006). For additional details see the Uncertainty Analysis in Annex 3.13. Uncertainty analysis for mineral soil C stock changes using the Tier 3 and Tier 2 methodologies are based on a Monte Carlo approach that is described in the *Cropland Remaining Cropland* section. The uncertainty for annual C emission estimates from

[54] Biogeochemical cycles are the flow of chemical elements and compounds between living organisms and the physical environment.

drained organic soils in *Land Converted to Grassland* is estimated using a Monte Carlo approach, which is also described in the *Cropland Remaining Cropland* section.

Uncertainty estimates are presented in Table 6-42 for each subsource (i.e., biomass C stocks, mineral soil C stocks and organic soil C stocks) and the method applied in the inventory analysis (i.e., Tier 2 and Tier 3). Uncertainty estimates from the Tier 2 and 3 approaches are combined using the simple error propagation methods provided by the IPCC (2006), i.e., by taking the square root of the sum of the squares of the standard deviations of the uncertain quantities. The combined uncertainty for total C stocks in *Land Converted to Grassland* ranges from 26 percent below to 27 percent above the 2014 stock change estimate of 40.4 MMT CO_2 Eq.

Table 6-42: Approach 2 Quantitative Uncertainty Estimates for Soil C Stock Changes occurring within *Land Converted to Grassland* (MMT CO_2 Eq. and Percent)

Source	2014 Flux Estimate (MMT CO_2 Eq.)	Uncertainty Range Relative to Flux Estimate[a] (MMT CO_2 Eq.)		(%)	
		Lower Bound	Upper Bound	Lower Bound	Upper Bound
Cropland Converted to Grassland	**(7.4)**	**(16.3)**	**1.4**	**-119%**	**+119%**
Mineral Soil C Stocks: Tier 3	(7.2)	(15.9)	1.6	-122%	+122%
Mineral Soil C Stocks: Tier 2	(1.4)	(2.2)	(0.8)	-55%	+47%
Organic Soil C Stocks: Tier 2	1.2	0.4	2.3	-63%	+96%
Forests Converted to Grassland	**48.7**	**42.8**	**54.9**	**-12%**	**13%**
Biomass C Stocks	49.5	43.7	55.6	-12%	12%
Mineral Soil C Stocks: Tier 2	(0.8)	(1.8)	0.1	-120%	112%
Organic Soil C Stocks: Tier 2	+	+	+	-100%	300%
Other Lands Converted to Grassland	**(0.8)**	**(1.3)**	**(0.4)**	**-55%**	**+47%**
Mineral Soil C Stocks: Tier 2	(0.8)	(1.3)	(0.4)	-54%	+46%
Organic Soil C Stocks: Tier 2	+	0.0	+	-100%	+179%
Settlements Converted to Grassland	**(0.1)**	**(0.2)**	**(+)**	**-63%**	**+56%**
Mineral Soil C Stocks: Tier 2	(0.1)	(0.2)	(0.1)	-55%	+47%
Organic Soil C Stocks: Tier 2	+	+	+	-79%	+125%
Wetlands Converted to Grasslands	**0.1**	**(0.1)**	**0.3**	**-314%**	**+382%**
Mineral Soil C Stocks: Tier 2	(0.2)	(0.4)	(0.1)	-52%	+44%
Organic Soil C Stocks: Tier 2	0.3	0.1	0.5	-51%	+71%
Total: Land Converted to Grassland	**40.4**	**29.8**	**51.2**	**-26%**	**27%**
Biomass C Stocks	**49.5**	**43.7**	**55.6**	**-12%**	**12%**
Mineral Soil C Stocks: Tier 3	**(7.2)**	**(15.9)**	**1.6**	**-122%**	**122%**
Mineral Soil C Stocks: Tier 2	**(3.4)**	**(4.7)**	**(2.2)**	**-39%**	**35%**
Organic Soil C Stocks: Tier 2	**1.5**	**0.7**	**2.6**	**-50%**	**77%**

+ Absolute value does not exceed 0.05 MMT CO_2 Eq.

[a] Range of C stock change estimates predicted by Monte Carlo Stochastic Simulation for a 95 percent confidence interval.

Notes: Totals may not sum due to independent rounding. Parentheses indicate negative values.

Uncertainty is also associated with lack of reporting non-CO_2 greenhouse gas emissions that occur with biomass burning. Grassland burning is not as common in the United States as in other regions of the world, but fires do occur through both natural ignition sources and prescribed burning. Changes in dead organic matter C stocks are assumed to be negligible in grasslands over annual time frames, although there are likely significant changes at sub-annual time scales across seasons.

Methodological recalculations are applied to the entire time series to ensure time-series consistency from 1990 through 2014. Details on the emission trends through time are described in more detail in the above Methodology section.

QA/QC and Verification

See the QA/QC and Verification section in *Cropland Remaining Cropland*.

Recalculations Discussion

Methodological recalculations in the current Inventory are associated with the following improvements, including: 1) incorporation of updated NRI data for 1990 through 2010; 2) inclusion of federal grasslands in the Tier 2 analysis; 3) improving the simulation of hydric soils in DAYCENT; and 4) incorporating the aboveground biomass C stock losses with *Forest Land Converted to Grassland*. As a result of these improvements to the Inventory, changes in stocks declined by an average of 49.0 MMT CO_2 Eq. annually over the time series. This represents a 565 percent increase in the losses of carbon with *Land Converted to Grassland* compared to the previous Inventory, and is largely driven by the inclusion of aboveground biomass C loss from *Forest Land Converted to Grasslands* in this category instead of *Forest Land Remaining Forest Land* where it was included in the previous Inventory submissions.

Planned Improvements

Soil C stock changes with land use conversion from forest land to grassland are undergoing further evaluation to ensure consistency in the time series. Different methods are used to estimate soil C stock changes in forest land and grasslands, and while the areas have been reconciled between these land uses, there has been limited evaluation of the consistency in C stock changes with conversion from forest land to grassland. This planned improvement may not be fully implemented for another year, depending on resource availability.

The impact of *Forest Land Converted to Grassland* on belowground biomass and dead organic matter pools are not estimated in the current Inventory, and so another planned improvement is to estimate changes in C stocks for these pools in the next Inventory. In addition, biomass C stock changes will be estimated for *Cropland Converted to Grassland*, and other land use conversions to grassland to the extent that data are available.

One additional planned improvement for the *Land Converted to Grassland* category is to develop an inventory of C stock changes for grasslands in Alaska. For information about other improvements, see the Planned Improvements section in *Cropland Remaining Cropland* and *Grassland Remaining Grassland*.

6.8 Wetlands Remaining Wetlands (IPCC Source Category 4D1)

Peatlands Remaining Peatlands

Emissions from Managed Peatlands

Managed peatlands are peatlands which have been cleared and drained for the production of peat. The production cycle of a managed peatland has three phases: land conversion in preparation for peat extraction (e.g., clearing surface biomass, draining), extraction, and abandonment, restoration, or conversion of the land to another use.

Carbon dioxide emissions from the removal of biomass and the decay of harvested peat constitute the major greenhouse gas flux from managed peatlands. Managed peatlands may also emit CH_4 and N_2O, however, this is a very small component of total emissions from this source category in the United States. The natural production of CH_4 is largely reduced but not entirely shut down when peatlands are drained in preparation for peat extraction (Strack et al. 2004 as cited in the *2006 IPCC Guidelines*). Drained land surface and ditch networks contribute to the CH_4 flux in peatlands managed for peat extraction. Methane emissions were considered insignificant under IPCC Tier 1 methodology (IPCC 2006), but are included in the emissions estimates for *Peatlands Remaining Peatlands* consistent with the *2013 Supplement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories: Wetlands* (IPCC 2013). Nitrous oxide emissions from managed peatlands depend on site fertility. In addition, abandoned and restored peatlands continue to release greenhouse gas emissions. This Inventory estimates CO_2, N_2O, and CH_4 emissions from peatlands managed for peat extraction in accordance with IPCC (2006 and 2013) guidelines.

CO_2, N_2O, and CH_4 Emissions from *Peatlands Remaining Peatlands*

IPCC (2013) recommends reporting CO_2, N_2O, and CH_4 emissions from lands undergoing active peat extraction (i.e., *Peatlands Remaining Peatlands*) as part of the estimate for emissions from managed wetlands. Peatlands occur where plant biomass has sunk to the bottom of water bodies and water-logged areas and exhausted the oxygen supply below the water surface during the course of decay. Due to these anaerobic conditions, much of the plant matter does not decompose but instead forms layers of peat over decades and centuries. In the United States, peat is extracted for horticulture and landscaping growing media, and for a wide variety of industrial, personal care, and other products. It has not been used for fuel in the United States for many decades. Peat is harvested from two types of peat deposits in the United States: sphagnum bogs in northern states (e.g., Minnesota) and wetlands in states further south (e.g., Florida). The peat from sphagnum bogs in northern states, which is nutrient poor, is generally corrected for acidity and mixed with fertilizer. Production from more southerly states is relatively coarse (i.e., fibrous) but nutrient rich.

IPCC (2006 and 2013) recommend considering both on-site and off-site emissions when estimating CO_2 emissions from *Peatlands Remaining Peatlands* using the Tier 1 approach. Current methodologies estimate only on-site N_2O and CH_4 emissions, since off-site N_2O estimates are complicated by the risk of double-counting emissions from nitrogen fertilizers added to horticultural peat, and off-site CH_4 emissions are not relevant given the non-energy uses of peat, so methodologies are not provided in IPCC (2013) guidelines. On-site emissions from managed peatlands occur as the land is cleared of vegetation and the underlying peat is exposed to sun and weather. As this occurs, some peat deposit is lost and CO_2 is emitted from the oxidation of the peat. Since N_2O emissions from saturated ecosystems tend to be low unless there is an exogenous source of nitrogen, N_2O emissions from drained peatlands are dependent on nitrogen mineralization and therefore on soil fertility. Peatlands located on highly fertile soils contain significant amounts of organic nitrogen in inactive form. Draining land in preparation for peat extraction allows bacteria to convert the nitrogen into nitrates which leach to the surface where they are reduced to N_2O, and contributes to the activity of methanogens, which produce CH_4, and methanotrophs which oxidize CH_4 into CO_2 (Blodau 2002; Treat et al. 2007 as cited in IPCC 2013). Ditch networks, which are constructed in order to drain the water off in preparation for peat extraction, also contribute to the flux of CH_4 through *in situ* production and lateral transfer of CH_4 from the organic soil matrix (IPCC 2013).

The two sources of off-site CO_2 emissions from managed peatlands are waterborne carbon losses and the horticultural and landscaping use of peat. Drainage waters in peatlands accumulate dissolved organic carbon which then reacts within aquatic ecosystems and is converted to CO_2 where it is then emitted to the atmosphere (Billet et al. 2004 as cited in IPCC 2013). Most (nearly 98 percent) of the CO_2 emissions from peat occur off-site, as the peat is processed and sold to firms which, in the United States, use it predominantly forhorticultural and landscaping purposes. Nutrient-poor (but fertilizer-enriched) peat tends to be used in bedding plants and in greenhouse and plant nursery production, whereas nutrient-rich (but relatively coarse) peat is used directly in landscaping, athletic fields, golf courses, and plant nurseries.

Total emissions from *Peatlands Remaining Peatlands* were estimated to be 0.8 MMT CO_2 Eq. in 2014 (see Table 6-43) comprising 0.8 MMT CO_2 Eq. (842 kt) of CO_2, 0.001 MMT CO_2 Eq. (0.002 kt) of N_2O, and 0.004 MMT CO_2 Eq. (0.17 kt) of CH_4. Total emissions in 2014 were about 9 percent larger than total emissions in 2013. Peat production in Alaska in 2014 was not reported in *Alaska's Mineral Industry 2013* report. However, peat production reported in the lower 48 states in 2014 was 10 percent more than in 2013, and as a result, the emissions from *Peatlands Remaining Peatlands* in the lower 48 states and Alaska were greater in 2014 compared to 2013.

Total emissions from *Peatlands Remaining Peatlands* have fluctuated between 0.8 and 1.3 MMT CO_2 Eq. across the time series with a decreasing trend from 1990 until 1993 followed by an increasing trend through 2000. After 2000, emissions generally decreased until 2006 and then increased until 2009, when the trend reversed until a slight increase from 2013 to 2014. Carbon dioxide emissions from *Peatlands Remaining Peatlands* have fluctuated between 0.8 and 1.3 MMT CO_2 across the time series, and these emissions drive the trends in total emissions. CH_4 and N_2O emissions remained close to zero across the time series.

Table 6-43: Emissions from *Peatlands Remaining Peatlands* (MMT CO_2 Eq.)

Gas	1990		2005		2010	2011	2012	2013	2014
CO_2	1.1		1.1		1.0	0.9	0.8	0.8	0.8
Off-site	1.0		1.0		1.0	0.9	0.8	0.7	0.8

On-site	0.1		0.1		0.1	0.1	0.1	+	0.1
N_2O (On-site)	+		+		+	+	+	+	+
CH_4 (On-site)	+		+		+	+	+	+	+
Total	**1.1**		**1.1**		**1.0**	**0.9**	**0.8**	**0.8**	**0.8**

+ Does not exceed 0.05 MMT CO_2 Eq.
Notes: These numbers are based on U.S. production data in accordance with Tier 1 guidelines, which does not take into account imports, exports, and stockpiles (i.e., apparent consumption). Off-site N_2O emissions are not estimated to avoid double-counting N_2O emitted from the fertilizer that the peat is mixed with prior to horticultural use (see IPCC 2006). Totals may not sum due to independent rounding.

Table 6-44: Emissions from *Peatlands Remaining Peatlands* (kt)

Gas	1990		2005		2010	2011	2012	2013	2014
CO_2	1,055		1,101		1,022	926	812	770	842
Off-site	985		1,030		956	866	760	720	787
On-site	70		71		66	60	53	50	55
N_2O (On-site)	+		+		+	+	+	+	+
CH_4 (On-site)	+		+		+	+	+	+	+

+ Does not exceed 0.5 kt.
Notes: These numbers are based on U.S. production data in accordance with Tier 1 guidelines, which does not take into account imports, exports, and stockpiles (i.e., apparent consumption). Off-site N_2O emissions are not estimated to avoid double-counting N_2O emitted from the fertilizer that the peat is mixed with prior to horticultural use (see IPCC 2006). Totals may not sum due to independent rounding.

Methodology

Off-site CO_2 Emissions

Off-site CO_2 emissions from domestic peat production were estimated using a Tier 1 methodology consistent with IPCC (2006). The emissions were calculated by apportioning the annual weight of peat produced in the United States (Table 6-45) into peat extracted from nutrient-rich deposits and peat extracted from nutrient-poor deposits using annual percentage-by-weight figures. These nutrient-rich and nutrient-poor production values were then multiplied by the appropriate default C fraction conversion factor taken from IPCC (2006) in order to obtain off-site CO_2 emission estimates. For the lower 48 states, both annual percentages of peat type by weight and domestic peat production data were sourced from estimates and industry statistics provided in the *Minerals Yearbook* and *Mineral Commodity Summaries* from the U.S. Geological Survey (USGS 1995–2015a; USGS 2015b). To develop these data, the U.S. Geological Survey (USGS; U.S. Bureau of Mines prior to 1997) obtained production and use information by surveying domestic peat producers. On average, about 75 percent of the peat operations respond to the survey; and USGS estimates data for non-respondents on the basis of prior-year production levels (Apodaca 2011).

The Alaska estimates rely on reported peat production from the annual *Alaska's Mineral Industry* reports (DGGS 1997–2014). Similar to the U.S. Geological Survey, the Alaska Department of Natural Resources, Division of Geological & Geophysical Surveys (DGGS) solicits voluntary reporting of peat production from producers for the *Alaska's Mineral Industry* report. However, the report does not estimate production for the non-reporting producers, resulting in larger inter-annual variation in reported peat production from Alaska depending on the number of producers who report in a given year (Szumigala 2011). In addition, in both the lower 48 states and Alaska, large variations in peat production can also result from variations in precipitation and the subsequent changes in moisture conditions, since unusually wet years can hamper peat production. The methodology estimates Alaska emissions separately from lower 48 emissions because the state conducts its own mineral survey and reports peat production by volume, rather than by weight (Table 6-46). However, volume production data were used to calculate off-site CO_2 emissions from Alaska applying the same methodology but with volume-specific C fraction conversion factors from IPCC (2006).[55] Peat production was not reported for 2014 in *Alaska's Mineral Industry 2013* report (DGGS 2014); therefore Alaska's peat production in 2014 (reported in cubic yards) was assumed to be equal to its peat production in 2013.

Consistent with IPCC (2013) guidelines, off-site CO_2 emissions from dissolved organic carbon transported off-site were estimated based on the total area of peatlands managed for peat extraction, which is calculated from production data using the methodology described in the *On-Site CO_2 Emissions* section below. Carbon dioxide emissions from dissolved organic C were estimated by multiplying the area of peatlands by the default emission factor for dissolved organic C provided in IPCC (2013).

The *apparent consumption* of peat, which includes production plus imports minus exports plus the decrease in stockpiles, in the United States is over two-and-a-half times the amount of domestic peat production. However, consistent with the Tier 1 method whereby only domestic peat production is accounted for when estimating off-site emissions, off-site CO_2 emissions from the use of peat not produced within the United States are not included in the Inventory. The United States has largely imported peat from Canada for horticultural purposes; from 2010 to 2013, imports of sphagnum moss (nutrient-poor) peat from Canada represented 63 percent of total U.S. peat imports (USGS 2015c). Most peat produced in the United States is reed-sedge peat, generally from southern states, which is classified as nutrient rich by IPCC (2006). Higher-tier calculations of CO_2 emissions from apparent consumption would involve consideration of the percentages of peat types stockpiled (nutrient rich versus nutrient poor) as well as the percentages of peat types imported and exported.

Table 6-45: Peat Production of Lower 48 States (kt)

Type of Deposit	1990		2005		2010	2011	2012	2013	2014
Nutrient-Rich	595.1		657.6		558.9	511.2	409.9	418.5	459.0
Nutrient-Poor	55.4		27.4		69.1	56.8	78.1	46.5	51.0
Total Production	**692.0**		**685.0**		**628.0**	**568.0**	**488.0**	**465.0**	**510.0**

Sources: United States Geological Survey (USGS) (1991–2015a) *Minerals Yearbook: Peat* (1994–2014); United States Geological Survey (USGS) (2015b) *Mineral Commodity Summaries: Peat* (2014).

Table 6-46: Peat Production of Alaska (Thousand Cubic Meters)

	1990		2005		2010	2011	2012	2013	2014
Total Production	49.7		47.8		59.8	61.5	93.1	93.1	93.1

Sources: Division of Geological & Geophysical Surveys (DGGS), Alaska Department of Natural Resources (1997–2014) *Alaska's Mineral Industry Report (1997–2013).*

On-site CO_2 Emissions

IPCC (2006) suggests basing the calculation of on-site emission estimates on the area of peatlands managed for peat extraction differentiated by the nutrient type of the deposit (rich versus poor). Information on the area of land managed for peat extraction is currently not available for the United States, but in accordance with IPCC (2006), an average production rate per area for the industry was applied to derive an area estimate. In a mature industrialized peat industry, such as exists in the United States and Canada, the vacuum method can extract up to 100 metric tons per hectare per year (Cleary et al. 2005 as cited in IPCC 2006).[56] In the lower 48 states, the area of land managed for peat extraction was estimated using nutrient-rich and nutrient-poor production data and the assumption that 100 metric tons of peat are extracted from a single hectare in a single year. The nutrient-rich and nutrient-poor annual land area estimates were then multiplied by the IPCC (2013) default emission factor in order to calculate on-site CO_2 emission estimates. Production data are not available by weight for Alaska. In order to calculate on-site

[55] Peat produced from Alaska was assumed to be nutrient poor; as is the case in Canada, "where deposits of high-quality [but nutrient poor] sphagnum moss are extensive" (USGS 2008).

[56] The vacuum method is one type of extraction that annually "mills" or breaks up the surface of the peat into particles, which then dry during the summer months. The air-dried peat particles are then collected by vacuum harvesters and transported from the area to stockpiles (IPCC 2006).

emissions resulting from *Peatlands Remaining Peatlands* in Alaska, the production data by volume were converted to weight using annual average bulk peat density values, and then converted to land area estimates using the same assumption that a single hectare yields 100 metric tons. The IPCC (2006) on-site emissions equation also includes a term which accounts for emissions resulting from the change in C stocks that occurs during the clearing of vegetation prior to peat extraction. Area data on land undergoing conversion to peatlands for peat extraction is also unavailable for the United States. However, USGS records show that the number of active operations in the United States has been declining since 1990; therefore, it seems reasonable to assume that no new areas are being cleared of vegetation for managed peat extraction. Other changes in C stocks in living biomass on managed peatlands are also assumed to be zero under the Tier 1 methodologies (IPCC 2006 and 2013).

On-site N_2O Emissions

IPCC (2006) suggests basing the calculation of on-site N_2O emission estimates on the area of nutrient-rich peatlands managed for peat extraction. These area data are not available directly for the United States, but the on-site CO_2 emissions methodology above details the calculation of area data from production data. In order to estimate N_2O emissions, the area of nutrient rich *Peatlands Remaining Peatlands* was multiplied by the appropriate default emission factor taken from IPCC (2013).

On-site CH_4 Emissions

IPCC (2013) also suggests basing the calculation of on-site CH_4 emission estimates on the total area of peatlands managed for peat extraction. Area data is derived using the calculation from production data described in the On-site CO_2 Emissions section above. In order to estimate CH_4 emissions from drained land surface, the area of *Peatlands Remaining Peatlands* was multiplied by the emission factor for direct CH_4 emissions taken from IPCC (2013). In order to estimate CH_4 emissions from drainage ditches, the total area of peatland was multiplied by the default fraction of peatland area that contains drainage ditches, and the appropriate emission factor taken from IPCC (2013).

Uncertainty and Time-Series Consistency

A Monte Carlo (Approach 2) uncertainty analysis was applied to estimate the uncertainty of CO_2, CH_4, and N_2O emissions from *Peatlands Remaining Peatlands*, using the following assumptions:

- The uncertainty associated with peat production data was estimated to be ± 25 percent (Apodaca 2008) and assumed to be normally distributed.
- The uncertainty associated with peat production data stems from the fact that the USGS receives data from the smaller peat producers but estimates production from some larger peat distributors. The peat type production percentages were assumed to have the same uncertainty values and distribution as the peat production data (i.e., ± 25 percent with a normal distribution).
- The uncertainty associated with the reported production data for Alaska was assumed to be the same as for the lower 48 states, or ± 25 percent with a normal distribution. It should be noted that the DGGS estimates that around half of producers do not respond to their survey with peat production data; therefore, the production numbers reported are likely to underestimate Alaska peat production (Szumigala 2008).
- The uncertainty associated with the average bulk density values was estimated to be ± 25 percent with a normal distribution (Apodaca 2008).
- IPCC (2006 and 2013) gives uncertainty values for the emissions factors for the area of peat deposits managed for peat extraction based on the range of underlying data used to determine the emission factors. The uncertainty associated with the emission factors was assumed to be triangularly distributed.
- The uncertainty values surrounding the C fractions were based on IPCC (2006) and the uncertainty was assumed to be uniformly distributed.
- The uncertainty values associated with the fraction of peatland covered by ditches was assumed to be ± 100 percent with a normal distribution based on the assumption that greater than 10 percent coverage, the upper uncertainty bound, is not typical of drained organic soils outside of The Netherlands (IPCC 2013).

The results of the Approach 2 quantitative uncertainty analysis are summarized in Table 6-47. Carbon dioxide emissions from *Peatlands Remaining Peatlands* in 2014 were estimated to be between 0.7 and 1.0 MMT CO_2 Eq. at the 95 percent confidence level. This indicates a range of 14 percent below to 19 percent above the 2014 emission estimate of 0.8 MMT CO_2 Eq. Methane emissions from *Peatlands Remaining Peatlands* in 2014 were estimated to be between 0.002 and 0.008 MMT CO_2 Eq. This indicates a range of 62 percent below to 61 percent above the 2014 emission estimate of 0.005 MMT CO_2 Eq. Nitrous oxide emissions from *Peatlands Remaining Peatlands* in 2014 were estimated to be between 0.0003 and 0.0010 MMT CO_2 Eq. at the 95 percent confidence level. This indicates a range of 51 percent below to 61 percent above the 2014 emission estimate of 0.0006 MMT CO_2 Eq.

Table 6-47: Approach 2 Quantitative Uncertainty Estimates for CO_2, CH_4, and N_2O Emissions from *Peatlands Remaining Peatlands* (MMT CO_2 Eq. and Percent)

Source	Gas	2014 Emission Estimate (MMT CO_2 Eq.)	Uncertainty Range Relative to Emission Estimate[a] (MMT CO_2 Eq.)		(%)	
			Lower Bound	Upper Bound	Lower Bound	Upper Bound
Peatlands Remaining Peatlands	CO_2	0.8	0.7	1.0	-14%	+19%
Peatlands Remaining Peatlands	CH_4	+	+	+	-62%	+61%
Peatlands Remaining Peatlands	N_2O	+	+	+	-51%	+61%

+ Does not exceed 0.05 MMT CO_2 Eq.

[a] Range of emission estimates predicted by Monte Carlo Stochastic Simulation for a 95 percent confidence interval.

Methodological recalculations were applied to the entire time-series to ensure time-series consistency from 1990 through 2014. Details on the emission trends through time are described in more detail in the Methodology section, above.

QA/QC and Verification

A QA/QC analysis was performed for data gathering and input, documentation, and calculation and no issues were identified.

Recalculations Discussion

The emission estimates for *Peatlands Remaining Peatlands* were updated for 2014 using the Peat section of the *Mineral Commodity Summaries 2015*. The new edition provided 2014 data for the lower 48 states, but data for Alaska were still unavailable. Because no peat production has been reported since *Alaska's Mineral Industry 2012* report, the 2013 and 2014 values were assumed to be equal to the 2012 value. If updated data are available for the next inventory cycle, this will result in a recalculation in the next Inventory report.

Planned Improvements

In order to further improve estimates of CO_2, N_2O, and CH_4 emissions from *Peatlands Remaining Peatlands*, future efforts will investigate if data sources exist for determining the quantity of peat harvested per hectare and the total area undergoing peat extraction.

The *2013 Supplement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories: Wetlands* describes inventory methodologies for various wetland source categories. In the 1990 through 2013 Inventory, updated methods for *Peatlands Remaining Peatlands* to align them with the *IPCC Supplement* were begun to be incorporated. For future inventories, the need for additional updates will be evaluated, in order to further address the IPCC Supplement for *Peatlands Remaining Peatlands*.

The *2006 IPCC Guidelines* do not cover all wetland types; they are restricted to peatlands drained and managed for peat extraction, conversion to flooded lands, and some guidance for drained organic soils. They also do not cover all of the significant activities occurring on wetlands (e.g., rewetting of peatlands). Since this Inventory only includes *Peatlands Remaining Peatlands*, additional wetland types and activities found in the *2013 IPCC Supplement* (IPCC 2013) will be reviewed to determine if they apply to the United States. For those that do, available data will be investigated to allow for the estimation of greenhouse gas fluxes in future Inventory reports.

Box 6-6: Progress on Inclusion of Managed Coastal Wetlands in the U.S. Greenhouse Gas Inventory

In 2014, the IPCC released the *2013 Supplement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories: Wetlands* (*Wetlands Supplement*). The *Wetlands Supplement* provides methods for estimating anthropogenic emissions and removals of greenhouse gases from wetlands and drained soils. Specific consideration is given here to the inclusion of coastal wetlands as part of LULUCF reporting for anthropogenic emissions and removals of CO_2 and CH_4 and N_2O emissions.

In preparation for the next submission of the U.S. Inventory, the United States is exploring methodological approaches based on guidance in the *Wetlands Supplement*. The goal is to assemble all necessary activity data and emission factors, implement the methods described in the *Wetlands Supplement* and generate estimates at the Tier 1 or 2 level for managed coastal wetlands in the conterminous United States.

Fundamental considerations for inclusion of coastal wetlands as part of LULUCF reporting are: (1) how to apply the guidance in the *Wetlands Supplement* to specify what coastal wetlands are managed; (2) understanding what land-use categories coastal wetlands are in (i.e., Forest Land, Cropland, Grassland, Wetlands, Settlements and Other Land) and ensuring there is no overlap or missing lands within the U.S. land use matrix; and (3) understanding how the guidance can be applied when significant greenhouse gas emissions and removals occur in managed coastal wetlands outside of the U.S. land use matrix (i.e., seagrass meadows). These issues are under consideration and review by an interagency (U.S. Government) and academic team in anticipation of the next submission of the U.S. Inventory.

The availability of data and resources will be primary drivers in determining how the approaches in the *Wetlands Supplement* are applied. Specifically, the United States will work toward developing its inventory reporting of greenhouse gas emissions and removals from coastal wetlands by: (1) obtaining, collating and refining land use and land-use change data including (a) creating the coastal wetland boundary, (b) recognizing management activities and coastal wetland change resulting in land-use conversion (c) creating seamless integration where coastal wetlands may overlap with other land-use categories, (d) distinguishing salinity levels and soil types to apply appropriate C stocks and emission factors; and (2) developing the sector-specific inventory report for each new category and sub-category by: (a) increasing efforts toward reconciling land cover and land cover change spatial databases (i.e., Coastal Change Analysis Program) with vegetation, soil C stock and stock change data, and other levels of disaggregation that improve estimation accuracy, (b) developing Tier 1 (or Tier 2, if activity data and emission factors are available) emissions estimates for new source/sink categories under Forest Land, Cropland, Grassland, Wetlands, Settlements and Other Land, and (c) developing Tier 1 (or Tier 2, if activity data and emission factors are available) estimates of new source/sink categories that fall under new subcategories under Wetlands (*Other Wetlands Remaining Other Wetlands* and *Land Converted to Other Wetlands*) from the following activities: i) forest management in mangroves, ii) extraction in mangroves, tidal marshes and seagrass meadows (including excavation, aquaculture and salt production), iii) rewetting, revegetation and creation in mangroves, tidal marshes and seagrass meadows, iv) soil drainage in mangroves and tidal marshes (CO_2) and v) new categories of CH_4 emissions from rewetting of mangroves and tidal marshes and N_2O emissions from aquaculture, and (d) developing QA/QC procedures and protocols to be used in generating the estimates, and (e) refining uncertainty estimates.

6.9 Land Converted to Wetlands (IPCC Source Category 4D2)

Land-use change is constantly occurring, and areas under a number of differing land-use types are converted to wetlands each year, just as wetlands are converted to other uses. While the magnitude of these area changes is known (see Table 6-7), research is ongoing to track greenhouse gas fluxes across *Wetlands Remaining Wetlands* and *Land Converted to Wetlands*. Until such time that reliable and comprehensive estimates of greenhouse gas fluxes across these land-use and land-use change categories can be produced, it is not possible to separate CO_2, CH_4 or N_2O fluxes on *Land Converted to Wetlands* from fluxes on *Wetlands Remaining Wetlands* at this time.

6.10 Settlements Remaining Settlements

Changes in Carbon Stocks in Urban Trees (IPCC Source Category 4E1)

Urban forests constitute a significant portion of the total U.S. tree canopy cover (Dwyer et al. 2000). Urban areas (cities, towns, and villages) are estimated to cover over 3 percent of the United States (U.S. Census Bureau 2012). With an average tree canopy cover of 35 percent, urban areas account for approximately 5 percent of total tree cover in the continental United States (Nowak and Greenfield 2012). Trees in urban areas of the United States were estimated to account for an average annual net sequestration of 76.4 MMT CO_2 Eq. (20.8 MMT C) over the period from 1990 through 2014. Net C flux from urban trees in 2014 was estimated to be −90.6 MMT CO_2 Eq. (−24.7 MMT C). Annual estimates of CO_2 flux (Table 6-48) were developed based on periodic (1990, 2000, and 2010) U.S. Census data on urbanized area. The estimate of urbanized area is smaller than the area categorized as *Settlements* in the Representation of the U.S. Land Base section developed for this report: over the 1990 through 2014 time series the Census urban area totaled, on average, about 63 percent of the *Settlements* area.

In 2014, Census urban area totaled about 68 percent of the total area defined as *Settlements*. Census area data are preferentially used to develop C flux estimates for this source category since these data are more applicable for use with the available peer-reviewed data on urban tree canopy cover and urban tree C sequestration. Annual sequestration increased by 50 percent between 1990 and 2014 due to increases in urban land area. Data on C storage and urban tree coverage were collected since the early 1990s and have been applied to the entire time series in this report. As a result, the estimates presented in this chapter are not truly representative of changes in C stocks in urban trees for *Settlements* areas, but are representative of changes in C stocks in urban trees for Census urban area. The method used in this report does not attempt to scale these estimates to the *Settlements* area. Therefore, the estimates presented in this chapter are likely an underestimate of the true changes in C stocks in urban trees in all *Settlements* areas—i.e., the changes in C stocks in urban trees presented in this chapter are a subset of the changes in C stocks in urban trees in all *Settlements* areas.

Urban trees often grow faster than forest trees because of the relatively open structure of the urban forest (Nowak and Crane 2002). Because tree density in urban areas is typically much lower than in forested areas, the C storage per hectare of land is in fact smaller for urban areas than for forest areas. To quantify the C stored in urban trees, the methodology used here requires analysis per unit area of tree cover, rather than per unit of total land area (as is done for forests). Expressed in this way per unit of tree cover, areas covered by urban trees actually have a greater C density than do forested areas (Nowak and Crane 2002). Expressed per unit of land area, however, the situation is the opposite: because tree density is so much lower in urban areas, these areas have a smaller C density per unit land area than forest areas.

Table 6-48: Net C Flux from Urban Trees (MMT CO_2 Eq. and MMT C)

Year	MMT CO_2 Eq.	MMT C
1990	(60.4)	(16.5)
2005	(80.5)	(22.0)
2010	(86.1)	(23.5)
2011	(87.3)	(23.8)
2012	(88.4)	(24.1)
2013	(89.5)	(24.4)
2014	(90.6)	(24.7)

Note: Parentheses indicate net sequestration.

Methodology

Methods for quantifying urban tree biomass, C sequestration, and C emissions from tree mortality and decomposition were taken directly from Nowak et al. (2013), Nowak and Crane (2002), and Nowak (1994). In general, the methodology used by Nowak et al. (2013) to estimate net C sequestration in urban trees followed three steps, each of which is explained further in the paragraphs below. First, field data from cities and states were used to develop allometric equations that are then used to estimate C in urban tree biomass from data on measured tree dimensions. Second, estimates of annual tree growth and biomass increment were generated from published literature and adjusted for tree condition, land-use class, and growing season to generate estimates of gross C sequestration in urban trees for all 50 states and the District of Columbia. Third, estimates of C emissions due to mortality and decomposition were subtracted from gross C sequestration values to derive estimates of net C sequestration.

For this Inventory report, net C sequestration estimates for all 50 states and the District of Columbia, that were generated using the Nowak et al. (2013) methodology and expressed in units of C sequestered per unit area of tree cover, were then used to estimate urban tree C sequestration in the United States. To accomplish this, we used urban area estimates from U.S. Census data together with urban tree cover percentage estimates for each state and the District of Columbia from remote sensing data, an approach consistent with Nowak et al. (2013).

This approach is also consistent with the default IPCC Gain-Loss methodology in IPCC (2006), although sufficient field data are not yet available to separately determine interannual gains and losses in C stocks in the living biomass of urban trees. Instead, the methodology applied here uses estimates of net C sequestration based on modeled estimates of decomposition, as given by Nowak et al. (2013).

The first step in the methodology is to develop allometric equations that can be used to estimate C in urban tree biomass. In order to generate these allometric relationships between tree dimensions and tree biomass for cities and states, Nowak et al. (2013) and previously published research (Nowak and Crane 2002; Nowak 1994, 2007b, 2009) collected field measurements in a number of U.S. cities between 1989 and 2012. For a sample of trees in representative cities, data including tree measurements of stem diameter, tree height, crown height and crown width, and information on location, species, and canopy condition were collected. The data for each tree were converted into C storage by applying allometric equations to estimate aboveground biomass, a root-to-shoot ratio to convert aboveground biomass estimates to whole tree biomass, moisture content, a C content of 50 percent (dry weight basis), and an adjustment factor of 0.8 to account for urban trees having less aboveground biomass for a given stem diameter than predicted by allometric equations based on forest trees (Nowak 1994). Carbon storage estimates for deciduous trees include only C stored in wood. These calculations were then used to develop an allometric equation relating tree dimensions to C storage for each species of tree, encompassing a range of diameters.

The second step in the methodology is to estimate rates of tree growth for urban trees in the United States. Tree growth was estimated using annual height growth and diameter growth rates for specific land uses and diameter classes. In the Nowak et al. (2013) methodology that is applied here, growth calculations were adjusted by a factor to account for tree condition (fair to excellent, poor, critical, dying, or dead). For each tree, the difference in C storage estimates between year 1 and year (x + 1) represents the gross amount of C sequestered. These annual gross C sequestration rates for each species (or genus), diameter class, and land-use condition (e.g., parks, transportation, vacant, golf courses) were then scaled up to city estimates using tree population information. The area of assessment for each city or state was defined by its political boundaries; parks and other forested urban areas were thus included in sequestration estimates (Nowak 2011).

Most of the field data used to develop the methodology of Nowak et al. (2013) were analyzed using the U.S. Forest Service's Urban Forest Effects (UFORE) model. UFORE is a computer model that uses standardized field data from random plots in each city and local air pollution and meteorological data to quantify urban forest structure, values of the urban forest, and environmental effects, including total C stored and annual C sequestration. UFORE was used with field data from a stratified random sample of plots in each city to quantify the characteristics of the urban forest (Nowak et al. 2007).

Where gross C sequestration accounts for all carbon sequestered, net C sequestration for urban trees takes into account C emissions associated with tree death and removals. In the third step in the methodology developed by Nowak et al. (2013), estimates of net C emissions from urban trees were derived by applying estimates of annual mortality and condition, and assumptions about whether dead trees were removed from the site to the total C stock estimate for each city. Estimates of annual mortality rates by diameter class and condition class were derived from a study of street-tree mortality (Nowak 1986). Different decomposition rates were applied to dead trees left standing compared with those removed from the site. For removed trees, different rates were applied to the removed/aboveground biomass in contrast to the belowground biomass. The estimated annual gross C emission rates for each species (or genus), diameter class, and condition class were then scaled up to city estimates using tree population information.

The data for all 50 states and the District of Columbia are described in Nowak et al. (2013) and reproduced in Table 6-49, which builds upon previous research, including: Nowak and Crane (2002), Nowak et al. (2007), Nowak and Greenfield (2012), and references cited therein. The full methodology development is described in the underlying literature, and key details and assumptions were made as follows. The allometric equations applied to the field data for the Nowak methodology for each tree were taken from the scientific literature (see Nowak 1994 and Nowak et al. 2002), but if no allometric equation could be found for the particular species, the average result for the genus was used. The adjustment (0.8) to account for less live tree biomass in urban trees was based on information in Nowak (1994). Measured tree growth rates for street (Frelich 1992; Fleming 1988; Nowak 1994), park (deVries 1987), and forest (Smith and Shifley 1984) trees were standardized to an average length of growing season (153 frost free days) and adjusted for site competition and tree condition. Standardized growth rates of trees of the same species or genus were then compared to determine the average difference between standardized street tree growth and standardized park and forest growth rates. Crown light exposure (CLE) measurements (number of sides and/or top of tree exposed to sunlight) were used to represent forest, park, and open (street) tree growth conditions. Local tree base growth rates (BG) were then calculated as the average standardized growth rate for open-grown trees multiplied by the number of frost free days divided by 153. Growth rates were then adjusted for CLE. The CLE adjusted growth rate was then adjusted based on tree health and tree condition to determine the final growth rate. Assumptions for which dead trees would be removed versus left standing were developed specific to each land use and were based on expert judgment of the authors. Decomposition rates were based on literature estimates (Nowak et al. 2013).

Estimates of gross and net sequestration rates for each of the 50 states and the District of Columbia (Table 6-49) were compiled in units of C sequestration per unit area of tree canopy cover. These rates were used in conjunction with estimates of state urban area and urban tree cover data to calculate each state's annual net C sequestration by urban trees. This method was described in Nowak et al. (2013) and has been modified here to incorporate U.S. Census data.

Specifically, urban area estimates were based on 1990, 2000, and 2010 U.S. Census data. The 1990 U.S. Census defined urban land as "urbanized areas," which included land with a population density greater than 1,000 people per square mile, and adjacent "urban places," which had predefined political boundaries and a population total greater than 2,500. In 2000, the U.S. Census replaced the "urban places" category with a new category of urban land called an "urban cluster," which included areas with more than 500 people per square mile. In 2010, the Census updated its definitions to have "urban areas" encompassing Census tract delineated cities with 50,000 or more people, and "urban clusters" containing Census tract delineated locations with between 2,500 and 50,000 people. Urban land area increased by approximately 23 percent from 1990 to 2000 and 14 percent from 2000 to 2010; Nowak et al. (2005) estimate that the changes in the definition of urban land are responsible for approximately 20 percent of the total reported increase in urban land area from 1990 to 2000. Under all Census (i.e., 1990, 2000, and 2010) definitions, the urban category encompasses most cities, towns, and villages (i.e., it includes both urban and suburban areas). *Settlements* area, as assessed in the Representation of the U.S. Land Base section developed for this report, encompassed all developed parcels greater than 0.1 hectares in size, including rural transportation corridors, and as previously mentioned represents a larger area than the Census-derived urban area estimates. However, the smaller, Census-derived urban area estimates were deemed to be more suitable for estimating national urban tree cover given the data available in the peer-reviewed literature (i.e., the data set available is consistent with Census urban rather than *Settlements* areas), and the recognized overlap in the changes in C stocks between urban forest and non-urban forest (see Planned Improvements below). U.S. Census urban area data is reported as a series of continuous blocks of urban area in each state. The blocks or urban area were summed to create each state's urban area estimate.

Net annual C sequestration estimates were derived for all 50 states and the District of Columbia by multiplying the gross annual emission estimates by 0.74, the standard ratio for net/gross sequestration set out in Table 3 of Nowak et al. (2013) (unless data existed for both gross and net sequestration for the state in Table 2 of Nowak et. al. (2013), in which case they were divided to get a state-specific ratio). The gross and net annual C sequestration values for each state were multiplied by each state's area of tree cover, which was the product of the state's urban/community area as defined in the U.S. Census (2012) and the state's urban/community tree cover percentage. The urban/community tree cover percentage estimates for all 50 states were obtained from Nowak and Greenfield (2012), which compiled ten years of research including Dwyer et al. (2000), Nowak et al. (2002), Nowak (2007a), and Nowak (2009). The urban/community tree cover percentage estimate for the District of Columbia was obtained from Nowak et al. (2013). The urban area estimates were taken from the 2010 U.S. Census (2012). The equation, used to calculate the summed carbon sequestration amounts, can be written as follows:

$$\text{Net annual C sequestration} = \text{Gross sequestration rate} \times \text{Net to Gross sequestration ratio} \times \text{Urban Area} \times \text{\% Tree Cover}$$

Table 6-49: Annual C Sequestration (Metric Tons C/yr), Tree Cover (Percent), and Annual C Sequestration per Area of Tree Cover (kg C/m²-yr) for 50 states plus the District of Columbia (2014)

State	Gross Annual Sequestration	Net Annual Sequestration	Tree Cover	Gross Annual Sequestration per Area of Tree Cover	Net Annual Sequestration per Area of Tree Cover	Net: Gross Annual Sequestration Ratio
Alabama	1,165,574	862,524	55.2	0.343	0.254	0.74
Alaska	44,744	33,111	39.8	0.168	0.124	0.74
Arizona	385,644	285,376	17.6	0.354	0.262	0.74
Arkansas	424,922	314,443	42.3	0.331	0.245	0.74
California	2,106,024	1,558,458	25.1	0.389	0.288	0.74
Colorado	153,806	113,817	18.5	0.197	0.146	0.74
Connecticut	771,006	570,544	67.4	0.239	0.177	0.74
Delaware	136,070	100,692	35.0	0.335	0.248	0.74
DC	14,559	11,569	35.0	0.263	0.209	0.79
Florida	3,429,742	2,538,009	35.5	0.475	0.352	0.74
Georgia	2,580,659	1,909,688	54.1	0.353	0.261	0.74
Hawaii	246,168	182,164	39.9	0.581	0.430	0.74
Idaho	25,533	18,894	10.0	0.184	0.136	0.74
Illinois	760,263	562,594	25.4	0.283	0.209	0.74
Indiana	406,015	375,425	23.7	0.250	0.231	0.92
Iowa	119,006	88,064	19.0	0.240	0.178	0.74
Kansas	186,077	144,799	25.0	0.283	0.220	0.78
Kentucky	243,641	180,295	22.1	0.286	0.212	0.74
Louisiana	749,632	554,727	34.9	0.397	0.294	0.74
Maine	108,092	79,988	52.3	0.221	0.164	0.74
Maryland	597,897	442,444	34.3	0.323	0.239	0.74
Massachusetts	1,309,649	969,140	65.1	0.254	0.188	0.74
Michigan	740,048	547,635	35.0	0.220	0.163	0.74
Minnesota	354,139	262,063	34.0	0.229	0.169	0.74
Mississippi	494,558	365,973	47.3	0.344	0.255	0.74
Missouri	498,925	369,205	31.5	0.285	0.211	0.74
Montana	53,940	39,916	36.3	0.184	0.136	0.74
Nebraska	50,920	42,970	15.0	0.238	0.201	0.84
Nevada	44,096	32,631	9.6	0.207	0.153	0.74
New Hampshire	250,531	185,393	66.0	0.217	0.161	0.74
New Jersey	1,201,070	888,792	53.3	0.294	0.218	0.74
New Mexico	70,002	51,801	12.0	0.263	0.195	0.74
New York	1,096,654	811,524	42.6	0.240	0.178	0.74
North Carolina	2,076,636	1,536,711	51.1	0.312	0.231	0.74
North Dakota	14,946	7,102	13.0	0.223	0.106	0.48
Ohio	927,316	686,214	31.5	0.248	0.184	0.74
Oklahoma	366,160	270,959	31.2	0.332	0.246	0.74
Oregon	261,067	193,190	36.6	0.242	0.179	0.74
Pennsylvania	1,264,702	935,879	41.0	0.244	0.181	0.74
Rhode Island	137,147	101,489	51.0	0.258	0.191	0.74
South Carolina	1,107,882	819,832	48.9	0.338	0.250	0.74
South Dakota	21,348	18,513	14.0	0.236	0.205	0.87
Tennessee	1,063,362	950,771	43.8	0.303	0.271	0.89
Texas	2,808,539	2,078,319	31.4	0.368	0.272	0.74
Utah	91,713	67,868	16.4	0.215	0.159	0.74

Vermont	46,571	34,462	53.0	0.213	0.158	0.74
Virginia	839,610	621,311	39.8	0.293	0.217	0.74
Washington	571,062	422,586	34.6	0.258	0.191	0.74
West Virginia	255,369	188,973	61.0	0.241	0.178	0.74
Wisconsin	364,611	269,812	31.8	0.225	0.167	0.74
Wyoming	19,203	14,210	19.9	0.182	0.135	0.74
Total	**33,056,852**	**24,712,872**				

Uncertainty and Time-Series Consistency

Uncertainty associated with changes in C stocks in urban trees includes the uncertainty associated with urban area, percent urban tree coverage, and estimates of gross and net C sequestration for each of the 50 states and the District of Columbia. A 10 percent uncertainty was associated with urban area estimates based on expert judgment. Uncertainty associated with estimates of percent urban tree coverage for each of the 50 states was based on standard error estimates reported by Nowak and Greenfield (2012). Uncertainty associated with estimate of percent urban tree coverage for the District of Columbia was based on the standard error estimate reported by Nowak et al. (2013). Uncertainty associated with estimates of gross and net C sequestration for each of the 50 states and the District of Columbia was based on standard error estimates for each of the state-level sequestration estimates reported by Nowak et al. (2013). These estimates are based on field data collected in each of the 50 states and the District of Columbia, and uncertainty in these estimates increases as they are scaled up to the national level.

Additional uncertainty is associated with the biomass equations, conversion factors, and decomposition assumptions used to calculate C sequestration and emission estimates (Nowak et al. 2002). These results also exclude changes in soil C stocks, and there may be some overlap between the urban tree C estimates and the forest tree C estimates. Due to data limitations, urban soil flux is not quantified as part of this analysis, while reconciliation of urban tree and forest tree estimates will be addressed through the land-representation effort described in the Planned Improvements section of this chapter.

A Monte Carlo (Approach 2) uncertainty analysis was applied to estimate the overall uncertainty of the sequestration estimate. The results of the Approach 2 quantitative uncertainty analysis are summarized in Table 6-50. The net C flux from changes in C stocks in urban trees in 2014 was estimated to be between −134.0 and −47.4 MMT CO_2 Eq. at a 95 percent confidence level. This indicates a range of 51 percent more sequestration to 46 percent less sequestration than the 2014 flux estimate of −90.6 MMT CO_2 Eq.

Table 6-50: Approach 2 Quantitative Uncertainty Estimates for Net C Flux from Changes in C Stocks in Urban Trees (MMT CO_2 Eq. and Percent)

Source	Gas	2014 Flux Estimate (MMT CO_2 Eq.)	Uncertainty Range Relative to Flux Estimate[a] (MMT CO_2 Eq.)		(%)	
			Lower Bound	Upper Bound	Lower Bound	Upper Bound
Changes in C Stocks in Urban Trees	CO_2	(90.6)	(134.0)	(47.4)	-51%	+46%

[a] Range of flux estimates predicted by Monte Carlo Stochastic Simulation for a 95 percent confidence interval.
Note: Parentheses indicate negative values or net sequestration.

Methodological recalculations were applied to the entire time series to ensure time-series consistency from 1990 through 2014. Details on the emission trends through time are described in more detail in the Methodology section, above.

QA/QC and Verification

Tier 1 and Tier 2 QA/QC activities were conducted consistent with the U.S. QA/QC plan. Source-specific quality control measures for urban trees included checking input data, documentation, and calculations to ensure data were properly handled through the Inventory process. Errors that were found during this process were corrected as necessary. One key edit in the current Inventory report is that Table 6-49 has been updated. For this Table, the values in the 1990 through 2012 Inventory and 1990 through 2013 Inventory reports were the same. The updated values for the current (1990 through 2014) Inventory were inserted here, noting that they represent a two-year increment in urban tree C sequestration from what was presented in the previous Inventory.

Planned Improvements

A consistent representation of the managed land base in the United States is discussed in the Representation of the U.S. Land Base section, and discusses a planned improvement by the USDA Forest Service to reconcile the overlap between urban forest and non-urban forest greenhouse gas inventories. Because some plots defined as "forest" in the Forest Inventory and Analysis (FIA) program of the USDA Forest Service actually fall within the boundaries of the areas also defined as Census urban, there may be "double-counting" of these land areas in estimates of C stocks and fluxes for this report. Specifically, Nowak et al. (2013) estimates that 1.5 percent of forest plots measured by the FIA program fall within land designated as Census urban, suggesting that approximately 1.5 percent of the C reported in the Forest source category might also be counted in the Urban Trees source category.

Future research may also enable more complete coverage of changes in the C stock in urban trees for all *Settlements* land. To provide estimates for all *Settlements*, research would need to establish the extent of overlap between the areas of land included in the *Settlements* land use category and Census-defined urban areas, and would have to separately characterize sequestration on non-urban *Settlements* land.

N_2O Fluxes from Settlement Soils (IPCC Source Category 4E1)

Of the synthetic N fertilizers applied to soils in the United States, approximately 3.1 percent are currently applied to lawns, golf courses, and other landscaping occurring within settlement areas. Application rates are lower than those occurring on cropped soils, and, therefore, account for a smaller proportion of total U.S. soil N_2O emissions per unit area. In addition to synthetic N fertilizers, a portion of surface applied sewage sludge is applied to settlement areas.

N additions to soils result in direct and indirect N_2O emissions. Direct emissions occur on-site due to the N additions. Indirect emissions result from fertilizer and sludge N that is transformed and transported to another location in a form other than N_2O (ammonia [NH_3] and nitrogen oxide [NO_x] volatilization, nitrogen trioxide [NO_3] leaching and runoff), and later converted into N_2O at the off-site location. The indirect emissions are assigned to settlements because the management activity leading to the emissions occurred in settlements.

Total N_2O emissions from settlement soils were 2.4 MMT CO_2 Eq. (8 kt of N_2O) in 2014. There was an overall increase of 78 percent from 1990 to 2014 due to an expanding settlement area requiring more synthetic N fertilizer. Interannual variability in these emissions is directly attributable to interannual variability in total synthetic fertilizer consumption and sewage sludge applications in the United States. Emissions from this source are summarized in Table 6-51.

Table 6-51: N_2O Fluxes from Soils in *Settlements Remaining Settlements* (MMT CO_2 Eq. and kt N_2O)

	1990		2005		2010	2011	2012	2013	2014
Direct N_2O Fluxes from Soils									
MMT CO_2 Eq.	1.0		1.8		1.8	1.9	1.9	1.8	1.8
kt N_2O	3		6		6	6	6	6	6
Indirect N_2O Fluxes from Soils									
MMT CO_2 Eq.	0.4		0.6		0.6	0.6	0.6	0.6	0.6
kt N_2O	1		2		2	2	2	2	2
Total									
MMT CO_2 Eq.	**1.4**		**2.3**		**2.4**	**2.5**	**2.5**	**2.4**	**2.4**
kt N_2O	**5**		**8**		**8**	**8**	**9**	**8**	**8**

Note: Totals may not sum due to independent rounding.

Methodology

For soils within *Settlements Remaining Settlements*, the IPCC Tier 1 approach is used to estimate soil N_2O emissions from synthetic N fertilizer and sewage sludge additions. Estimates of direct N_2O emissions from soils in settlements are based on the amount of N in synthetic commercial fertilizers applied to settlement soils, and the amount of N in sewage sludge applied to non-agricultural land and surface disposal (see Annex 3.12 for a detailed discussion of the methodology for estimating sewage sludge application).

Nitrogen applications to settlement soils are estimated using data compiled by the USGS (Ruddy et al. 2006). The USGS estimated on-farm and non-farm fertilizer use is based on sales records at the county level from 1982 through 2001 (Ruddy et al. 2006). Non-farm N fertilizer is assumed to be applied to settlements and forest lands; values for 2002 through 2014 are based on 2001 values adjusted for annual total N fertilizer sales in the United States because there is no new activity data on application after 2001. Settlement application is calculated by subtracting forest application from total non-farm fertilizer use. Sewage sludge applications are derived from national data on sewage sludge generation, disposition, and N content (see Annex 3.12 for further detail). The total amount of N resulting from these sources is multiplied by the IPCC default emission factor for applied N (one percent) to estimate direct N_2O emissions (IPCC 2006).

For indirect emissions, the total N applied from fertilizer and sludge is multiplied by the IPCC default factors of 10 percent for volatilization and 30 percent for leaching/runoff to calculate the amount of N volatilized and the amount of N leached/runoff. The amount of N volatilized is multiplied by the IPCC default factor of one percent for the portion of volatilized N that is converted to N_2O off-site and the amount of N leached/runoff is multiplied by the IPCC default factor of 0.075 percent for the portion of leached/runoff N that is converted to N_2O off-site. The resulting estimates are summed to obtain total indirect emissions.

Uncertainty and Time-Series Consistency

The amount of N_2O emitted from settlements depends not only on N inputs and fertilized area, but also on a large number of variables, including organic C availability, oxygen gas partial pressure, soil moisture content, pH, temperature, and irrigation/watering practices. The effect of the combined interaction of these variables on N_2O flux is complex and highly uncertain. The IPCC default methodology does not explicitly incorporate any of these variables, except variations in fertilizer N and sewage sludge application rates. All settlement soils are treated equivalently under this methodology.

Uncertainties exist in both the fertilizer N and sewage sludge application rates in addition to the emission factors. Uncertainty in fertilizer N application is assigned a default level of ±50 percent.[57] Uncertainty in the amounts of sewage sludge applied to non-agricultural lands and used in surface disposal is derived from variability in several factors, including: (1) N content of sewage sludge; (2) total sludge applied in 2000; (3) wastewater existing flow in 1996 and 2000; and (4) the sewage sludge disposal practice distributions to non-agricultural land application and surface disposal. In addition, the uncertainty ranges around 2005 activity data and emission factor input variables are directly applied to the 2014 emission estimates. Uncertainty in the direct and indirect emission factors is provided by IPCC (2006).

Uncertainty is quantified using simple error propagation methods (IPCC 2006), and the results are summarized in Table 6-52. Direct N_2O emissions from soils in *Settlements Remaining Settlements* in 2014 are estimated to be between 0.9 and 4.8 MMT CO_2 Eq. at a 95 percent confidence level. This indicates a range of 49 percent below to 163 percent above the 2014 emission estimate of 1.8 MMT CO_2 Eq. Indirect N_2O emissions in 2014 are between 0.1 and 1.9 MMT CO_2 Eq., ranging from a -85 percent to 212 percent around the estimate of 0.6 MMT CO_2 Eq.

Table 6-52: Quantitative Uncertainty Estimates of N_2O Emissions from Soils in *Settlements Remaining Settlements* (MMT CO_2 Eq. and Percent)

Source	Gas	2014 Emissions (MMT CO_2 Eq.)	Uncertainty Range Relative to Emission Estimate (MMT CO_2 Eq.)		(%)	
Settlements Remaining Settlements:			**Lower Bound**	**Upper Bound**	**Lower Bound**	**Upper Bound**
Direct N_2O Fluxes from Soils	N_2O	1.8	0.9	4.8	-49%	+163%
Indirect N_2O Fluxes from Soils	N_2O	0.6	0.1	1.9	-85%	+212%

Note: These estimates include direct and indirect N_2O emissions from N fertilizer additions to both *Settlements Remaining Settlements* and from *Land Converted to Settlements*.

57 No uncertainty is provided with the USGS fertilizer consumption data (Ruddy et al. 2006) so a conservative ±50 percent is used in the analysis.

Methodological recalculations were applied to the entire time series to ensure time-series consistency from 1990 through 2014. Details on the emission trends through time are described in more detail in the Methodology section, above.

QA/QC and Verification

The spreadsheet containing fertilizer and sewage sludge applied to settlements and calculations for N_2O and uncertainty ranges have been checked and verified.

Planned Improvements

A minor improvement is planned to update the uncertainty analysis for direct emissions from settlements to be consistent with the most recent activity data for this source.

6.11 Land Converted to Settlements (IPCC Source Category 4E2)

Land-use change is constantly occurring, and land under a number of uses undergoes urbanization in the United States each year. Given the lack of available information relevant to this particular IPCC source category, it is not possible to separate CO_2 or N_2O fluxes on *Land Converted to Settlements* from fluxes on *Settlements Remaining Settlements* at this time.

6.12 Other Land Remaining Other Land (IPCC Source Category 4F1)

Land use is constantly occurring, and areas under a number of differing land-use types remain in their respective land-use type each year, just as other land can remain as other land. While the magnitude of *Other Land Remaining Other Land* is known (see Table 6-7), research is ongoing to track C pools in this land use. Until such time that reliable and comprehensive estimates of C for *Other Land Remaining Other Land* can be produced, it is not possible to estimate CO_2 or N_2O fluxes on *Other Land Remaining Other Land* at this time.

6.13 Land Converted to Other Land (IPCC Source Category 4F2)

Land-use change is constantly occurring, and areas under a number of differing land-use types are converted to other land each year, just as other land is converted to other uses. While the magnitude of these area changes is known (see Table 6-7), research is ongoing to track C across *Other Land Remaining Other Land* and *Land Converted to Other Land*. Until such time that reliable and comprehensive estimates of C across these land-use and land-use change categories can be produced, it is not possible to separate CO_2, CH_4 or N_2O fluxes on *Land Converted to Other Land* from fluxes on *Other Land Remaining Other Land* at this time.

6.14 Other (IPCC Source Category 4H)

Changes in Yard Trimming and Food Scrap Carbon Stocks in Landfills

In the United States, yard trimmings (i.e., grass clippings, leaves, and branches) and food scraps account for a significant portion of the municipal waste stream, and a large fraction of the collected yard trimmings and food scraps are put in landfills. Carbon (C) contained in landfilled yard trimmings and food scraps can be stored for very long periods.

Carbon-storage estimates are associated with particular land uses. For example, harvested wood products are accounted for under *Forest Land Remaining Forest Land* because these wood products are considered a component of the forest ecosystem. The wood products serve as reservoirs to which C resulting from photosynthesis in trees is transferred, but the removals in this case occur in the forest. Carbon stock changes in yard trimmings and food scraps are associated with settlements, but removals in this case do not occur within settlements. To address this complexity, yard trimming and food scrap C storage is reported under the "Other" source category.

Both the amount of yard trimmings collected annually and the fraction that is landfilled have declined over the last decade. In 1990, over 53 million metric tons (wet weight) of yard trimmings and food scraps were generated (i.e., put at the curb for collection to be taken to disposal sites or to composting facilities) (EPA 2015a). Since then, programs banning or discouraging yard trimmings disposal have led to an increase in backyard composting and the use of mulching mowers, and a consequent 2.3 percent decrease in the tonnage of yard trimmings generated (i.e., collected for composting or disposal). At the same time, an increase in the number of municipal composting facilities has reduced the proportion of collected yard trimmings that are discarded in landfills—from 72 percent in 1990 to 32 percent in 2014. The net effect of the reduction in generation and the increase in composting is a 57 percent decrease in the quantity of yard trimmings disposed of in landfills since 1990.

Food scrap generation has grown by 55 percent since 1990, and though the proportion of food scraps discarded in landfills has decreased slightly from 82 percent in 1990 to 76 percent in 2014, the tonnage disposed of in landfills has increased considerably (by 45 percent). Although the total tonnage of food scraps disposed in landfills has increased from 1990 to 2014, the annual carbon stock net changes from food scraps have decreased (as shown in Table 6-53 and Table 6-54), due to smaller annual differences in the amount of food waste disposed in landfills. Overall, the decrease in the landfill disposal rate of yard trimmings has more than compensated for the increase in food scrap disposal in landfills, and the net result is a decrease in annual landfill C storage from 26.0 MMT CO_2 Eq. (7.1 MMT C) in 1990 to 11.6 MMT CO_2 Eq. (3.2 MMT C) in 2014 (Table 6-53 and Table 6-54).

Table 6-53: Net Changes in Yard Trimming and Food Scrap Carbon Stocks in Landfills (MMT CO_2 Eq.)

Carbon Pool	1990		2005		2010	2011	2012	2013	2014
Yard Trimmings	**(21.0)**		**(7.4)**		**(9.3)**	**(9.2)**	**(9.1)**	**(8.5)**	**(8.5)**
Grass	(1.8)		(0.6)		(0.9)	(0.9)	(0.9)	(0.8)	(0.8)
Leaves	(9.0)		(3.4)		(4.2)	(4.2)	(4.2)	(3.9)	(3.9)
Branches	(10.2)		(3.4)		(4.1)	(4.1)	(4.1)	(3.8)	(3.8)
Food Scraps	**(5.0)**		**(4.0)**		**(3.9)**	**(3.5)**	**(3.1)**	**(3.2)**	**(3.1)**
Total Net Flux	**(26.0)**		**(11.4)**		**(13.2)**	**(12.7)**	**(12.2)**	**(11.7)**	**(11.6)**

Notes: Totals may not sum due to independent rounding. Parentheses indicate net sequestration.

Table 6-54: Net Changes in Yard Trimming and Food Scrap Carbon Stocks in Landfills (MMT C)

Carbon Pool	1990		2005		2010	2011	2012	2013	2014
Yard Trimmings	**(5.7)**		**(2.0)**		**(2.5)**	**(2.5)**	**(2.5)**	**(2.3)**	**(2.3)**
Grass	(0.5)		(0.2)		(0.3)	(0.2)	(0.2)	(0.2)	(0.2)

Leaves	(2.5)	(0.9)	(1.2)	(1.1)	(1.1)	(1.1)	(1.1)
Branches	(2.8)	(0.9)	(1.1)	(1.1)	(1.1)	(1.0)	(1.0)
Food Scraps	**(1.4)**	**(1.1)**	**(1.1)**	**(1.0)**	**(0.9)**	**(0.9)**	**(0.8)**
Total Net Flux	**(7.1)**	**(3.1)**	**(3.6)**	**(3.5)**	**(3.3)**	**(3.2)**	**(3.2)**

Notes: Totals may not sum due to independent rounding. Parentheses indicate net sequestration.

Methodology

When wastes of biogenic origin (such as yard trimmings and food scraps) are landfilled and do not completely decompose, the C that remains is effectively removed from the terrestrial C cycle. Empirical evidence indicates that yard trimmings and food scraps do not completely decompose in landfills (Barlaz 1998, 2005, 2008; De la Cruz and Barlaz 2010), and thus the stock of C in landfills can increase, with the net effect being a net atmospheric removal of C. Estimates of net C flux resulting from landfilled yard trimmings and food scraps were developed by estimating the change in landfilled C stocks between inventory years, based on methodologies presented for the Land Use, Land-Use Change, and Forestry sector in IPCC (2003). Carbon stock estimates were calculated by determining the mass of landfilled C resulting from yard trimmings or food scraps discarded in a given year; adding the accumulated landfilled C from previous years; and subtracting the mass of C that was landfilled in previous years that decomposed.

To determine the total landfilled C stocks for a given year, the following were estimated: (1) The composition of the yard trimmings; (2) the mass of yard trimmings and food scraps discarded in landfills; (3) the C storage factor of the landfilled yard trimmings and food scraps; and (4) the rate of decomposition of the degradable C. The composition of yard trimmings was assumed to be 30 percent grass clippings, 40 percent leaves, and 30 percent branches on a wet weight basis (Oshins and Block 2000). The yard trimmings were subdivided, because each component has its own unique adjusted C storage factor (i.e., moisture content and C content) and rate of decomposition. The mass of yard trimmings and food scraps disposed of in landfills was estimated by multiplying the quantity of yard trimmings and food scraps discarded by the proportion of discards managed in landfills. Data on discards (i.e., the amount generated minus the amount diverted to centralized composting facilities) for both yard trimmings and food scraps were taken primarily from *Advancing Sustainable Materials Management: Facts and Figures 2013* (EPA 2015a), which provides data for 1960, 1970, 1980, 1990, 2000, 2005, 2009 and 2011 through 2013. To provide data for some of the missing years, detailed backup data were obtained from historical data tables that EPA developed for 1960 through 2013 (EPA 2015b). Remaining years in the time series for which data were not provided were estimated using linear interpolation. Data for 2014 are not yet available, so they were set equal to 2013 values. The EPA (2015a) report and historical data tables (EPA 2015b) do not subdivide the discards (i.e., total generated minus composted) of individual materials into masses landfilled and combusted, although it provides a mass of overall waste stream discards managed in landfills[58] and combustors with energy recovery (i.e., ranging from 67 percent and 33 percent, respectively, in 1960 to 92 percent and 8 percent, respectively, in 1985); it is assumed that the proportion of each individual material (food scraps, grass, leaves, branches) that is landfilled is the same as the proportion across the overall waste stream.

The amount of C disposed of in landfills each year, starting in 1960, was estimated by converting the discarded landfilled yard trimmings and food scraps from a wet weight to a dry weight basis, and then multiplying by the initial (i.e., pre-decomposition) C content (as a fraction of dry weight). The dry weight of landfilled material was calculated using dry weight to wet weight ratios (Tchobanoglous et al. 1993 as cited by Barlaz 1998) and the initial C contents and the C storage factors were determined by Barlaz (1998, 2005, 2008) (Table 6-55).

The amount of C remaining in the landfill for each subsequent year was tracked based on a simple model of C fate. As demonstrated by Barlaz (1998, 2005, 2008), a portion of the initial C resists decomposition and is essentially persistent in the landfill environment. Barlaz (1998, 2005, 2008) conducted a series of experiments designed to

[58] EPA (2015a and 2015b) reports discards in two categories: "combustion with energy recovery" and "landfill, other disposal," which includes combustion without energy recovery. For years in which there is data from previous EPA reports on combustion without energy recovery, EPA assumes these estimates are still applicable. For 2000 to present, EPA assumes that any combustion of MSW that occurs includes energy recovery, so all discards to "landfill, other disposal" are assumed to go to landfills.

measure biodegradation of yard trimmings, food scraps, and other materials, in conditions designed to promote decomposition (i.e., by providing ample moisture and nutrients). After measuring the initial C content, the materials were placed in sealed containers along with methanogenic microbes from a landfill. Once decomposition was complete, the yard trimmings and food scraps were re-analyzed for C content; the C remaining in the solid sample can be expressed as a proportion of the initial C (shown in the row labeled "C Storage Factor, Proportion of Initial C Stored (Percent)" in Table 6-55).

The modeling approach applied to simulate U.S. landfill C flows builds on the findings of Barlaz (1998, 2005, 2008). The proportion of C stored is assumed to persist in landfills. The remaining portion is assumed to degrade over time, resulting in emissions of CH_4 and CO_2. (The CH_4 emissions resulting from decomposition of yard trimmings and food scraps are accounted for in the Waste chapter.) The degradable portion of the C is assumed to decay according to first-order kinetics. The decay rates for each of the materials are shown in Table 6-55.

The first-order decay rates, *k*, for each refuse type were derived from De la Cruz and Barlaz (2010). De la Cruz and Barlaz (2010) calculate first-order decay rates using laboratory data published in Eleazer et al. (1997), and a correction factor, *f*, is found so that the weighted average decay rate for all components is equal to the EPA AP-42 default decay rate (0.04) for mixed MSW for regions that receive more than 25 inches of rain annually (EPA 1995). Because AP-42 values were developed using landfill data from approximately 1990, 1990 waste composition for the United States from EPA's *Characterization of Municipal Solid Waste in the United States: 1990 Update* was used to calculate *f*. This correction factor is then multiplied by the Eleazer et al. (1997) decay rates of each waste component to develop field-scale first-order decay rates.

De la Cruz and Barlaz (2010) also use other assumed initial decay rates for mixed MSW in place of the AP-42 default value based on different types of environments in which landfills in the United States are found, including dry conditions (less than 25 inches of rain annually, k=0.02) and bioreactor landfill conditions (moisture is controlled for rapid decomposition, k=0.12). As in Section 7.1 Landfills (which estimates CH_4 emissions), the overall MSW decay rate is estimated by partitioning the U.S. landfill population into three categories, based on annual precipitation ranges of: (1) Less than 20 inches of rain per year; (2) 20 to 40 inches of rain per year; and (3) greater than 40 inches of rain per year. These correspond to overall MSW decay rates of 0.020, 0.038, and 0.057 $year^{-1}$, respectively.

De la Cruz and Barlaz (2010) calculate component-specific decay rates corresponding to the first value (0.020 $year^{-1}$), but not for the other two overall MSW decay rates. To maintain consistency between landfill methodologies across the Inventory, the correction factors (*f*) were developed for decay rates of 0.038 and 0.057 $year^{-1}$ through linear interpolation. A weighted national average component-specific decay rate was calculated by assuming that waste generation is proportional to population (the same assumption used in the landfill methane emission estimate), based on population data from the 2000 U.S. Census. The component-specific decay rates are shown in Table 6-55.

For each of the four materials (grass, leaves, branches, food scraps), the stock of C in landfills for any given year is calculated according to Equation 1:

$$LFC_{i,t} = \sum_{n}^{t} W_{i,n} \times (1 - MC_i) \times ICC_i \times \{[CS_i \times ICC_i] + [(1 - (CS_i \times ICC_i)) \times e^{-k(t-n)}]\}$$

where,

t	=	Year for which C stocks are being estimated (year),
i	=	Waste type for which C stocks are being estimated (grass, leaves, branches, food scraps),
$LFC_{i,t}$	=	Stock of C in landfills in year *t*, for waste *i* (metric tons),
$W_{i,n}$	=	Mass of waste *i* disposed of in landfills in year *n* (metric tons, wet weight),
n	=	Year in which the waste was disposed of (year, where 1960 < *n* < *t*),
MC_i	=	Moisture content of waste *i* (percent of water),
CS_i	=	Proportion of initial C that is stored for waste *i* (percent),
ICC_i	=	Initial C content of waste *i* (percent),
e	=	Natural logarithm, and
k	=	First-order decay rate for waste *i*, ($year^{-1}$).

For a given year *t*, the total stock of C in landfills ($TLFC_t$) is the sum of stocks across all four materials (grass, leaves, branches, food scraps). The annual flux of C in landfills (F_t) for year *t* is calculated in Equation 2 as the change in stock compared to the preceding year:

$$F_t = TLFC_t - TLFC_{(t-1)}$$

Thus, as seen in Equation 1, the C placed in a landfill in year *n* is tracked for each year *t* through the end of the Inventory period (2014). For example, disposal of food scraps in 1960 resulted in depositing about 1,135,000 metric tons of C. Of this amount, 16 percent (179,000 metric tons) is persistent; the remaining 84 percent (956,000 metric tons) is degradable. By 1965, more than half of the degradable portion (518,000 metric tons) decomposes, leaving a total of 617,000 metric tons (the persistent portion, plus the remainder of the degradable portion).

Continuing the example, by 2014, the total food scraps C originally disposed of in 1960 had declined to 179,000 metric tons (i.e., virtually all degradable C had decomposed). By summing the C remaining from 1960 with the C remaining from food scraps disposed of in subsequent years (1961 through 2014), the total landfill C from food scraps in 2014 was 41.5 million metric tons. This value is then added to the C stock from grass, leaves, and branches to calculate the total landfill C stock in 2014, yielding a value of 264.7 million metric tons (as shown in Table 6-56). In exactly the same way total net flux is calculated for forest C and harvested wood products, the total net flux of landfill C for yard trimmings and food scraps for a given year (Table 6-54) is the difference in the landfill C stock for that year and the stock in the preceding year. For example, the net change in 2014 shown in Table 6-54 (3.2 MMT C) is equal to the stock in 2014 (264.7 MMT C) minus the stock in 2013 (261.5 MMT C).

The C stocks calculated through this procedure are shown in Table 6-56.

Table 6-55: Moisture Contents, C Storage Factors (Proportions of Initial C Sequestered), Initial C Contents, and Decay Rates for Yard Trimmings and Food Scraps in Landfills

Variable	Yard Trimmings			Food Scraps
	Grass	Leaves	Branches	
Moisture Content (% H_2O)	70	30	10	70
C Storage Factor, Proportion of Initial C Stored (%)	53	85	77	16
Initial C Content (%)	45	46	49	51
Decay Rate ($year^{-1}$)	0.323	0.185	0.016	0.156

Table 6-56: C Stocks in Yard Trimmings and Food Scraps in Landfills (MMT C)

Carbon Pool	1990	2005	2010	2011	2012	2013	2014
Yard Trimmings	**155.8**	**202.9**	**213.6**	**216.1**	**218.6**	**220.9**	**223.2**
Grass	14.5	18.1	19.0	19.3	19.5	19.7	20.0
Leaves	66.7	87.3	92.2	93.4	94.5	95.6	96.6
Branches	74.6	97.5	102.3	103.4	104.5	105.6	106.6
Food Scraps	**17.6**	**32.8**	**38.0**	**38.9**	**39.8**	**40.7**	**41.5**
Total Carbon Stocks	**173.5**	**235.6**	**251.6**	**255.0**	**258.4**	**261.5**	**264.7**

Uncertainty and Time-Series Consistency

The uncertainty analysis for landfilled yard trimmings and food scraps includes an evaluation of the effects of uncertainty for the following data and factors: disposal in landfills per year (tons of C), initial C content, moisture content, decay rate, and proportion of C stored. The C storage landfill estimates are also a function of the composition of the yard trimmings (i.e., the proportions of grass, leaves and branches in the yard trimmings mixture). There are respective uncertainties associated with each of these factors.

A Monte Carlo (Approach 2) uncertainty analysis was applied to estimate the overall uncertainty of the sequestration estimate. The results of the Approach 2 quantitative uncertainty analysis are summarized in Table 6-57. Total yard trimmings and food scraps CO_2 flux in 2014 was estimated to be between -18.0 and -4.5 MMT CO_2 Eq. at a 95 percent confidence level (or 19 of 20 Monte Carlo stochastic simulations). This indicates a range of

44 percent below to 64 percent above the 2014 flux estimate of -11.6 MMT CO_2 Eq. More information on the uncertainty estimates for Yard Trimmings and Food Scraps in Landfills is contained within the Uncertainty Annex.

Table 6-57: Approach 2 Quantitative Uncertainty Estimates for CO_2 Flux from Yard Trimmings and Food Scraps in Landfills (MMT CO_2 Eq. and Percent)

Source	Gas	2014 Flux Estimate (MMT CO_2 Eq.)	Uncertainty Range Relative to Flux Estimate[a] (MMT CO_2 Eq.)		(%)	
			Lower Bound	Upper Bound	Lower Bound	Upper Bound
Yard Trimmings and Food Scraps	CO_2	(11.6)	(18.0)	(4.5)	-44%	+64%

[a] Range of flux estimates predicted by Monte Carlo Stochastic Simulation for a 95 percent confidence interval.
Note: Parentheses indicate negative values or net C sequestration.

Methodological recalculations were applied to the entire time series to ensure time-series consistency from 1990 through 2014. Details on the emission trends through time are described in more detail in the Methodology section, above.

QA/QC and Verification

A QA/QC analysis was performed for data gathering and input, documentation, and calculation. The QA/QC analysis did not reveal any inaccuracies or incorrect input values.

Recalculations Discussion

The current Inventory has been revised relative to the previous report. Generation and recovery data for yard trimmings and food scraps was not previously provided for every year from 1960 in the *Advancing Sustainable Materials Management: Facts and Figures 2013* report. EPA has since released historical data, which included data for each year from 1960 through 2013. The recalculations based on these historical data resulted in changes ranging from a one percent increase in sequestration in 2001 to a 7 percent decrease in sequestration in 2013, and an average 0.66 percent decrease in sequestration across the 1990 through 2013 time series compared to the previous Inventory.

Planned Improvements

Future work is planned to evaluate the consistency between the estimates of C storage described in this chapter and the estimates of landfill CH_4 emissions described in the Waste chapter. For example, the Waste chapter does not distinguish landfill CH_4 emissions from yard trimmings and food scraps separately from landfill CH_4 emissions from total bulk (i.e., municipal solid) waste, which includes yard trimmings and food scraps.

In addition, additional data will be evaluated from recent peer-reviewed literature that may modify the default C storage factors, initial C contents, and decay rates for yard trimmings and food scraps in landfills. Based upon this evaluation, changes may be made to the default values. Whether to update the weighted national average component-specific decay rate using new U.S. Census data, if any are available, will also be investigated.

The yard waste composition will also be evaluated to determine if changes need to be made based on changes in residential practices, research will be conducted to determine if there are changes in the allocation of yard trimmings. For example, leaving grass clippings in place is becoming a more common practice, thus reducing the percentage of grass clippings in yard trimmings disposed in landfills.