# Recent Improvements to the State Inventory Tool Land-Use Change and Forestry Module

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## ABSTRACT

The State Inventory Tool (SIT) was developed under the EPA's state Emission Inventory Improvement Program (EIIP) to assist states in the inventory process. The SIT covers most major sources of GHG emissions and incorporates state-of-the-art accounting methods into a user-friendly, worksheet-style format that reduces the resource intensity of developing GHG estimates while increasing accuracy and consistency across states. Land-use change and forestry has historically been one of the hardest categories of GHG emissions and sinks to quantify at the state level. This presentation will discuss major advances EPA has made to expand and improve upon earlier methods and tools.

The Land-Use Change and Forestry (LUCF) module of the SIT covers GHG sources and sinks related to land-use change and forestry activities. These sources and sinks include forest carbon flux, non-$CO_2$ emissions from forest fires, carbon flux in urban trees, carbon emissions from liming of agricultural soils, carbon storage in landfilled yard trimmings and food scraps, and $N_2O$ emissions from settlement soils. This module has recently been updated to improve the accuracy of estimates and increase their consistency with the national *Inventory of U.S. Greenhouse Gas Emissions and Sinks*. Updates include the incorporation of new or revised default data and emission factors as well as the addition of a source previously not included (i.e., $N_2O$ emissions from settlement soils). Default data through 2005 was also added where possible for all sources/sinks.

## INTRODUCTION

The State Inventory Tool (SIT) was developed under the EPA's state Emission Inventory Improvement Program (EIIP) to assist states in the inventory process. The EIIP was a joint program sponsored by EPA and the State and Territorial Air Pollution Program Administrators/Association of Local Air Pollution Control Officials (STAPPA/ALAPCO). The goal of EIIP was to help states produce cost-effective and reliable greenhouse gas (GHG) emission inventories. Prior to the development of the SIT, EPA developed the States Workbook for estimating GHG emissions. In 1998, EPA revisited the States Workbook and expanded it to follow the format of EIIP guidance documents for criteria air pollutants. The result was a comprehensive, stepwise approach to estimating GHG emissions at the state level. This detailed methodology was appreciated by states with the capacity to devote considerable time and resources to the development of emission inventories. For other states, the EIIP guidance was overwhelming and impractical for them to follow from scratch. EPA recognized the resource constraints facing the states and developed the SIT. The ten modules of the SIT corresponded to the EIIP chapters and attempted to automate the steps states would need to take in developing their own emission estimates in a manner that was consistent with prevailing national and state guidelines. EIIP is no longer funded as such, but work on the SIT and related state inventory material continues under the auspices of EPA's State and Local Branch.

The SIT covers most major sources of GHG emissions and incorporates state-of-the-art accounting methods into a user-friendly, worksheet-style format that reduces the resource intensity of developing GHG estimates while increasing accuracy and consistency across states. The SIT is divided into modules based on the source of emissions inventoried, as shown in Figure 1.

**Figure 1. Modules and Sectors Included in the State Inventory Tool**

| Modules | Sub-Sectors | |
|---|---|---|
| Carbon Dioxide from Fossil Fuel Combustion ($CO_2$) | • Residential<br>• Commercial<br>• Transportation | • Electric Power<br>• Bunker Fuels<br>• Industrial |
| Stationary Combustion ($CH_4$ & $N_2O$) | • Residential<br>• Commercial | • Electric Power<br>• Industrial |
| Mobile Combustion ($CH_4$ & $N_2O$) | • Highway Vehicles<br>• Aviation<br>• Boats & Vessels | • Locomotives<br>• Other Non-Highway Sources<br>• Alternative Fuel Vehicles |
| Coal ($CH_4$) | • Coal Mining | • Abandoned Underground Coal Mines |
| Natural Gas and Oil ($CO_2$ & $CH_4$) | • Natural Gas - Production<br>• Natural Gas - Transmission<br>• Natural Gas - Distribution | • Natural Gas - Venting & Flaring<br>• Petroleum Systems |
| Industrial Processes ($CO_2$,$CH_4$, & $N_2O$) | • Cement Production<br>• Lime Manufacture<br>• Limestone and Dolomite Use<br>• Soda Ash Manufacture and Consumption<br>• Iron and Steel Production<br>• Ammonia Manufacture<br>• Nitric Acid Production<br>• Adipic Acid Production | • Aluminum Production<br>• HCFC-22 Production<br>• Consumption of Substitutes for Ozone-Depleting Substances<br>• Semiconductor Manufacture<br>• Electric Power Transmission and Distribution<br>• Magnesium Production and Processing |
| Agriculture ($CH_4$ & $N_2O$) | • Enteric Fermentation<br>• Manure Management<br>• Agricultural Soil Management | • Rice Cultivation<br>• Agricultural Residue Burning |
| Land-Use Change and Forestry ($CO_2$,$CH_4$, & $N_2O$) | • Forest Carbon Flux<br>• Liming of Agricultural Soils<br>• Urban Trees<br>• $N_2O$ from Settlement Soils | • Non-$CO_2$ Emissions from Forest Fires<br>• Landfilled Yard Trimmings and Food Scraps |
| Solid Waste ($CO_2$ & $CH_4$) | • Landfills | • Waste Combustion |
| Wastewater ($CH_4$ & $N_2O$) | • Municipal Wastewater | • Industrial Wastewater - Fruits & Vegetables, Red Meat, Poultry, Pulp & Paper |
| Synthesis Tool | • Gathers emissions from all modules into one summary table | |
| Projection Tool | • Projects emissions estimates into the future | |

The SIT utilizes the methodologies used in the U.S. national inventory report (NIR)—the annual *Inventory of U.S. Greenhouse Gas Emissions and Sinks*. In some cases, slight modifications are necessary to make the methodologies applicable at the state level. The U.S. NIR follows internationally accepted GHG inventory preparation guidelines produced by the Intergovernmental Panel on Climate Change (IPCC). The SIT, thus, strives to provide states with a tool that will produce state-level estimates that are in accordance with national and international Inventory practices to the extent possible.

EPA reviews the SIT modules annually to assess what improvements can be made to each module. Improvements can include the incorporation of new activity data, updates to methodology or emission factors, or the inclusion of new sources or sinks. All of these types of changes were recently made to the LUCF module. This paper provides an overview of the LUCF module and then summarizes the recent changes for each LUCF source or sink. It concludes with a look forward to expected future improvements to the LUCF module.

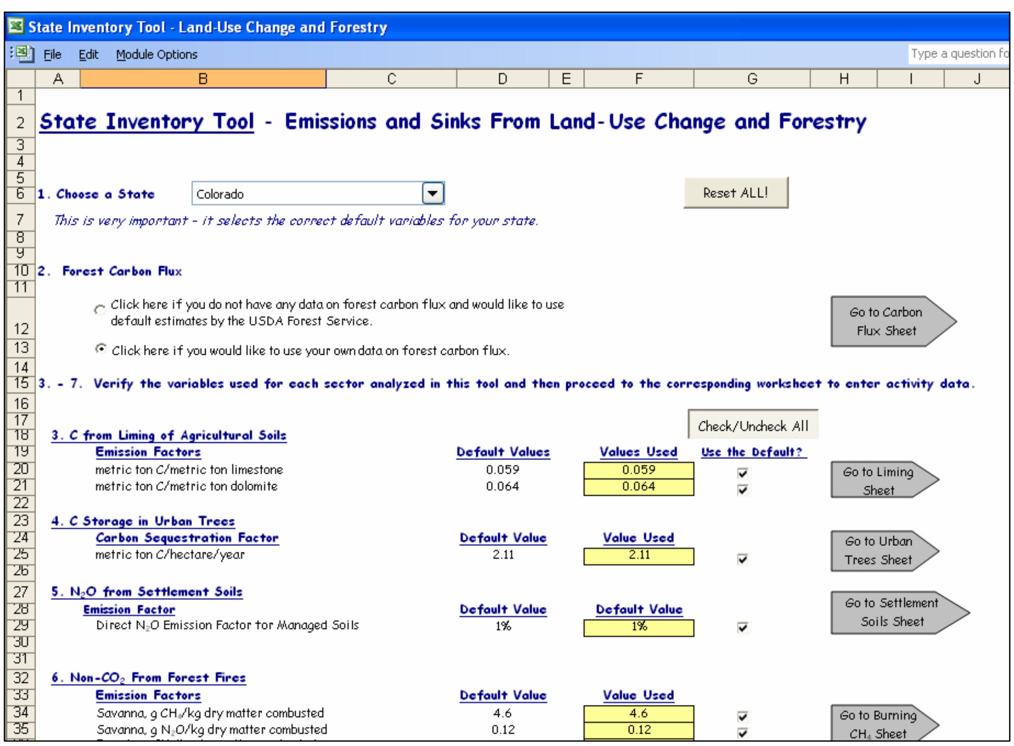
## BODY

### The LUCF Module

When humans use and alter the biosphere through land-use change and forest management activities, the balance between the emission and uptake of GHGs changes, affecting their atmospheric concentration; this balance between emission and uptake is known as GHG flux. Such activities can include clearing an area of forest to create cropland, restocking a logged forest, draining a wetland, or allowing a pasture to revert to grassland. In the United States, forest management is believed to be the primary activity responsible for current GHG fluxes from land use, and carbon dioxide ($CO_2$) is the gas most significantly affected. Carbon in the form of yard trimmings and food scraps can also be sequestered in landfills, as well as in trees in urban areas. In addition to carbon flux from forest management, urban trees, and landfills, other sources of GHGs under the category of land-use change and forestry are $CO_2$ emissions from liming of agricultural soils, emissions of methane ($CH_4$), and nitrous oxide ($N_2O$) from forest fires, and $N_2O$ emissions from fertilization of settlement and forest soils.

The LUCF module (Figure 2) allows states to calculate $CO_2$ emissions from liming of soils, $N_2O$ emissions from fertilization of settlement soils, and non- $CO_2$ ($N_2O$ and $CH_4$) emissions forest fires, as well as carbon flux from forest management, urban trees, and landfilled yard trimmings and food scraps. The specific sectors and gases covered in the module are listed in Figure 3. Some additional source and sink categories are included in the NIR, but have not yet been incorporated into the SIT. These sources

**Figure 2.** Screen shot of LUCF Module Control Worksheet



include: carbon flux associated with managed cropland and grassland soils, and $N_2O$ emissions from forest soils.  These sources comprise a relatively small portion of total Land Use, Land-Use Change and Forestry (LULUCF) emissions at the national level, with carbon flux from soils totaling about 6 to 8 percent of the national LULUCF total and $N_2O$ emissions from forest soils contributing from 0.01 to 0.05 percent of the total.  Developing state-level estimates is also still somewhat complex, particularly for estimating soil carbon emissions due to the complexity of the national-scale modeling underlying national estimates.

**Figure 3. Sources Included in the LUCF Module**

| Source Included | GHGs Measured |
| --- | --- |
| Forest Carbon Flux | Carbon |
| Liming of Agricultural Soils | $CO_2$ |
| Urban Trees | Carbon |
| $N_2O$ from Settlement Soils | $N_2O$ |
| Non-$CO_2$ Emissions from Forest Fires | $N_2O$, $CH_4$ |
| Carbon Storage in Landfilled Yard Trimmings & Food Scraps | Carbon |

Recent updates to the SIT LUCF module include (1) updates to activity data, (2) the addition of a source category already included in the NIR, but previously not included in the SIT—$N_2O$ from Settlement Soils, and (3) updates to emission factors and methodologies used in developing estimates for urban trees and landfilled yard trimmings and food scraps.  These changes are described in more detail below for each of the source categories that were modified in this latest round of improvements.

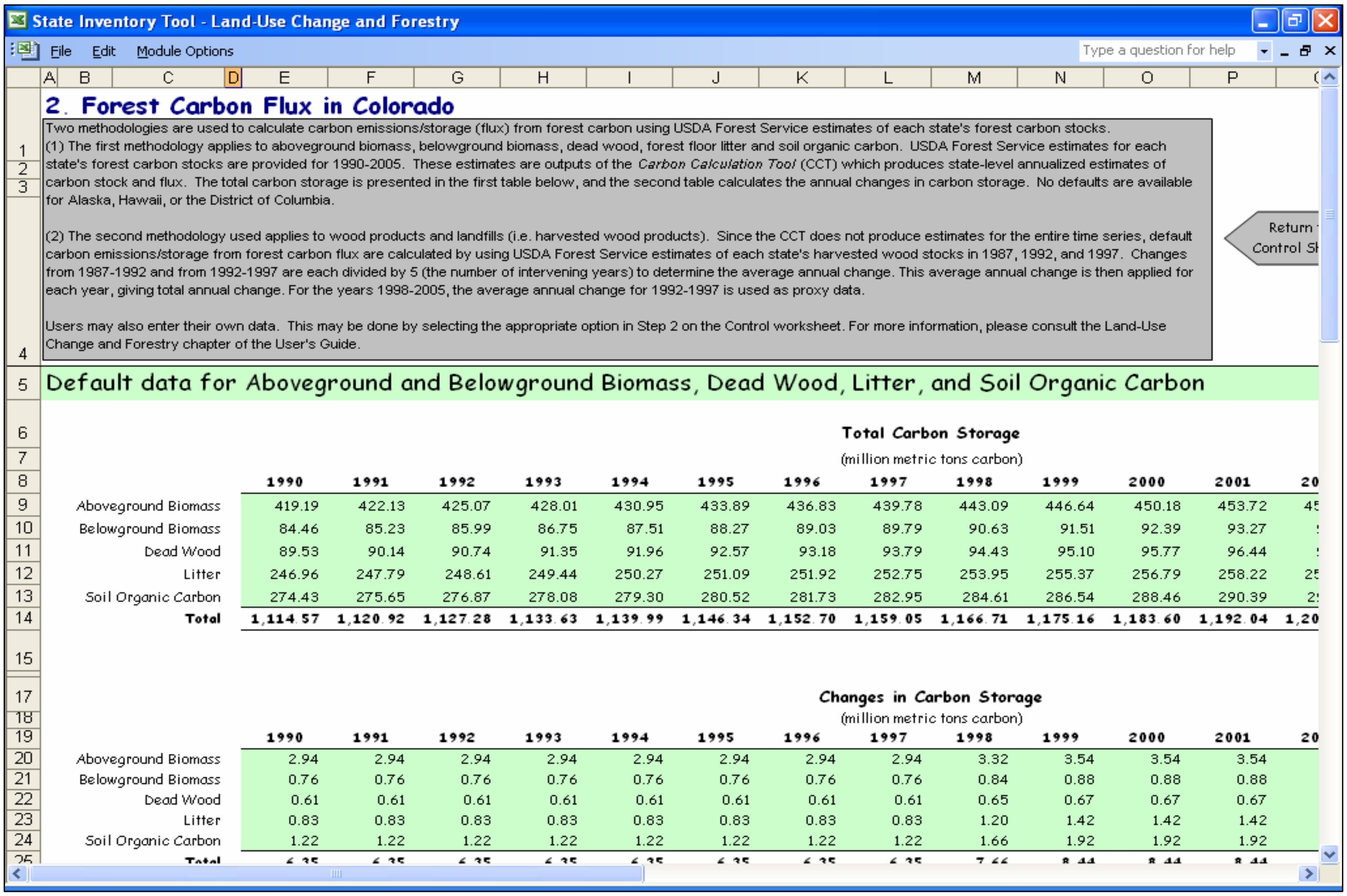
### Forest Carbon Flux

The default forest carbon flux data available to tool users was updated to include new state-level annualized data from the Carbon Calculation Tool (CCT) developed by the U.S. Forest Service (USFS). The CCT is designed to retrieve new Forest Inventory and Analysis (FIA) data each year and produce state-level annualized estimates of carbon stock and flux for the five forest carbon pools included in the NIR: Aboveground Biomass, Belowground Biomass, Dead Wood, Litter, and Soil Organic Carbon.  The USFS data accounts for the net change in the amount of carbon stored in each of these pools over time.

National estimates are derived by summing state-level estimates of net changes in forest carbon across these five pools.  The inclusion of the USFS data in the SIT tool as the default for state users, thus, means that state estimates of forest carbon flux developed using the SIT will correspond with the national estimates reported in the NIR.  Figure 4 shows an example of the forest carbon flux worksheet in the LUCF module when it is populated with the new default USFS data for Colorado.

The USFS data covers all states except Alaska and Hawaii for the years 1990 through 2005. Forest inventory data is limited or non-existent in Alaska, Hawaii, and U.S. territories.  Agroforestry systems (including riparian forest buffers, windbreaks, alley cropping, silvopasture, forest farming and special applications) are also not currently accounted for in the USFS data.  They are not explicitly inventoried by either of the two primary national natural resource inventory programs: the Forest Inventory and Analysis (FIA) program of the USDA Forest Service and the National Resources Inventory (NRI) of the USDA Natural Resources Conservation Service (Perry et al. 2005).

**Figure 4.** Screen shot of Forest Carbon Flux page of LUCF Module



State Inventory Tool - Land-Use Change and Forestry

File Edit Module Options

2. Forest Carbon Flux in Colorado

Two methodologies are used to calculate carbon emissions/storage (flux) from forest carbon using USDA Forest Service estimates of each state's forest carbon stocks.
(1) The first methodology applies to aboveground biomass, belowground biomass, dead wood, forest floor litter and soil organic carbon. USDA Forest Service estimates for each state's forest carbon stocks are provided for 1990-2005. These estimates are outputs of the *Carbon Calculation Tool* (CCT) which produces state-level annualized estimates of carbon stock and flux. The total carbon storage is presented in the first table below, and the second table calculates the annual changes in carbon storage. No defaults are available for Alaska, Hawaii, or the District of Columbia.

(2) The second methodology used applies to wood products and landfills (i.e. harvested wood products). Since the CCT does not produce estimates for the entire time series, default carbon emissions/storage from forest carbon flux are calculated by using USDA Forest Service estimates of each state's harvested wood stocks in 1987, 1992, and 1997. Changes from 1987-1992 and from 1992-1997 are each divided by 5 (the number of intervening years) to determine the average annual change. This average annual change is then applied for each year, giving total annual change. For the years 1998-2005, the average annual change for 1992-1997 is used as proxy data.

Users may also enter their own data. This may be done by selecting the appropriate option in Step 2 on the Control worksheet. For more information, please consult the Land-Use Change and Forestry chapter of the User's Guide.

Default data for Aboveground and Belowground Biomass, Dead Wood, Litter, and Soil Organic Carbon

Total Carbon Storage
(million metric tons carbon)

| | 1990 | 1991 | 1992 | 1993 | 1994 | 1995 | 1996 | 1997 | 1998 | 1999 | 2000 | 2001 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Aboveground Biomass | 419.19 | 422.13 | 425.07 | 428.01 | 430.95 | 433.89 | 436.83 | 439.78 | 443.09 | 446.64 | 450.18 | 453.72 |
| Belowground Biomass | 84.46 | 85.23 | 85.99 | 86.75 | 87.51 | 88.27 | 89.03 | 89.79 | 90.63 | 91.51 | 92.39 | 93.27 |
| Dead Wood | 89.53 | 90.14 | 90.74 | 91.35 | 91.96 | 92.57 | 93.18 | 93.79 | 94.43 | 95.10 | 95.77 | 96.44 |
| Litter | 246.96 | 247.79 | 248.61 | 249.44 | 250.27 | 251.09 | 251.92 | 252.75 | 253.95 | 255.37 | 256.79 | 258.22 |
| Soil Organic Carbon | 274.43 | 275.65 | 276.87 | 278.08 | 279.30 | 280.52 | 281.73 | 282.95 | 284.61 | 286.54 | 288.46 | 290.39 |
| **Total** | **1,114.57** | **1,120.92** | **1,127.28** | **1,133.63** | **1,139.99** | **1,146.34** | **1,152.70** | **1,159.05** | **1,166.71** | **1,175.16** | **1,183.60** | **1,192.04** |

Changes in Carbon Storage
(million metric tons carbon)

| | 1990 | 1991 | 1992 | 1993 | 1994 | 1995 | 1996 | 1997 | 1998 | 1999 | 2000 | 2001 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Aboveground Biomass | 2.94 | 2.94 | 2.94 | 2.94 | 2.94 | 2.94 | 2.94 | 2.94 | 3.32 | 3.54 | 3.54 | 3.54 |
| Belowground Biomass | 0.76 | 0.76 | 0.76 | 0.76 | 0.76 | 0.76 | 0.76 | 0.76 | 0.84 | 0.88 | 0.88 | 0.88 |
| Dead Wood | 0.61 | 0.61 | 0.61 | 0.61 | 0.61 | 0.61 | 0.61 | 0.61 | 0.65 | 0.67 | 0.67 | 0.67 |
| Litter | 0.83 | 0.83 | 0.83 | 0.83 | 0.83 | 0.83 | 0.83 | 0.83 | 1.20 | 1.42 | 1.42 | 1.42 |
| Soil Organic Carbon | 1.22 | 1.22 | 1.22 | 1.22 | 1.22 | 1.22 | 1.22 | 1.22 | 1.66 | 1.92 | 1.92 | 1.92 |
| **Total** | **6.35** | **6.35** | **6.35** | **6.35** | **6.35** | **6.35** | **6.35** | **6.35** | **7.66** | **8.44** | **8.44** | **8.44** |

## Urban Trees

The Urban Trees sink category was updated to include new urban area estimates, making it possible to develop annualized estimates of carbon storage across the entire inventory time series from 1990 through 2005. Net carbon flux from urban trees is calculated in the SIT by multiplying the percent of urban area covered by trees by the total urban area for a state by a carbon sequestration factor, as shown in Equation (1) below.

Equation (1) Sequestration ($MMTCO_2E$) = Total Urban Area ($km^2$) × Urban Area with Tree Cover (%) × 100 ($ha/km^2$) × C Sequestration Factor (metric tons C/ha/yr) × 44/12 (ratio of $CO_2$ to C) ÷ 1,000,000 (to yield $MMTCO_2E$)

Previously, the SIT estimation methodology only included 1990 U.S. Census data on urban area. Since urban area is a key variable in the calculation of carbon storage in urban trees, the SIT previously had the capability to only provide one estimate that was assumed to remain static across the entire time series in a state's inventory. The inclusion of 2000 U.S. Census data on urban area in the most recent round of LUCF module improvements made it possible to develop annualized state-level estimates. U.S. Census estimates of urban area from 1990 and 2000 were used as the basis for interpolating and extrapolating, respectively, estimates of urban area in the intervening years (1991-1999) and subsequent years (2001-2005). This approach was implemented last year at the national level for the NIR. The percent of urban area with tree cover for each state was based on a 2000 study (Dwyer et al. 2000), which was multiplied by the urban areas for each state to determine the total urban area with tree cover.

## Liming of Agricultural Soils

The Liming of Agricultural Soils source category was updated to include recent revisions to the emission factors used in the NIR. The emissions factors in both the NIR and SIT were updated based on recent research (West and McBride 2005) on the fate of carbon in limestone ($CaCO_3$) and dolomite ($CaMg(CO_3)_2$) following application to agricultural soils. When these compounds come in contact with acidic soils, they degrade, thereby generating $CO_2$. Equation (2) presents the methodology for calculating $CO_2$ emissions from the application of limestone and dolomite to agricultural soils.

Equation (2) Emissions ($MMTCO_2E$) = Total Limestone or Dolomite Applied to Soil (1000 metric tons) × Emission Factor (tons C/ton limestone or dolomite) × 44/12 (ratio of $CO_2$ to C) ÷ 1,000,000 (to yield $MMTCO_2E$)

IPCC default emission factors were previously used in the SIT. The research conducted by West and McBride described the agricultural lime dissolution pathway in detail and cumulatively accounted for carbon at each step to derive revised emission factors. West and McBride's proposed emission factors first replaced the IPCC default emission factors in the 1990-2004 NIR, when it was determined that their approach and assumptions were likely to provide more accurate estimates. The revised limestone and dolomite emission factors (0.059 metric ton C/metric ton limestone, 0.064 metric ton C/metric ton dolomite) are about half the magnitude of the IPCC default emission factors, and, thus, result in a downward adjustment in the estimates of emissions from limestone and dolomite applied to agricultural soils.

Newly available default activity data on the quantity of limestone and dolomite applied in each state for the years 2004 and 2005 were also incorporated into the LUCF module.

## Landfilled Yard Trimmings and Food Scraps

The Landfilled Yard Trimmings and Food Scraps sink category was updated to include newly available generation and disposal data and to revise the methodology to make it consistent with recent changes to the methodological assumptions used in the NIR. Carbon storage factors in the SIT were updated to reflect a mass balance adjustment made in the 1990-2004 NIR. When applying the C storage data reported by Barlaz (1998) in the NIR, an adjustment was made to the reported values to attain a perfect mass balance on total C for each of the materials. There are four principal elements in the mass balance:

- Initial C content (ICC, measured),
- C output as methane ($CH_4$-C, measured),
- C output as $CO_2$ ($CO_2$-C, not measured), and
- Residual stored C (CS, measured).

In accounting for a perfect carbon balance, the carbon storage factors of branches and food scraps were adjusted to account for a slight increase in methane yield, and the carbon storage factor of grass was adjusted to account for a slight decrease in landfill carbon storage. Overall, this adjustment changed the 2004 carbon storage factor to 0.30 kg C sequestered / dry kg waste for grass, 0.38 kg C sequestered / dry kg waste for branches, and 0.08 kg C sequestered / dry kg waste for food scraps from previous values of 0.32 kg C sequestered / dry kg waste, 0.38 kg C sequestered / dry kg waste, and 0.08 kg C sequestered / dry kg waste respectively.

Newly generated experimental results for leaves, provided by Barlaz (2005), indicated more decomposition than the previous analysis. A new estimate of initial carbon content for leaves was incorporated into the NIR, and the same changes were made to the SIT LUCF module.

**$N_2O$ from Settlement Soils**

This source was newly added to the LUCF module this year. The SIT applies the methodology used in the NIR methodology to state data to produce state-level data. The NIR and SIT assume that approximately 10 percent of the fertilizers applied to soils in the US are applied to lawns, golf courses, and other landscaping occurring within settled areas. The NIR further includes estimates of emissions from application of sewage sludge to settlement soils; this component of the source was not included in the LUCF module calculations due to data limitations and the proportional insignificance of this sub-source in terms of the magnitude of its contribution to total emissions. The LUCF module estimates $N_2O$ emissions due to the application of fertilizers to settlement soils using Equation (3).

Equation (3) Emissions ($MMTCO_2E$) = Total Synthetic Fertilizer Applied to Settlement Soils (metric ton N) × Emission Factor (1 percent) × 0.01 (metric tons $N_2O$-N/metric ton N) × 44/28 (Ratio of $N_2O$ to $N_2O$-N) × 310 (GWP) ÷ 1,000,000 ($MT/MMTCO_2E$)

## CONCLUSIONS

The LUCF module and other SIT modules will continue to be updated and improved. Some additional improvements are already planned for the LUCF module, as outlined below.

### 2006 IPCC Guidelines for National Greenhouse Gas Inventories

The release of the 2006 IPCC Guidelines for National Greenhouse Gas Inventories (2006 GL) may bring some structural and organizational changes to the SIT LUCF and Agriculture modules as well as prompting updates to some emission and stock change factors. Nearly 140 scientists and national experts from more than thirty countries collaborated in the creation of the *Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories* to ensure that the emission inventories submitted to the UNFCCC are consistent and comparable between nations. These guidelines were recently updated and revised to produce the *2006 IPCC Guidelines for National Greenhouse Gas Inventories*. When the organizational structure outlined in the 2006 IPCC Guidelines is fully implemented, the Agriculture and LULUCF chapters of the NIR will be combined into a single Agriculture, Forestry, and Other Land Uses (AFOLU) chapter covering six land-use categories (Forest Land, Cropland, Grassland, Wetlands, Settlements, and Other Land). The Agriculture and LUCF modules of the SIT may be similarly combined and reorganized to maintain consistency with national and international inventory approaches. These changes will likely be incorporated in the next round of revisions to the SIT modules.

### Other Improvements

Future improvements to the SIT LUCF module may also include the addition of sources currently accounted for at the national level, such as carbon flux associated with management of cropland and grassland soils. EPA is exploring the option of requesting that national-level modeling efforts currently undertaken to develop national-level estimates be disaggregated to the state level. The availability of state-level estimates would make it possible to easily include default data or estimates for this source in the LUCF module.

Estimates of $N_2O$ emissions from agricultural soil management developed using sophisticated process-based modeling techniques may also be available at the state level in coming years. This source is currently covered in the SIT Agriculture module, but the availability of new state-level estimates may make it possible to include improvements to this source in a new combined AFOLU module.

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## KEY TERMS

Greenhouse Gas Emissions; Greenhouse Gas Inventory; Land-Use Change and Forestry