California Environmental Protection Agency

# Air Resources Board

# California's 1990-2004 Greenhouse Gas Emissions Inventory and 1990 Emissions Level

## Forest and Rangelands Methods excerpted from the full Technical Support Document

(Link to full document)

**State of California**
**Air Resources Board**
**Planning and Technical Support Division**

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*Note: Original technical support document table 2 and figure 3 were modified to include the latest estimates.*

## Acknowledgments

This document was developed by the following Air Resources Board staff members:

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## Disclaimer

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# INTRODUCTION

The Global Warming Solutions Act of 2006 (AB 32, Nunez, Statutes of 2006, chapter 488) requires that the California Air Resources Board (ARB or the Board) determine the statewide 1990 greenhouse gas emissions level and approve a statewide greenhouse gas emissions limit, equal to that level, to be achieved by 2020. Assembly Bill 1803, which became law in 2006, transferred the responsibility to prepare, adopt, and update California's greenhouse gas inventory from the California Energy Commission (CEC) to the ARB beginning in January 2007.

This technical support document presents the comprehensive and detailed discussion of the methods, equations, data sources, and references that ARB staff employed to develop ARB's first edition of California's greenhouse gas (GHG) inventory, including those used in determining the statewide 1990 GHG emissions level and 2020 limit. The structure of this report follows the categorization of GHG emissions to, and removal from, the atmosphere contained in the *2006 IPCC Guidelines*. The technical background of each category is presented followed by a discussion of the methodology used to estimate emissions or removals of GHG, including calculation equations, data sources, and future improvements to the estimations. For each category, the complete list of activity and parameter values used in the equations is made available in an online documentation annex linked to this report.

In developing the ARB's first GHG inventory, staff began by reviewing the last edition of CEC's GHG inventory, consulting with other State agencies, and engaging stakeholders and the public through a series of workshops and technical discussions. That public process resulted in a number of revisions to the CEC inventory, including changes to the classification of emissions and sinks, selected emission estimation methods, GHG emission factors, and other parameters. These revisions aligned the inventory with the International Panel on Climate Change (IPCC) latest guidelines, published in 2006. Revisions also incorporated methodologies and data from the *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2005*, published in April 2007 by the U.S. Environmental Protection Agency (USEPA).

California's GHG inventory, covering years 1990 to 2004, was published on ARB's website (http://www.arb.ca.gov/cc/inventory/archive/archive.htm) on November 19, 2007. Based upon this inventory work, ARB staff recommended an amount of 427 million metric tonnes of carbon dioxide equivalent (MMT$CO_2$e) as the total statewide greenhouse gas 1990 emissions level and 2020 emissions limit. The Board approved the 2020 limit on December 6, 2007. A staff report titled "*California 1990 Greenhouse Gas Emissions Level and 2020 Emissions Limit*" discussed the development of the 1990 statewide emissions level and provided a summary of the methodologies and main sources of data used to calculate the GHG emissions (http://www.arb.ca.gov/cc/inventory/1990level/1990level.htm).

# III. Agriculture Forestry and Other Land Use

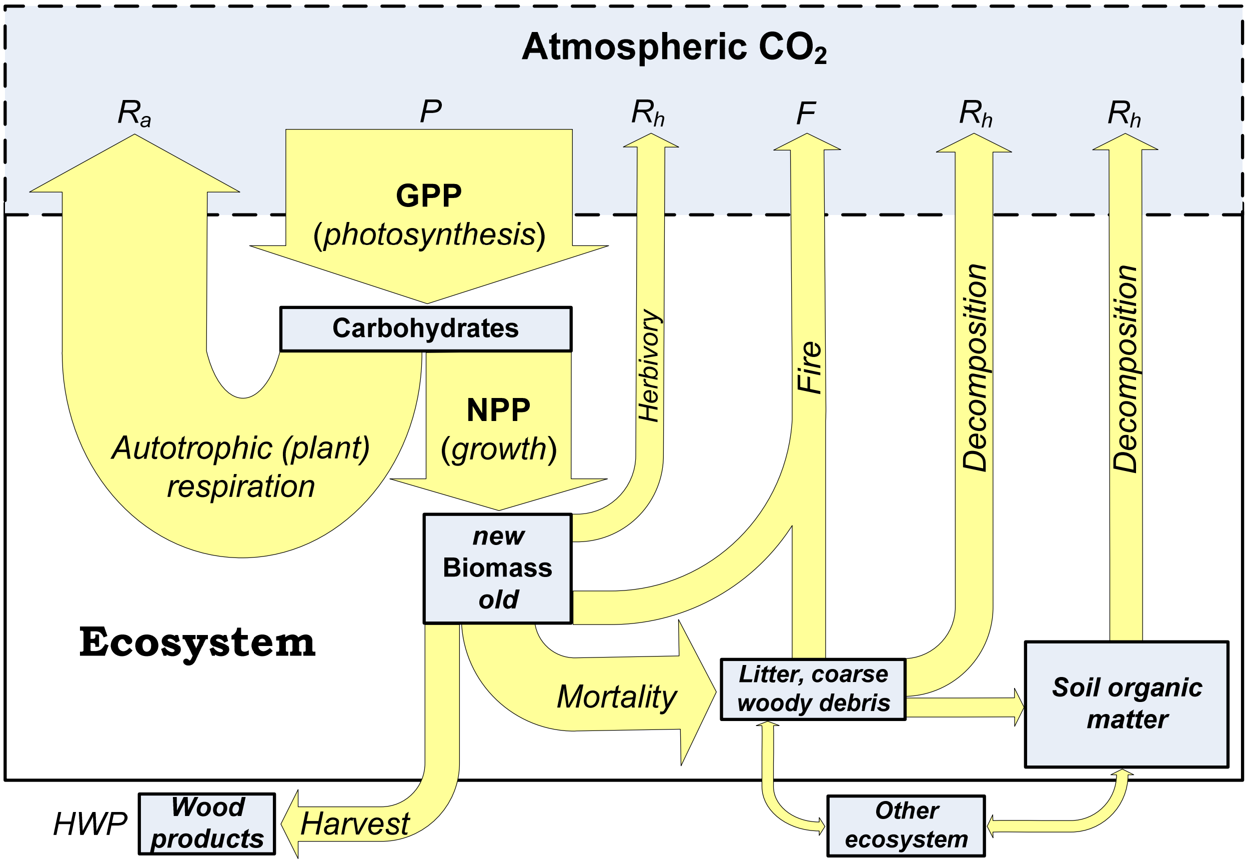
## *C. Land - Forests and Rangelands (IPCC 3B)*

### 1. Background

Trees and other green plants can remove $CO_2$ from the atmosphere via photosynthesis. Light energy is captured by chlorophyll in plant cells and used to convert water, carbon dioxide, and minerals into oxygen and energy-rich organic compounds (carbohydrates). Nearly all life on Earth either directly or indirectly depends on this process as a source of energy. The total amount of energy stored into carbohydrates through photosynthesis is called *Gross Primary Production* (GPP), see Figure 1. GPP is generally expressed as a mass of carbon per unit area per unit of time. Plants use some of their carbohydrates for energy through cellular respiration, and that process releases carbon back to the atmosphere as $CO_2$. About half of GPP is respired by plants, the remaining carbohydrates being used to build plant tissues (e.g., roots, stalks, leaves, seeds). These tissues constitute the plant biomass and, as they die, dead biomass. GPP minus respiration is called *Net Primary Production* (NPP), the amount of production of living and dead biomass per unit area per unit of time. The carbon tied in carbohydrates in plant tissues is sequestered away from the atmosphere for a period of time. However, it will eventually be released back into the atmosphere: rapidly through combustion by fire, or slowly via decomposition. NPP minus the losses from the decomposition of organic matter in dead wood, litter and soils is called *Net Ecosystem Production* (NEP). Changes in NEP are used to estimate atmospheric $CO_2$ removals, and emissions due to disturbance (fire, harvest, etc.) in this section of the GHG inventory called Land –Forests and Rangelands.

The concept of distinct reservoirs or pools is useful to keep track of the fate of the carbon that has been removed from the atmosphere by plants. The United Nations Framework Convention on Climate Change (UNFCCC) defines reservoirs as “components of the climate system where a GHG or a precursor of a GHG is stored”. In forestry, these reservoirs are referred to as “pools.” The pools in a forested landscape include: the above and below ground live vegetation pools (trunks, stems, foliage, roots); the dead organic matter pools (standing or downed dead wood, litter); and the soil organic matter pool (living and non-living). Greenhouse gas inventories also include a forest biomass pool called Harvested Wood Products (HWP). Over time, carbon is transferred among these “reservoirs” or “pools”. For instance, when a tree is harvested some of its carbon is transferred from the live tree pool to the harvested wood product pool; during a fire carbon may flow form the dead wood pool to the cinders pool.

*Figure 1: Carbon fluxes of terrestrial ecosystems (after Schulze et al., 2000 and Lovett et al., 2006)*




**Carbon Fluxes of Terrestrial Ecosystems**

► Gross Primary Production (GPP) = Carbon assimilation by photosynthesis (*P*)
► Net Primary Production (NPP) = GPP – Autotrophic respiration ($R_a$)
► Net Ecosystem Production (NEP) = NPP – Heterotrophic respiration ($R_h$)
► Organic Carbon accumulation ($\Delta C_{org}$) = NEP + Carbon imports form other ecosystems – Fire (*F*) – Harvested wood products (*HWP*) – Carbon exports to other ecosystems

Greenhouse gas fluxes in this section may be estimated using two main approaches (IPCC, 2003), either singly or in combination. The first, called the stock-change approach, estimates the net change in carbon over all reservoirs in the system. The second, called the atmospheric flow approach, directly estimates gas fluxes between each of the reservoirs and the atmosphere. ARB staff has used the atmospheric flow approach (Figure 3) to estimate the net flux of $CO_2$ for the forested lands and wood products pools in California. This net $CO_2$ flux is reported under IPCC category 3B.

Ecosystems also emit $N_2O$ and $CH_4$ through soil microbial processes and the combustion of organic matter. Estimates of $CH_4$ and $N_2O$ emissions from fire and other disturbances are reported under IPCC Category 3B1.

The 2003 IPCC Good Practice Guidance for Land Use, Land-Use Change and Forestry (IPCC, 2003) and the 2006 IPCC Guidelines for National Greenhouse

Gas Inventories (IPCC, 2006g) specify additional land-use categories for GHG flux estimation, including croplands, wetlands, and urban areas. This edition of California's GHG inventory does not include $CO_2$ fluxes from agricultural lands because of a lack of data and a need to adapt methodologies to reflect California's large set of crops. Non-$CO_2$ emissions from agriculture are reported under IPCC category 3C. Greenhouse gas emissions from fossil fuel use in forestry and agriculture are included in Section I.C of the full version of the Technical Support Document (Link to full document).

## 2. Methodology

### *2.1 Forest and Range Lands Biomass*

Carbon dioxide removal from the atmosphere can be estimated from an increase in biomass (stock change) on a landscape over a time interval (i.e., years). Likewise, decreases in biomass may be used to estimate $CO_2$ emissions back to the atmosphere. However, not all of the gross decreases in biomass on a forest site result in an emission, because a fraction of the removed biomass carbon may be transferred to a product pool rather than released to the atmosphere. For example, live tree biomass removed from a forest to make a long-term wood product such as a house, represents a cessation of atmospheric $CO_2$ removal, and a transfer of carbon from the live tree pool to a wood product pool. The harvest event is causing some $CO_2$ emissions through the decomposition (or combustion) of on-site harvest residues ("slash") and soil disturbance. The carbon in the wood product, on the other hand, will not be released to the atmosphere until the product reaches its end of use (e.g., when a wood pallet or a piece of furniture is discarded). To avoid over-estimating emissions it is necessary to account for all pool-to-pool transfers and determine the net biomass stock change.

Conventionally, forest biomass is estimated using statistically designed networks of on-the-ground sampling plots (or transects) and measurement protocols. Equations are used to estimate the biomass present in various pools from measured variables (such as tree diameter at breast height [4.5 ft or 1.37 m], or DBH). Additional equations are used to scale-up from plot scale (tens of square meters) to larger areas (hectares). Plots are re-sampled at annual or multi-year intervals in order to track biomass changes over time. Examples of landscape biomass monitoring networks include the USDA Forest Service Forest Inventory and Analysis (FIA) program. Emerging approaches to landscape biomass estimation include satellite or aircraft remote sensing coupled with ground sampling (e.g., Dong et al. 2003; Hurtt et al. 2004; Potter et al. 2007a, 2007b; Treuhaft et al. 2003, 2004; Zhang and Kondragunta 2006).

For this version of California's GHG inventory, ARB staff used data and analyses results from a recent project, "Baseline Greenhouse Gas Emissions for Forest, Range and Agricultural Lands in California", carried out for the California Energy Commission (CEC, 2004a). In this work, Winrock

International, a non-profit research organization, used a methodology combining satellite-based forest change detection with ground-based data, and derived empirical relationships between tree canopy cover and biomass for various forest types. Their methods were consistent with IPCC Tier 3 approaches (IPCC, 2006g), as they employed "regional data, models, and measurement systems repeated over time using comprehensive field sampling and/or GIS-based systems." These methods are not discussed here in detail: particulars can be found in the California Energy Commission (CEC) project report (CEC, 2004a). Instead, a general description is presented here together with a worked example.

Researchers estimated the biomass of forests and wooded range lands in 1994 and 2000 in three northern California project areas representing 84 percent of forest lands and 42 percent of range lands in the state (CEC, 2004a). The year 1994 represented "time zero" or initial condition stocks. Biomass estimates were based on empirical relationships between tree canopy cover and biomass for five forest types, and determined for each cell of a grid (with 100 m x 100 m = 1 hectare grid cell size) covering the regions. Gross stock changes between 1994 and 2000 were used to estimate atmospheric $CO_2$ removals, and net stock changes were used to estimate $CO_2$ emissions and emissions of other GHGs over the interval. Changes in forest canopy cover detected by satellite were attributed to events or "change agents" (such as growth, fire, harvest, etc.) using ground survey data. For each type of disturbance event (fire, harvest, etc.), specified amounts of biomass carbon were allocated through various pathways to destination pools. Pre- and post-event biomass pools were used to estimate gross and net stock change.

### *2.2 Fire*

Fire events were categorized into low, middle, or high intensities depending on the relative change in tree canopy cover detected by satellite. Fire causes biomass carbon to be redistributed through various pathways (Figure 2). A fraction of the carbon is volatilized, while other fractions become soot, charcoal, dead wood or survive as vegetation. The proportion of carbon volatilized versus surviving as vegetation varies with the fire intensity (Table 1). For example, following intense fires 60 percent of the affected carbon volatilizes, 11 percent survives as vegetation, and 29 percent remains as charcoal, soot, and dead wood. A greater fraction of vegetation survives in low intensity fires, and a smaller fraction of the affected carbon volatilizes. Regardless of fire intensity, a decay rate of 0.05 $yr^{-1}$ is applied to the dead wood fraction for two years post-fire.

*Figure 2: Flow diagram of carbon fate after fire. Adapted from Figure 1-5 in CEC (2004).*

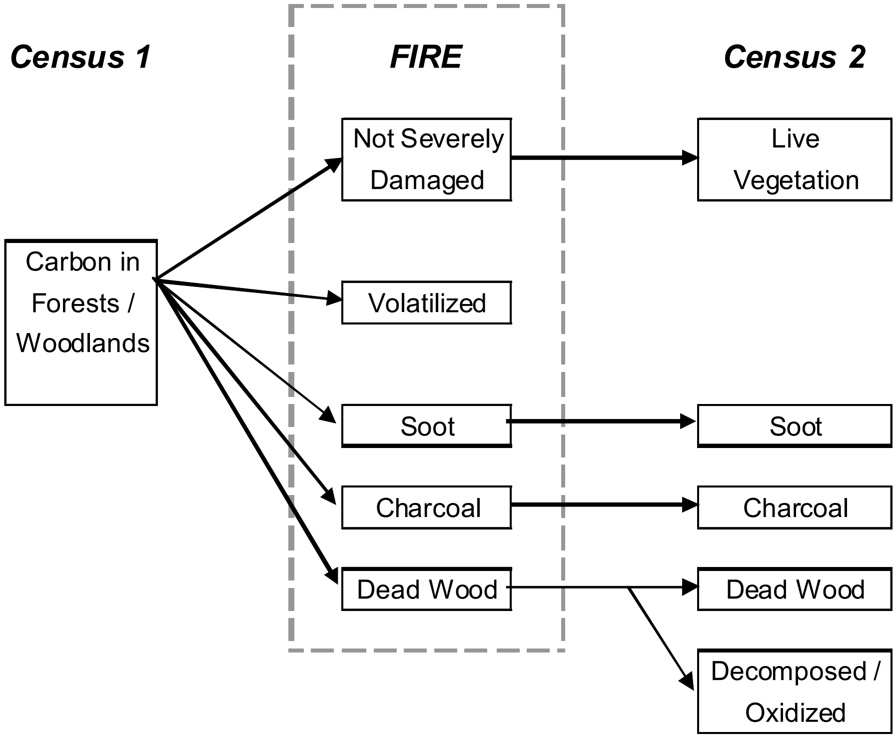



*Table 1: Carbon fate assumptions after decreases in canopy cover caused by fire (percent).*

| Carbon fate | High Intensity Fire | Medium Intensity Fire | Low Intensity Fire |
|---|---|---|---|
| Fraction volatilized | 60 | 40 | 20 |
| Fraction not volatilized | 29.4 | 27.3 | 28.6 |
| ▪ Charcoal | 6.5 | 5.8 | 6.4 |
| ▪ Soot | 13.3 | 12.4 | 12.9 |
| ▪ Dead wood | 9.6 | 9.1 | 9.3 |
| Surviving vegetation | 10.6 | 32.7 | 51.4 |
| Total | 100 | 100 | 100 |

Based on data in the CEC report by Winrock International (CEC, 2004a).

The following example lists the stock changes and resultant emissions inferred for a large decrease in tree canopy cover resulting from intense fire in a dense-canopied Douglas-fir forest:

- Region: North Coast
- Forest Type: Douglas-fir
- Pre-fire canopy cover: Dense (>= 60 percent)
- Fire Intensity: High
- Affected area: 390 hectares
- Pre-Fire Biomass: 152875.7 tonnes
- Post-Fire Biomass: 67696.5 tonnes
- Gross Stock Change: -85179.2 tonnes

- Post-Fire Charcoal: (Pre-Fire Biomass – Post-Fire Biomass) x 0.065 = 5536.6 tonnes
- Post-Fire Soot: (Pre-Fire Biomass – Post-Fire Biomass) x 0.133 = 11328.8 tonnes
- Post-Fire Dead Wood after 2-year decomposition: (Pre-Fire Biomass – Post-Fire Biomass) x 0.096 x 0.95 x 0.95 = 7379.9 tonnes
- Post-Fire Biomass, Charcoal, Soot, Dead Wood: 91941.9 tonnes
- Net Stock Change: (Post-Fire Biomass, Charcoal, Soot, Dead Wood) – (Pre-Fire Biomass) =
    - Biomass: -60933.8 tonnes
    - Carbon released: 30466.9 tonnes of C, or
    - $CO_2$ emissions: 111712 tonnes of $CO_2$

By convention, minus signs denote stock decreases, while reported emissions to the atmosphere are denoted with a positive sign. To further estimate the stock changes and resultant emissions from fire for the Douglas-fir forest type, the approach is performed for other pre-fire canopy cover classes (Moderate, Open, etc.) and fire intensity categories (moderate, light). The process is repeated for fires in other forest types (Fir-Spruce, Hardwood, etc.) in the region. Results for the North Coast region are listed in Table 1-9 of the report (CEC, 2004a).

Methane and nitrous oxide emissions from fire are estimated from the mass of carbon released, using the default IPCC approach (IPCC, 2003):

*Equation 1: $CH_4$ emissions from fires*

$$E_{CH4} = M_c \bullet 0.012 \bullet 1.3357$$

Where,

| | |
|---|---|
| $E_{CH4}$ | = $CH_4$ emissions from fire (tonnes) |
| $M_C$ | = Mass of carbon released (tonnes) |
| 0.012 | = Proportion of carbon emitted as methane |
| 1.3357 | = Molecular weight ratio of $CH_4$ to C |

*Equation 2: $N_2O$ emissions from fires*

$$E_{N2O} = M_C \bullet 0.01 \bullet 0.007 \bullet 1.5711$$

Where,

| | |
|---|---|
| $E_{N2O}$ | = $N_2O$ emissions from fire (tonnes) |
| $M_C$ | = Mass of carbon released (tonnes) |
| 0.01 | = Nitrogen to carbon ratio in biomass |
| 0.007 | = Proportion of nitrogen emitted as nitrous oxide |
| 1.5711 | = Molecular weight ratio of $N_2O$ to $N_2$ |

### *2.3 Harvest*

Tree harvests transfer a fraction of tree carbon from live biomass to wood products pools. A portion of the wood products are long-lasting and do not generate $CO_2$ emissions in the short term. Emissions from such products occur after end of use and disposal, and are discussed in the Wood Products Section (III.C.2.7 below), and in the Landfills Section (IV.A) of the full Technical Support Document (Link to full document).

Emissions associated with harvest events for softwood and hardwood forests were estimated in a manner similar to disturbance by fire, accounting for net changes in biomass resulting from the transfer of carbon from trees to products. Pre- and post-harvest biomass was estimated on a grid with a one hectare cell size from satellite imagery for various forest types and canopy cover classes. For harvested softwood forests, the wood product fraction was 44 percent of the extracted biomass, where extracted biomass was defined as 75 percent of the gross stock change. For harvested hardwood forests, 23 percent of the extracted biomass became product, where the extracted fraction was defined as 73 percent of the gross stock change. For softwood forests the on-site residue (slash) fraction was defined as 25 percent of the gross stock change. For hardwood forests, the slash fraction was defined as 27 percent of the gross stock change. A 0.05 $yr^{-1}$ decomposition rate was applied to all slash for two years. Net stock change was estimated by the difference between pre-harvest stock and post-harvest stock, plus persistent slash and wood product. The net stock change was converted from biomass to carbon and reported as $CO_2$. Post-harvest methane emissions were estimated using a default rate (0.94 kg/ha/yr).

### 2.4 Other Disturbances

Emissions associated with stock changes inferred from forest canopy cover declines due to land use change (development) or other forces are described in the Winrock report (CEC, 2004a).

### 2.5 Scaling to State-Wide Estimates

Average annual rates of $CO_2$ removals and GHG emissions for forests and range lands were derived from the estimates made over the three northern California study regions over the 1994 to 2000 time interval (CEC, 2004a). Then, these average annual rates were scaled-up to the entire state of California using factors based on the fraction of statewide forests (0.84) and range lands (0.42) represented in the study (CEC, 2006a). Scaling the regional results to statewide estimates was necessary because satellite-based change detection data for central and southern California were not available at the time of the study.

### 2.6 Back-casting to 1990, Forecasting to 2004

State-wide $CO_2$ removals and GHG emissions estimates for 1994 to 2000 were extrapolated to cover the 1990–1993 and 2001–2004 GHG inventory periods (CEC, 2006a). To do this, estimates were back-cast and forecast using factors based on forest land area trends reported in publications of the California

Department of Forestry and Fire Protection and the USDA-Forest Service (Shih 1998; Alig and Butler 2004). The back-cast scale factor was based on a 0.1707 percent yearly decline in forest land area reported for the period 1953 to 1994, while the forecast factor was a 0.0755 percent per year decline in forest land area projected for 1997 to 2050.

### *2.7 Wood Products*

Because carbon stored in wood can persist for long periods of time, the fate of wood products is an important element in GHG inventories. California uses a wide range of wood products and, once discarded, these wood products arrive at a variety of destinations, such as landfills, recycling, and composting facilities. ARB staff estimated the emissions from the statewide use and disposal of wood products in landfills and composting operations for years 1990 through 2004. To do this, a time series of statewide wood products (paper, lumber, etc.) use and disposal was developed from output of the WOODCARB model (Skog and Nicholson 1998, Skog et al. 2004) provided by the USDA-Forest Service Forest Products Laboratory and from waste characterization data from the California Integrated Waste Management Board (CIWMB). For landfilled wood product waste, a first-order decay model (IPCC, 2006h) was applied to estimate $CO_2$ and $CH_4$ emissions for years 1990 through 2004. The model estimates the fraction of carbon eventually released to the atmosphere and the fraction that persists in landfills. For composted wood products, CIWMB staff recommended assuming that 15 percent of their dry mass is released as $CO_2$ in one year (Oliver, 2007). According to CIWMB staff, 10 million short tons of composting are currently permitted under CIWMB's authority each year. This amount does not include any composting of agricultural products, which is appropriate for the current GHG inventory since it considers only forest sector biomass and assumes that agriculture biomass production and decay balances out to a net zero $CO_2$ emission, pending further study. The national trend of composting prevalence over time was used to scale the 10 million tons composting rate back in time to 1990. Details of these methodologies are given in the Landfills Section (IV.A) of the full Technical Support Document (Link to full document).

### *2.8 Net $CO_2$ Fluxes*

ARB staff used the Atmospheric Flow Approach (IPCC, 2006g) to inventory the fluxes of $CO_2$ to and from the atmosphere for the forested lands and wood products pools within the state (Table 2). This table focuses on forested lands and $CO_2$ removals and emissions from (non-woody) crop lands are not included, pending further study. The Atmospheric Flow Approach explicitly delineates land-atmosphere $CO_2$ fluxes, pool-to-pool transfers, and the fate of wood products (Figure 3). Details on wood product stock changes in landfills and associated emissions are given in Section (IV.A) of the full Technical Support Document (Link to full document). The 2006 edition of the CEC GHG inventory reported forest and range land $CO_2$, $CH_4$, and $N_2O$ emissions as a combined single $CO_2$-equivalent value. Table 2 reports individual $CO_2$ emissions by process (e.g., fire, harvest). Non-$CO_2$ emissions are reported separately elsewhere in the inventory. ARB staff estimated the net $CO_2$ flux for forests and rangelands by summing the $CO_2$ removals from the atmosphere and $CO_2$ emissions to the atmosphere for these lands and for the wood products pool (Table 2). Forest and range land $CO_2$ removals and emissions reported for the years 1994 through 2000 are constant because they were derived as annual averages over the period.

## 3. Data Sources

### *3.1 Forest and Range Lands*

The inventory of $CO_2$ removals and GHG emissions by forest and range lands for years 1994 to 2000 is based upon prior work performed under the auspices of the CEC Public Interest Energy Research (PIER) program (CEC, 2004a). Data sources used in that project included peer-reviewed scientific publications on forest biomass (principally Birdsey and Lewis 2003, and Smith et al. 2003), satellite remote sensing and GIS products from the Fire and Resource Assessment Program (FRAP) of the California Department of Forestry and Fire Protection (CDF, now CalFire), and FIA data from the USDA-FS.

### *3.2 Wood Products*

Estimates of national wood product use and disposal (landfill, recycling, composting, etc.) generated by the USDA-FS WOODCARB model were provided by the Forest Service and scaled to California based on population. The composition of the wood product waste stream entering landfills in California was derived from data provided by the CIWMB. Wood products decay rates were from data published by USEPA (RTI, 2004).

## 4. Future Improvements

### *4.1 Forest and Range Lands*

The USDA-Forest Service uses FIA data and models to estimate biomass and track carbon transfers among forest and product pools, and to estimate forest land GHG fluxes for the USEPA national inventory. The FIA network is designed to statistically sample conditions over large forested areas. Forest inventories derived from FIA data and protocols are designed to be accurate within plus or minus 3 percent at the 67 percent confidence interval per million acres (USEPA 2006). California has approximately 31 million acres of forested land (CDF 2003) and over 9,000 FIA plots. The current statewide forest and range land GHG inventory was developed from exploratory methods applied to a region of the state and with limited use of FIA. In partnership with state and federal land management agencies and the academic community, ARB will seek to improve the statewide forest and range lands GHG inventory through improvements in biomass and flux estimation, based on FIA and other relevant products and methods.

Soil organic carbon (SOC) is a significant carbon reservoir on forest and range lands and is included in the national GHG inventory (USEPA 2006). The current ARB edition of the GHG inventory does not include SOC. Future editions of the sector inventory will include SOC and soil fluxes of $CO_2$ and other greenhouse gases.

### *4.2 Other Land Use Types*

IPCC guidance specifies additional land use types for inclusion in the Land category of GHG inventories, such as agricultural lands, wetlands, and urban areas. ARB staff plans to improve California's GHG inventory by including $CO_2$ fluxes associated with these land use categories in the future.

Agriculture uses 11 percent of the land in the state, while 31 percent is used by forests (CDF 2003). Farming management practices such as tillage, fertilization and irrigation affect soil organic carbon dynamics and GHG emissions. Soil organic carbon (SOC) constitutes a large reservoir of carbon; changes to SOC content are currently reported in the national GHG inventory (USEPA 2006). Staff will assess available methods and data sources from which to estimate fluxes of $CO_2$ in and out of agricultural soils for future editions of the inventory.

Changes in live and dead biomass pools on crop lands also correspond to atmospheric $CO_2$ removals and emissions. They are not included in this edition of the inventory due to data limitations. For annual crops, it is unclear whether the annual cycling of biomass through growth, harvest, and the disposition of post-harvest residue results in significant net $CO_2$ fluxes. In the case of woody crops (e.g., vineyards and orchards), carbon removed from the atmosphere may persist in woody tissue for decades, although emissions occur from the combustion of prunings and other dead biomass, and/or their decomposition. Changes in woody crops biomass are likely to result in significant net $CO_2$ fluxes.

Urban areas comprise 5 percent of land use in the state (CDF 2003) and exhibit about 13 percent tree canopy cover (Nowak and Crane 2002). California's urban forests account for a small but growing fraction of the state atmospheric $CO_2$ removals, and emissions by urban forests are included in the national GHG inventory. Soil organic carbon (SOC) is also a significant carbon pool in urban green space (Jo and McPherson 1995). The current GHG inventory does not include atmospheric $CO_2$ fluxes from urban forests, but methods and state-specific data exist from which to develop an inventory of $CO_2$ removals and GHG emissions from the state's urban forests for future editions of this inventory.

*Table 2: Forested Lands and Wood Products Biodegradable Carbon Emissions & Sinks (MMTCO$_2$). Original technical support document table was modified to include the latest estimates.*

| Category | 2000 | 2001 | 2002 | 2003 | 2004 | 2005 | 2006 | Data Source |
|---|---|---|---|---|---|---|---|---|
| ***Sinks (million tonnes of CO$_2$)*** | | | | | | | | |
| Forested Lands Removals | | | | | | | | |
| ▪ *Forest woody biomass growth* | *-13.052* | *-13.042* | *-13.032* | *-13.022* | *-13.012* | *-13.002* | *-12.993* | *Winrock* |
| ▪ *Rangeland woody biomass growth* | *-1.097* | *-1.096* | *-1.095* | *-1.094* | *-1.093* | *-1.093* | *-1.092* | *Winrock* |
| **Total Sinks** | **-14.148** | **-14.137** | **-14.127** | **-14.116** | **-14.105** | **-14.095** | **-14.084** | |
| ***Emissions (million tonnes of CO$_2$)*** | | | | | | | | |
| Forested Lands Emissions | | | | | | | | |
| ▪ *Forest and rangeland fires* | *2.018* | *2.017* | *2.015* | *2.014* | *2.012* | *2.010* | *2.009* | *Winrock* |
| ▪ *Other disturbances (such as insect pests damage)* | *1.200* | *1.199* | *1.198* | *1.197* | *1.196* | *1.195* | *1.194* | *Winrock* |
| ▪ *Development of forest or range lands (Landuse change)* | *0.021* | *0.021* | *0.021* | *0.021* | *0.021* | *0.021* | *0.021* | *Winrock* |
| ▪ *Timber harvest slash* | *0.155* | *0.155* | *0.155* | *0.155* | *0.155* | *0.155* | *0.155* | *Winrock* |
| Wood Products Emissions | | | | | | | | |
| ▪ *Fuel wood* | *1.521* | *1.520* | *1.519* | *1.518* | *1.517* | *1.515* | *1.514* | *Winrock* |
| ▪ *Wood Waste Dumps* | *0.000* | *0.000* | *0.000* | *0.000* | *0.000* | *0.000* | *0.000* | *CIWMB* |
| ▪ *Discarded wood and paper in landfills* | *3.753* | *3.942* | *4.077* | *4.034* | *4.044* | *4.201* | *4.310* | *ARB Model* |
| ▪ *Composting of wood waste materials* | *0.743* | *0.743* | *0.745* | *0.800* | *0.803* | *0.805* | *0.808* | *CIWMB/USEPA* |
| **Total Emissions** | **9.411** | **9.597** | **9.730** | **9.738** | **9.747** | **9.904** | **10.012** | |
| **Net CO$_2$ Flux (million tonnes of CO$_2$)** | | | | | | | | |
| **Sinks + Emissions** | **-4.737** | **-4.540** | **-4.397** | **-4.378** | **-4.358** | **-4.191** | **-4.073** | |

**Methodology**

The net $CO_2$ flux for the forest sector is estimated by summing $CO_2$ removals from the atmosphere and $CO_2$ emissions to the atmosphere of managed lands and the wood products pool. Removals of $CO_2$ from the atmosphere occur as a result of vegetation biomass growth. Emissions of $CO_2$ to the atmosphere occur as a result of a variety of activities. These include emissions from oxidation of timber harvest slash, fuel wood, biomass consumed in wildfires, other disturbance (land use change or unspecified), or from the decomposition of landfilled or composted wood products consumed in the state. $CO_2$ removals and emissions by urban forests will be included pending further data. This table focuses on forested lands, therefore $CO_2$ removals and emissions on (non)woody crop lands are not reported, pending further study.

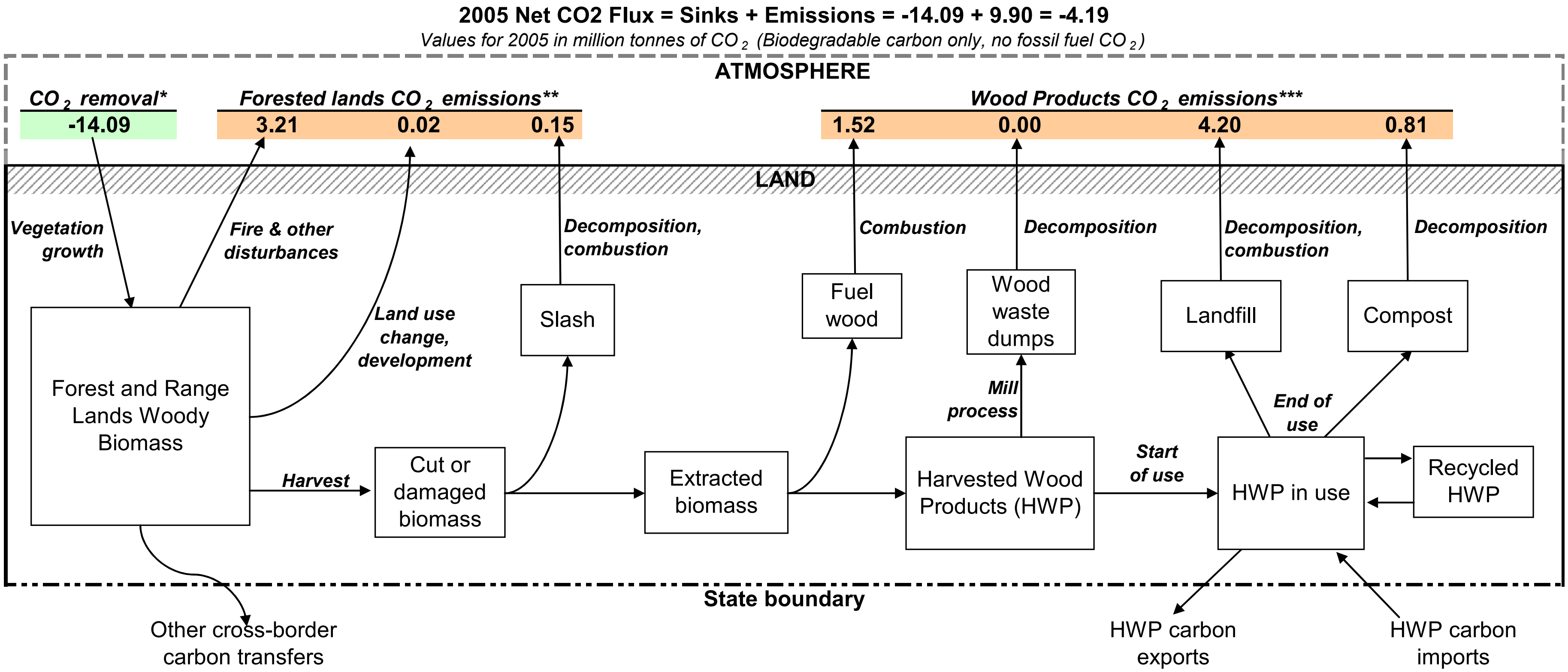
**Data Sources**

● **Winrock: CEC (2004).** Baseline Greenhouse Gas Emissions for Forest, Range, and Agricultural Lands in California. CEC PIER final report CEC-500-04-069F. Annual average forest and range land CO2 removal and emission rates for period 1994 - 2000 in Table 1-21, CEC (2004) scaled to state-wide in CEC (2006): Inventory of California Greenhouse Gas Emissions and Sinks: 1990 to 2004. Publication CEC-600-2006-013-SF. Emissions and removals are back-cast to 1990 from 1994 using 0.1707% per year forest land area trend from 1953 to 1994, from p. 14 in Shih (1998): The Land Base of California's Forests. Fire and Resource Assessment Program, California Dept. of Forestry and Fire Protection. Emissions and removals forecasted from 2000 using 4% forest land area decline predicted for 1997 to 2050 in the Pacific Coast Region, from p. 53 in: Area Changes for Forest Cover Types in the United States, 1952 to 1997, with projections to 2050. (2004) USDA Forest Service, Pacific Northwest Research Station, publication PNW-GTR-61

● **CIWMB/USEPA:** California Integrated Waste Management Board SWIS waste-in-place and landfill survey data, USEPA Harvested Wood Products use data provided by Kenneth Skog (Forest Products Laboratory, USDA Forest Service, Madison, WI), scaled to state based on population.

● **ARB Model:** From IPCC Mathematically Exact First-Order Decay Model, with CIWMB SWIS waste-in-place and landfill survey data.

*Figure 3: Diagram of the Atmospheric Flow Approach to forested lands and wood products carbon accounting for the California GHG inventory. Original technical support document figure was modified to include the latest estimates.*




* ***$CO_2$ removals*** from the atmosphere include vegetation biomass growth in forests and wooded range lands.

** ***Forested lands $CO_2$ emissions*** to the atmosphere include biomass oxidation resulting from from forest and range lands fires and other disturbances such as insect pests, forest and range land use change (development), decomposition/combustion of slash after tree harvest.

*** ***Wood Products $CO_2$ emissions*** to the atmosphere include: fuel wood combustion, decomposition of wood mill waste and discarded wood products in landfills and composting facilities.

**Adapted from:**

1) Figure 12.A.2. System boundary of the Atmospheric Flow Approach. In: Chapter 12, Harvested Wood Products. Volume 4, Agriculture, Forestry, and Other Land Use (AFOLU). 2006 IPCC Guidelines for National Greenhouse Gas Inventories. IPCC National Greenhouse Gas Inventories Programme.

2) Figure 1-6. Flow diagram illustrating the various destinations of pre-harvest carbon after commercial harvest. In: Baseline Greenhouse Gas Emissions for Forest, Range, and Agricultural Lands in California. (2004) California Energy Commission PIER final report 500-04-069F.

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