California Environmental Protection Agency

Air Resources Board

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

Technical Support Document

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

Marc Vayssières, Ph.D. (project lead)
Larry Hunsaker, P.E.
Klaus Scott
Kevin Eslinger
LinYing Li, Ph.D.
Karen Lutter, P.E.

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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 (MMTCO$_2$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).

SUMMARY OF DATA SOURCES AND ESTIMATION METHODS

A “top-down” inventory

The methods used to estimate greenhouse gas (GHG) emissions in this inventory generally follow a top-down approach. In the top down approach, estimates are made on the basis of nation-wide or state-wide activity data. For instance, aggregate data from the U.S. Energy Information Administration (EIA) for the various fuels combusted by California’s power plants are used to estimate the emissions from in-state electricity production (see Section I.A below). In a bottom-up approach to estimating GHG emissions, data from individual activity units are used to compute unit level emissions that are then aggregated to the national or state level. For example, a bottom-up inventory for in-state electricity production would calculate greenhouse gas emissions from the fuel combustion at each individual power plant and sum the emissions of all such facilities in the state.

In the absence of a comprehensive GHG emission reporting system, top-down approaches are usually more accurate than bottom-up ones. Aggregate levels of activity are in general more robust because they are augmented by, or checked against, other statistics. For instance, survey and census data can be supplemented with sales tax records, or with the balance of national production plus imports and minus exports. This makes top-down inventories more comprehensive, and less likely to undercount emissions. However, these national level statistics are not always available at the state level. This is true in particular of import–export records between California and other states, since interstate commerce is under federal jurisdiction. For this reason, state-level inventories more difficult to develop than national inventories. In the case of some categories, as state-level data were lacking, staff opted to use national-level aggregate data adjusted pro-rata to the population or to production capacity, to estimate California’s emissions.

Consistent with the International Panel on Climate Change (IPCC) guidelines

The IPCC guidelines are the recognized international standard for developing national greenhouse gas inventories. They were developed through an international process which included work by teams of experts from many countries; technical and regional workshops held in Africa, Asia, Latin America, Central Europe and Western Europe; testing of the methods through the actual development of inventories; and country studies to assess the methods in a variety of national contexts.

The first version of the IPCC Guidelines was accepted in 1994 and published in 1995, and underwent a first major revision in 1996 (IPCC, 1997). The Third Conference of Parties (COP-3) of the United Nations Framework Convention on Climate Change (UNFCCC) adopted the Kyoto Protocol in 1997 and reaffirmed that the *Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories* should be used as "methodologies for estimating anthropogenic emissions by sources and removals by sinks of greenhouse gases" in the calculation of legally-binding targets. In 2000, the IPCC published its *Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Inventories* report (IPCC, 2000) and, in 2003, the *Good Practice Guidance for Land Use, Land Use Change and Forestry* (IPCC, 2003) as supplements to the Revised 1996 Guidelines. A second major revision of the guidelines was initiated in 2003, building upon the Revised 1996 Guidelines and the subsequent Good Practice reports and incorporating improved scientific and technical knowledge. The new *2006 IPCC Guidelines* (IPCC, 2006a) include new sources and gases as well as updates to the previously published methods and default emission factors.

The IPCC Guidelines provide advice on estimation methods. They include summaries of the methods' scientific background, estimation equations, default emission factors and other parameters to use in generating the estimates, and sources of activity data. The Guidelines' methods are ranked in three tiers:

- Tier 1 methods are the simplest and most accessible. Mostly based on activity levels and emission factors, they use the provided default values for emissions factors and other parameters.
- Tier 2 methods are intermediate in complexity and data requirements. Refinements include disaggregating activity data among contrasting processes, using process- or country-specific emission factors and/or parameter values, etc.
- Tier 3 methods are the most complex. Often based on mathematical models of the processes involved, they typically require having extensive knowledge of management practices and detailed activity data.

Properly implemented, all tiers are intended to provide unbiased estimates, and accuracy and precision should, in general, improve from Tier 1 to Tier 3. The IPPC recommends using Tier 2 or Tier 3 methods for *key categories*. Key categories are defined as are those with a significant influence on a country's total inventory of greenhouse gases in terms of the absolute level, the trend, or the uncertainty in emissions and removals.

In the process of establishing California's 1990 emissions level, California Air Resources Board (ARB) staff updated the methods and parameters used in the GHG inventory to be consistent with the new 2006 guidelines. However, because of time constraints, a few categories still follow the Revised 1996 guidelines. References are made throughout this report to indicate which version of the Guidelines and which Tier the inventory methods are consistent with.

Built upon previous work

The inventory used for the 1990 emissions level, ARB's first Greenhouse Gas Inventory, is a refinement of previous statewide inventory work. The California Energy Commission (CEC) published the first multi-year California GHG inventory (CEC, 1998), covering years 1990 through 1994 and forecasting emissions for 2000, 2005 and 2010. The emission estimates presented in that report were based on methods from USEPA's "State Workbook: Methodologies for Estimating Greenhouse Gas Emissions" (USEPA, 1995b). This first multi-year GHG inventory was following the publication of two single year estimates: one for 1988 (CEC, 1990) the other for 1990 (CEC, 1997).

In September 2000, the California Legislature passed Senate Bill 1771 requiring the CEC, in consultation with other state agencies, to update California's inventory of greenhouse gas emissions. The second California GHG inventory (CEC, 2002), compiled with the assistance of consulting firms, covered years 1990 to 1999. It was based on emissions estimation methods from the 1996 Revised IPCC Guidelines (IPCC, 1997), the 1990-1999 national GHG inventory (USEPA, 2001), and USEPA's Emission Inventory Improvement Program (USEPA, 1999). The methodology used to estimate net carbon flux from forest lands came from the USDA-Forest Service (Birdsey and Lewis, 2001, 2003).

The third California GHG inventory extended the covered period through 2002 (CEC, 2005). This inventory initiated the reporting of GHG emissions from out-of-state electricity imported in California along with in-state GHG emissions, and discussed methods to make these estimates. It also excluded all international fuel uses from the inventory totals, reporting them on separate lines.

The fourth California GHG inventory (CEC, 2006a) covered the 1990-2004 period. The main methodological changes introduced with that inventory were the use of the *California Energy Balance* database work (Murtishaw et al. 2005) to disaggregate fuel use information by sector of activity, and the *Baseline GHG emissions for forest, range and agricultural lands in California* report (CEC, 2004a) to estimate land use, land use change and forestry emissions and sinks.

In 2006, Assembly Bill 1803 transferred the responsibility to prepare, adopt, and update California's greenhouse gas inventory from the CEC to the California Air Resources Board. The same year, Assembly Bill 32 required that the Air Resources Board determine the statewide greenhouse gas emissions level in 1990 and approve a statewide greenhouse gas emissions limit, equal to that level, to be achieved by 2020. ARB staff endeavored to satisfy these requirements by reviewing and revising 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 workgroups.

Updates to the 1990-2004 California GHG inventory included changes to the classification of emissions and sinks, methods, emission factors and other parameters to bring them in accord with the 2006 IPCC guidelines. In April 2007, the USEPA published the *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2005* (USEPA, 2007a), which included updated methodologies consistent with the new 2006 IPCC Guidelines. Inputs from the national inventory were particularly useful in two main cases:

- Activity data were lacking at the state level for a particular GHG generating activity (e.g., nitric acid production, CO_2 consumption). ARB staff used the latest national-level data by adjusting them pro-rata to the population or to production capacity.
- USEPA and its contractors had developed complex models for estimating some categories of emissions and the ARB had neither the time nor the resources to develop California specific methods. Enteric fermentation is an example of such a model for which USEPA had California specific data that they shared with ARB. The use of ODS substitutes is another example for which national data had to be adjusted pro-rata to the population.

An on-going improvement process

ARB staff made many improvements, beyond the changes discussed above, to the 1990-2004 California GHG Inventory released by the CEC in 2006. ARB's first edition of California's GHG inventory (published on the ARB website on November 19, 2007) and the statewide 1990 GHG emissions level and 2020 limit (adopted by the Board on December 6, 2007) are the results of these enhancements. Here is a list of the most notable changes:

- Distinguishing between associated gas and natural gas in oil and gas production (Section I.E) and electricity and heat production (Section I.A.3.3).
- Including more numerous specified imports sources for estimating the emissions from imported electricity production (Section I.B.3.1).
- Using additional waste-to-energy data for calculating emissions from electricity and heat production (Section I.A.3.3).
- Including line losses and gross imported electricity instead of net imports (gross imports minus exports) in the calculation of emissions from imported electricity production (Section I.B.3).
- Distinguishing between catalyst coke and petroleum coke based on data from the CEC's Petroleum Industry Information Reporting Act (PIIRA) database, for the calculation of emissions from petroleum refining (I.C).
- Adding the estimation of emissions from Hydrogen Production (Section II.K).
- Adding the estimation of emissions from Geothermal Power Production (Section I.G).
- Calculating on-road gasoline and diesel vehicles emissions directly from the output of ARB's EMission FACtors (EMFAC) model scaled to fuel sales data (Section I.D.2.1).
- Disaggregating domestic aviation emissions among intra-state and inter-state flights (Section I.D.2.2).
- Apportioning marine navigation fuel combustion between intrastate, interstate and among port activities, harbor craft, transit (within 24 nautical miles from California's coast) and outside of California waters using an ARB model designed for the Goods Movement Plan (Section I.D.2.2).

- Using IPCC's Atmospheric Flow Approach to forest and wood product accounting and the determination of net CO_2 fluxes from forests and rangelands (Section III.C.2.8).
- Adding data sources for the explicit inclusion of cement kiln dust in the estimation of cement production's process emissions (Section II.A).
- Adding emissions from effluents, industrial co-discharge and non-consumption protein to the waste water treatment category (Section IV.A).
- Using waste data obtained from CIWMB and information from a survey of landfills in conjunction with IPCC's First Order Decay (FOD) model to estimate emissions from landfills (IV.A).

Emission inventories are, by nature, the reflection of the best available data and the most applicable methods at the time of their compilation. As data grow and understanding develops they can be updated and improved. Throughout this report, sections about "future improvements" summarize staff's assessment of current methodologies and potential developments for future versions of California's GHG inventory.

I. Energy

A. Electricity and Heat Production – In State (IPCC 1A1a)

1. Background

Sources of energy used for electricity generation are varied in nature and origin: fuel combustion, hydropower, nuclear, solar, wind, and geothermal energy. The dominant source of energy for electricity and heat production in California is fuel combustion, and greenhouse gases (GHG) are emitted during this process. Other energy sources do not emit GHG in the energy conversion process, except for fugitive emissions of CO_2 released from geologic formations tapped for geothermal energy. Emissions from fuel combustion activities are estimated and tallied under this category (1A1a); CO_2 emissions from geothermal power are included in the inventory and reported under category 1B3 (Other Emissions from Energy Production). Note also that the SF_6 emissions from electricity distribution through the power grid are reported under IPCC code 2G1b (Use of Electrical Equipment).

The California GHG inventory includes the emissions of CO_2, CH_4 and N_2O resulting from the combustion of fossil fuels, including gaseous fuels (natural gas, refinery gas, associated gas, etc.), liquid fuels (distillate, residual fuel oil, jet fuel, etc.), and solid fuels (coal, petroleum coke, etc.). Various renewable fuels (wood, agricultural biomass and landfill or digester gas) are also used to produce heat and electricity. The GHG inventory includes only the CH_4 and N_2O emissions resulting from the combustion of renewable fuels since the CO_2 emissions would have occurred eventually as the biomass decayed. These CO_2 emissions, labeled “from biogenic materials”, are estimated and tracked, but are not included in California’s GHG inventory.

Within this inventory category (IPCC 1A1a), power plants are classified by fuel, and by type of generation: either electricity generation or combined heat and power (CHP). The CHP process makes use of otherwise wasted exhaust heat, making CHP plants one of the most efficient means of generating electricity. The GHG emissions associated with “useful thermal output” (UTO) from CHP are not attributed to the electric power sector; they are reported separately for the sector (industrial or commercial) in which the UTO is used. CHP plants are classified by the sector to which they provide their UTO, and thus labeled either as “CHP: Commercial” or “CHP: Industrial”. Non-CHP power plants are classified under IPCC code 1A1ai (Electricity Generation), CHP plants are classified under IPCC code 1A1aii (Combined Heat and Power Generation). Please note that the UTO part of CHP plants emissions is also tallied under 1A1aii but is not counted as part of the electric power sector emissions. Geothermal emissions are classified under IPCC code 1B3 (Other Emissions from Energy Production).

Power plants are also classified into two ownership categories: “Utility owned” or “Merchant owned”. Utility owned plants are those under direct ownership of a public or investor-owned utility responsible for providing electricity to their customers. Merchant owned plants are under private or corporate ownership, engaging in the buying and selling of electricity in the open market, and eventually selling to utilities that cannot provide all the electricity they need through their own plants.

2. Methodology

The method for estimating emissions follows IPCC 2006 guidelines for stationary combustion (IPCC, 2006a). California or US-specific emission factors and heat content values are used when available.

Equation 1: Emissions from stationary combustion

$$\boxed{E_{GHG,\ fuel} = FC_{fuel} \bullet HC_{fuel} \bullet EF_{GHG,\ fuel}}$$

Where,

$E_{GHG,\ fuel}$ = Emissions of the given GHG for the type of fuel (g of GHG)

FC_{fuel} = Amount of fuel combusted (in units of tons for solid fuels, gallons for liquid fuels or standard cubic feet for gaseous fuels)

HC_{fuel} = Heat content of the type of fuel (BTU / unit)

$EF_{GHG,\ fuel}$ = Emission factor of the given GHG by the type of fuel (g GHG / BTU)

With,

GHG = [CO2, CH4, N2O]

Fuel = [associated gas, biomass, bituminous coal, digester gas, distillate, jet fuel, kerosene, landfill gas, lignite coal, municipal solid waste, natural gas, other coal, petroleum coke, propane, refinery gas, residual fuel oil, tires, waste oil]

A variant of this estimation method was used to estimate CO_2 emissions in the case of partially renewable fuels. These fuels are a mix of materials from renewable and fossil origins. Municipal solid waste (MSW) and used tires are two such fuels.

Equation 2: Variant for partially renewable fuels

$$\boxed{E_{GHG,\ fuel,\ origin} = E_{GHG,\ fuel} \bullet P_{fuel,\ origin}}$$

Where,

$E_{GHG,\ fuel,\ origin}$ = Emissions of the given GHG for the proportion of materials of given origin for the type of fuel (g of GHG)

$E_{GHG,\ fuel}$ = Emissions of the given GHG for the type of fuel (g of GHG)

$P_{fuel,\ origin}$ = proportion of material of given origin in the type of fuel (fraction)

With,

GHG = [CO_2]

Fuel = [MSW, tires]
Origin = [Fossil, Renewable]

For a list of yearly activity, heat content and emission factor values used in the emission estimation equations, please consult the online documentation annex at: http://www.arb.ca.gov/cc/inventory/doc/methods_v1/annex_1a_electricity_and_heat_production_in_state.pdf

3. Data Sources

Fuel-use data for 1990-2000 was obtained through personal correspondence with the U.S. Energy Information Administration (Schnapp, 2007), the statistical arm of the U.S. Department of Energy. Fuel use data for 2001-2004 data was downloaded from U.S. Energy Information Administration (EIA) databases published online (EIA, 2007e). In the case of natural gas and associated gas use, staff combined EIA data with data from the California Energy Commission's (CEC) Quarterly Fuels and Energy Report (QFER) (Gough, 2007) in the manner described in 3.3 below.

Heat content data for most fuels came from the U.S. Energy Information Administration (Schnapp, 2007; EIA, 2007e). Heat content values for associated gas were obtained from the Western State Petroleum Association (Wang, 2007) and heat content of biomass fuel was from USEPA Climate Leaders Greenhouse Gas Protocols (USEPA, 2004a).

CO_2 Emissions factors are from USEPA 1990-2005 greenhouse gas inventory (USEPA, 2007c). CH_4 and N_2O emissions factors come from the IPCC 2006 guidelines for stationary combustion (IPCC, 2006b).

3.1 Mapping EIA codes to ARB categories

Fuel use and heat content data reported by the EIA are grouped as indicated in Table 1 and Table 2. The EIA fuel codes and sector codes provide the information necessary to break up ARB's emissions estimates into the categories presented in the inventory.

Table 1: EIA to ARB fuel mapping

ARB GHG Inventory Fuel	***EIA Fuel Code(s) Included***
Associated Gas	n/a (estimates based on CEC QFER data)
Biomass	AB, BLQ, OBL, OTH, SLW, WDL, WDS
Bituminous Coal	BIT
Digester Gas	OBG
Distillate Oils	DFO, JF, KER, RFO, WO
Geothermal	GEO
Jet Fuel	JF
Kerosene	KER
Landfill Gas	LFG, OBG
Lignite Coal	LIG
Municipal Solid Waste (MSW)	MSW

ARB GHG Inventory Fuel	EIA Fuel Code(s) Included
Natural Gas	NG
Other Coal	SC, WC
Petroleum Coke	PC
Propane	PG
Refinery Gas	OG
Residual Fuel Oil	RFO
Tires	TDF
Waste Oil	WO

Table 2: EIA to ARB category mapping

ARB GHG Inventory Category	EIA Sector Code (EIA #)
Utility Owned	1
Merchant Owned	2, 4, 6
CHP: Commercial	5
CHP: Industrial	3, 7

3.2 Combined Heat and Power

CHP plants report separate amounts of fuel and heat for electricity generation and for useful thermal output (UTO) to the EIA. Staff attributed the amount reported under electricity generation to the electric power sector and the remainder to either the industrial or commercial sector under “useful thermal output.”

3.3 Associated gas vs. natural gas designation

Natural gas originates from oil and gas wells and may be extracted alone (from gas wells) or with crude oil (from oil wells, where it rises up with the oil and is “associated” with it). Thus, the raw natural gas coming from oil wells is often called “associated gas”, while that coming from gas wells is simply termed "natural gas".

Raw natural gas is composed of methane, ethane and other combustible hydrocarbons, but it may also contain water vapor, hydrogen sulfide, carbon dioxide, nitrogen, and helium. During processing, many of these components are removed to improve the quality of the natural gas or to make it easier to move the gas over great distances through pipelines. The resulting processed natural gas contains mostly methane and ethane, although there is no such thing as a "typical" natural gas. Raw natural gas burns much like processed natural gas, though with a lower heating value per standard cubic foot.

To make a distinction between raw and processed natural gas in the GHG inventory, ARB staff uses the following terminology: *associated gas* for raw gas from either oil or gas wells, and *natural gas* for processed, pipeline-quality gas. The EIA, however, combines raw gas and processed gas together under the designation “natural gas”. This presented a challenge in categorizing these data for the inventory.

In Table 1 *associated gas* is the only GHG inventory fuel that is not mapped to EIA codes. Data for *associated* gas and *natural gas* were obtained from the CEC's QFER database. The CEC keeps track of gas provided by "gas producers" as a separate source in the QFER database and —based on a description provided by CEC staff of this source of fuel— the assumption was made that gas from "gas producers" is what ARB call *associated gas*, rather than pipeline-quality *natural gas*.

To eliminate this confusion, ARB staff attempted to separate the gas reported by the EIA as "natural gas" into ARB's definitions of *natural gas* (pipeline quality only) and *associated gas* (raw gas from oil or gas wells). Although QFER does report *associated gas* use for the Oil & Gas sector, it does not break it down into CHP vs. non-CHP use. To estimate how much *associated gas* was used for Industrial CHP each year, staff used the definitions noted above and compared the amount of "natural gas" reported to EIA for CHP plants in the Oil & Gas sector (staff assumed this was the only sector using *associated gas* for electricity generation) against the natural gas data reported to QFER for the same CHP end use. Because EIA reports both *associated gas* and *natural gas* used for CHP together as "natural gas," and QFER reports only pipeline quality natural gas used for CHP, the amount reported in EIA data should be higher. Then, the *associated gas* used for CHP should be the difference between this higher EIA value and the QFER pipeline-quality natural gas value.

Over the period 1993-2004, EIA fuel use for CHP was indeed higher than QFER's fuel use for CHP. Thus, for these years, staff used QFER pipeline-quality natural gas data for the *natural gas* fuel use for CHP by the Oil & Gas sector, and the difference between EIA and the QFER as the *associated gas* fuel use for CHP in this sector. For 1990-1992, however, staff found that QFER pipeline-quality natural gas use for the Oil & Gas sector CHP was greater than EIA "natural gas" use for the same. Staff will continue to work to reconcile this data, but for the purposes of this inventory, staff assumed that no associated gas was burned for CHP in the Oil & Gas sector during these years (1990-1992) and that all the EIA fuel use data reported for this category is actually pipeline-quality natural gas.

3.4 Partially renewable fuels

Certain fuels, namely, municipal solid waste (MSW) and used tires, are not completely composed of fossil carbon, but contain carbon from renewable sources as well. Staff determined that tires contain approximately 20 percent renewable natural rubber based on data from the Rubber Manufacturers Association (RMA, 2007). Staff used source test data from Covanta Energy (Hahn, 2007) to estimate that, on a carbon basis, about 66 percent of the MSW burned for energy is from renewable biomass origin.

4. Future Improvements

Staff is seeking to obtain facility specific data on natural gas users to better estimate associated gas use. Better methods to allocate the cogeneration emissions between the electric power and UTO components are being developed by staff with stakeholder input.

B. Electricity Production – Imports (IPCC 1A1a)

1. Background

California's highly interconnected electricity system relies on imports as well as in-state generation. The Global Warming Solutions Act of 2006 (AB 32) requires that ARB include estimates of out-of-state GHG emissions from imported electricity in California's GHG inventory. Imported power may come from a variety of energy sources but, while the sources of in-state generation are well known, the origin of imported electricity is often unknown. Emissions from imports that can be directly linked to a known out-of-state power plant are tallied under "specified imports" (Section I.B.3.1 below); emissions from all other imports are discussed in the "unspecified imports" (Section I.B.3.2 below).

Specified imports are those with a well-known and documented generation source. In these cases, the specific amount of fuel used to generate the imported power can be obtained and used to determine emissions. Thus far, the specified imports consist of those listed in Table 3 below. Note that the Palo Verde plant (nuclear power) and Hoover Dam (hydro power) are only included for balancing the imported electricity against the unspecified imports, and do not actually appear in the inventory, as they have no quantifiable GHG emissions.

Table 3: Specified imports

Plant Name-Primary Fuel (EIA ID)	State (Import Region)
Boardman-Coal (6106)	OR (Pacific Northwest)
Colstrip-Coal (6076)	MT (Pacific Northwest)
Bonanza-Coal (7790)	UT (Pacific Southwest)
Four Corners-Coal (2442)	NM (Pacific Southwest)
Intermountain-Coal (6481)	UT (Pacific Southwest)
Mohave-Coal (2341)	NV (Pacific Southwest)
Navajo-Coal (4941)	AZ (Pacific Southwest)
Reid Gardner-Coal (2324)	NV (Pacific Southwest)
San Juan-Coal (2451)	NM (Pacific Southwest)
Yucca/Yuma Axis-Natural Gas (120 & 121)	AZ (Pacific Southwest)
Palo Verde-Nuclear (6008)	AZ (Pacific Southwest)
Hoover Dam-Hydro (8902 & 154)	AZ/NV (Pacific Southwest)

Unspecified imports, because they cannot be exactly linked to a plant of origin, are not assigned an actual fuel value in the inventory; rather, a composite emission factor was developed, based on data provided by the CEC.

As electrical power is transmitted through power lines, losses occur because of resistance and other physical factors. Therefore, more electrical power must be generated than is actually delivered and consumed in California. Staff accounted for these losses and the emissions associated with them in the inventory since they occur as a result of California's demand for imports. In the case of most specified imports, the amount of electricity generated at the plant of origin was known and thus there was no need for line loss corrections. In two cases (Colstrip and Bonanza) the amount of electricity produced at the plant of origin was not known: only the amount received by the purchasing agency at the point of reception was available. The actual amount of electricity generated at the plant of origin can be estimated by applying a plant specific line loss factor to the amount of electrical power received from the plant. Staff used line loss factors of 7.5 percent for imports from Colstrip and 3 percent for imports from Bonanza. These factors reflect the line loss estimates included in contracts for power purchases from these plants by LADWP (Parsons, 2007). Line losses from unspecified imports were estimated using the CEC suggested loss factor of 7.5 percent.

Imports are often reported as net imports (gross imports – exports). However, accounting for all emissions resulting from the generation of electrical power received in California requires estimating the gross import value. Actual export data was obtained from the CEC for 2001-2005 and estimates were made for 1990-2000 based on these data. These export estimates were then added to the net import value to obtain the gross import number.

All imports of electricity are classified under IPCC code 1A1ai (Electricity Generation), while SF_6 emissions from imported power are under IPCC code 2G1b (Use of Electrical Equipment). These SF_6 emissions are attributed to the electric power sector.

2. Data Sources

Imported electric power emissions estimates are based primarily on fuel use, heat and electricity generation data obtained from the U.S. Energy Information Administration (EIA). Data for 1990-2000 was obtained through personal correspondence with Robert Schnapp of U.S. Energy Information Administration (Schnapp, 2007). Data for 2001-2004 data was downloaded from U.S. Energy Information Administration databases published online (EIA, 2007e). The Los Angeles Department of Water and Power (LADWP), an importer of out-of-state power, provided fuel use and heat content data for plants (Intermountain, Mohave, and Navajo) for which they have ownership (Parsons, 2007). Data obtained directly from out-of-state power plants via LADWP were deemed to be more precise and up to date than datasets available from EIA.

Fuel CO_2 Emissions factors are from USEPA 1990-2005 greenhouse gas inventory (USEPA, 2007c). Fuel CH_4 and N_2O emissions factors come from the IPCC 2006 guidelines for stationary combustion (IPCC, 2006b).

Net Imports data are from the California Department of Finance's (CDOF) California Statistical Abstract Table J-11 (CDOF, 2007b). The California Energy Commission (CEC) provided data on line losses, exports (Alvarado, 2007), ownership and entitlement shares (Griffin, 2007), and assumptions for the fuel mix of unspecified imports (CEC, 2006b).

3. Methodology

3.1 Emissions from Specified Imports

Ownership, entitlement or contracted import amounts were provided by the CEC except for Intermountain, Mohave, Navajo, Colstrip, and Bonanza plants, for which data were obtained from LADWP staff. For Colstrip and Bonanza, the amount of imported power received, rather than generated, was the value documented. Line loss factors were used to adjust these amounts to estimate the actual plant generation required to supply LADWP with imported power. For all other specified plants, the ownership share, entitlement share or plant generation share was used, and because these apply directly to the plant itself, no line loss adjustment was needed. These import amounts were compared to the total generation from the plant in question, for each year imports from the plant occurred, to calculate the percentage of plant electricity generation imported by California that year. A subset of these percentages is shown in Table 4 below.

Table 4: Percent of plant electricity generation imported by California

Plant Name (State) – Fuel	***1990***	***2002***	***2003***	***2004***
Boardman (OR)-Coal	19.74	15.95	15.95	15.95
Colstrip (MT)-Coal	17.17	0.00*	0.00*	0.00*
Bonanza (UT)-Coal	21.53	0.00*	0.00*	0.00*
Four Corners (NM)-Coal	34.61	36.05	36.05	36.05
Intermountain (UT)-Coal	100.00	97.03	99.32	99.80
Mohave (NV)-Coal	76.00	66.02	66.12	66.11
Navajo (AZ)-Coal	20.92	21.37	21.51	21.07
Reid Gardner (NV)-Coal	29.22	28.88	28.88	28.88
San Juan (NM)-Coal	4.37	24.08	24.08	24.08
Yucca/Yuma Axis (AZ)-Natural Gas	42.61	42.61	42.61	42.61
Palo Verde (AZ)-Nuclear	36.75	36.75	36.75	36.75
Hoover Dam (AZ/NV)-Hydro	60.00	60.00	60.00	60.00

*LADWP imported from Colstrip for years 1990-1999 and from Bonanza for years 1990-1997. All other specified imports continued at least up to 2004.

Staff use the percent of plant electricity imported by California, EIA or plant specific data on fuel use and heat content, and fuel specific emission factors to estimate emissions from fuel combustion as follows:

Equation 3: Emissions from specified imports

$$E_{GHG,\ fuel} = FC_{fuel} \bullet I_{plant} \bullet HC_{fuel} \bullet EF_{GHG,\ fuel}$$

Where,

$E_{GHG,\ fuel}$ = Emissions of the given GHG for the type of fuel (g of GHG)
I_{plant} = Percent of plant electricity imported by California
FC_{fuel} = Amount of fuel combusted (in units of tons for solid fuels, gallons for liquid fuels or standard cubic feet for gaseous fuels)
HC_{fuel} = Heat content of the type of fuel (BTU / unit)
$EF_{GHG,\ fuel}$ = Emission factor of the given GHG by the type of fuel (g GHG / BTU)

With,

GHG = [CO_2, CH_4, N_2O]
Fuel = [coal, distillate, natural gas, residual fuel oil]
Plant = [Boardman, Colstrip, Bonanza, Four Corners, Intermountain, Mohave, Navajo, Reid Gardner, San Juan, Yucca/Yuma Axis]

For the sake of brevity, only the percentage values for 1990, 2002-2004 are provided in Table 4. Values for all years 1990-2004, as well as the EIA or plant specific heat inputs and emission factors, are available upon request. For a list of yearly activity, heat content and emission factor values used in the emission estimation equation, please consult the online documentation annex at: http://www.arb.ca.gov/cc/inventory/doc/methods_v1/annex_1b_electricity_production_imports.pdf

3.2 Emissions from Unspecified Imports

The fuel mix used for unspecified imports and the resulting GHG emissions are somewhat controversial, and improvements to these estimates will continue to be a high priority for ARB staff in the years ahead. Currently, staff has chosen to use the CEC's estimation method for determining the emission factor for unspecified imports. ARB staff relies on the expertise of CEC staff in this matter. Any future updates on fuels used in the production of unspecified power will involve collaboration between staff of ARB and CEC.

Data presented in this section are limited to values for 1990, and 2002-2004. Data used for all years from 1990 to 2004 is available upon request. Electricity imported into California originates from two regions: the Pacific Northwest (PNW) and Pacific Southwest (PSW).

(a) Net Imports Data

Net imports data come from the California Department of Finance (CDOF) California Statistical Abstract -- Table J-11 (CDOF, 2007b)

Table 5: Net imports from CDOF table J-11 data (GWh)

Region	**1990**	**2002**	**2003**	**2004**
PNW	31,665	27,186	22,303	20,831
PSW	30,294	35,673	39,508	45,447

(b) Known Exports Data

Known exports from California were based on California Energy Commission data:

Table 6: California exports from CEC (GWh)

Region	1990	2002	2003	2004
PNW	Unknown	1,020	1,471	1,532
PSW	Unknown	5,514	4,555	3,292

(c) Estimation of Unknown Exports

First, staff used the 2002-2005 known exports data from the CEC (Table 6 above shows years 2002-2004 of these data), and determined the average ratio of exports to net imports in gigawatt-hour (GWh) as follows:

Equation 4: Average ratio of exports to net imports of electricity

$$\boxed{Ratio = \frac{\sum_{y=2002}^{2005} Exports_y}{\sum_{y=2002}^{2005} Net\_imports_y}}$$

Note that there was an electricity supply crisis in California in 2001, and for that reason export and import data for that year were not used in the ratio determination. The export to import ratio is equal to 7 percent (0.07) for the PNW and 10 percent (0.010) for the PSW.

The export to import ratio for the PNW was then applied to the net imports for years 1990-2000 to estimate the exports for those years. However, based on CEC staff recommendation, ARB staff assumed that there were no exports to the PSW during 1990-1997 (the years before electricity market deregulation). Thus the export to import ratio for the PSW was used to estimate exports only for years 1998 to 2000.

Table 7: Estimate of California exports (GWh)

Region	1990	2002	2003	2004
PNW	2,127	See Table 6	See Table 6	See Table 6
PSW	0	See Table 6	See Table 6	See Table 6

(d) Estimation of Gross Imports

Gross imports are equal to net imports (Table 5) plus exports (Table 6 & Table 7)

Table 8: Gross imports (GWh)

Region	1990	2002	2003	2004
PNW	33,792	28,206	23,775	22,363
PSW	30,294	41,187	44,062	48,740

(e) Estimation of Gross Generation for Imports

Gross generation for imports, the actual power generated by out-of-state sources for California's electricity imports, is estimated by adding an assumed 7.5 percent line loss to the gross import number. This was done by dividing the values of Table 8 by 0.925 (i.e., 1 – 0.075):

Table 9: Gross generation for imports (GWh)

Region	1990	2002	2003	2004
PNW	36,532	30,494	25,703	24,176
PSW	32,750	44,526	47,635	52,692

(f) Amount of Specified Imports included in Net Imports Data

To avoid double counting emissions, specified imports (3.1 above) were removed from the amount listed in CDOF's table J-11. Per CEC staff, import data in CDOF's table J-11 did not include ownership share generation prior to 2001, and the Intermountain and Mohave plants were never included in J-11 imports line items for PNW and PSW. On the basis of this information, ARB staff assumed that, since entitlements from Hoover Dam hydro power are not ownership share generation, Hoover Dam imports were included in table J-11 before 2001 and needed to be removed.

For 1990-2000, only Hoover Dam, a PSW import, was removed. For 2001-2004, all the specified imports (except for Intermountain and Mohave) were removed:

Table 10: Specified imports included in CDOF table J-11 (GWh)

Region	1990	2002	2003	2004
PNW	0	602	686	565
PSW	2,572	26,988	26,083	26,190

(g) Unspecified Imports Energy

Unspecified imports were calculated by subtracting Table 10 from Table 9 values:

Table 11: Unspecified imports (GWh)

Region	1990	2002	2003	2004
PNW	36,532	29,892	25,017	23,611
PSW	30,178	17,538	21,553	26,502

(h) Fuel Mix of Unspecified Imports

The fuel mix of unspecified imports was based on the CEC methodology contained in the *Inventory of California Greenhouse Gas Emissions and Sinks: 1990 to 2004* (CEC, 2006b):

Table 12: Fuel-mix of unspecified imports (percentage)

Region	Fuel	1990	2002	2003	2004
PNW	Coal	20%	19%	34%	29%
PNW	Natural Gas	0%	6%	9%	11%
PNW	Non-Emitting	80%	75%	57%	60%
PSW	Coal	74%	61%	62%	60%
PSW	Natural Gas	0%	19%	20%	24%
PSW	Non-Emitting	26%	20%	18%	16%

(i) Average Heat Contents and Emission Factors for Unspecified Imports

(i.i) Weighted Average Heat Contents

Weighted average heat contents (in BTU per MWh) were calculated by region by year for coal and natural gas. Staff obtained plant specific data for amounts of fuel combusted, heat content values and generated power from the EIA. Data from Oregon, Washington, Idaho and Montana were included in calculations for the PNW region; and data from Arizona, Colorado, New Mexico, Nevada and Utah for the PSW region. The weighted average heat contents were calculated as follows:

Equation 5: Weighted average heat contents of fuels

$$WHC_f = \frac{\sum_{t,p} (FC_{f,t,p} \bullet HC_{f,t,p})}{\sum_{t,p} PG_{f,t,p}}$$

Where,

WHC_f = Weighted average heat content for the given fuel f (btu per MWh)

$FC_{f,t,p}$ = Amount of the given fuel f of type t combusted by plant p (tons for coal, scf for natural gas)

$HC_{f,t,p}$ = Heat content of the given fuel f of type t combusted by plant p (btu / ton for coal, btu / scf for natural gas)

$PG_{f,t,p}$ = Power generated with given fuel f of type t combusted by plant p (MWh)

With,

f: fuel = [coal, natural gas]

t : type of fuel = [bituminous, lignite, etc.], applies only to coal

p: power plants in either Pacific Northwest or Pacific Southwest region

(i.ii) Weighted average emission factors

Weighted average emission factors (in grams per BTU) were calculated by region and by year for coal and natural gas. Staff obtained fuel specific emission factor values from the EIA for CO_2 and from the IPCC guidelines for CH_4 and N_2O. Emission factors for non-emitting sources of electrical power were assumed to be zero. Staff included data from Oregon, Washington, Idaho and Montana in calculations for the PNW region; and from Arizona, Colorado, New Mexico, Nevada and Utah for the PSW region. The weighted average emissions factors were calculated as follows:

Equation 6: Weighted average fuel emission factors of unspecified imports

$$\boxed{WEF_{g,f} = \frac{\sum_{p}(FC_{f,p} \bullet HC_{f,p} \bullet EF_{g,f,p})}{\sum_{p}(FC_{f,p} \bullet HC_{f,p})}}$$

Where,

$WEF_{g,f}$ = Weighted average emission factor for one of the given GHG g, for a given fuel f (grams per btu)

$FC_{f,p}$ = Amount of the given fuel f combusted by plant p (tons for coal, scf for natural gas)

$HC_{f,p}$ = Heat content of the given fuel f combusted by plant p (btu / ton for coal, btu / scf for natural gas)

$EF_{g,f,p}$ = Emission factor for GHG g from fuel f combusted by plant p (g of GHG per btu)

With,

f: fuel = [coal, natural gas]

g: GHG = [CO_2, CH_4, N_2O]

p: power plants in either Pacific Northwest or Pacific Southwest region

(i.iii) Combined-GHG emission factors

Combined-GHG emission factors (in lbs of CO_2 equivalent per MWh) may be computed from the GHG-specific factors above for the purpose of comparison with other such published factors. For each year and each region, they are the result of:

Equation 7: Combined-GHG emission factors of unspecified imports

$$\boxed{CEF_{f} = \frac{\sum_{g}(WHC_{f} \bullet WEF_{g,f} \bullet GWP_{g})}{453.6}}$$

Where,

WHC_f = Weighted average heat content for the given fuel f (btu per MWh)

$WEF_{g,f}$ = Weighted average emission factor for the given GHG g, for a given fuel f (grams per btu)

GWP_g = Global Warming Potential of GHG g (unitless)

453.6 = number of grams in a pound

With,

f: fuel = [coal, natural gas]

g : GHG = [CO_2, CH_4, N_2O]

The combined-GHG emission factors are listed below, in units of pounds of CO_2 equivalents (lbs CO_2e) per MWh:

Table 13: Fuel-specific combined-GHG emission factors for Unspecified Imports (lbs CO_2e / MWh)

Region	Fuel	1990	2002	2003	2004
PNW	Coal	2,374	2,374	2,346	2,362
PNW	Natural Gas	1,107	1,109	1,060	1,111
PNW	Non-Emitting	0	0	0	0
PSW	Coal	2,279	2,233	2,230	2,230
PSW	Natural Gas	1,307	1,093	1,143	1,064
PSW	Non-Emitting	0	0	0	0

(j) Regional Fuel-mix Heat Contents and Emission Factors for Unspecified Imports

Regional fuel-mix heat contents for the Pacific Northwest and Pacific Southwest regions can be estimated by multiplying the weighted average heat contents computed in Section I.B.3.2(i.i) above by the regional fuel mix values of Table 12.

Equation 8: Regional fuel-mix heat contents for unspecified imports

$$\boxed{RHC_r = \sum_f WHC_f \bullet P_{f,r}}$$

Where,

RHC_r = Regional fuel-mix heat content for region r (btu per MWh)
WHC_f = Weighted average heat content for the given fuel f (btu per MWh)
$P_{f,r}$ = Proportion of power generated in region r using fuel f (percent)

With,

f: fuel = [coal, natural gas]
r: region = [PNW, PSW]

Regional fuel-mix emission factors for the Pacific Northwest and Pacific Southwest regions may be estimated by multiplying the weighted average emission factors computed in Section I.B.3.2(i.i) above by the regional fuel mix values of Table 12.

Equation 9: Regional fuel-mix emission factors for unspecified imports

$$\boxed{REF_{g,r} = \sum_f WEF_{g,f} \bullet P_{f,r}}$$

Where,

$REF_{g,r}$ = Regional fuel-mix emission factor for GHG g for region r (g / btu)
$WEF_{g,f}$ = Weighted average emission factor for GHG g for fuel f (g / btu)
$P_{f,r}$ = Proportion of power generated in region r using fuel f (percent)

With,

f: fuel = [coal, natural gas]
g: GHG = [CO_2, CH_4, N_2O]
r: region = [PNW, PSW]

For a list of yearly activity, heat content and emission factor values used in the equations, please consult the online documentation annex at:

http://www.arb.ca.gov/cc/inventory/doc/methods_v1/annex_1b_electricity_production_imports.pdf

Regional combined-GHG emission factors for unspecified import (in lbs of CO_2 equivalent per MWh) may be computed for the purpose of comparison with other such published factors. These factors are the result of multiplying the fuel-mix percentages (Table 12) by the corresponding combined-GHG fuel-specific emissions factors (Table 13) and summing to arrive at a single factor for each region by year:

Table 14: Regional emission factors for Unspecified Imports (lb CO_2e / MWh)

Region	1990	2002	2003	2004
PNW	475	530	879	816
PSW	1,687	1,561	1,595	1,579

(k) Emissions from Unspecified Imports

Emissions from unspecified imports were estimated by multiplying the amount of unspecified import power (Table 11) by the regional fuel-mix heat content and the corresponding regional fuel-mix emission factors:

Equation 10: Emissions from unspecified imports

$$\boxed{E_{g,r} = UI_r \bullet RHC_r \bullet REF_{g,r}}$$

Where,

$E_{g,r}$ = Emissions of GHG g for unspecified imports from region r (g of GHG)
UI_r = Amount of unspecified import power from region r (MWh)
RHC_r = Regional fuel-mix heat content for region r (btu per MWh)
$REF_{g,r}$ = Regional fuel-mix emission factor for GHG g for region r (g / btu)

With,

g: GHG = [CO_2, CH_4, N_2O]
r: region = [PNW, PSW]

4. Future Improvements

Future improvements will include improved estimates of the region specific emission factors for unspecified imports of power and better assessment of line losses.

C. Fuel Combustion in Industrial, Commercial, Residential, Agricultural and Other Sectors (IPCC 1A1b, 1A2, 1A4 & 1A5)

1. Background

Fuel combustion is used as a source of energy to power machinery and heat buildings throughout California. In this section we discuss the emissions from fuel combustion by petroleum refineries (IPCC 1A1b); manufacturing industries and construction (IPCC category 1A2); in agriculture, forestry, commercial and institutional settings and residential dwellings (category 1A4); and other non-identified activities (category 1A5). Emissions from fuel combustion for transportation (category 1A3) are discussed in another section (I.D below).

Fuels used by manufacturing industries and construction include: biomass waste fuel, coal, distillate, fossil waste fuel, gasoline, kerosene, LPG, natural gas, natural gas liquids, petroleum coke, residual fuel oil, tires, and wood. Fuels used in commercial, institutional and residential settings are: coal, distillate, gasoline, kerosene, LPG, natural gas, residual fuel oil, and wood. Some LPG and natural gas are also used for certain non-identified activities.

The inventory includes the emissions of CO_2, CH_4 and N_2O resulting from the combustion of fossil fuels. Some renewable fuels (biomass waste fuel, wood) are also used as a source of energy. The GHG inventory includes only the CH_4 and N_2O emissions resulting from the combustion of renewable fuels since the CO_2 emissions would have occurred eventually as the biomass decayed. These CO_2 emissions, labeled “from biogenic materials”, are estimated and tracked, but are not included in California’s GHG inventory. Other combustibles used as fuels, such as used tires, are made in part from renewable materials (e.g., natural rubber). In this case, two values for CO_2 emissions are estimated in proportion to the renewable and fossil components. Only the CO_2 from the fossil component is included in the inventory.

2. Methodology

The method for estimating emissions follows IPCC 2006 guidelines for stationary combustion (IPCC, 2006a). California or US-specific emission factors and heat content values were used when available.

Equation 11: Emissions from stationary combustion

$$\boxed{E_{GHG,\ fuel} = FC_{fuel} \bullet HC_{fuel} \bullet EF_{GHG,\ fuel}}$$

Where,

$E_{GHG,\ fuel}$ = Emissions of the given GHG for the type of fuel (g of GHG)
FC_{fuel} = Amount of fuel combusted (in units of tons for solid fuels, gallons for liquid fuels or standard cubic feet for gaseous fuels)
HC_{fuel} = Heat content of the type of fuel (BTU / unit)
$EF_{GHG,\ fuel}$ = Emission factor of the given GHG by the type of fuel (g GHG / BTU)

With,

GHG = [CO_2, CH_4, N_2O]
Fuel = [biomass waste fuel, catalyst coke, coal, distillate, fossil waste fuel, gasoline, kerosene, LPG, natural gas, natural gas liquids, petroleum coke, refinery gas, residual fuel oil, and wood]

A variant of this estimation method was used to estimate CO_2 emissions in the case of partially renewable fuels. These fuels are a mix of materials from renewable and fossil origins. Used tires are such a fuel.

Equation 12: Variant for partially renewable fuels

$$\boxed{E_{GHG,\ fuel,\ origin} = E_{GHG,\ fuel} \bullet P_{fuel,\ origin}}$$

Where,

$E_{GHG,\ fuel,\ origin}$ = Emissions of the given GHG for proportion of materials of given origin for the type of fuel (g of GHG)
$E_{GHG,\ fuel}$ = Emissions of the given GHG for the type of fuel (g of GHG)
$P_{fuel,\ origin}$ = proportion of material of given origin in the type of fuel (fraction)

With,

GHG = [CO_2]
Fuel = [tires]
Origin = [Fossil, Renewable]

3. Data Sources

The data sources for estimating emissions include the California Energy Balance database (CALEB), the Energy Information Administration State Energy Consumption Price and Expenditure Estimates (EIA SEDS), the US Environmental Protection Agency, the Intergovernmental Panel on Climate Change (IPCC), and selected industry associations.

Fuel use data are primarily from CALEB (Murtishaw et al. 2005). In cases where data for a particular year were missing, staff used interpolation or averaging to fill in the missing values. Petroleum refineries use of refinery gas and catalyst coke data were summarized from the CEC’s Petroleum Industry Information Reporting Act (PIIRA) database (Schremp, 2007). Wood fuel use came from EIA SEDS (EIA, 2007a). Data on fuel use by California’s cement plants were supplied by the Portland Cement Association (O'Hare, 2007). Natural gas use by the glass packaging industries was provided by one of its consultants (Ross, 2007).

Heat content values for natural gas are from EIA SEDS (EIA, 2007a). Heat content data for coal, natural gas liquids, LPG, gasoline, fossil waste fuel are from CALEB (Murtishaw et al. 2005). Heat content for biomass waste fuel, tires and wood are from the EIA (EIA, 2007c) and other heat content values from USEPA (USEPA, 2007c).

Emission factor values for CO_2 for biomass waste fuel and fossil waste fuel burned in cement plants are from PCA (O'Hare, 2007), and from USEPA (USEPA, 2007c) for other fuels. Emissions factor values for CH_4 and N_2O are from the 2006 IPCC guidelines (IPCC, 2006b).

For a list of individual activity and parameter values used in the equations, please consult the online documentation annex at: http://www.arb.ca.gov/cc/inventory/doc/methods_v1/annex_1c_fuel_combustion_in_industrial_commercial_residential_agricultural_and_other_sectors.pdf

D. Transport (IPCC 1A3)

1. Background

Emissions from the transportation sector include emissions from civil aviation (IPCC category 1A3a); road transportation, also referred to as "on-road" or "highway" vehicles (category 1A3b); railways (category 1A3c); and water-borne navigation (category 1A3d).

The Intergovernmental Panel on Climate Change (IPCC) guidelines recommend separating international from domestic aviation emissions. In the case of a state-level rather than a national inventory, this raises the question of how to treat emissions from interstate flights. Based upon jurisdictional interpretation of IPCC protocols, ARB staff opted to estimate, but not include, the emissions resulting from aviation fuel purchased in California but used for interstate flights. Intrastate aviation was defined as those flights with both origin and destination in California. The aviation fuel purchased in California was apportioned to intrastate and interstate aviation according to miles flown. Emissions resulting from international flights were also excluded in accordance with international convention, and appear as an "excluded line item" in the inventory.

The railways portion of the inventory quantifies emissions based exclusively on fuel purchased in California.

Emissions from on-road vehicles include emissions from passenger cars; light duty trucks (pick-ups, SUVs, and medium-duty vehicles with a gross weight of 8500 lbs or less); heavy-duty vehicles (trucks over 8500 lbs, buses, and motor-homes); and motorcycles. The State of California defines these vehicle classes by type and/or weight during the vehicle certification process. Emissions from each category were based upon total fuel sales and apportioned based on vehicle miles traveled.

California's water-borne navigation emissions include emissions from shipping activities which occur in California or within 24 nautical miles of the coast (harbor craft, in-port, and transit emissions). All emissions from shipping activities occurring further than 24 nautical miles from California's coast are excluded regardless of trip origin or destination (in accordance with ARB's pre-existing regulatory purview for criteria pollutants). Emissions from international bunker fuels used for navigation (in excess of the amount that was combusted within 24 nautical miles from the coast) were estimated but excluded from the inventory in accordance with international convention.

2. Methodology

Staff used two different methodologies to estimate transport emissions. One based on amount of fuel combusted and emission factors, consistent with the tier 2 IPCC methodology. The other, more complex methodology uses an emission model based on tail pipe measurements and is consistent with the tier 3 IPCC methodology. The model-based methodology was used for estimating emissions from on-road gasoline and diesel vehicles. The simpler methodology was used for on-road vehicles combusting natural gas and all other transportation categories.

2.1 On-road Gasoline & Diesel Vehicles (based on EMFAC model)

To quantify GHG emissions from on-road gasoline and diesel emissions, staff used outputs from the EMission FACtors model (ARB, 2007d). ARB staff chose to use EMFAC in part because it allows for apportioning fuel sales data (for gasoline and distillate) among different categories of vehicles, and thus calculate emissions for each of the classes of vehicles. Also, EMFAC has a rigorous scientific foundation (i.e., tailpipe measurements) and multiple versions have been vetted through various stakeholder reviews. Furthermore, the Air Resources Board State Implementation Plan (SIP) relies on EMFAC outputs for determining transportation emissions and helping to develop mitigation strategies for criteria pollutants. For the greenhouse gas inventory, staff used EMFAC modeled outputs for the amount of fuel combusted, and CO_2 (carbon dioxide), CO (carbon monoxide), total hydrocarbons (THC), and NOx emissions. EMFAC outputs were scaled so that EMFAC fuel combustion numbers would match fuel sales numbers obtained from the California Board of Equalization.

The EMFAC model is a transportation emissions model developed by the ARB to quantify on-road vehicle emissions (THC, CH_4, CO, NOx, CO_2, particulate matter, lead, SOx, etc.). The two primary information sources that feed into the EMFAC model are: 1) activity data (e.g., vehicle miles traveled - VMT) from local and regional transportation surveys and models, and 2) tailpipe emissions tests data from representative vehicle types. EMFAC reports emissions by: a) vehicle type (as listed in Section I.D.1 above), and b) fuel-specific emission control technology. For example, EMFAC has outputs for non-catalyzed gasoline passenger cars, catalyzed gasoline passenger cars, and diesel passenger cars. Diesel vehicles currently in use typically do not have catalysts so there is no catalyzed/non-catalyzed differentiation for that type of vehicles.

EMFAC uses a bottom-up approach (local-level data aggregated to the state level) and, therefore, the total fuel consumption computed by EMFAC differs somewhat from the values in top-down fuel inventories. As mentioned above, staff decided to scale EMFAC outputs to match the fuel sales numbers reported by the California Board of Equalization (BOE) in order to maintain a consistent state-level energy balance. This was done by scaling EMFAC model outputs using the ratio of the BOE fuel sales over the modeled EMFAC fuel consumption. That way, emission estimates do remain consistent with EMFAC outputs (in terms of emissions per gallon combusted for each vehicle type) but the total emissions match the amount of fuel reported by California's Board of Equalization (BOE). Fuel sales are closely correlated with actual fuel use, and BOE numbers are widely used in other institutions' publications; including the

Federal Highway Administration (FHWA) Highway Statistics annual reports and the Lawrence Berkeley National Laboratory's (LBNL) California Energy Balance (CALEB) report. Staff chose to use the state energy balance work in CALEB (Murtishaw et al. 2005) as the reference for all fuel use, including on-road vehicles. This ensures that the GHG inventory is consistent throughout all sectors with respect to fuel consumption.

Estimation of the on-road gasoline and diesel vehicles emissions involved the following steps:

(a) Converting EMFAC outputs per weekday to outputs per year

EMFAC emissions outputs are in short tons per weekday (note that some raw EMFAC outputs are in thousand units, such as CO_2, gallons, and VMT). In order to convert from EMFAC's average weekday (i.e., any day of the week other than Saturday or Sunday) outputs to an average day, staff divided EMFAC outputs by a conversion factor (1.05 for gasoline, and 1.12 for diesel). Once an average number of "tons per day" was calculated, we multiplied it by 365.25 to get tons per year, and then by 0.90718474 to convert from short tons (2000 pounds) to metric tonnes (1000 kilograms).

Equation 13: Conversion of emissions per weekday to emissions per year

$$\boxed{Y = \frac{W}{C_{fuel}} \bullet 365.25 \bullet 0.90718474}$$

Where,

Y	= Emission value in tonnes per year
W	= Emission value in tons per weekday
C_{fuel}	= factor to convert from average weekday value to average day value for a given fuel (1.05 for gasoline, and 1.12 for diesel).
0.90718474	= factor to convert short tons to metric tonnes, and
365.25	= average number of days in a year

(b) Scaling EMFAC outputs to match BOE fuel sales

Staff accounted for year-to-year differences between EMFAC fuel consumption and BOE fuel sales values by calculating fuel-specific ratios for each year of the inventory, as follows:

Equation 14: Ratio of EMFAC fuel combustion to BOE fuel sales

$$\boxed{R_{\text{fuel, year}} = \frac{S_{\text{fuel, year}}}{M_{\text{fuel, year}}}}$$

Where,

$R_{\text{fuel, year}}$	= Ratio of EMFAC modeled fuel combustion to BOE fuel sales for a given fuel in a given year
$S_{\text{fuel, year}}$	= BOE sales of the given fuel in the given year (gallons)
$M_{\text{fuel, year}}$	= modeled fuel consumption of the given fuel in the given year (gallons)

With,

Fuel = [Gasoline, Distillate]
Year = [1990 – 2004]

Table 15: Ratio of EMFAC modeled fuel combustion to BOE fuel sales

Year	***Fuel***	***BOE (gal)***	***EMFAC (gal)***	***Ratio***
1990	Gasoline	12637497939	13639555100	0.926533
1991	Gasoline	12338747509	13486584921	0.9148904
1992	Gasoline	13056175585	13386482071	0.9753254
1993	Gasoline	12843615551	13461504421	0.9540996
1994	Gasoline	12796082876	13510280950	0.9471367
1995	Gasoline	13035911481	13530213164	0.9634668
1996	Gasoline	13241954296	13449858164	0.9845423
1997	Gasoline	13428553265	13440507764	0.9991106
1998	Gasoline	13710068388	13715662764	0.9995921
1999	Gasoline	14096599514	13982858793	1.0081343
2000	Gasoline	14308616857	14402325807	0.9934935
2001	Gasoline	14692046835	15255167164	0.9630866
2002	Gasoline	15386147717	15417818207	0.9979459
2003	Gasoline	14961706228	15937360243	0.938782
2004	Gasoline	15579787590	16545748471	0.9416188
1990	Diesel	1819718000	2157919828	0.8432741
1991	Diesel	1769575000	2143052196	0.8257265
1992	Diesel	1842723000	2174678933	0.847354
1993	Diesel	1824363000	2144372967	0.8507676
1994	Diesel	1985649000	2165231350	0.9170609
1995	Diesel	2089687000	2217005538	0.9425718
1996	Diesel	2115704000	2271147328	0.9315574
1997	Diesel	2288069000	2274803089	1.0058317
1998	Diesel	2339261000	2304675321	1.0150067
1999	Diesel	2458325000	2345929004	1.0479111
2000	Diesel	2632760000	2375325107	1.1083788
2001	Diesel	2627366000	2478449531	1.0600845
2002	Diesel	2703680000	2476368911	1.0917921
2003	Diesel	2773909941	2790995913	0.9938782
2004	Diesel	2844139882	2700110625	1.053342

Source: BOE (also cited by FHWA & CALEB), EMFAC

All EMFAC emissions outputs were scaled using the ratios from Table 15 above according to the following equation:

Equation 15: Scaling of EMFAC emissions to fuel sales

$$\boxed{Z_{fuel,year} = Y_{\text{fuel, year}} \bullet R_{fuel,year}}$$

Where,

$Z_{\text{fuel, year}}$ = Scaled emission value from a given fuel in a given year (tonnes per year)
$Y_{\text{fuel, year}}$ = Emission value from a given fuel in a given year (tonnes per year)

$R_{fuel,\ year}$ = Ratio of EMFAC modeled fuel combustion to BOE fuel sales for a given fuel in a given year

With,
Fuel = [Gasoline, Distillate]
Year = [1990 – 2004]

(c) Calculating CO_2 emissions from carbon-laden tailpipe emissions

Since vehicles do not achieve 100 percent combustion efficiency (meaning that not all fuel carbon turns directly into CO_2), EMFAC outputs CO_2 emissions and other carbon-laden tailpipe emissions: CO and total hydrocarbons (THC). Staff converted these emissions into mass of CO_2 and added them to the CO_2 emissions because these gases would eventually form CO_2 in the atmosphere. This also presents the advantage to remain consistent with standard IPCC guidelines methodology (which assumes 100 percent combustion).

In order to calculate carbon dioxide emissions from EMFAC outputs, staff used three emissions outputs: CO_2, CO, and total hydrocarbons (THC). After scaling each emission, we converted the scaled CO and THC emissions into a mass of CO_2 based on the relative molecular weights of the molecules. THC emissions data displayed in EMFAC are based on tailpipe measurements which weigh THC as if they were all CH_2 (Hancock, 2007). We used the following molecular weights values (IUPAC, 2006): 12.0107 grams per mole for carbon, 15.9994 g $mole^{-1}$ for oxygen, and 1.00794 g $mole^{-1}$ for hydrogen, therefore CO_2 =44.0095 g $mole^{-1}$, CO =28.0101 g $mole^{-1}$, and THC = CH_2 =14.02658 g $mole^{-1}$.

The total CO_2 emissions are calculated by adding the resulting molecularly-converted scaled CO and THC model outputs to the scaled CO_2 model output.

Equation 16: Transportation - on road CO_2 emissions

$$\boxed{E_{CO2} = O_{CO2} + (O_{CO} \bullet \frac{44.0095}{28.0101}) + (O_{THC} \bullet \frac{44.0095}{14.02658})}$$

Where,
E_{CO2} = CO_2 emissions of a category of gasoline vehicles (grams)
O_{CO2} = scaled EMFAC output for CO_2 emitted by that category of vehicles (grams)
O_{CO} = scaled EMFAC output for CO emitted by that category of vehicles (grams)
44.0095 = molecular weight of CO_2 (grams per mole)
28.0101 = molecular weight of CO (grams per mole)
O_{THC} = scaled EMFAC output for THC emitted by that category of vehicles (grams of CH_2 equivalent)
14.02658 = molecular weight of CH_2 (grams per mole)

(d) Calculating N_2O emissions from gasoline and diesel vehicles

We calculated N_2O emissions from gasoline vehicles using a linear regression correlating NO_x with N_2O based on ARB tailpipe test data.

Equation 17: Transportation - on road N_2O emissions (gasoline vehicles)

$$\boxed{E_{N2O} = 0.0167 + 0.0318 \bullet O_{NOx}}$$

Where,

E_{N2O} = N_2O emissions of a category of gasoline vehicles (grams)
0.0167 = a constant, the intercept of the linear regression
0.0318 = a multiplier, the slope of the linear regression
O_{NOx} = scaled EMFAC output for NO_x emitted by that category of gasoline vehicles (grams)

Based on ongoing ARB-supervised diesel tailpipe research, staff determined that the N_2O emission factor for diesel vehicles was 0.3316 grams of N_2O per gallon. Diesel vehicles N_2O emissions are computed by multiplying the emission factor by BOE diesel fuel sales, for each category of vehicles:

Equation 18: Transportation - on road N_2O emissions (diesel vehicles)

$$\boxed{E_{N2O} = FC \bullet EF_{N2O}}$$

Where,

E_{N2O} = N_2O emissions of a category of diesel vehicles (grams)
FC = fuel consumption of that category of diesel vehicles (gallons)
EF_{N2O} = Emission factor for diesel vehicles (grams per gallon)

The emissions calculation methodologies for on-road vehicles running on natural gas are based on emission factors and are discussed in the following section alongside airplanes, trains, and ships due to methodological similarities.

2.2 Other on-road vehicles, Airplanes, Trains, Ships

To estimate the emissions from other on-road vehicles (using natural gas as a fuel), airplanes, trains, ships and from a few unspecified uses of fuel combustion for transportation, staff used the simpler methodology based on the amount of fuel combusted and emission factors, consistent with the tier 2 IPCC methodology. IPCC assumes a combustion efficiency of 100 percent, and the following equations reflect that assumption. Note: we did not estimate indirect emissions resulting from the energy consumed by pure electric vehicles in the transportation sector because those emissions occur upstream (during electricity generation) and are discussed under Section I.A above.

(a) Apportionment of amounts of fuel combusted

For the reasons discussed in Section I.D.1 above, we apportioned the amount of jet fuel used for domestic aviation between intrastate and interstate flights using miles traveled data (Table 16) compiled from the U.S. Department of Transportation's (DOT) Research and Innovative Technology Administration (RITA) Bureau of Transportation Statistics database (RITA, 2007).

Table 16: Miles travelled by interstate and intrastate flights

Year	Interstate miles travelled	Intrastate miles travelled
1990	431942393	105297652
1991	424249133	97790646
1992	433649929	87830076
1993	440093406	76990935
1994	456936408	76499206
1995	490153349	89351344
1996	515135873	90708125
1997	536140888	86094116
1998	540644443	86441468
1999	562453729	90020078
2000	597365782	84970841
2001	607024609	115889649
2002	590700391	80883787
2003	637465224	96580332
2004	688772237	99378300

We also apportioned distillate and residual fuels oil between intrastate, interstate and among port activities, harbor craft, transit (within 24 nautical miles from California's coast) and outside of California waters using an ARB model based on geographically specific shipping activity data which was used in the Goods Movement Plan (ARB, 2007b; ARB, 2007c).

(b) Emission calculations

All CO_2 emissions and the CH_4 and N_2O emissions from LPG and natural gas where estimated using the fuel combustion equation based on heat content:

Equation 19: Emissions from mobile source combustion (case 1)

$$\boxed{E_{GHG,\ fuel} = FC_{fuel} \bullet HC_{fuel} \bullet EF_{GHG,\ fuel}}$$

Where,

$E_{GHG,\ fuel}$ = Emissions of the given GHG for the type of fuel (g of GHG)
FC_{fuel} = Amount of fuel combusted (in units of gallons for liquid fuels or standard cubic feet for gaseous fuels)
HC_{fuel} = Heat content of the type of fuel (BTU / unit)
$EF_{GHG,\ fuel}$ = Emission factor of the given GHG by the type of fuel (g GHG / BTU)

With,

(1) GHG = [CO_2] and Fuel = [aviation gasoline, distillate, jet fuel, LPG, natural gas, residual fuel oil]
(2) GHG = [CH_4, N_2O] and Fuel = [LPG, Natural Gas]

A slightly different equation was used for estimating CH_4 and N_2O emissions from aviation gasoline, distillate, jet fuel and residual fuel oil, because the country specific emissions factors available were expressed by mass of fuel rather than by volume.

Equation 20: Emissions from mobile source combustion (case 2)

$$\boxed{E_{GHG,\ fuel} = FC_{fuel} \bullet D_{fuel} \bullet EF_{GHG,\ fuel}}$$

Where,

$E_{GHG,\ fuel}$ = Emissions of the given GHG for the type of fuel (g of GHG)
FC_{fuel} = Amount of fuel combusted (in units of gallons for liquid fuels or standard cubic feet for gaseous fuels)
D_{fuel} = Density of the type of fuel (kg / unit)
$EF_{GHG,\ fuel}$ = Emission factor of the given GHG by the type of fuel (g GHG / kg fuel)

With,

GHG = [CH_4, N_2O]
Fuel = [aviation gasoline, distillate, jet fuel, residual fuel oil]

3. Data Sources

On-road gasoline, on-road diesel, and aviation gasoline fuel sales numbers are from the Board of Equalization. These numbers are also referenced in the Federal Highway Administration (FHWA) Highway Statistics annual reports (FHWA, various years) and California Energy Balance (Murtishaw et al. 2005). All other fuel data was obtained through the California Energy Balance report (Murtishaw et al. 2005) which cites: The Energy Information Administration's (EIA) State Energy Consumption, Price, and Expenditure Estimates (SEDS) database (EIA, 2007a) and EIA Petroleum Marketing reports.

Heat content values are from CALEB (Murtishaw et al. 2005) for distillate, gasoline, and LPG; from the EIA SEDS database (EIA, 2007a) for natural gas; and from USEPA (USEPA, 2007c) for aviation gasoline, distillate, jet fuel and residual fuel oil.

CO_2 emission factor values are from CALEB (Murtishaw et al. 2005) for jet fuel and LPG; from USEPA (USEPA, 2007c) for natural gas, aviation gasoline, and distillate and residual fuel oil used in international shipping; and from ARB's Goods Movement Plan (ARB, 2007b; ARB, 2007c) for distillate and residual fuel oil used by ships within California waters.

CH_4 and N_2O emission factors values are from IPCC guidelines (IPCC, 2006b) for natural gas and LPG; from USEPA (USEPA, 2007d) for aviation gasoline, jet fuel, and distillate and residual fuel oil used in international shipping; and from ARB's Goods Movement Plan (ARB, 2007b; ARB, 2007c) for distillate and residual fuel oil used by ships within California waters.

For a list of individual activity and parameter values used in the equations, please consult the online documentation annex at:
http://www.arb.ca.gov/cc/inventory/doc/methods_v1/annex_1d_transport.pdf

4. Future Improvements

ARB is currently investigating the feasibility of updating EMFAC to directly calculate emission outputs for on-road vehicles' N_2O emissions and to better characterize CO_2 and CH_4 emissions. ARB is also considering pursuing research on the quantification of airplane emissions. Train and ship emissions will be updated as improved activity and emissions data become available.

E. Oil and Gas Production (IPCC 1A1cii)

1. Background

This section discusses combustion emissions arising from the energy-producing industries own (on-site) energy use for oil and gas extraction and the processing and upgrading of natural gas. The fuels used for these processes may be produced on site (crude oil, associated gas, natural gas) or may have gone through a refinery (distillate, residual fuel oil).

When crude oil is first brought to the surface, it may contain a mixture of associated gas and produced fluids such as salt water, and both dissolved and suspended solids. Water (which can constitute more than 90 percent of the fluid extracted in older wells) is separated out, as are solids and any associated gas. The crude oil is then prepared for shipment to storage facilities and ultimately to refineries. The separated associated gas consists predominantly of methane and carbon dioxide, but ethane, propane, and butane are also significant components. The heavier components, including propane and butane, liquefy when cooled and compressed; these are often separated and processed as natural gas liquids. This associated gas is typically consumed on site as an energy source for steam generation. When consumed in this way, this gas is also called lease fuel.

Natural gas is produced from dry gas wells that produce no oil, and is typically sent to natural gas processing plants for distribution and sale through natural gas pipelines. Natural gas is composed of methane, ethane and other combustible hydrocarbons, but it may also contain water vapor, hydrogen sulfide, carbon dioxide, nitrogen, and helium. During processing, many of these components are removed to improve the quality of the natural gas or to make it easier to move the gas over great distances through pipelines. The resulting processed natural gas contains mostly methane and ethane, although there is no such thing as a "typical" natural gas.

2. Methodology

The method for estimating emissions follows IPCC 2006 guidelines for stationary combustion (IPCC, 2006a). California or US-specific emission factors and heat content values were used when available.

Equation 21: Emissions from oil and gas production

$$\boxed{E_{GHG,\ fuel} = FC_{fuel} \bullet HC_{fuel} \bullet EF_{GHG,\ fuel}}$$

Where,

$E_{GHG,\ fuel}$ = Emissions of the given GHG for the type of fuel (g of GHG)

FC_{fuel} = Amount of fuel combusted (in units of gallons for liquid fuels or standard cubic feet for gaseous fuels)
HC_{fuel} = Heat content of the type of fuel (BTU / unit)
$EF_{GHG,\ fuel}$ = Emission factor of the given GHG by the type of fuel (g GHG / BTU)

With,
GHG = [CO_2, CH_4, N_2O]
Fuel = [Associated gas, Crude oil, Distillate, Natural Gas, Residual fuel oil]

3. Data Sources

The data sources for estimating emissions include the California Energy Balance database (CALEB), the California Energy Commission's Quarterly Fuels and Energy Report (QFER), the CA Department of Conservation Division of Oil, Gas & Geothermal Resources (DOGGR), the Energy Information Administration State Energy Consumption Price and Expenditure Estimates (EIA SEDS), the US Environmental Protection Agency, the Intergovernmental Panel on Climate Change (IPCC), and the Western States Petroleum Association (WSPA).

Distillate and residual fuel oil use are from CALEB (Murtishaw et al. 2005). Some yearly residual fuel oil combustion data were missing and staff used averaging to fill in the missing values. The QFER (Gough, 2007) provided natural and associated gas fuel use, and the EIA provided data on "natural gas" fuel used for CHP in the oil & gas sector. Note that EIA "natural gas" is in quotes to indicate it represents the sum of both natural gas and associated gas. The EIA data was used to reconcile with the total fuel use provided through the QFER, so only fuel used for a non-CHP purpose was assigned to this category. CHP fuel use was assigned to the electric generation section of the inventory. The DOGGR (Campion, 2007) provided data on crude oil combustion that occurred in the early 1990's and has since been discontinued.

Natural gas heat content values are from EIA SEDS (EIA, 2007a), associated gas values from WSPA (Wang, 2007) and other heat content values from USEPA (USEPA, 2007c).

Emission factor values for CO_2 are from WSPA (Wang, 2007) for associated gas and from USEPA (USEPA, 2007c) for other fuels. Emissions factor values for CH_4 and N_2O are from the 2006 IPCC guidelines (IPCC, 2006b).

For a list of individual activity and parameter values used in the equations, please consult the online documentation annex at:
http://www.arb.ca.gov/cc/inventory/doc/methods_v1/annex_1e_oil_and_gas_production.pdf

4. Future Improvements

Improved data on associated gas combustion and the amount used for CHP will be pursued by ARB staff.

F. Fugitive Emissions from Oil & Natural Gas (IPCC 1B2)

1. Background

This section discusses emissions associated with fugitive leaks associated with the pumping/pressurization of pipelines used to transport crude oil, refined petroleum products, natural gas liquids and natural or associated gases, and with their storage in tanks.

Fugitive emissions occur when methane leaks from tanks and pipeline cracks or joints. Sources of such emissions included in this section of the GHG inventory include: petroleum gas seeps; process losses, storage tanks from oil and gas extraction, petroleum refining and marketing activities; and a variety of manufacturing activities such as construction, chemicals, plastics and rubber, electric and electronic equipment, food products, etc.

2. Methodology

Staff queried ARB's California Emission Inventory Development and Reporting System (CEIDARS) database for total organic gases (TOG) emissions and then speciated the results to estimate fugitive emissions of CH_4. In the CEIDARS database, total organic gases include emissions of compounds of carbon, excluding carbon monoxide, carbon dioxide, carbonic acid, metallic carbides or carbonates, and ammonium carbonate. The ARB maintains and updates estimates of the chemical composition and size fractions of particulate matter (PM) and the chemical composition and reactive fractions of total organic gases (TOG) in CEIDARS, for a variety of emission source categories. These speciation profiles provide estimates of the chemical composition of the emissions, and are used in the emission inventory and air quality models. For more information see: http://arb.ca.gov/ei/speciate/speciate.htm

3. Data Sources

The California Air Resources Board (ARB) has collected information on emissions from air pollution sources since 1969. Data are gathered on an ongoing basis and stored in the California Emission Inventory Development and Reporting System (CEIDARS) database. See: http://www.arb.ca.gov/ei/general.htm

4. Future Improvements

Improved data on fugitive emissions from tanks and pipelines will be pursued by ARB staff.

G. Carbon Dioxide from Geothermal Power (IPCC 1B3)

1. Background

Geothermal power plants use high-pressure hot water and steam from deep inside the earth crust to turn turbine generators to produce electricity. The geothermal wells and gathering systems collect and convey the deep geothermal fluid to the power plants. Geothermal fluids contain minerals leached from the reservoir rock and variable quantities of gas, mainly carbon dioxide and a smaller amount of hydrogen sulfide (H_2S). The quantity and composition of dissolved gases depend on the local geological conditions. When the steam cools it turns back into water and is re-injected back into the reservoir, with most of its mineral content and some of the gases. Most of the non- condensable gases are released to the environment. Some plants remove the H_2S in a gas treatment process before releasing the CO_2 to the environment.

2. Methodology

To estimate the CO_2 emissions resulting from the exploitation of geothermal power, staff obtained data from the EIA for the amount of geothermal heat used by utility owned and merchant owned power plants and applied the same CO_2 emission factor USEPA used in the inventory.

Equation 22: CO_2 emissions from geothermal power

$$\boxed{E = GH \bullet EF}$$

Where,

E = CO_2 emissions by geothermal plants (g of CO_2)
GH = Amount of geothermal heat used by the plants (btu)
EF = CO_2 emission factor (g of CO_2 per btu)

3. Data Sources

Geothermal heat data was obtained from the U.S. Energy Information Administration (EIA). Data for 1990-2000 was obtained through personal correspondence with Robert Schnapp of U.S. Energy Information Administration (Schnapp, 2007). Data for 2001-2004 data was downloaded from U.S. Energy Information Administration databases published online (EIA, 2007e). The emission factor comes from USEPA 1990-2005 inventory annex 2.1 (USEPA, 2007c).

For a list of individual activity and parameter values used in the equations, please consult the online documentation annex at: http://www.arb.ca.gov/cc/inventory/doc/methods_v1/annex_1g_carbon_dioxide_from_geothermal_power.pdf

4. Future Improvements

Geothermal power plant CO_2 emissions can vary from plant to plant depending on the characteristics of the reservoir fluid and the type of power generation plant. Staff will seek plant specific data to improve the estimates.

II. Industrial Processes and Product Use

A. Cement Production (IPCC 2A1)

1. Background

In cement manufacture CO_2 emissions occur during the production of clinker, an intermediate product that is the main component of hydraulic (usually portland) cements.

To produce clinker, limestone (mainly made up of calcium carbonate $CaCO_3$) is heated at high temperature in a kiln to produce lime (CaO), and CO_2. This process is called calcination. The CaO then reacts with silica (SiO_2), alumina (Al_2O_3), and iron oxide (Fe_2O_3) in the raw materials to make the clinker minerals (chiefly calcium silicates). During the making of clinker some cement kiln dust (CKD) may leave the kiln system. Since that CKD is made up of partially calcined carbonates, cement manufacture emission estimates should also account for the CO_2 emissions associated with the CKD.

Masonry cement is produced by adding lime or ground limestone to portland cement. Since the emissions associated with the lime is already accounted for under the lime production section of the inventory, the production of masonry cement does not lead to additional emissions in this section. Similarly, the emissions resulting from the combustion of fuels to heat the kiln are accounted for in another section of the inventory.

2. Methodology

We estimated the cement manufacture CO_2 emissions using Tier 2 methodology from the 2006 IPCC Guidelines for National Greenhouse Gas Inventories (IPCC, 2006a). These guidelines recommend using the following two equations.

Equation 23: CO_2 emissions from cement production (equation 2.2 of the guidelines)

$$\boxed{E = M_{cl} \bullet EF_{cl} \bullet CF_{ckd}}$$

Where,

E = emissions of CO_2 from cement production, tonnes
M_{cl} = weight (mass) of clinker produced, tonnes
EF_{cl} = emission factor for clinker, tonnes CO2/tonne clinker. This clinker emission factor (EFcl) is not corrected for CKD.
CF_{ckd} = emissions correction factor for CKD, dimensionless (see Equation 24)

Equation 24: Emission correction factor for CKD (equation 2.5 of the guidelines)

$$\boxed{CF_{ckd} = 1 + \left(\frac{M_d}{M_{cl}}\right) \bullet C_d \bullet F_d \bullet \left(\frac{EF_c}{EF_{cl}}\right)}$$

Where,

CF_{ckd} = emissions correction factor for CKD, dimensionless
M_d = weight of CKD not recycled to the kiln, tonnes
M_{cl} = weight of clinker produced, tonnes
C_d = fraction of original carbonate in the CKD (i.e., before calcination), fraction
F_d = fraction calcination of the original carbonate in the CKD, fraction
EF_c = emission factor for the carbonate, tonnes CO_2/tonne carbonate
EF_{cl} = emission factor for clinker uncorrected for CKD, tonnes CO_2/tonne clinker

Substituting the expression for CF_{ckd} from Equation 24 into Equation 23, one gets Equation 25.

Equation 25: Substituting for CF_{ckd} into Equation 23

$$\boxed{E = (M_{cl} \bullet EF_{cl}) + (M_d \bullet C_d \bullet F_d \bullet EF_c)}$$

And considering that ($C_d \bullet F_d \bullet EF_c$) constitutes EF_d the emission factor of the CKD, Equation 25 can be simply written as:

Equation 26: CO_2 emissions from cement production

$$\boxed{E = (M_{cl} \bullet EF_{cl}) + (M_d \bullet EF_d)}$$

3. Data Sources

The Portland Cement Association (PCA) provided clinker production data (M_{cl}) for all California Portland cement plants for years 1990, 1995, 2000 and 2005 (O'Hare, 2007). The PCA also provided the amount of cement kiln dust and bypass dust leaving the kiln system (M_d) for the same set of years. ARB staff used interpolation to estimate the values for M_{cl} and M_d for the missing intervening years.

The default values from the 2006 IPCC guidelines (IPCC, 2006a) were used for the emission factors, that is:

- The emission factor of clinker (EF_{cl}) assumes that the clinker is 65 percent CaO, that this CaO is 100 percent derived from $CaCO_3$ and that the kiln achieves 100 percent calcination. Since 1 tonne of clinker contains 0.65 tonnes CaO and $CaCO_3$ is 56.03 percent CaO and 43.97 percent CO_2 by weight, the amount of $CaCO_3$ needed to yield 1 tonne of clinker is: 0.65/0.5603 = 1.1601 tonnes of $CaCO_3$. The amount of CO_2 released by calcining this $CaCO_3$ = 1.1601 • 0.4397 = 0.5101 tonne CO_2 (unrounded). Thus EF_{cl} = 0.51 tonne of CO_2 per tonne of clinker.
- The emission factor of CKD (EF_d) assumes that the fraction of original carbonate in the CKD (C_d) = 0.85, that the fraction calcination of the original carbonate in the CKD (F_d) = 0.50, and that the original carbonate in CKD is all $CaCO_3$ (hence EF_c = 0.4397 tonne CO_2/tonne carbonate). Thus EF_d = 0.85 x 0.50 x 0.4397 = 0.19 tonne of CO_2 per tonne of CKD.

For a list of individual activity and parameter values used in the equations, please consult the online documentation annex at:
http://www.arb.ca.gov/cc/inventory/doc/methods_v1/annex_2a_cement_production.pdf

4. Future Improvements

ARB would like to obtain cement plant-specific data on the mass and composition of individual carbonates consumed in the kiln to produce clinker. Such data would allow for using the Tier 3 approach of the IPCC 2006 guidelines and thus produce a more precise estimate of CO_2 emissions from cement manufacture in California.

B. Lime Production (IPCC 2A2)

1. Background

Lime production involves three key stages: stone preparation, calcination, and hydration. This section focuses on the CO_2 emitted during the calcination process, when limestone (mostly $CaCO_3$) is heated in a kiln to produce lime (CaO) and CO_2 as a by-product.

Equation 27: Calcination process

$$\boxed{CaCO_3 + \text{Heat} \rightarrow CaO + CO_2}$$

Lime is used in a variety of industrial applications, such as in steelmaking, water and sewage treatment, and paper manufacturing.

2. Methodology

Since a mole of CO_2 is emitted for each mole of CaO in the lime, first we estimate the amount of CaO by multiplying the mass of lime produced by the average proportion of CAO in high-calcium lime. Then, multiplying the amount of CaO by the molecular weight ratio of CO_2 to CaO gives the amount of CO_2 emissions. This methodology is consistent with emission estimation methodology used by USEPA (USEPA, 2004c), and with the Tier 1 method of the 2006 IPCC guidelines.

Equation 28: CO_2 emissions from lime production

$$\boxed{E = WLP \bullet P_{CaO} \bullet 0.7848}$$

Where,

E = CO_2 emissions from lime production (tonnes)
WLP = Weight (mass) of lime produced in California (tonnes)
P_{CaO} = Proportion of CaO in lime (unitless)
0.7848 = Molecular weight ratio of CO_2 to CaO

3. Data Sources

Lime production data for California came from the last California Energy Commission's greenhouse gas inventory (CEC, 2006a): data for 1990-2000 were obtained through a personal communication with Susan Kohler of the California Department of Conservation (Kohler, 2001), and values for years 2001-2004 were extrapolated from previous years. The value for the average proportion of CaO in high-calcium lime (0.95) came from USEPA (USEPA, 2004c). The molecular weight ratio of CO_2 to CaO (0.7848) is from the International Union of Pure and Applied Chemistry (IUPAC, 2006).

For a list of individual activity and parameter values used in the equations, please consult the online documentation annex at:
http://www.arb.ca.gov/cc/inventory/doc/methods_v1/annex_2b_lime_production.pdf

4. Future Improvements

ARB staff will acquire the most recent data for California lime production. Also, staff will investigate the possibility of using a Tier 2 IPCC methodology by using a lime kiln dust (LKD) correction factor for future lime production emission estimates. Including a LKD correction factor would account for emissions associated with LKD that is not recycled back in the manufacturing process.

C. Non-energy Uses of Fossil Fuels (IPCC 2B, 2D)

1. Background

Some fossil fuels are also consumed for non-energy uses. These non-energy uses include feedstocks for the chemical industry (IPCC category 2B) for the manufacture of plastics, rubber, synthetic fibers and other materials, and other non-energy products such as lubricants, waxes, and asphalt (category 2D).The fuels used for these purposes include natural gas, liquefied petroleum gases (LPG), asphalt, naphtha, petroleum coke and other petroleum products.

Non-energy uses of fossil fuels often do generate some CO_2 emissions. Emissions may occur during the manufacture of various products from fuel-derived feedstocks. Emissions may occur during the product's lifetime, for instance some of the lubricant in motors will end up being burned. However, emissions form lubricants, solvents and materials made from fossil fuels that are combusted after the end of the useful life are not accounted in this section but under the appropriate fuel combustion category in Section I above.

2. Methodology

Staff used a simple methodology from the California Energy Balance (Murtishaw et al. 2005). This methodology is consistent with that used by USEPA for the national GHG inventory (USEPA, 2007a). The proportion of the carbon that is stored in the derived product and thus not oxidized is used to modify the carbon oxidation formula used for fuel combustion. The proportion of carbon stored can vary from 1 (all of the fuel's carbon is stored) as in the case of asphalt used for pavement, to 0 (none of the carbon is stored) as in the case of natural gas or naphtha used for hydrogen production.

Equation 29: CO_2 emissions from non-energy uses of fossil fuels

$$\boxed{E_{fuel} = FC_{fuel} \bullet HC_{fuel} \bullet EF_{fuel} \bullet (1 - CS_{fuel})}$$

Where,

E_{fuel} = CO_2 emissions for the particular fuel used as feedstock or other non-energy use (g)

FC_{fuel} = Amount of fuel used as feedstock or other non-energy use (in units of gallons for liquid fuels or standard cubic feet for gaseous fuels)

HC_{fuel} = Heat content of the type of fuel (BTU / unit)

EF_{fuel} = CO_2 emission factor for the type of fuel (g / BTU)

CS_{fuel} = Proportion of carbon that is stored in the derived product (unitless)

With,

fuel = [asphalt, LPG, lubricants, naphtha, natural gas, petroleum feedstocks, other petroleum products, waxes]

3. Data sources

Fuel consumption values, heat contents, proportion of carbon stored and CO_2 emission factors came from the California Energy Balance (Murtishaw et al. 2005), except for: the heat content of natural gas was from the Energy Information Administration State Energy Consumption Price and Expenditure Estimates (EIA, 2007a)); and the CO_2 emission factor for natural gas was from USEPA inventory annex 2 (USEPA, 2007c).

For a list of individual activity and parameter values used in the equations, please consult the online documentation annex at: http://www.arb.ca.gov/cc/inventory/doc/methods_v1/annex_2c_non-energy_uses_of_fossil_fuels.pdf

4. Future Improvements

ARB staff will seek to obtain more detailed data about non-energy use of fuel in California and better estimates of the proportion of carbon stored in derived products.

D. Nitric Acid Production (IPCC 2B2)

1. Background

The main use of nitric acid (HNO_3) is for the manufacture of nitrogen fertilizer. It is also used in the production of adipic acid and explosives (e.g., dynamite), for metal etching and in the processing of ferrous metals. During the production of nitric acid, N_2O is generated as an unintended by-product of the high temperature catalytic oxidation of ammonia (NH_3), and is released into the atmosphere. The amount of N_2O formed varies with the process conditions (pressure, temperature), catalyst composition and age, etc. Some nitric acid manufacturing plants have emissions control devices that reduce the amount of N_2O released to the atmosphere.

2. Methodology

ARB staff did not have access to HNO_3 production numbers for California and continued to employ the estimation method used by CEC in their last GHG inventory (CEC, 2006a). This approach estimates California production by scaling the national production by the ratio of California's nitric acid production capacity to the national production capacity.

Equation 30: California nitric acid production

$$\boxed{P_{CA} = P_{US} \bullet \left(\frac{PC_{CA}}{PC_{US}} \right)}$$

Where,

P_{CA} = California nitric acid production (g)
P_{US} = US nitric acid production (g)
PC_{CA} = California nitric acid production capacity (tonnes)
PC_{US} = US nitric acid production capacity (tonnes)

Then, the emissions of N_2O are estimated following USEPA EIIP guidance (USEPA, 2004c). This is consistent with the Tier 1 method of the 2006 IPCC guidelines.

Equation 31: N_2O emissions from nitric acid production

$$\boxed{E = P_{CA} \bullet EF}$$

Where,

E = N_2O emissions from nitric acid production (g)
P_{CA} = California nitric acid production (g)
EF = N_2O emission factor (g / g)

3. Data sources

Data for US nitric acid production are from the USEPA national GHG inventory (USEPA, 2007a) and N_2O emission factors from USEPA EIIP guidance (USEPA, 2004c). Data for California and US nitric acid production capacity are from the CEC GHG inventory (CEC, 2006a) and missing values where either interpolated or extrapolated.

For a list of individual activity and parameter values used in the equations, please consult the online documentation annex at:
http://www.arb.ca.gov/cc/inventory/doc/methods_v1/annex_2d_nitric_acid_production.pdf

4. Future Improvements

ARB staff will obtain updated data about California nitric acid production for future inventories.

E. Semiconductor Manufacturing (IPCC 2E)

1. Background

Manufacturers of semiconductors use fluorinated greenhouse gases in plasma etching and plasma enhanced chemical vapor deposition processes. Plasma etching of dielectric films creates the pattern of pathways connecting individual circuit components in semiconductors. Vapor deposition chambers are used for depositing the dielectric films, and are cleaned periodically using fluorinated gases. Fluorinated gases are converted to fluorine atoms in plasma, which etches away dielectric material or cleans the chamber walls and hardware. Undissociated fluorinated gases and other products end up in the waste streams and, unless captured by abatement systems, into the atmosphere. Some fluorinated compounds can also be transformed in the plasma processes into other compounds (e.g., CF_4 generated from C_2F_6). If they are not captured by emission control systems the process-generated gases will also be released into the atmosphere.

2. Methodology

The USEPA has developed estimates of the national GHG emissions from semiconductor manufacture based in part upon information reported by participants in its PFC Reduction/Climate Partnership for the Semiconductor Industry (USEPA, 2007a). ARB staff estimated emissions from semiconductor manufacturing in California by apportioning U.S. semiconductor manufacture emissions using the ratio of California to U.S. semiconductor shipments. This approach is consistent with USEPA's – EIIP guidance of 2004 (USEPA, 2004c). Note that in this case ARB staff did not obtain individual gas emission estimates from the USEPA and used the aggregated national emissions data expressed in CO_2 equivalent. Gases included in the aggregate emissions are: CF_4, C_2F_6, C_3F_8, C_4F_8, HFC-23 and SF_6.

Equation 32: Emissions from semiconductor manufacturing

$$\boxed{E = E_{US} \bullet \left(\frac{SS_{CA}}{SS_{US}} \right)}$$

Where,

E = Estimate of GHG emissions from semiconductor manufacturing in California (g of CO_2 equivalent)

E_{US} = Estimate of GHG emissions from semiconductor manufacturing in the entire US (g of CO_2 equivalent)

SS_{CA} = Value of California semiconductor shipments (thousand dollars)

SS_{US} = Value of US semiconductor shipments (thousand dollars)

3. Data Sources

Estimates of emissions from semiconductor manufacturing for the United States are from the US Environmental Protection Agency (USEPA, 2007b). Semiconductor shipment data for the United States and California are from the US Census Bureau economic data (USCB, various years b).

For a list of parameter values used in the equations, please consult the online documentation annex at:
http://www.arb.ca.gov/cc/inventory/doc/methods_v1/annex_2e_semiconductor_manufacturing.pdf

4. Future Improvements

Staff will work with industry to obtain facility-specific semiconductor manufacturing and emission data to implement a bottom-up inventory.

F. Use of ODS Substitutes (IPCC 2F)

1. Background

Ozone-depleting substances (ODS) are being phased out under the terms of the Montreal Protocol, and the Clean Air Act Amendments of 1990. Many of the substances approved to replace them, including hydrofluorocarbons (HFCs) and perfluorocarbons (PFCs), are greenhouse gases. Historically, ozone-depleting substances (chlorofluorocarbons (CFCs), halons, carbon tetrachloride, hydrochlorofluorocarbons (HCFCs), and methyl chloroform) have been used in applications such as refrigeration and air conditioning equipment, solvent cleaning, foam production, sterilization, fire extinguishing, and aerosols. HFCs and PFCs are now replacing them in most of these applications and, as a result of that switch, emissions of ODS substitutes have been steadily increasing since 1990.

2. Methodology

Emissions of ODS substitutes occur when they are released into the atmosphere (e.g., from fire extinguishers or aerosol cans) or when they leak out of equipment such as refrigerators and air conditioning units. Estimating these emissions is difficult because the sources are diffuse and the emissions occur over the life time of equipment. The US EPA has implemented a detailed "vintaging" model of ODS-containing equipment and products that can be used to estimate the actual (versus potential) emissions of various ODS substitutes, including HFCs and PFCs (USEPA, 2007a). The model tracks the use and emissions of various compounds for the annual "vintages" of new equipment that enter service in each end-use, and estimates emissions by applying annual leak rates and release profiles over time.

ARB staff estimated California's share of ODS substitute emissions by apportioning national emissions numbers on the basis of population. This approach is consistent with USEPA's - EIIP guidance of 2004 (USEPA, 2004c).

Equation 33: Emissions of ODS substitutes

$$\boxed{E_{CA,GHG} = E_{US,GHG} \bullet Rpop}$$

Where,

$E_{CA,\,GHG}$ = Estimate of the given GHG (ODS substitute) emissions in California (g)
$E_{US,\,GHG}$ = Estimate of the given GHG (ODS substitute) emissions in the entire US (g)
Rpop = Ratio of the population of California to the population of the entire US (unitless)

With,

GHG = [CF4, HFC-125, HFC-134a, HFC-143a, HFC-23, HFC-236fa, HFC-32, other ODS substitutes]

Note: other ODS substitutes include HFC-152a, HFC-227ea, HFC-245fa, HFC-4310mee, and PFC/PFPEs (various PFCs and perfluoropolyethers (PFPEs) employed for solvent applications). The GWP value used for PFC/PFPEs was based upon that of C_6F_{14}.

3. Data Sources

Estimates of emissions of ODS substitutes for the United States were provided by the US Environmental Protection Agency (Godwin, 2007). Population estimates for the United States and California were from the US Census Bureau (USCB, various years a).

For a list of parameter values used in the equations, please consult the online documentation annex at:
http://www.arb.ca.gov/cc/inventory/doc/methods_v1/annex_2f_use_of_ods_substitutes.pdf

4. Future Improvements

ARB Staff will seek more specific sources of data to estimate ODS substitute emissions.

G. Sulfur Hexafluoride from Use of Electrical Equipment (IPCC 2G1b)

1. Background

Sulfur hexafluoride gas (SF_6) is used by the electric power industry in gas-insulated substations, circuit breakers, and other switchgear because of its dielectric strength and arc-quenching characteristics. Fugitive emissions of SF_6 are the result of leaks through seals of gas-insulated substations and switch gear. SF_6 can also be released during equipment installation and servicing.

2. Methodology

The USEPA has developed estimates of the national SF_6 emissions from use of electrical equipment based in part upon information reported by participants in its SF_6 Emission Reduction Partnership for Electric Power Systems (USEPA, 2007a). ARB staff estimated SF_6 emissions in California by apportioning U.S. emissions using the ratio of the sum of the power generated and imported in California to the national power generation. This approach is consistent with USEPA's – EIIP guidance of 2004 (USEPA, 2004c).

Equation 34: SF_6 emissions from use of electrical equipment

$$\boxed{E_{CA} = E_{US} \bullet \frac{(G_{CA} + G_{IMP})}{G_{US}}}$$

Where,

E_{CA} = California SF_6 emissions (grams)
E_{US} = National SF_6 emissions (grams)
G_{CA} = California in-state electricity generation (gigawatt-hours)
G_{IMP} = Electricity generation imported into California (gigawatt-hours)
G_{US} = National electricity generation (gigawatt-hours)

3. Data sources

Estimates of the national SF_6 emissions are from the USEPA greenhouse gas inventory (USEPA, 2007a), national and California electricity generation data are from the Energy Information administration, California electricity imports (Table 17) are from data discussed in the Electricity Production – Imports (IPCC 1A1a) category (i.e., Table 11 + Specified Imports).

Table 17: California electricity imports (gigawatt-hours)

Region	***1990***	***2002***	***2003***	***2004***
Specified Imports	*41,209*	*47,337*	*46,680*	*47,930*
Unspecified Imports	*66,710*	*47,430*	*46,569*	*50,113*
Total Imports	107,919	94,766	93,249	98,043

4. Future Improvements

SF_6 emissions estimates could be improved by using California specific data which staff is currently working to obtain. SF_6 emissions estimates could also be improved with region specific data (from the PNW and PSW regions) on SF_6 use, which the ARB will seek to obtain.

H. Carbon Dioxide Consumption (IPCC 2G4a)

1. Background

Carbon dioxide (CO_2) is used in chemical production, food processing, carbonated beverages, refrigeration, and for enhanced oil recovery (EOR) in petroleum production. Except in the case of EOR (where CO_2 is injected in underground reservoirs), the CO_2 used in these applications is eventually released in the atmosphere.

The CO_2 used for these applications is either produced as a by-product from energy production (fossil fuel combustion) and industrial processes (e.g., ethanol production), as a by-product from the extraction of crude oil and natural gas, or from naturally occurring CO_2 reservoirs. However, CO_2 originating from biogenic sources (e.g., ethanol production plants) is not included in the inventory, so it is not considered here. CO_2 captured from crude oil and gas production is used in EOR applications and should be reported in the energy section. CO_2 from fuel combustion or other industrial process is already accounted for in the appropriate fossil fuel combustion or industry section of the inventory where it is assumed to have been emitted to the atmosphere. This leaves only the CO_2 extracted from naturally occurring CO_2 reservoirs to be accounted for in this section.

2. Methodology

ARB staff did not have access to specific CO_2 consumption data for California and continued to employ the estimation method used by CEC in their last GHG inventory (CEC, 2006a). This approach estimates California emissions by scaling the national emissions from CO_2 consumption estimates by the ratio of California's CO_2 production capacity to the national production capacity.

Equation 35: Emissions from CO_2 consumption

$$\boxed{E_{CA} = E_{US} \bullet \left(\frac{PC_{CA}}{PC_{US}} \right)}$$

Where,

E_{CA} = California emissions from CO_2 consumption (g)
E_{US} = US emissions from CO_2 consumption (g)
PC_{CA} = California CO_2 production capacity (tonnes)
PC_{US} = US CO_2 production capacity (tonnes)

3. Data sources

Data for US emissions from CO_2 consumption are from the USEPA national GHG inventory (USEPA, 2007b). Data for California and US CO_2 production capacity are from the CEC GHG inventory (CEC, 2006a; SRI, various years) and missing values where either interpolated or extrapolated.

For a list of individual activity and parameter values used in the equations, please consult the online documentation annex at: http://www.arb.ca.gov/cc/inventory/doc/methods_v1/annex_2h_carbon_dioxide_consumption.pdf

4. Future Improvements

ARB staff will seek to obtain more specific data about California CO_2 consumption for future inventories.

I. Limestone and Dolomite Consumption (IPCC 2G4b)

1. Background

Limestone ($CaCO_3$) and dolomite ($CaCO_3MgCO_3$) are used by a wide variety of industries such as construction, agriculture, chemical and glass manufacture, metallurgy, and environmental pollution control. In some of these applications limestone (or dolomite) is heated to a high temperature during the process and generates CO_2 as a by-product.

This section accounts for uses of limestone and dolomite resulting in CO_2 emissions in the following applications: flux stone (metallurgical furnaces), glass manufacturing, flue gas desulfurization systems, chemical stone, mine dusting or acid water treatment, acid neutralization, and sugar refining.

2. Methodology

The USEPA has developed estimates of the national GHG emissions from limestone and dolomite consumption based upon information from the US geological Survey (USEPA, 2007a). ARB staff estimated emissions from limestone and dolomite consumption in California by apportioning U.S. emissions using the ratio of California to U.S. consumption of limestone and dolomite. This approach is consistent with USEPA's – EIIP guidance of 2004 (USEPA, 2004c).

Equation 36: CO_2 emissions from limestone and dolomite consumption

$$\boxed{E_{CA} = E_{US} \bullet \left(\frac{C_{CA}}{C_{US}} \right)}$$

Where,

E_{CA} = California emissions from limestone and dolomite consumption (g)
E_{US} = US emissions from limestone and dolomite consumption (g)
C_{CA} = California limestone and dolomite consumption (tonnes)
C_{US} = US limestone and dolomite consumption (tonnes)

3. Data sources

Data for US emissions from limestone and dolomite consumption are from the USEPA national GHG inventory (USEPA, 2007b). Data for California's consumption of limestone and dolomite is from the California department of conservation and the US Geological Survey (USGS, various years a), national consumption data came from the USGS (USGS, various years b).

For a list of individual activity and parameter values used in the equations, please consult the online documentation annex at: http://www.arb.ca.gov/cc/inventory/doc/methods_v1/annex_2i_limestone_and_dolomite_consumption.pdf

J. Soda Ash Consumption (IPCC 2G4c)

1. Background

Sodium carbonate (Na_2CO_3), also called soda ash, is a strongly alkaline chemical used in a variety of industrial processes. The most important use of soda ash is in glass production, but it also enters in the fabrication of many common products such as soap and detergents, paper, textiles and processed food. As soda ash is consumed for these purposes, CO_2 is usually emitted. It is assumed that one mole of C is released for every mole of soda ash used.

Note that some soda ash manufacturing processes also generate CO_2 emissions. However, according to the USEPA, in California, soda ash is manufactured using sodium carbonate-bearing brines instead of trona ore. These complex brines are first treated with CO_2 in carbonation towers to convert the sodium carbonate into sodium bicarbonate, which then precipitates from the brine solution. The precipitated sodium bicarbonate is then calcined back into sodium carbonate. Although CO_2 is generated as a by-product, the CO_2 is recovered and recycled for use in the carbonation stage and is not emitted (USEPA, 2007a). For this reason, there is no “Soda ash production” section (IPCC category 2B7) in the California GHG inventory.

2. Methodology

ARB staff did not have access to soda ash consumption numbers for California and used the estimation method recommended by the USEPA EIIP guidance (USEPA, 2004c). This approach first estimates California’s consumption by scaling the national consumption by the ratio of California population to that of the entire United States.

Equation 37: California soda ash consumption

$$\boxed{C_{CA} = C_{US} \bullet Rpop}$$

Where,
C_{CA} = California soda ash consumption (g)
C_{US} = US soda ash consumption (g)
Rpop = Ratio of the population of California to the population of the entire US (unitless)

Then, the emissions of CO_2 are estimated using the emission factor from USEPA EIIP guidance (USEPA, 2004c).

Equation 38: CO_2 emissions from soda ash consumption

$$\boxed{E = C_{CA} \bullet EF}$$

Where,

E = CO_2 emissions from soda ash consumption (g)
C_{CA} = California soda ash consumption (g)
EF = CO_2 emission factor (g / g)

3. Data sources

Data for the US soda ash consumption are from the US Geological Survey (USGS, 2006) and population estimates for the United States and California come from the US Census Bureau (USCB, various years a). The emissions factor of soda ash consumption is from the USEPA EIIP guidance (USEPA, 2004c).

For a list of individual activity and parameter values used in the equations, please consult the online documentation annex at: http://www.arb.ca.gov/cc/inventory/doc/methods_v1/annex_2j_soda_ash_consumption.pdf

K. Fuel Consumption as Feedstock for Hydrogen Production (IPCC 2H3)

1. Background

In California, hydrogen (H_2) production by and for refineries generates substantial amounts of CO_2 because the most common processes use carbon-based feedstock inputs (e.g., methane from natural gas) as a source of hydrogen and emit the carbon as CO_2. Hydrogen production is not a direct part of the petroleum refining process but it provides the hydrogen gas needed to upgrade heavier fractions into lighter, more valuable products.

2. Methodology

2.1 CO_2 emissions

Data on H_2 production from the Oil and Gas Journal's "Historical Worldwide Refinery Survey" database were provided to staff by the Western States Petroleum Association (Shires, 2007). This database contains data on the three basic types of H_2 production processes used by California refineries: steam-methane reforming, steam-naphtha reforming, and partial-oxidation. Staff assumed that steam-naphtha reforming used naphtha as the feedstock, partial-oxidation used residual fuel oil as the feedstock, and steam-methane reforming used either natural gas or refinery gas as the methane feedstock source. Because the feedstock was not listed, staff assumed that a 50 percent-50 percent mix of natural gas and refinery gas was used for methane-steam reforming.

Hydrogen gas production rates were reported in million cubic feet per day (MMCFd), and staff converted these production rates into million cubic feet per year (MMCF) by multiplying the original value by 365 days per year. Staff assumed that standard cubic feet were measured at 60° F and 1 atmosphere of pressure. To estimate the CO_2 emissions from the amount of H_2 produced, staff made stoichiometric assumptions for each process type as described below.

The methane reforming processes were assumed to generate 1 mole of CO_2 for every 4 moles of H_2 produced:

Equation 39: Methane reforming process stoichiometric assumption

$$\boxed{CH_4 + 2H_2O \rightarrow CO_2 + 4H_2}$$

The naphtha and partial oxidation methods were assumed to generate 1 mole of CO_2 for every 3 moles of H_2 produced, based on the assumption that each carbon in their longer chain carbon molecules contained 2 hydrogen atoms on average, since the other 2 carbon bonds (normally bonded to another 2 hydrogen atoms in methane for a total of 4 hydrogen atoms for each methane carbon) would be most often attached to another carbon atom in the chain.

Equation 40: Naphtha reforming and partial oxidation stoichiometric assumption

$$\boxed{CH_2 + 2H_2O \rightarrow CO_2 + 3H_2}$$

Based on these assumptions, CO_2 emissions can be derived from the volume of hydrogen produced in a given year:

Equation 41: CO_2 emissions from hydrogen production

$$\boxed{E_{process} = V_{process} \bullet 1{,}195{,}250 \bullet R_{process} \bullet 44}$$

Where,

$E_{process}$ = Emissions of CO_2 from hydrogen production with a given process (grams)

$V_{process}$ = Volume of hydrogen produced with a given process (million cubic feet)

1,195,250 = Moles of H_2 per million cubic feet (at 60° F and 1 atmosphere of pressure)

$R_{process}$ = stoichiometric molar ratio of CO_2 to H_2 for the given process = 1/4 for steam-methane, 1/3 for steam-naphtha and 1/3 for partial oxidation

44 = molecular weight of CO_2 (grams per mole)

With,

Process = [steam-methane, steam-naphtha, partial oxidation]

2.2 Fuel consumed as feedstock

Staff estimated the amount of fuel consumed as feedstock by the H_2 production processes using their heat content and combustion emission factor. Input fuels were assumed to be natural gas and refinery gas for methane-steam reforming (half and half), naphtha for naphtha-steam reforming, and residual fuel oil for partial oxidation.

Equation 42: Amount of fuel consumed as feedstock for hydrogen production

$$\boxed{Q_{fuel} = \frac{E_{process}}{(HC_{fuel} \bullet EF_{fuel})}}$$

Where,

Q_{fuel} = amount of the corresponding fuel consumed by a given hydrogen production process (in units of gallons for liquid fuels or standard cubic feet for gaseous fuels)

$E_{process}$ = Emissions of CO_2 from hydrogen production with a given process (grams)

HC_{fuel} = Heat content of the fuel (BTU per unit)

EF_{fuel} = CO_2 emission factor of the fuel (grams per BTU)

With,

Process = [steam-methane, steam-naphtha, partial oxidation]

Fuel = [natural gas, refinery gas, naphtha, residual fuel oil]

3. Data Sources

Data on H_2 production from the Oil and Gas Journal's "Historical Worldwide Refinery Survey" database were provided to staff by the Western States Petroleum Association (Shires, 2007).

Heat content data came from the U.S. Energy Information Administration (Schnapp, 2007; EIA, 2007e). CO_2 Emissions factors are from USEPA 1990-2005 greenhouse gas inventory (USEPA, 2007c).

III. Agriculture Forestry and Other Land Use

A. Enteric Fermentation (IPCC 3A1)

1. Background

The microbial fermentation that occurs in the digestive system of some animals is called enteric fermentation. It is a normal digestive process during which microbes break down indigestible carbohydrates (e.g., cellulose, hemi-cellulose) and reprocess them into nutrients that can be absorbed by the animal. This microbial fermentation process produces CH_4 as a by-product, which is then exhaled, eructated or passed out as gas by the animal. The amount of CH_4 produced and emitted by an animal depends on its anatomy and the amount and type of feed it consumes.

Among domesticated animal species, ruminants (e.g., cattle, buffalo, sheep, goats) are the main emitters of CH_4. Ruminants have a large "fore-stomach" with four chambers in which microbial fermentation breaks down the feed they consume into products that can be absorbed and metabolized in the stomach and intestines. This fermentation-based digestive system enables ruminants to live on a diet of coarse plant material. Some non-ruminant domesticated animals (e.g., swine, horses, and mules) also rely on microbial fermentation as part of their digestive system although this microbial fermentation occurs in the caecum and the large intestine. Individuals of these species also emit CH_4 but less than ruminants of similar sizes because the capacity of their fermentation chambers is lower.

Aside from the type of digestive system, the quantity and quality of feed ingested by the animal also affects CH_4 emissions. The amount of food an animal consumes is a function of its size, its growth rate and production (e.g., milk production, wool growth, pregnancy, or work in the case of draft animals), and as the amount ingested increases so does the CH_4 production. As for the quality of the feed, coarser, more fibrous feed (i.e., straw, hay) generally also leads to higher CH_4 emissions than more concentrated feed such as grains.

2. Methodology

The USEPA estimates the greenhouse gas emissions from enteric fermentation in consultation with ICF International for the national GHG inventory (USEPA, 2007a). For California's GHG inventory, ARB staff extracted California specific information from a detailed set of inventory data and model results obtained from the USEPA's Climate Change Division (Wirth, 2007).

USEPA used two different methodologies to estimate enteric fermentation emissions: one for cattle and another for other livestock. For complete detail on these methodologies, see Annex 3.9 of the Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2005 (USEPA, 2007e).

2.1 Methane Emissions from Cattle

Because of their large population, large size, and the fact that they are ruminants, cattle are responsible for the majority of CH_4 emissions from enteric fermentation in the United States. Therefore, USEPA developed a more detailed methodology, consistent with the Tier 2 methodology of IPCC guidelines, for cattle emissions (with the exception of bulls).

This methodology consists of five steps:

(a) Characterization of cattle populations

The amount of methane emitted by cattle at different stages of their lifecycle varies greatly. Also, while the emissions are reported on a yearly basis, some of these stages may last less than a year (e.g., pregnancy, young before the age of weaning, etc.). Thus, a monthly approach is needed to account for the different level of CH_4 emissions associated with each lifecycle stage and livestock category. USEPA used a cattle lifecycle model to simulate each stage of the cattle lifecycle on a per month basis to estimate the number of individuals in each cattle population category from birth to slaughter. The model disaggregates dairy and beef cattle populations into the sub-populations of Table 18, based upon cattle population data from the U.S. Department of Agriculture statistics (USDA, 2007a), calving rates, average weights and weight gains, feedlot placement statistics, pregnancy and lactation, and death rates.

Table 18: Cattle population categories based on life-cycle

Dairy cattle	***Beef cattle***
Calves Dairy replacements (12-23 months) Dairy replacements (7-11 months) Dairy cows	Calves Beef replacements (12-23 months) Beef replacements (7-11 months) Beef cows Bulls
	Heifer stockers Feedlot heifers Steer stockers Feedlot steers

The cattle population numbers from this monthly lifecycle modeling may differ from the annual livestock population data published by the U.S. Department of Agricultural (USDA) National Agricultural Statistics Service (NASS). The reason being that USDA NASS population numbers are point estimates for a specific date (e.g., January 1 or July 1), whereas the lifecycle model outputs represent an annual average based on the estimated monthly fluctuations.

(b) Characterization of Cattle Diets

To determine the digestible energy (DE, the percent of gross energy intake digested by the animal) and CH_4 conversion rates (Y_m, the fraction of gross energy converted to CH_4) for each of the cattle categories, the USEPA collected data on diets considered representative of different regions (California was one of these regions). Data from state livestock specialists for each of the diets were used to estimate feed chemical composition, DE and Y_m for each animal type.

DE and Y_m values for dairy cows were estimated using a model (Donovan and Baldwin, 1999) representing the physiological processes occurring in ruminants. For grazing beef cattle, USEPA used diet descriptions to calculate weighted DE values for a combination of forage and supplemental diets. Y_m values for all grazing beef cattle were set at 6.5 percent. For feedlot animals, DE and Y_m values were taken from the literature.

(c) Calculation of Gross Energy Intake

Gross Energy is derived based on several net energy (NE) estimates and feed characteristics. Net energy equations are provided in the IPCC Guidelines (IPCC, 2006d). The general form of these equations is:

Equation 43: Gross energy intake

$$GE = \frac{\left(\dfrac{NE_m + NE_{mobilized} + NE_a + NE_l + NE_p}{\dfrac{NE_{ma}}{DE}} \right) + \left(\dfrac{NE_g}{\dfrac{NE_{ga}}{DE}} \right)}{\dfrac{DE\%}{100}}$$

Where,
GE = Gross energy (MJ/day)
NE_m = Net energy required by the animal for maintenance (MJ/day)
$NE_{mobilized}$ = Net energy due to weight loss –mobilization of fat reserves– (MJ/day)
NE_a = Net energy for animal activity (MJ/day)
NE_l = Net energy for lactation (MJ/day)
NEp = Net energy required for pregnancy (MJ/day)
NE_{ma} = Net energy available in a diet for maintenance (MJ/Day)
DE = Digestible energy consumed (MJ/day)
NE_g = Net energy needed for growth (MJ/day)
NE_{ga} = Net energy available for growth in a diet (MJ/Day)
DE% = Digestibility of the diet (digestible energy content in percent)

(d) Calculation of Emission Factors

The daily emission factors for each category are computed from the gross energy value and the methane conversion factor, as follows:

Equation 44: Daily CH_4 emission factor for a cattle population category

$$EF = \frac{GE \bullet Y_m}{55.65}$$

Where,
EF = Emission factor (kg CH_4 per head per day)
GE = Gross energy intake (MJ per head per day)
Y_m = CH_4 conversion rate, which is the fraction of gross energy in feed converted to CH_4 (unitless)
55.65 = the energy content of methane (MJ per kg)

(e) Estimation of Yearly Emissions

Emissions are then summed for each month for each population category using the daily emission factor for a representative animal and the number of animals in the category, as shown in the following equation:

Equation 45: Yearly CH_4 emissions of a cattle population category

$$E = \sum_{month} EF \bullet D_{month} \bullet N_{month}$$

Where,

E = Yearly CH_4 emissions of a cattle population category (kg)
EF = Emission factor for the population category (kg CH_4 per head per day)
D_{month} = number of days in the month
N_{month} = number of animals in the population category during the month

With,
Month = each month of the given year.

This yields the estimated yearly methane emissions for the cattle population category for the given year.

2.2 Methane Emissions from Other Livestock

Following USEPA, ARB staff used the simpler Tier 1 IPCC method to estimate enteric fermentation emissions from bulls and other livestock.

Equation 46: CH_4 emissions of bulls and other livestock

$$\boxed{E = N \bullet EF}$$

Where,
E = CH_4 emissions of a type of other livestock
N = Number of individuals of the type of livestock (animals)
EF = Methane emission factor for the type of livestock (kg per animal per year)

Other livestock population data, except for horses, come from the USDA NASS reports (USDA, 2007a), see the USEPA GHG inventory (USEPA, 2007e) for further detail and references. Horse population data are from the Food and Agriculture Organization (FAO) FAOSTAT database (FAO, 2006).

Default methane emission factors for bulls and other livestock, shown in Table 19 below, are from IPCC Guidelines (IPCC, 2006d).

Table 19: Methane emission factors for bulls and other livestock (kg/animal/year)

Livestock Type	***Emission Factor***
Bulls	53
Horses	18
Sheep	8
Swine	1.5
Goats	5

3. Data Sources

All data used by ARB staff were from a detailed set of data and model results obtained from the USEPA Climate Change Division (Wirth, 2007), and from the IPCC guidelines (IPCC, 2006d).

For a list of livestock population numbers and parameter values used in the estimates, please consult the online documentation annex at:
http://www.arb.ca.gov/cc/inventory/doc/methods_v1/annex_3a_enteric_fermentation.pdf

B. Manure Management (IPCC 3A2)

1. Background

Anthropogenic CH_4 and N_2O emissions can result from manure management operations. CH_4 is produced by the anaerobic decomposition of manure. N_2O is produced as part of the nitrogen cycle through the nitrification and denitrification of nitrogen in livestock manure and urine.

When livestock or poultry manure is stored or treated in systems that promote anaerobic conditions (such as liquid/slurry, lagoons, tanks, ponds or pits), the decomposition of organic material by methanogenic bacteria produces CH_4 emissions. Manure stored as a solid (e.g., in stacks or drylots) or deposited on pasture, range, or paddock lands, tends to decompose aerobically and produce little or no CH_4. Temperature, moisture, residency time are factors that affect the amount of CH_4 produced by bacteria. The quality of the feed also plays a role; manure from animals eating higher energy content feed has greater potential for CH_4 emissions.

Manure and urine composition, the type of bacteria involved in the process, and the amount of oxygen and liquid in the manure system influence the amount of N_2O emissions. Overall only a small portion of the excreted nitrogen is converted to N_2O during manure management operations.

Note that N_2O emissions from livestock manure and urine deposited on pasture, range, or paddock lands, and emissions from manure and urine spread onto fields either directly as “daily spread” or after it is removed from manure management systems are discussed and estimated in Section III.E below: N_2O Emissions from Managed Soils (IPCC category 3C4 & 3C5).

2. Methodology

The USEPA developed methods to estimate the CH_4 and N_2O emissions from manure management in consultation with ERG, a consulting firm, for the national GHG inventory (USEPA, 2007a). ARB staff extracted California specific information from a detailed set of data and parameters obtained from the USEPA Climate Change Division (Wirth, 2007) and computed emissions for California’s GHG inventory using USEPA’s methodology.

USEPA methods are consistent with the Tier 2 methodology of the IPCC Guidelines (IPCC, 2006a). For complete detail on these methodologies, see Annex 3.10 of the Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2005 (USEPA, 2007e).

The estimation of CH_4 and N_2O emissions involves the following steps:

2.1 Characterization of Livestock Populations

First, animal population data are compiled into livestock groups reflecting differences in diet, size and animal management systems (Table 20). Annual animal population data for all livestock types, except horses and goats were obtained from the U.S. Department of Agriculture (USDA) National Agricultural Statistics Service (NASS) (USDA, 2007a). Horse population data were obtained from the FAOSTAT database (FAO, 2006). Goat population data were obtained from the Census of Agriculture. Additional data sources and personal communications with experts used to make adjustments to these data are described in the USEPA inventory report (USEPA, 2007f).

Table 20: Livestock groups used for manure management emissions estimates

Dairy Cattle	**Beef Cattle**	**Swine**	**Poultry**	**Others**
Dairy Cows	Beef Cows	Market Swine <60 lbs	Layer Hens >1 yr	Sheep
Dairy Heifers	Bulls >500 lbs	Market Swine 60-119 lbs	Layers – Pullets	Goats
	Calves <500 lbs	Market Swine 120-179 lbs	Layers – Other Chickens	Horses
	Heifers >500 lbs	Market Swine 180+ lbs	Broilers	
	Steers >500 lbs	Breeding Swine	Turkeys	
	Feedlot Heifers			
	Feedlot Steers			

2.2 Characterization of Animal Waste

Methane and nitrous oxide emissions estimates are based on the following animal characteristics for each of the relevant livestock groups:

- Typical animal mass (TAM), in kg per animal
- Volatile solids excretion rate (VS) in g per kg of TAM per day. Excreted volatile solids are the portion of organic matter in the diet that was not digested by the animal and is thus available for use by methanogenic bacteria. For dairy cattle, it is calculated by the enteric fermentation model of Section III.A above.
- Maximum methane producing capacity (B_0) of excreted volatile solids (m^3 of CH_4 per g of VS). This is a characteristic of the volatile solids found in a particular livestock group's manure.
- Nitrogen excretion rate (Nex). This is the amount of Kjeldahl nitrogen excreted per animal per day (g of N per kg of TAM per day). The values used are based on measurements made on manure of each of the livestock groups.

For further information about how to calculate VS for livestock cattle, swine and poultry, as well as the sources of data for the VS, TAM and B_0 parameters see USEPA, 2007f.

2.3 Compilation of Waste Management System Usage Data

USEPA compiled data on the distribution of the manure of the various livestock groups among waste management systems, by state and by year. Table 21 lists the various waste management systems used for livestock groups in California in 2005. Note that the manure from not-on-feed beef cattle, sheep, horses and goats that is directly deposited on pasture, range or paddocks, or the manure spread daily do not enter a "waste management system". Thus these livestock groups are not listed in the table.

Table 21: Waste management systems used by livestock group in California in 2005

Feedlot Heifers and Steers	**Dairy Cows**	**Dairy Heifers**	**Swine**	**Layer Poultry**	**Broilers and Turkeys**
- Dry Lot - Liquid/ Slurry	- Pasture - Daily Spread - Solid Storage - Liquid/Slurry - Anaerobic Lagoon - Deep Pit	- Dry Lot - Liquid/ Slurry	- Pasture - Solid Storage - Liquid Slurry - Anaerobic Lagoon - Deep Pit	- Anaerobic Lagoon - Poultry without litter	- Pasture - Poultry with litter

Note: the manure of some livestock groups does not enter any waste management systems. It is directly deposited on pasture, range, or paddock lands, and some is spread daily on agricultural land.

2.4 Calculation of Methane Conversion Factors (MCF)

The methane conversion factor (MCF) is the portion of the maximum methane producing capacity of the manure that is achieved in given conditions. It varies with the waste management system and with temperature. Climate-based default values from the 2006 IPCC Guidelines (IPCC, 2006d) are used for all dry systems. For lagoons and liquid systems, USEPA developed a country-specific methodology using the van't Hoff-Arrhenius equation to estimate state-specific MCF values based on state by state temperature data.

For each animal group, an annual state weighted-average methane conversion factor (SWMCF) is calculated that takes into account the fraction of the manure of a livestock group in each waste management system in a particular state.

Equation 47: State weighted-average CH_4 conversion factor for a livestock group

$$\boxed{SWMCF_{group} = \sum_{system} (MCF_{system} \bullet M_{group,system})}$$

Where,

$SWMCF_{group}$ = State weighted CH_4 conversion factor for the given livestock group in California (fraction)

MCF_{system} = CH_4 conversion factor for the given waste management system (fraction)

$M_{group,\ system}$ = fraction of the livestock group's manure that is managed in the waste management system in California.

With,

Group = livestock group from Table 20

System = waste management system from Table 21.

2.5 Estimation of Methane emissions

Methane emissions of each of the livestock group are then calculated using the following equation:

Equation 48: CH_4 emissions of a livestock group

$$E_{CH4,group} = N_{group} \bullet TAM_{group} \bullet VS_{group} \bullet 365.2425 \bullet SWMCF_{group} \bullet B_0 \bullet 662$$

Where,

$E_{CH4,\ group}$	= CH_4 emissions of the given livestock group (grams)
N_{group}	= Number of animals in the livestock group (heads)
TAM_{group}	= Typical Animal Mass of animals in the group (kg per head)
VS_{group}	= Volatile Solids Production rate of livestock group (g per kg per day)
365.2425	= Average number of days in a year (days)
$SWMCF_{group}$	= State weighted methane conversion factor for the group in California (fraction)
B_o	= Maximum methane producing capacity (m^3 per g)
662	= Density of methane (g / m^3), at 22ºC and 1 atm.

With,

Group	= livestock group from Table 20.

2.6 Calculation of State Weighted N as N_2O Emission Factors

State weighted emission factors are calculated for each livestock group in the State to reflect the distribution of manure by waste management system, using the equation provided below. The nitrous oxide emission factors of individual waste management systems are from the 2006 IPCC Guidelines (IPCC, 2006d).

Equation 49: State weighted N as N_2O emission factor for a livestock group

$$SWEF_{group} = \sum_{system} (EF_{system} \bullet M_{group,system})$$

Where,

$SWEF_{group}$	= State weighted N as N_2O emissions factor for the given livestock group in California (fraction of N)
EF_{system}	= N as N_2O emission factor for the given waste management system (fraction of N)
$M_{group,\ system}$	= fraction of the livestock group’s manure that is managed in the waste management system in California.

With,

Group	= livestock group from Table 20
System	= waste management system from Table 21.

2.7 Estimation of Nitrous Oxide Emissions

Nitrous oxide emissions of each of the livestock group are then calculated using the following equation:

Equation 50: N_2O emissions of a livestock group

$$\boxed{E_{N2O,group} = N_{group} \bullet PMS_{group} \bullet TAM_{group} \bullet NER_{group} \bullet 365.2425 \bullet SWEF_{group} \bullet 1.5711}$$

Where,

$E_{N2O,\ group}$ = N_2O emissions of the given livestock group (grams)
N_{group} = Number of animals in the livestock group (heads)
PMS_{group} = Proportion of livestock group in a managed system (unitless)
TAM_{group} = Typical Animal Mass of animals in the group (kg per head)
NER_{group} = Nitrogen excretion rate of animals in the group (g per kg per day)
365.2425 = Average number of days in a year (days)
$SWEF_{group}$ = State weighted N as N_2O emissions factor for the group in California (fraction of N)
1.5711 = Molecular weight ratio of N_2O to N_2

With,

Group = livestock group from Table 20.

3. Data Sources

All data used by ARB staff were from a detailed set of data and parameters obtained from the USEPA Climate Change Division (Wirth, 2007), and from the IPCC guidelines (IPCC, 2006d).

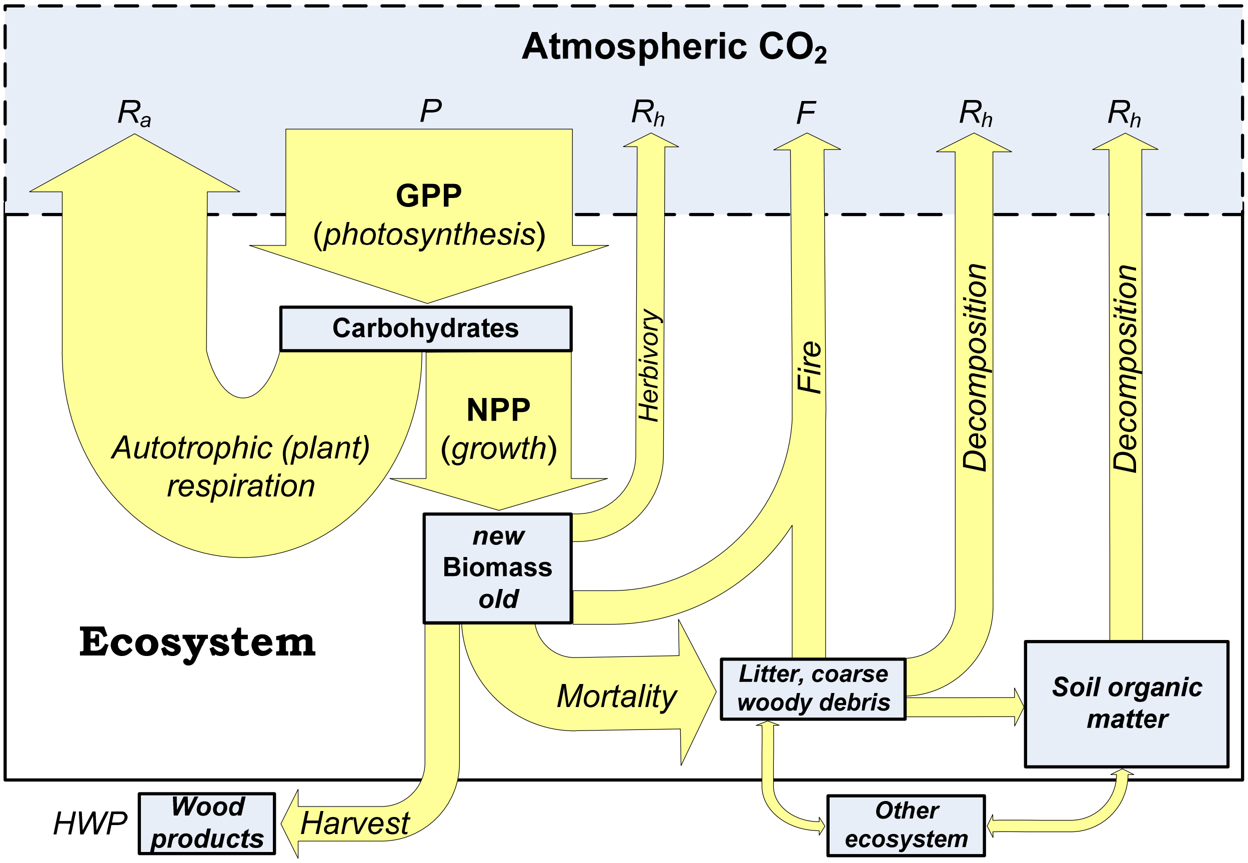
For a list of livestock population numbers and parameter values used in the estimates, please consult the online documentation annex at: http://www.arb.ca.gov/cc/inventory/doc/methods_v1/annex_3b_manure_management.pdf

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.

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 (ΔC_{org}) = NEP + Carbon imports form other ecosystems – Fire (*F*) – Harvested wood products (*HWP*) – Carbon exports to other ecosystems

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.

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 above.

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 22). 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).

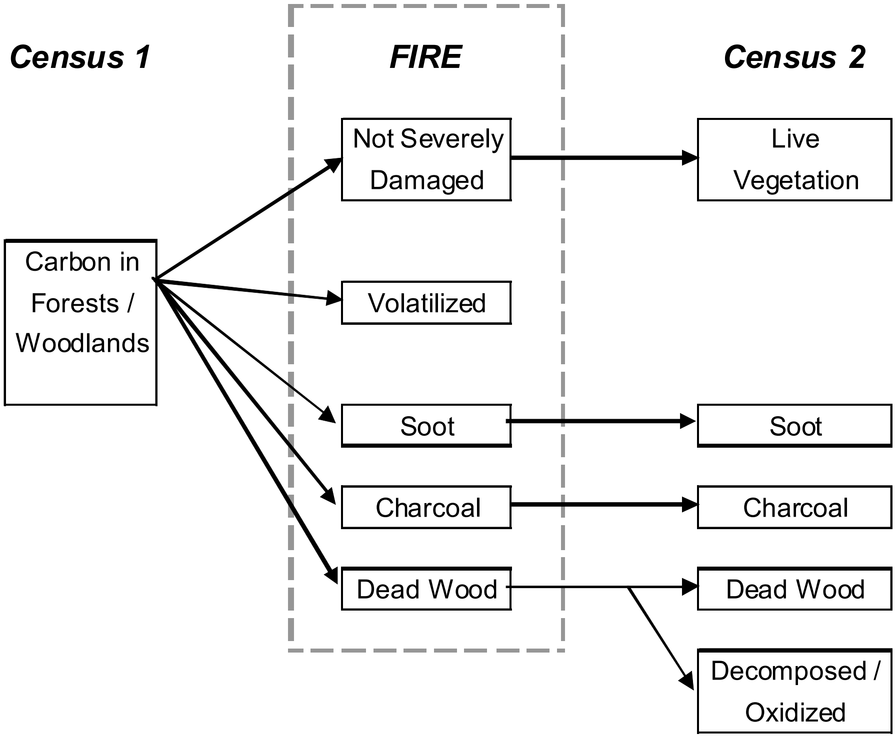


Table 22: Carbon fate assumptions after decreases in canopy cover caused by fire (percent).

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 51: CH_4 emissions from fires

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

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 52: N_2O emissions from fires

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

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 below).

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 below) of this report.

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 23). 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. 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 23 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 23). 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 23: Forested Lands and Wood Products Biodegradable Carbon Emissions & Sinks (MMTCO_2)

Category [Data Source]	***1990***	***1991***	***1992***	***1993***	***1994***	***1995***	***1996***	***1997***	***1998***	***1999***	***2000***	***2001***	***2002***	***2003***	***2004***
Sinks															
Forested Lands Removals															
Forest woody biomass growth [1]	-13.141	-13.118	-13.096	-13.074	-13.052	-13.052	-13.052	-13.052	-13.052	-13.052	-13.052	-13.042	-13.032	-13.022	-13.012
Rangeland woody biomass growth [1]	-1.104	-1.102	-1.100	-1.099	-1.097	-1.097	-1.097	-1.097	-1.097	-1.097	-1.097	-1.096	-1.095	-1.094	-1.093
Total Sinks	-14.245	-14.221	-14.197	-14.172	-14.148	-14.148	-14.148	-14.148	-14.148	-14.148	-14.148	-14.137	-14.127	-14.116	-14.105
Emissions															
Forested Lands Emissions															
Forest and rangeland fires [1]	2.032	2.028	2.025	2.022	2.018	2.018	2.018	2.018	2.018	2.018	2.018	2.017	2.015	2.014	2.012
Other disturbances[1]	1.208	1.206	1.204	1.202	1.200	1.200	1.200	1.200	1.200	1.200	1.200	1.199	1.198	1.197	1.196
Development of forest or range lands (Landuse change) [1]	0.021	0.021	0.021	0.021	0.021	0.021	0.021	0.021	0.021	0.021	0.021	0.021	0.021	0.021	0.021
Timber harvest slash [1]	0.156	0.156	0.156	0.156	0.155	0.155	0.155	0.155	0.155	0.155	0.155	0.155	0.155	0.155	0.155
Wood Products Emissions															
Fuel wood [1]	1.532	1.529	1.526	1.524	1.521	1.521	1.521	1.521	1.521	1.521	1.521	1.520	1.519	1.518	1.517
Wood waste dumps [2]	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Discarded wood and paper in landfills [3]	2.350	2.438	2.577	2.815	2.988	3.170	3.268	3.261	3.392	3.357	3.469	3.655	3.779	3.746	3.740
Composting of wood waste materials [2]	0.255	0.305	0.354	0.403	0.451	0.500	0.549	0.597	0.646	0.694	0.743	0.743	0.745	0.800	0.803
Total Emissions	7.555	7.683	7.863	8.142	8.355	8.586	8.733	8.774	8.953	8.967	9.127	9.310	9.432	9.450	9.444
Net CO_2 Flux															
Net CO_2 Flux	-6.690	-6.537	-6.333	-6.030	-5.793	-5.563	-5.415	-5.374	-5.195	-5.181	-5.021	-4.827	-4.695	-4.666	-4.662

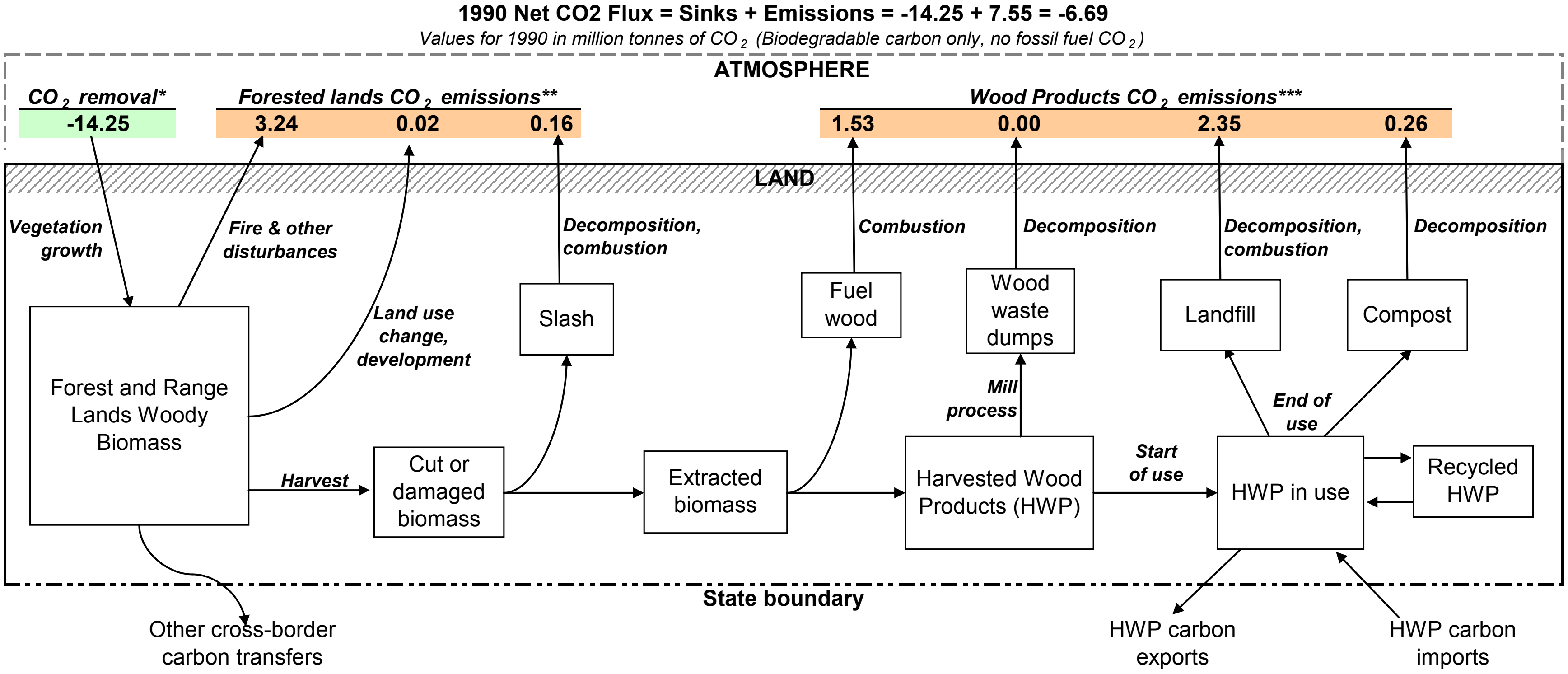
Data sources:

[1] – Winrock report: 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 CO_2 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 percent 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 percent 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-613.

[2] - 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.

[3] - 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.



* **CO2 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 forest and range lands fires and other disturbances such as insect pest damage, 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.

D. Agricultural Residue Burning (IPCC 3C1b)

1. Background

Open burning of agricultural biomass is a common practice in California and a source of nitrogen oxide (N_2O) and methane (CH_4) emissions. Carbon dioxide (CO_2) emissions from agricultural biomass burning is not considered a net source of emissions because the carbon released to the atmosphere as CO_2 from the combustion of agricultural biomass is assumed to have been absorbed during the previous (or a recent) growing season. Therefore, emissions from CO_2 are estimated but not included in California's GHG inventory total.

2. Methodology

The methodology for estimating greenhouse gas emissions from agricultural residue burning of agricultural biomass is consistent with the IPCC Tier 2 approach as it uses California specific emission factors. Researchers at University of California, Davis developed emission factors for six crops including, almond, walnut, wheat, barley, corn and rice (Jenkins et al. 1996). These six crops account for a majority of the orchard and field biomass burned in California. Emissions are calculated as follows:

Equation 53: GHG emissions from residue burning

$$\boxed{E_{GHG,crop} = A_{crop} \bullet FB_{crop} \bullet MR_{crop} \bullet (1 - RMC_{crop}) \bullet EF_{GHG,crop} \bullet 907184.7}$$

Where,

$E_{GHG,\ crop}$ = Emissions of the given GHG from the given crop residue burning (g)

A_{crop} = Area planted in the given crop (acres)

FB_{crop} = Fraction of area planted in the given crop on which residues are burned (unitless)

MR_{crop} = Mass of the given crop's residue burned (tons / acre)

RMC_{crop} = Residue moisture content of the given crop (unitless)

$EF_{GHG,\ crop}$ = Emission factor for the given GHG and crop (unit mass of GHG per unit mass of residue dry matter)

907184.7 = Short ton to gram conversion factor

With,

GHG = [CO_2, CH_4, N_2O]

Crop = [Almond, Barley, Corn, Rice, Walnut, Wheat]

3. Data Sources

Areas planted in a particular crop were obtained from the crop production summary reports published by the U.S. Department of Agriculture's National Agricultural Statistics Service (USDA, 2007b; USDA, 2007d). The fractions of crop acreage on which residues are burned, and residue moisture content are taken from survey data gathered and published by B.M. Jenkins (Jenkins et al. 1992) and assumed constant over the 1990-2004 period, except for rice. The

1991 rice straw burning phase-down law required the incremental reduction of rice straw burning in the Sacramento Valley. Rice straw burning decreased over a period of ten years, with progressively fewer acres of rice fields burned each year. An ARB progress report (ARB, 2003) on the phase down of rice straw burning provided the percent of acres planted that were actually burned per year. Values for the mass of crop residues burned (where burning occurs) were taken from a USEPA compilation of emissions factors (USEPA, 1995a). Emissions factors are taken from a study report by UC researchers (Jenkins et al. 1996).

For a list of parameter values used in the equations, please consult the online documentation annex at: http://www.arb.ca.gov/cc/inventory/doc/methods_v1/annex_3d_agricultural_residue_burning.pdf

4. Future Improvements

ARB staff is seeking more specific data on the number of acres burned by crop to improve yearly estimates.

E. Carbon Dioxide from Liming (IPCC 3C2)

1. Background

Liming is used to reduce soil acidity and thus improve plant growth in agricultural fields and managed forests. Adding carbonates to soils in the form of lime (e.g., calcic limestone ($CaCO_3$), or dolomite ($CaMg(CO_3)_2$) leads to CO_2 emissions as the carbonate limes dissolve and release bicarbonate ($2HCO_3^-$), which evolves into CO_2 and water (H_2O).

2. Methodology

ARB staff used methods consistent with the Tier 1 methodology of the 2006 IPCC Guidelines (IPCC, 2006d). Total CO_2 emissions from liming are estimated as follows:

Equation 54: CO_2 emissions from liming

$$\boxed{E = [(M_L \bullet EF_L) + (M_D \bullet EF_D)] \bullet 3.6642}$$

Where,

E = CO_2 emissions from liming (g)
M_L = Mass of limestone applied to soils (g)
EF_L = Limestone C emissions factor (0.12 g C per g limestone)
M_D = Mass of dolomite applied to soils (g)
EF_D = Dolomite C emissions factor (0.13 g C per g dolomite)
3.6642 = Molecular weight ratio of CO_2 to C

To estimate the mass of limestone and dolomite applied to soils from reported amount of “lime” (not distinguishing between limestone and dolomite) applied to agricultural soils, staff used the following equations:

Equation 55: Mass of limestone applied to soils

$$\boxed{M_L = L_{AG} \bullet \frac{T_L}{(T_L + T_D)}}$$

Equation 56: Mass of dolomite applied to soils

$$\boxed{M_D = L_{AG} \bullet \frac{T_D}{(T_L + T_D)}}$$

Where,

M_L = Mass of limestone applied to soils (g)
M_D = Mass of dolomite applied to soils (g)
L_{AG} = Total “lime” applied to agricultural soils in California (g)
T_L = Total limestone sold or used in California (g)
T_D = Total dolomite sold or used in California (g)

3. Data Sources

Data for the mass of “lime” applied to agricultural soils are from yearly editions of the *Fertilizing Materials Tonnage Report* published by the California Department of Food and Agriculture (CDFA, various years). Due to a lack of data specific to 1990 and 1991, total amounts of lime applied in these years were back-cast based on the trend for 1992 to 2000. Limestone and dolomite sold or used in California are reported in the *Minerals Yearbook* by the U.S. Geological Survey (Tepordei, various years). The amount of limestone and dolomite sold or used in 1992 were interpolated from 1991 and 1993 data, and use in 1990 was based on a trend for 1991 through 1999. Limestone and dolomite emission factors are from the 2006 IPCC Guidelines (IPCC, 2006f).

For a list of individual activity and parameter values used in the equations, please consult the online documentation annex at: http://www.arb.ca.gov/cc/inventory/doc/methods_v1/annex_3e_carbon_dioxide_from_liming.pdf

F. Nitrous Oxide from Agricultural Soil Management (IPCC 3C4 & 3C5)

1. Background

Modern agriculture is characterized by the intensive use of fertilizers, especially synthetic nitrogen fertilizers. The large scale input of nitrogen into agricultural soils has greatly increased the nitrogen availability for microbial processes such as nitrification and denitrification. Nitrous oxide is an intermediate gaseous product of denitrification and a by-product of nitrification that leaks from microbial cells into the soil and ultimately into the atmosphere. There are many sources of nitrogen input into agricultural soils aside from synthetic fertilizers: application of organic fertilizers, manure and sewage sludge; production of N-fixing crops, decomposition of crop residues; and mineralization of N in soil organic matter following drainage of organic soils (histosols). All these human activities increase the supply of mineral nitrogen, and therefore N_2O emissions from agricultural soils. These emissions are called *direct emissions* because they occur directly from the soils to which N is applied, and are reported under IPCC category 3C4.

In addition to the direct emissions of N_2O from managed soils, emissions of N_2O also take place through two indirect pathways. The first indirect pathway is the volatilization of a portion of the applied nitrogen as NH_3 and oxides of N (NO_x). Eventually, this volatilized N is deposited onto soils and the surface of lakes and other waters where nitrification and denitrification processes cause N_2O emissions. The second pathway is the leaching and runoff from land of N from synthetic and organic fertilizer additions, crop residues, mineralization of N in soil organic matter following drainage of organic soils, and urine and dung deposition from grazing animals. This nitrogen ends up in the groundwater below the land to which the N was applied, in riparian zones receiving drain or runoff water, or in the ditches, streams, rivers and estuaries (and their sediments) into which the land drainage water eventually flows. There, it is subject to the nitrification and denitrification processes that produces N_2O emissions. These *indirect emissions* are reported under IPCC category 3C5.

2. Methodology

ARB staff used emission factor equations, which are based on the USEPA Emission Inventory Improvement Program (EIIP) guidance (USEPA, 2004b) and the Tier 1 methodology of the 2006 IPCC guidelines (IPCC, 2006f).

2.1 Emission Estimation

N_2O emissions are estimated separately for direct emissions and indirect emissions. The following equations describe the IPCC methods and steps in calculating N_2O emissions from managed soils.

(a) Direct N_2O Emissions (IPCC category 3C4)

Direct N_2O emissions are calculated with the following equation:

Equation 57: Direct N_2O emissions from managed soils

$$E_{direct} = \left\{ \begin{array}{l} \left[N_{SF} \bullet (1 - V_1) + N_{OF} \bullet (1 - V_2) + N_{FX} + N_{CR} \right] \bullet EF_1 \\ + \left(N_{SD} + N_{PRP} \right) \bullet EF_2 \\ + A_{OS} \bullet EF_3 \end{array} \right\} \bullet 1.5711$$

Where,

E_{direct} = Direct N_2O emissions from managed soils (kg N_2O)

N_{SF} = Amount of N from synthetic fertilizers applied to soils (kg N)

N_{OF} = Amount of N from organic fertilizers applied to soils (kg N)

N_{FX} = Amount of N input to soils from N-fixing crops (i.e., plants that convert atmospheric N2 to biologically available N) (kg N)

N_{CR} = Amount of N in crop residues that is returned to soils (kg N)

N_{SD} = Amount of N from animal manure that is spread daily on soils (kg N)
N_{PRP} = Amount of N from urine and dung deposited by grazing animals on pastures, rangelands, and paddocks (PRP) (kg N)
A_{OS} = Area of cultivated organic soil (histosols) (ha)
V_1 = Fraction of synthetic fertilizer N that volatilizes (unitless)
V_2 = Fraction of organic fertilizer and manure N that volatilizes (unitless)
EF_1 = Emission factor: proportion of N applied to agricultural soils that is emitted as N_2O
EF_2 = Emission factor: proportion of N deposited on pastures, rangelands, and paddocks (PRP) that is emitted as N_2O
EF_3 = Emission factor: N emitted as N_2O per unit area of cultivated of organic soils (kg N per ha)
1.5711 = Molecular weight ratio of N_2O to N_2

(b) Indirect N_2O emissions (IPCC category 3C5)

Indirect N_2O emissions are calculated with the following equations:

Equation 58: Indirect N_2O emissions from managed soils

$$\boxed{E_{indirect} = E_V + E_{LR}}$$

Where,
$E_{indirect}$ = Indirect N_2O emissions from managed soils (kg N_2O)
E_V = Indirect N_2O emissions through nitrogen volatilization (kg N_2O)
E_{LR} = Indirect N_2O emissions through nitrogen leaching and runoff (kg N_2O)

(b.i) Emissions from volatilization (E_V)

Indirect emissions from volatilized N are estimated as follows:

Equation 59: Indirect N_2O emissions from volatilization

$$\boxed{E_V = \left[N_{SF} \bullet V_1 + (N_{OF} + N_{AM}) \bullet V_2\right] \bullet EF_4 \bullet 1.5711}$$

Where,
E_V = Emissions of N_2O from volatilization (kg)
N_{SF} = Amount of N from synthetic fertilizers applied to soils (kg N)
N_{OF} = Amount of N from organic fertilizers applied to soils (kg N)
N_{AM} = Amount of N from animal manure applied to soils (kg N)
V_1 = Fraction of synthetic fertilizer N that volatilizes (unitless)
V_2 = Fraction of organic fertilizer and manure N that volatilizes (unitless)
EF_4 = Emission factor: proportion of N volatilized and re-deposited on soils that is emitted as N_2O

(b.ii) Emissions from leaching and runoff (E_{LR})

Indirect emissions from N lost to leaching and runoff are estimated as:

Equation 60: Indirect N_2O emissions from N lost to leaching and runoff

$$\boxed{E_{LR} = \left[N_{SF} \bullet (1-V)_1 + (N_{OF} + N_{AM}) \bullet (1-V_2)\right] \bullet L \bullet EF_5 \bullet 1.5711}$$

Where,
E_{LR} = Emissions of N_2O from leaching and run-off (kg)
N_{SF} = Amount of N from synthetic fertilizers applied to soils (kg N)
N_{OF} = Amount of N from organic fertilizers applied to soils (kg N)
N_{AM} = Amount of N from animal manure applied to soils (kg N)
V_1 = Fraction of synthetic fertilizer N that volatilizes (unitless)
V_2 = Fraction of organic fertilizer and manure N that volatilizes (unitless)
L = Leaching factor: proportion of N lost by leaching and runoff for regions where the soil water-holding capacity is exceeded as a result of rainfall and/or irrigation.
EF_5 = Emission factor: Proportion of N lost to leaching and runoff that is emitted as N_2O

The values for the emission, volatilization and leaching-runoff factors are given in Table 24.

Table 24: Factors for the estimation of N_2O emissions from agricultural soil management

Emission factor	**Description**	**Default Value**
EF_1	Proportion of N applied to agricultural soils that is emitted as N_2O	0.01
EF_2	Proportion of N deposited on pastures, rangelands, and paddocks (PRP) that is emitted as N_2O	0.02
EF_3	N emitted as N_2O per unit area of cultivated of organic soils (kg N per ha)	8
EF_4	Proportion of N volatilized and re-deposited on soils that is emitted as N_2O	0.01
EF_5	Proportion of N lost to leaching and runoff that is emitted as N_2O	0.0075
V_1	Fraction of synthetic fertilizer N that volatilizes	0.1
V_2	Fraction of organic fertilizer and manure N that volatilizes	0.2
L	Leaching rate: fraction of N lost by leaching and runoff for regions where the soil water-holding capacity is exceeded as a result of rainfall and/or irrigation	0.3

Source: IPCC 2006 guidelines.

2.2 Calculation of nitrogen inputs from various sources

To limit the number of subcategories in the inventory, staff compiled the nitrogen inputs from fertilizers, animal manure, crop residues, N-fixing crops and aggregated them into the following categories.

(a) Synthetic and Organic Fertilizers Nitrogen

The amount of nitrogen in synthetic fertilizers (N_{SF}) and organic fertilizers (N_{OF}) applied to soils were compiled from the data published in California Department of Food and Agriculture *Fertilizing Materials Tonnage Reports* (CDFA, various years)

(b) Animal Manure Nitrogen

The amount of nitrogen from animal manure (N_{AM}) was estimated using following equation:

Equation 61: Amount of nitrogen from animal manure

$$N_{AM} = \sum_{group} N_{group} \bullet TAM_{group} \bullet NER_{group} \bullet 365.2465$$

Where,

N_{AM} = Amount of nitrogen in the manure of a given livestock group (grams)
N_{group} = Number of animals in the livestock group (heads)
TAM_{group} = Typical Animal Mass of animals in the group (kg per head)
NER_{group} = Nitrogen excretion rate of animals in the group (g per kg per day)
365.2425 = Average number of days in a year (days)

With,

Group = Livestock group from Table 25.

Table 25: Typical animal mass (TAM) and Kjeldahl nitrogen factors for various animals

Livestock Group	**TAM (kg per head)**	**Nitrogen Excretion Rate (g per kg per day)**
Dairy Cows	604	0.44
Dairy Heifers	476	0.31
Feedlot Steers	420	0.3
Feedlot Heifers	420	0.3
Not On Feed Bulls	750	0.31
Not On Feed Calves	159	0.3
Not On Feed Cows	590	0.33
Not On Feed Steers	318	0.31
Not On Feed Heifers	420	0.31
Market < 60 lb	15.88	0.60
Market 60-119 lb	40.60	0.42
Market 120-179 lb	67.82	0.42
Market 180+ lb	90.75	0.42
Breeding Swine	198	0.24
Hens > 1 yr	1.8	0.83
Pullets	1.8	0.62
Chickens	1.8	0.83
Broilers	0.9	1.1
Turkeys	6.8	0.74
Sheep	27	0.42
Goats	64	0.45
Horses	450	0.3

Source: USEPA Climate Change Division (Wirth, 2007)

The amount of nitrogen contained in animal manure by animal group and by year is shown in Table 26 to Table 29.

Table 26: Nitrogen in animal manure - Beef and dairy cattle (tonnes)

Year	Feedlot Steers	Feedlot Heifers	Not On Feed Bulls	Not On Feed Calves	Not On Feed Heifers	Not On Feed Steers	Not On Feed Cows	Dairy Cows	Dairy Heifers
1990	17082	4159	5995	21358	11154	12394	68333	108078	28037
1991	14030	4130	5946	23280	11236	10377	64825	110626	27221
1992	12649	3752	5889	21069	11429	11652	63384	112360	29778
1993	14782	4134	5839	21636	10536	11091	61068	116655	29525
1994	12511	3064	6348	23471	11299	12989	61997	119269	32358
1995	14023	3470	6385	23177	10865	12021	61186	123311	33020
1996	11149	2986	5960	23242	11406	13216	60017	127908	33338
1997	12632	3122	5877	23319	10748	12428	58563	133735	33540
1998	13309	3325	5432	23773	10079	11048	58717	135811	34340
1999	13469	3732	5835	25505	10688	11626	57908	139813	37021
2000	14441	3909	5940	18281	11168	12450	56142	144534	38779
2001	13797	3771	5940	18281	10835	11874	55431	151324	40395
2002	13981	3725	5516	18107	10645	12090	54010	157144	41472
2003	13429	4185	5516	18629	11976	11622	52588	161994	42549
2004	13981	3587	5516	18281	10312	12090	51167	164904	39317

Source: Calculations made for the Manure Management Section (III.B above)

Table 27: Nitrogen in animal manure – Swine (tonnes)

Year	Breeding Swine	Market < 60 lb	Market 60-119 lb	Market 120-179 lb	Market 180+ lb
1990	476	209	305	322	376
1991	493	223	317	416	431
1992	628	285	361	468	598
1993	560	257	373	509	612
1994	543	243	405	468	598
1995	526	226	361	457	584
1996	459	198	317	416	487
1997	459	209	280	468	459
1998	459	243	311	416	320
1999	425	191	311	364	348
2000	340	111	268	468	139
2001	340	122	156	114	264
2002	374	136	199	302	390
2003	340	122	156	291	376
2004	340	122	156	291	376

Source: Calculations made for the Manure Management Section (III.B above)

Table 28: Nitrogen in animal manure – Poultry (tonnes)

Year	Layers	Hens > 1 yr	Pullets	Chickens	Broilers	Turkeys
1990	17136	9816	7206	115	15183	24106
1991	16725	9379	7291	55	15781	21593
1992	16020	9652	6314	55	15308	19285

Year	Layers	Hens > 1 yr	Pullets	Chickens	Broilers	Turkeys
1993	15040	8998	5988	55	14191	15894
1994	15216	9379	5792	45	14861	14464
1995	14437	9194	5194	49	15492	14783
1996	14425	9009	5389	27	15387	14759
1997	14550	8327	6147	76	15591	13455
1998	14209	7825	6337	46	15591	11897
1999	14612	7399	7169	44	15591	10714
2000	11316	5718	5565	34	15590	33060
2001	11316	5718	5565	34	15590	34346
2002	11316	5718	5565	34	15590	32509
2003	9762	4932	4801	29	15590	31775
2004	9762	4932	4801	29	15590	31775

Source: Calculations made for the Manure Management Section (III.B above)

Table 29: Nitrogen in animal manure – Other species and grand total (tonnes)

Year	Sheep	Goats	Horses	All Livestock Groups (N_{AM})
1990	4139	354	31270	370466
1991	4201	354	31452	363658
1992	4118	354	31574	360961
1993	3704	368	31635	358413
1994	4470	381	31513	366469
1995	4222	395	31635	370577
1996	3808	409	31756	371643
1997	3642	422	31756	375254
1998	3311	422	31877	374889
1999	3353	422	32284	384211
2000	3353	420	32275	402984
2001	3332	420	32275	409924
2002	3125	420	32275	413326
2003	3022	420	32275	416617
2004	2815	420	32275	413077

Source: Calculations made for the Manure Management Section (III.B above)

The amount of N from animal manure that is spread daily on soils (N_{SD}) is computed as the total of N in the manure from the “Dairy Cows” and “Dairy Heifers” livestock groups multiplied by the fraction of these categories manure that is spread daily.

The amount of N from urine and dung deposited by grazing animals on pastures, rangelands, and paddocks (PRP) (N_{PRP}) is computed as the total of N in the manure from all livestock groups multiplied by the fraction of these categories manure that is deposited on pastures, rangelands, and paddocks. Most of N_{PRP} comes from “Not on Feed” Beef Cattle groups, Horses and Sheep.

(c) Crop Residues and N-fixing Crops Nitrogen

The amount of nitrogen from crop residues (N_{CR}) is calculated using the following equation:

Equation 62: Amount of nitrogen from crop residues

$$N_{CR} = \sum_{crop} P_{crop} \bullet RC_{crop} \bullet DM_{crop} \bullet RR_{crop} \bullet NCR_{crop}$$

Where,

N_{CR} = Amount of N in a given crop residues that is returned to soils (kg)
P_{crop} = Crop production (kg)
RC_{crop} = Ratio of residue mass to crop mass (kg residue per kg crop)
DM_{crop} = Dry matter content of residue (fraction)
RR_{crop} = Fraction of residue that is returned to soils
NCR_{crop} = Nitrogen content of crop residue (kg N per kg of dry matter)

With,

Crop = crops listed in Table 30.

The amount of nitrogen from N-fixing crops (N_{FX}) is calculated using the following equation:

Equation 63: Amount of nitrogen from N-fixing crops

$$N_{FX} = \sum_{crop} P_{crop} \bullet (1 + RR_{crop}) \bullet DM_{crop} \bullet NCB_{crop}$$

Where,

$N_{CR,\ crop}$ = Amount of N in a given crop residues that is returned to soils (kg)
P_{crop} = Crop production (kg)
RR_{crop} = Ratio of residue mass to crop mass (kg residue per kg crop)
DM_{crop} = Dry matter content of residue (fraction)
NCB_{crop} = N content of aboveground biomass for N-fixing crop production (kg N per kg of dry matter)

With,

Crop = N-fixing crops listed in Table 30.

Variables for the two equations above are in Table 30. Most values are from USEPA EIPP (USEPA, 2004b); some values, taken from CEC's last GHG inventory (CEC, 2006a), had been adjusted to reflect California specific information.

Table 30: Parameters to calculate nitrogen inputs from crop residues and nitrogen-fixing crops

Crop	***Ratio of residue mass to crop mass (RR_{crop})***	***Dry matter content of residue (DM_{crop})***	***Fraction of residue that is returned to soils (RR_{crop})***	***Nitrogen content of crop residue (NCR_{crop})***	***Nitrogen content of biomass of N-fixing crop (NCB_{crop})***
Alfalfa [NF]	0	0.85	0.9	0.03	0.03
Corn	0.229 [a]	0.91	0.97 [a]	0.0058	n/a

Crop	Ratio of residue mass to crop mass (RR_{crop})	Dry matter content of residue (DM_{crop})	Fraction of residue that is returned to soils (RR_{crop})	Nitrogen content of crop residue (NCR_{crop})	Nitrogen content of biomass of N-fixing crop (NCB_{crop})
Wheat	0.614 [a]	0.93	0.89 [a]	0.0062	n/a
Barley	0.659 [a]	0.93	0.93 [a]	0.0077	n/a
Sorghum	1.4	0.91	0.9	0.0108	n/a
Oats	1.3	0.92	0.9	0.007	n/a
Rye	1.6	0.9	0.9	0.0048	n/a
Rice (1990-2000)	0.761 [a]	0.91	0.01 [a]	0.0072	n/a
Rice (from 2001 on)	0.697 [a]	0.91	0.75 [a]	0.0072	n/a
Soybeans [NF]	2.1	0.86	0.9	0.023	0.03
Peanuts [NF]	1	0.9	0.9	0.0106	0.03
Dry Edible Beans [NF]	2.1	0.86	0.9	0.0062	0.03
Dry Edible Peas [NF]	1.5	0.87	0.9	0.0062	0.03

Source: [a] marks values adjusted in CEC's last GHG inventory (CEC, 2006a), other values are from USEPA EIPP (USEPA, 2004b). Note: [NF] Indicates a N-fixing crop.

The amount of nitrogen retuned to soils from crop residues and N-fixing crops are shown in Table 31 and Table 32.

Table 31: Amount of nitrogen returned to the soil from crop residues (tonnes)

Year	Alfalfa	Corn	Wheat	Barley	Sorghum	Oats	Rye	Rice	Pea-nuts	Dry Edible Beans	Dry Edible Peas	TOTAL
1990	0	6100	4965	4539	199	375	9	72	0	2633	166	19059
1991	0	6418	3600	1660	168	457	15	67	0	2355	134	14874
1992	0	6687	4584	1672	166	336	14	80	2	2094	110	15745
1993	0	7209	4493	1706	148	293	3	89	0	1808	109	15857
1994	0	7404	4830	1777	120	222	4	103	0	2183	155	16798
1995	0	8006	2806	1338	183	279	2	80	0	1252	143	14090
1996	0	8441	4438	1089	493	246	2	85	0	1063	139	15997
1997	0	9741	3574	817	455	262	2	96	0	1371	122	16441
1998	0	10676	3306	717	210	246	11	71	0	710	114	16061
1999	0	10324	3240	612	193	232	13	83	0	1122	120	15940
2000	0	10610	3173	617	863	205	14	98	0	941	139	16661
2001	0	10827	3011	557	872	164	11	5980	0	684	128	22232
2002	0	12521	2727	509	1422	287	16	6679	0	805	86	25052
2003	0	12309	3130	355	1901	306	17	6065	0	631	144	24858
2004	0	11428	3104	387	3036	232	17	7886	0	532	144	26767

Table 32: Amount of nitrogen returned to soils from nitrogen fixing crops (tonnes)

Year	Alfalfa	Clover	Peanuts	Dry Edible Beans	Dry Edible Peas	TOTAL
1990	193217	443	0	20900	1490	216050
1991	189987	430	0	18689	1204	210310
1992	170986	1063	13	16618	988	189668
1993	159295	1754	0	14347	978	176374
1994	173571	1550	0	17322	1392	193835
1995	150045	1430	0	9940	1282	162696
1996	152219	955	0	8435	1249	162859
1997	158234	706	0	10884	1091	170914
1998	160316	464	0	5638	1025	167443
1999	167603	901	0	8906	1077	178487
2000	165174	522	0	7470	1248	174413
2001	163555	522	0	5427	1144	170648
2002	185161	522	0	6392	768	192843
2003	176509	522	0	5006	1289	183326
2004	170032	522	0	4219	1289	176062

3. Data Sources

Fertilizer use data was obtained from *Fertilizing Materials Tonnage Reports*, published by the California Department of Food and Agriculture (CDFA, various years). Crop production data were taken from USDA National Agriculture Statistics Services (USDA, 2007a). The animal population data used to estimate the amount of nitrogen excreted in manure were obtained from USEPA Climate Change Division (Wirth, 2007), see Section III.B above. Variables for the crop residues and N-fixing crop estimates are mostly from USEPA EIPP (USEPA, 2004b); although some values, taken from CEC last GHG inventory (CEC, 2006a), had been adjusted to reflect California specific information. Histosols cultivation acreage was estimated based on the expert judgment of two California State soil scientists (Simpson, 2001 and Vinson, 2001). The emission factors and conversion factors were from IPCC guidelines (IPCC, 2006a).

For a list of individual activity and parameter values used in the equations, please consult the online documentation annex at: http://www.arb.ca.gov/cc/inventory/doc/methods_v1/annex_3f_nitrous_oxide_from_agricultural_soil_management.pdf

4. Future Improvements

The methods for the estimation of N_2O emissions from managed lands used for this version of the inventory are still in part based on older IPCC guidelines (IPCC, 1997). Although staff has been using the updated (and somewhat lower) default 2006 IPCC values for emission, volatilization and leaching run/off factors, the methods do not yet reflect the all changes made in the 2006 guidelines methodology. In the next version of the California GHG inventory we will fully implement the latest Tier 1 methodology for these categories.

Simple emission factor models can not reflect variations in emissions due to the many factors (such as climate, soil, cropping systems and agricultural practices) that affect N_2O emissions. Process based models can be constructed to quantify the physical, chemical, biological and physiological processes associated with nitrification and denitrification in managed soils. A modeling approach to estimating emissions is generally considered to be more accurate, but it also requires more extensive data. US EPA started using the DAYCENT model in 2005 to calculate N_2O emissions from major agricultural crops (USEPA, 2007a). The California Energy Commission sponsored a scoping study through the PIER program to explore the possibility of using the DNDC model to estimate GHG emissions from California agricultural systems at the county scale (CEC, 2004b). More applied research work is still needed to acquire the data necessary to parameterize and validate such models for the diverse agricultural crops grown in California.

G. Rice Cultivations (3C7)

1. Background

Methane is produced by the anaerobic decomposition of organic material in flooded rice fields. It escapes to the atmosphere mostly through the rice plants aerenchyma system. The amount of CH_4 emitted annually per unit area is a function of: the number and duration of crops grown, the flooding regime before and during the cultivation period, the amount of organic and inorganic soil amendments, the soil type and temperature, and the rice cultivar.

2. Methodology

The methodology used for estimating CH_4 emissions from rice cultivation follows the revised 1996 IPCC guidelines (IPCC, 1997). The computation is:

Equation 64: CH_4 emissions from rice cultivation

$$\boxed{E = A \bullet EF}$$

Where,

E = Amount of CH_4 emitted by rice cultivation (g)

A = Harvested rice area (ha)

EF = California specific CH_4 emission factor (g/ha)

3. Data Sources

Harvested rice area data are from the crop production summary reports published by the U.S. Department of Agriculture's National Agricultural Statistics Service (USDA, 2007b). The California-specific emission factor is from CEC's 2002 GHG inventory report (CEC, 2002). This factor was computed at the time from values taken from four papers reporting California specific measurements. Measured seasonal CH_4 emissions were averaged to represent the wide range of rice cultivation conditions that exist in California. Experiments on fields with and without added nitrogen fertilizer, with and without winter flooding, and with all variations of rice straw management (incorporated, rolled, or burned) were included.

For a list of individual activity and parameter values used in the equations, please consult the online documentation annex at: http://www.arb.ca.gov/cc/inventory/doc/methods_v1/annex_3g_rice_cultivations.pdf

4. Future Improvements

The current IPCC guidelines (IPCC, 2006a), recognizing that the natural conditions and agricultural management of rice production may be highly variable, advise that it is good practice to account for this variability by disaggregating the total harvested area into sub-units (e.g., different water regimes, amendments). Then, the harvested area for each sub-unit is multiplied by the respective cultivation period and emission factor that is representative of the conditions that define the sub-unit. The total annual emissions are equal to the sum of emissions from each sub-unit of harvested area. ARB staff will be seeking the information necessary to apply this updated methodology in future editions of the GHG inventory.

IV. Waste

A. Landfills (IPCC 4A1)

1. Background

Landfills are sites for solid waste disposal in which refuse is buried between layers of dirt so as to fill in or reclaim low-lying ground or excavated pits; they are the oldest form of waste treatment. There are numerous types of landfills accepting different types of waste. The GHG inventory is concerned only with landfills that contain and/or receive biodegradable, carbon-bearing waste. The California Integrated Waste Management Board (CIWMB) has identified 372 such landfills in the State. Most of the waste contained in these landfills (94 percent) is currently under some form of control that reduces the emissions of methane, the principal GHG pollutant generated by landfills.

Landfilled carbon-bearing waste degrades mainly through anaerobic biodegradation. In an anaerobic environment (i.e., without oxygen from the air), water (H_2O) is the source of oxygen (O) for oxidation and becomes the limiting reactant for biodegradation. The water content of a landfill determines how fast the waste degrades. If water is not available, the waste does not degrade. This anaerobic biodegradation process generates approximately equal amounts of CO_2 and CH_4 gas as a byproduct:

Equation 65: Anaerobic biodegradation process

$$\boxed{2C + 2H_2O \rightarrow CO_2 + CH_4}$$

A large fraction (57 percent to 66 percent) of the waste will not degrade under these anaerobic conditions and the carbon it contains is effectively sequestered. This carbon will remain sequestered as long as the landfill's anaerobic conditions persist.

The various gases produced as the waste degrades are collectively called "landfill gas". Landfill gas is an odor nuisance, a source of air toxics and may even be a physical danger to those living near a landfill because the methane it contains is combustible. For these reasons, most landfills in the State (holding about 94 percent of the waste) are equipped with a gas collection system. However, although those collection systems are designed to collect landfill gas, it is known that a portion of the gas does escape into the atmosphere.

Once collected, landfill gas can simply be vented to the air if the only reason for the collection was to address offsite gas migration issues. Alternatively, the collected landfill gas may be stripped of its non-methane components via carbon adsorption, which main purpose is to reduce odors and/or volatile organic compounds (VOC) and toxics. Carbon adsorption allows most (99 percent) of the CH_4 to escape. Most commonly, the collected landfill gas is combusted, either in a flare (to destroy odors and VOC and toxic components in the gas), or in an engine or turbine to generate electricity.

2. Methodology

ARB staff requested site-specific landfill gas collection data through landfill surveys, but received answers for only certain years and for less than half of the landfilled waste (e.g., approximately 42 percent in 2005). Therefore, staff opted to use a model to estimate landfill emissions for all sites, and used the survey data to supplement these predictions where available.

Staff used the Mathematically Exact First-Order Decay (FOD) model from the 2006 Intergovernmental Panel on Climate Change (IPCC) Guidelines (IPCC, 2006e). In summary, this model assumes that a fixed fraction of the waste available at any moment will degrade. The amount that degrades over a given amount of time is determined by a factor (k), which is tied to the moisture content in the landfill. The k values used in the model were obtained from USEPA and are function of the annual precipitation occurring at each landfill; rainfall being used as a surrogate for landfill moisture content. The model assumes that the waste carbon is biodegraded into equal amounts of CO_2 and CH_4 (see Equation 65).

2.1 Model Equations

The inputs to the model are the amount of anaerobically degradable organic carbon (ANDOC), the delay in months before waste begins to decay anaerobically (*M*), the rate at which waste decays (*k*), and the fraction of degraded carbon that is converted into CH_4 (F_{CH4}). Of these four inputs, three are set by using default values: a six month default for *M*, a 50 percent default for F_{CH4} and USEPA defaults based on rainfall levels for *k*. Only *ANDOC* requires a more detailed method of derivation, which is the focus below. The inputs for calculating *ANDOC* are therefore important determinants of landfill emissions estimates.

(a) Anaerobically Degradable Organic Carbon (*ANDOC*)

Equation 66: Anaerobically degradable organic carbon

$$ANDOC = WIP \bullet 0.9072 \bullet \sum_{component} (FW_{component} \bullet DOC_{component} \bullet DANF_{component})$$

Where,

ANDOC = Anaerobically Degradable Organic Carbon: the amount of waste carbon that is biodegradable in an anaerobic environment (Mg (i.e., 10^6 grams) of carbon)

WIP = Waste-in-Place: the landfilled waste (wet weight) as reported to the California Integrated Waste Management Board (tons)

0.9072 = Short ton to Mg (a.k.a. tonne or metric ton) conversion

$FW_{component}$ = Fraction of a given waste component in the landfilled waste

$DOC_{component}$ = Degradable Organic Carbon (DOC) content of the given waste component.

$DANF_{component}$ = Decomposable Anaerobic Fraction (DANF) of the given waste component.

With,

Component = [Newspaper, Office Paper, Corrugated Boxes, Coated Paper, Food, Grass, Leaves, Branches, Lumber, Textiles, Diapers, Construction/Demolition, Medical Waste, Sludge/Manure]

(a.i) Waste-In-Place (WIP)

The California Integrated Waste Management Board (CIWMB) staff provided ARB staff with Waste-in-Place (*WIP*) data in two basic forms: 1) the cumulative amount of waste deposited, by landfill, up to the year 1990 and, 2) the amounts deposited, by landfill, each year from 1991 to 2005 for those landfills still receiving waste after 1990. CIWMB staff also furnished the amounts of green waste and sludge used as daily cover by each landfill from 1995 to 2005. CIMWB staff provided data on 372 landfills known to contain waste that is biodegradable. Landfills containing only inert waste, like ash and masonry from demolition sites, were excluded. ARB staff also received survey data from 30 of these landfills (comprising 41.8 percent of the 2005 WIP) and used them to update the CIWMB data. In most cases, however, these updates were modest.

Yearly amounts of deposited waste are necessary inputs for the IPCC FOD model to work properly. Yearly data were not available before 1990, however, only the cumulative WIP totals in 1990 were known. This led staff to estimate how much of these cumulative amounts were deposited each year from the landfills' opening year to 1990 (or up to their closure year if they closed before 1990). This estimation was made as follows. First, ARB staff inquired about the opening and closure dates for all landfills. CIWMB staff had closure dates for all 372 landfills of interest, but did not have a complete list of opening dates, so an estimate was made for those cases where the opening date was missing. Once these dates were established, the cumulative total of WIP in each landfill was distributed over the pre-1990 years (from opening to 1990, or opening to closure if before 1990) in a manner commensurate to the trend in California's population over those years. As a result, a larger proportion of the waste in place was distributed in the later years of this range than in the earlier ones, since the population kept growing over the time period.

(a.ii) Components of the Waste-in-Place

To determine its DOC and DANF, the WIP must first be disaggregated into its component parts. Disaggregation was done on the basis of waste characterization studies from the CIWMB and the USEPA. The CIWMB studies were conducted in 1999 and 2004; the1999 study was used to characterize waste for 1995 to 2002 and the 2004 study for 2003 and beyond, as suggested by the CIWMB staff. For years prior to 1995, staff used the USEPA study that best applied to a given year. The USEPA did waste characterization studies in 1960, 1970, 1980 and 1990. Staff used the waste profiles from those studies as follows: up to 1964 (1960 survey), 1965-1974 (1970 survey), 1975-1984 (1980 survey) and 1985-1994 (1990 survey). Applying these profiles allowed disaggregating the waste deposited each year into its component parts. The components of interest to estimate TDOC (i.e., those containing biodegradable carbon content) are listed in Table 33.

Table 33: Waste characterization – Percentage of each component in the overall waste in place

Waste Component	***Up to 1964***	***1965 - 1974***	***1975 - 1984***	***1985 - 1994***	***1995 - 2002***	***2003+***
Newspaper	6.4%	6.4%	5.9%	4.8%	4.3%	2.2%
Office Paper	7.4%	8.2%	11.6%	12.5%	4.4%	2.0%
Corrugated Boxes	13.8%	16.2%	11.4%	10.6%	4.6%	5.7%
Coated Paper	2.5%	2.4%	2.9%	2.5%	16.9%	11.1%
Food	14.8%	11.3%	9.5%	12.1%	15.7%	14.6%
Grass	12.1%	10.3%	10.1%	9.0%	5.3%	2.8%
Leaves	6.1%	5.1%	5.0%	4.5%	2.6%	1.4%
Branches	6.1%	5.1%	5.0%	4.5%	2.4%	2.6%
Lumber	3.7%	3.3%	5.1%	7.0%	4.9%	9.6%
Textiles	2.1%	1.8%	1.7%	4.0%	2.1%	4.4%
Diapers	0.1%	0.3%	1.4%	1.6%	6.9%	4.4%
Construction/Demolition	2.6%	2.5%	3.5%	3.9%	6.7%	12.1%
Medical Waste	-	-	-	-	0.0%	0.0%
Sludge/Manure	-	-	-	-	0.1%	0.1%

* Dash indicates no data available; percentage assumed to be zero.

The combined amounts of green waste and sludge used as daily cover were included with landfills WIP. According to CIWMB staff, most of the daily cover is green waste, thus ARB staff assumed that 10 percent of the daily cover amounts were percent sludge and 90 percent green waste. Green waste was further split based on USEPA study assumptions that 50 percent is Grass, 25 percent Leaves and 25 percent Branches (Table 34).

Table 34: Waste characterization of daily cover material

Daily Cover Waste Component	***Assumed Content Percentage***
Sludge/Manure	10%
Grass	45%
Leaves	22.5%
Branches	22.5%

(a.iii) Degradable Organic Carbon (DOC) content

Staff obtained values for the Degradable Organic Carbon (DOC) content of solid waste components from USEPA (Newspaper, Office Paper, Corrugated Boxes, Coated Paper, Food, Grass, Leaves, Branches) and from the 2006 IPCC Guidelines (Lumber, Textiles, Diapers, Construction/Demolition, Medical Waste, Sludge/Manure). These values are summarized in Table 35.

Table 35: Degradable Organic Carbon (DOC) content of different MSW components

Waste Component	***DOC Fraction (Mg DOC / Mg wet waste)***	***Source***
Newspaper	0.465	USEPA
Office Paper	0.398	USEPA
Corrugated Boxes	0.405	USEPA
Coated Paper	0.405	USEPA
Food	0.117	USEPA
Grass	0.192	USEPA
Leaves	0.478	USEPA
Branches	0.279	USEPA
Lumber	0.430	IPCC
Textiles	0.240	IPCC
Diapers	0.240	IPCC
Construction/Demolition	0.040	IPCC
Medical Waste	0.150	IPCC
Sludge/Manure	0.050	IPCC

(a.iv) Decomposable Anaerobic Fraction (DANF)

Theoretically, all biodegradable carbon-bearing waste can degrade, but only a portion actually degrades in the special anaerobic environment of landfills. The carbon in the waste that does not decompose remains sequestered.

Values for the DANF of different MSW components came from USEPA (Newspaper, Office Paper, Corrugated Boxes, Coated Paper, Food, Grass, Leaves, and Branches), the CEC (lumber) and the IPCC guidelines (default of 50 percent anaerobic decomposition for Textiles, Diapers, Construction/Demolition, Medical Waste, and Sludge/Manure).

Table 36: Decomposable anaerobic fraction (DANF) of the DOC of different MSW components

Waste Component	**Decomposable Anaerobic Fraction**	**Source**
Newspaper	0.161	USEPA
Office Paper	0.874	USEPA
Corrugated Boxes	0.383	USEPA
Coated Paper	0.210	USEPA
Food	0.828	USEPA
Grass	0.322	USEPA
Leaves	0.100	USEPA
Branches	0.176	USEPA
Lumber	0.233	CEC
Textiles	0.500	IPCC
Diapers	0.500	IPCC
Construction/Demolition	0.500	IPCC
Medical Waste	0.500	IPCC
Sludge/Manure	0.500	IPCC

(a.v) Overall Waste Profile and Estimate of landfilled Carbon Sequestration

With the data described above, staff calculated the overall waste profile for California (Table 37). Staff also estimated the amount of non-decomposable organic carbon in landfills, that is, the carbon which is expected to remain sequestered until removed from the anaerobic conditions present in landfills (Table 38).

Table 37: Overall waste profile for California - Percentage of each component in the overall waste in place

Waste Type	**Up to 1964**	**1965 - 1974**	**1975 - 1984**	**1985 - 1994**	**1995 - 2002**	**2003+**
Biodegradable Carbon	23.36%	22.96%	23.07%	23.54%	21.78%	19.00%
▪ Decomposable	8.85%	8.90%	9.47%	10.17%	7.81%	6.72%
▪ Sequestered	14.51%	14.06%	13.60%	13.37%	13.97%	12.28%
Other Materials	76.64%	77.04%	76.93%	76.46%	78.22%	81.00%

Most of the waste in landfills is non-biodegradable. Of that portion that is biodegradable (19 percent to 24 percent) most will not decompose in a landfill environment and instead will remain permanently sequestered.

Table 38: Estimate of carbon sequestration in landfills (million metric tonnes of carbon)

Waste Component	**1990**	**2004**
Newspaper	0.772	0.339

Waste Component	***1990***	***2004***
Office Paper	0.258	0.039
Corrugated Boxes	1.092	0.567
Coated Paper	0.330	1.400
Food	0.100	0.115
Grass	0.480	0.144
Leaves	0.793	0.238
Branches	0.424	0.235
Lumber	0.952	1.256
Textiles	0.198	0.210
Diapers	0.079	0.206
Construction/Demolition	0.032	0.095
Medical Waste	-	0.001
Sludge/Manure	-	0.001
TOTAL	5.51	4.85

Note: comprehensive carbon sequestration estimates for all years 1990-2004 are available upon request.

(b) <u>Change in ANDOC</u>

Next, staff used the IPCC FOD model to calculate the change in ANDOC over time, determining how much of the anaerobically degradable organic carbon remains at the end of each year:

Equation 67: Change in anaerobically degradable organic carbon in landfills

$$ANDOCstock_{Year(i+1)} = \left\{ \begin{array}{l} ANDOCstock_{year(i)} \bullet e^{-k} \\ + ANDOCadded_{year(i-1)} \bullet [\frac{1}{k} \bullet (e^{-k \bullet [1-\frac{M}{12}]} - e^{-k}) - \frac{M}{12} \bullet e^{-k}] \\ + ANDOCadded_{year(i)} \bullet [\frac{1}{k} \bullet (1 - e^{-k \bullet [1-\frac{M}{12}]}) + \frac{M}{12}] \end{array} \right\}$$

Where,

$ANDOCstock_{Year(i+1)}$ = stock of ANDOC remaining un-decomposed at the end of inventory year i, and thus present in the landfill at the beginning of the next year (year i+1), (g)

$ANDOCstock_{Year(i)}$ = stock of ANDOC present in the landfill at the beginning of inventory year i, i.e., remaining un-decomposed at the end of the previous year (i-1), (g)

$ANDOCadded_{Year(i-1)}$ = ANDOC added during the previous inventory year (year i-1), (g)

$ANDOCadded_{Year(i)}$ = ANDOC added during inventory year i, (g)

M = Assumed delay before newly deposited waste begins to undergo anaerobic decomposition (months), default value = 6 months

k = Assumed rate constant for anaerobic decomposition; k = ln2/half-life (years); the half-life being the number of years required for half of the original mass of carbon to degrade (Table 39).

This calculation is performed iteratively for all subsequent years, starting with the landfill opening year and ending with the inventory year of interest.

Table 39: Assumed rate constant values for anaerobic decomposition (k)

Average Rainfall (Inches/Year)	***k value***
<20	0.02
20-40	0.038
>40	0.057

Source: USEPA

(c) Methane Generation

Equation 68: Methane generation in landfills

$$G_{CH4} = F_{CH4} \bullet \left\{ \begin{array}{l} ANDOCstock_{year(i)} \bullet (1 - e^{-k}) \\ - ANDOCadded_{year(i-1)} \bullet [\frac{1}{k} \bullet (e^{-k \bullet [1-\frac{M}{12}]} - e^{-k}) - \frac{M}{12} \bullet e^{-k}] \\ + ANDOCadded_{year(i)} \bullet [1 - \frac{M}{12} - \frac{1}{k} \bullet (1 - e^{-k \bullet [1-\frac{M}{12}]})] \end{array} \right\}$$

Where,

G_{CH4} = CH_4 generated during inventory year i (g)

F_{CH4} = Fraction of decomposing carbon that is converted into CH_4, default value = 0.5

$ANDOCstock_{Year(i)}$ = Stock of ANDOC present in the landfill at the beginning of inventory year i (g)

$ANDOCadded_{Year(i-1)}$ = ANDOC added during the previous inventory year (year i-1)

$ANDOCadded_{Year(i)}$ = ANDOC added during inventory year i (g)

M = Assumed delay before newly deposited waste begins to undergo anaerobic decomposition (months), default value = 6 months

k = Assumed rate constant for anaerobic decomposition; k = ln2/half-life (years); the half-life being the number of years required for half of the original mass of carbon to degrade (Table 39).

(d) Emissions Estimates

Equation 69: CH_4 emissions from landfills

$$E_{CH4} = G_{CH4} \bullet CE_{LFG} \bullet (1 - DE_{LFG}) + G_{CH4} \bullet (1 - CE_{LFG}) \bullet (1 - O_{CH4})$$

Where,

E_{CH4} = Emissions of CH_4 from landfill (g)

G_{CH4} = Amount of CH_4 generated by the landfill during the inventory year (g)

CE_{LFG} = Landfill Gas Collection Efficiency, the fraction of generated landfill gas captured by the collection system (default value = 0.75)

DE_{LFG} = Landfill Gas Destruction Efficiency, the fraction of CH_4 in the captured landfill gas oxidized to CO_2 (default values = 0.99 for combustion/thermal oxidation, and 0.01 for carbon filtration)

O_{CH4} = Fraction of uncollected CH_4 that is oxidized to CO_2 in the landfill cover (default value = 0.1)

CIWMB staff provided information about which landfills have gas collection systems and what control method they use, if any. Responses to an ARB survey allowed staff to update a portion of the CIWMB numbers. For years where CIWMB data was lacking on the year of collection system installation (primarily years 1991 - 2003), staff used existing regulatory requirements to help estimate the installation dates. Staff intends to improve the accuracy of collection system installation dates in the future.

Staff assumed that a landfill gained the full benefits of gas collection beginning with the year in which the system was first installed. In the future, as the exact month of installation and start-up operation becomes available, it will be factored in and the collection efficiency for that year may be prorated.

CIWMB staff also provided the type of control landfills are using, including: simple venting to the atmosphere, carbon adsorption, or combustion (flaring, engines, thermal oxidizers, etc.). In the case of combustion, ARB staff assumed that 99 percent of the CH_4 was converted into CO_2 and 1 percent escaped as CH_4. For carbon adsorption, 1 percent of the CH_4 was assumed captured and 99 percent released. For venting 100 percent of the CH_4 was assumed released.

Each site with a gas collection system was assigned a default of 75 percent collection efficiency and a default of 10 percent oxidation for the uncollected landfill gas as it migrates through the landfill cover into the air. Using these default values (the defaults of 75 percent for collection efficiency and 10 percent for oxidation fraction) has been the object of some debate. Staff recognizes that many values can be found for these factors in the literature and that some site-specific measurements and local estimates do exist. However, given the current lack of rigorous, scientifically-based measurement data, staff chose to use the default values established by USEPA. As better data become available through current and future research, staff will update the collection efficiency and oxidation factors for estimating landfill gas emissions.

(d.i) Use of Site Specific Survey Data

Using the First Order Decay model from the IPCC guidelines, staff estimated the amount of carbon sequestered and the amount of CH_4 emitted by each of the 372 landfills of interest in California.

ARB staff also surveyed landfill operators and some landfills provided site-specific landfill gas collection data for certain years of operations (30 of the 372 landfills submitted site specific survey data). These data were used either to replace or to improve the model's estimates for that landfill.

When staff received landfill survey data for a particular year, it used the survey information in place of the model estimate. However, survey data included only the amount of gas collected, and not the amount generated since landfill operators only know what is measured at the point of collection. To estimate the amount of gas generated, a default collection efficiency of 75 percent was used and the amount of collected gas was divided by 0.75 to obtain an estimate of the generated gas. Then, the estimate of gas generated—based on the amount of gas collected—was used to replace the model estimate for that year.

When an actual value for the CH_4 fraction in landfill gas was reported in the survey, staff used it instead of the general default landfill gas composition assumption of 50 percent CH_4 and 50 percent CO_2. However, because CO_2 specific fractions were not obtained from the site specific survey data (only CH_4 fractions were obtained), it was assumed that whatever was not reported as CH_4 was CO_2. Staff recognizes that N_2 gas and small amounts of O_2 are expected to be present, and therefore not all of the remaining gas (i.e., the fraction that is not CH_4) is CO_2. Nevertheless, the amounts of these other gases were considered to be negligible for the purpose of estimating the CO_2 emissions from landfills. As data improves, this conservative assumption may be revisited.

When landfill survey data was provided for some of the years and not others, staff used the provided years to improve the model estimates for the missing years by interpolating or extrapolating using the model predicted trend for that landfill. For example, if the years 1990-1993 were missing from a set of survey data for a particular landfill, but the year 1994 was available, then the years 1990-1993 were extrapolated from this 1994 data point by following the trend the model showed for that landfill. So if the model indicated that the CH_4 generation in 1993 was 3 percent lower than the 1994 predicted value, the available 1994 value from the survey was multiplied by 97 percent to estimate the 1993 point, and so on. This method of filling missing data preserves a consistent trend that smoothly joins the survey data. The same methodology was used to estimate CO_2 emissions when missing survey data were encountered.

An exception was made to these procedures in the case of survey-reported first years of operation of a collection system. These reported values were not used as a substitute for model estimates, as it was not known if the indicated first year represented a full year of operation. Staff assumed that the second year of reported data was a complete year and used that year as the starting point, ignoring data from the first year. For surveys with collection system data dating back to 1990, staff assumed that the 1990 value represented a full year of operations and always made use of it. Staff made this assumption since data was not available to indicate if 1990 was the first year of operation and no survey data was available for 1989.

(d.ii) Emissions from Landfill Gas Combustion

Emissions of N2O from the combustion of landfill gas are included in the inventory. These emissions are a function of the BTU content of the landfill gas being burned. The amount of landfill gas burned (LFG) is determined from model output for the amount of gas collected and from CIWMB data indicating which landfills burn their captured gas.

Equation 70: N_2O emissions from landfill gas combustion

$$\boxed{E_{N2O} = LFG \bullet F_{CH4} \bullet HC_{CH4} \bullet EF_{CH4}}$$

Where,

E_{N2O} = N_2O emissions from landfill gas combustion (grams)
LFG = Landfill gas captured and burned (standard cubic feet)
F_{CH4} = CH_4 fraction of landfill gas (unitless)
HC_{CH4} = Heat content of CH_4 (BTU / standard cubic foot)
EF_{CH4} = N_2O emission factor of CH_4 (grams per BTU)

3. Data Sources

The First order decay model is from the 2006 IPCC guidelines (IPCC, 2006h). Waste characterization data was obtained from studies made by the California Integrated Waste Management Board (CIWMB, 2007) and by the USEPA (USEPA, 2007i). Degradable Organic Carbon (DOC) content and values for Decomposable Anaerobic Fraction (DANF) were taken from USEPA (USEPA, 2002). DANF data for lumber comes from the California Energy Commission (CEC, 2006a). Default values used for DANF and DOC content of waste in place, and CH_4 combustion emission factors were taken from the 2006 IPCC Guidelines (IPCC, 2006h). Default collection capture efficiency and CH_4 oxidation factor values were obtained from the USEPA through personal correspondence (Weitz, 2007). Landfill gas collection, geographic coordinates and control data for California landfills were provided by CIWMB staff through personal communication (Walker, 2007). Average precipitation data for the landfills was extracted from a map published by the NRCS (NRCS, 2007). Methane and nitrous oxide emissions factors are from IPCC Guidelines (IPCC, 2006b).

For a list of yearly activity and parameter values used in the equations, please consult the online documentation annex at:
http://www.arb.ca.gov/cc/inventory/doc/methods_v1/annex_4a_landfills.pdf

4. Future Improvements

More complete, California-specific landfill survey data on landfill gas collection and composition will help improve outputs from the IPCC model. Improved survey data should also establish actual opening dates for landfills and perhaps provide better data on the percent CO_2 content of landfill gas. Better information on the cover types present at landfills and further details on gas collection systems will allow for better collection and oxidation factor estimates. Ongoing research and other studies will be followed closely by staff to improve estimates of landfill gas emissions.

B. Wastewater Treatment and Discharge (IPCC 4D)

1. Background

Wastewater from households, commercial activities, and industrial production contains soluble organic matter, suspended particles, pathogenic organisms, and chemical contaminants. In California, a large percentage of wastewater is collected and processed in centralized wastewater treatment plants. Methane is emitted from wastewater when it is treated in anaerobic conditions. Nitrous oxide is emitted as the result of the nitrification and denitrification processes, which take place at wastewater treatment plants, but also in the water bodies where effluent is discharged.

The magnitude of CH_4 emissions is determined by the amount of degradable organic component in the wastewater, the temperature, and the type of treatment system. The more organic material and the higher the temperature of the wastewater, the more CH_4 will be generated. The degradable organic material content in wastewater is quantified by its Biochemical Oxygen Demand (BOD) and Chemical Oxygen Demand (COD). The BOD measures the amount of biodegradable organic material present in wastewater, while the COD measures all organic materials both biodegradable and non-biodegradable.

N_2O emissions are associated with the degradation of nitrogen compounds present in the wastewater. N_2O is generated during the nitrification and denitrification processes, which occur at wastewater treatment plants and in water bodies that accept discharges of wastewater or treatment plant effluent. Emissions of N_2O at wastewater treatment plants are generally small compared to the emissions from effluent discharged into aquatic environments.

2. Methodology

Most CH_4 and all N_2O emissions from wastewater treatment and discharge were estimated using methodology from the USEPA Emission Inventory Improvement Program State Tools (USEPA, 2004d) with parameter values updated to those published in the 1990-2004 National GHG Inventory (USEPA, 2007h. This methodology is consistent with Tier-1 and Tier-2 methods of the IPCC Guidelines (IPCC, 2006a), and incorporates some USEPA improvements and California-specific data when available. Exceptions to using this methodology were made in the case of the CH_4 emissions from industrial wastewater treatment plants of the following industries: Manufacturing, Oil & Gas extraction, Petroleum marketing and Petroleum refining. For these wastewater treatment plants, emission data was available in ARB's California Emission Inventory Development and Reporting System (CEIDARS) database that allowed for an estimation of their CH_4 emissions.

2.1 Methane Emissions

Methane emissions from wastewater are estimated from the volume of wastewater generated, organic loading in wastewater (measured in BOD or COD), and percentage of wastewater that is anaerobically digested. The volume of wastewater discharged into municipal sewage system is estimated from the State population. The volume of wastewater generated from a particular industrial sector is estimated by the quantity of product it manufactured or processed, and the wastewater output intensity of that particular industry.

(a) Domestic Wastewater Methane Emissions

Equation 71: CH_4 emissions from domestic wastewater treatment

$$\boxed{E_{CH4} = P \bullet BOD_5 \bullet 365.2425 \bullet PAD_{BOD5} \bullet EF_{CH4}}$$

Where,

E_{CH4} = Emissions of methane (gram)
P = California population (person)
BOD_5 = Per capita biological organic demand (BOD_5) - (gram / person / day)
365.2425 = Average number of days per year (day)
PAD_{BOD5} = Proportion of BOD5 anaerobically digested (unitless)
EF_{CH4} = Methane emission factor (unit mass of CH_4 per unit mass BOD_5)

(b) Industrial Wastewater Methane Emissions

(b.i) Processing of Fruits and vegetables, red meat and poultry

For each of the type of product processed, the CH_4 emissions are estimated using the following equation:

Equation 72: CH_4 emissions from industrial wastewater treatment

$$\boxed{E_{CH4,product} = QP_{product} \bullet WWO_{product} \bullet COD_{product} \bullet PAD_{COD,product} \bullet EF_{CH4,product}}$$

Where,

$E_{CH4,\ product}$ = Emissions of methane form the treatment of wastewater associated with processing the given product (gram)
$QP_{product}$ = Quantity of the given product processed (gram)
$WWO_{product}$ = Wastewater outflow associated with processing the given product (liter / gram)
$COD_{product}$ = Chemical oxygen demand of the wastewater associated with the processing of the given product (gram / liter)
$PAD_{COD,\ product}$ = Proportion of COD anaerobically degraded by the treatment of the wastewater associated with the processing of the given product (unitless)
$EF_{CH4,\ product}$ = Methane emission factor specific to the wastewater associated with the processing of the given product (unit mass of CH_4 per unit mass COD)

With,

Product = [Fruits and vegetables, Red meat, Poultry]

(b.ii) Manufacturing, Oil & Gas extraction, Petroleum marketing and Petroleum refining

Staff queried ARB's California Emission Inventory Development and Reporting System (CEIDARS) database for total organic gases (TOG) emissions; and then speciated the results to estimate emissions of CH_4. In CEIDARS, total organic gases include emissions of compounds of carbon, excluding carbon monoxide, carbon dioxide, carbonic acid, metallic carbides or carbonates, and ammonium carbonate. The ARB maintains and updates estimates of the chemical composition and size fractions of particulate matter (PM) and the chemical composition and reactive fractions of total organic gases (TOG) in CEIDARS, for a variety of emission source categories. These speciation profiles provide estimates of the chemical composition of the emissions, and are used in the emission inventory and air quality models. For more information see: http://arb.ca.gov/ei/speciate/speciate.htm

2.2 Nitrous Oxide Emissions

Neither the IPCC nor USEPA has a separate category for N_2O emissions from industrial wastewater. The methodologies for estimating N_2O emissions from wastewater focus on emissions from municipal wastewater treatment plants and estimate the amount of nitrogen in wastewater on the basis of human protein consumption. In the USEPA methodology, the nitrogen from industrial wastewater is factored into the estimation by applying a coefficient to account for industrial and commercial co-discharge into municipal sewage treatment plants (estimated at 25 percent). This coefficient is then combined with another adjustment for the protein nitrogen that will enter sewage treatment plants without being consumed by people (e.g., through garbage disposals). USEPA estimated that an extra 40 percent of protein enters wastewater treatment plants that way. The value of this combined factor, called "Non-consumption protein factor" by USEPA, is thus: 1.25 x 1.4 = 1.75.

Emissions of nitrous oxide occur from wastewater in treatment plants and from effluents discharged into surface waters, thus:

Equation 73: N_2O emissions from wastewater treatment

$$\boxed{E_{N2O} = E_{N2O,Plant} + E_{N2O,Effluent}}$$

(a) Emissions at the wastewater treatment plants

Plant emissions ($E_{N2O,\ Plant}$) are estimated with the following equation:

Equation 74: N_2O emissions at the water treatment plant

$$\boxed{E_{N2O,Plant} = P \bullet FP_{Plant} \bullet EF_{N2O,Plant}}$$

Where,

$E_{N2O,\ Plant}$ = N_2O emissions from wastewater treatment plants (gram)
P = California population (person)
FP_{Plant} = Fraction of population using centralized wastewater treatment plants

$EF_{N2O, Plant}$ = N_2O emissions factor for plant emissions (gram / person)

(b) Emissions from Nitrogen-containing effluent discharged into water bodies

Effluent emissions ($E_{N2O,\ Effluent}$) are estimated using the following equations:

Equation 75: N_2O emissions from wastewater effluent

$$\boxed{E_{N2O,Effluent} = N_{Effluent} \bullet EF_{Effluent} \bullet 1.571}$$

Where,

$E_{N2O, Effluent}$ = Effluent N_2O emissions (gram)
$N_{Effluent}$ = Amount of nitrogen in the effluent discharged to surface waters (gram)
$EF_{Effluent}$ = N_2O emission factor for effluent emissions (gram of N emitted as N_2O per gram N)
1.571 = Molecular weight ratio of N_2O to N_2

Equation 76: Amount of nitrogen in the effluent discharged to surface waters

$$\boxed{N_{Effluent} = (P \bullet PC \bullet FN \bullet FNC) - N_{Sludge} - (E_{N2O,Plant} \bullet 0.6365)}$$

Where,

$N_{Effluent}$ = Amount of nitrogen in the effluent discharged to surface waters (gram)
P = California population (person)
PC = Annual per capita protein consumption (gram / person)
FN = Fraction of nitrogen in protein (unitless)
FNC = Factor for non-consumption protein (unitless)
N_{Sludge} = Sewage sludge N not entering aquatic environment (gram)
0.6365 = Molecular weight ratio of N_2 to N_2O

Note that some of the N_2O emissions from sewage sludge are accounted for in the Agricultural Soil Management Section (III.F above) when sludge has been reported as a source of organic fertilizer. The nitrogen removed with the sewage sludge from centralized wastewater treatment plants that is used as a fertilizer on soils (N_{Sludge}) is thus deducted from effluent nitrogen to avoid double counting.

3. Data Sources

The State population numbers were obtained from the California Department of Finance (CDOF, 2007a). The production data for fruits and vegetables, red meat, and poultry are from the California Food and Agricultural Department (CDFA) and USDA National Agriculture Statistics Services (USDA, 2007a). Sewage sludge used as an organic fertilizer is reported in CDFA's *Fertilizing Materials Tonnage Reports* (CDFA, various years). Other factors used in the equations are from USEPA 1990-2004 GHG Inventory (USEPA, 2007h).

The California Air Resources Board (ARB) has collected information on emissions from air pollution sources since 1969. Data are gathered on an ongoing basis and stored in the California Emission Inventory Development and Reporting System (CEIDARS) database. See: http://www.arb.ca.gov/ei/general.htm

For a list of yearly activity and parameter values used in the equations, please consult the online documentation annex at: http://www.arb.ca.gov/cc/inventory/doc/methods_v1/annex_4b_wastewater_treatment_and_discharge.pdf

4. Future Improvements

Emissions from pulp and paper manufacturing industries are not included in this emission inventory because of the lack of state-specific production data. ARB staff will seek pulp and paper production data to include emissions from this category in a future edition of the GHG inventory. Also, no distinction has been made in this edition between treatment in septic tanks and in centralized plants, nor between wastewater treatment plants with and without controlled nitrification and denitrification. Staff anticipates being able to include these distinctions in future inventories.

DATA STORAGE AND MANAGEMENT

Greenhouse gas inventories involve a wide range of human activities. Estimating the amount of greenhouse gases generated by these activities requires using a multiplicity of data sources and a diverse set of methodologies. Storing, cataloging and documenting such a multifaceted set of information is challenging.

ARB staff has designed a custom relational database to hold California's greenhouse gas inventory information and created a set of web pages to disseminate it.

1. Inventory Database

We implemented the GHG inventory database using Microsoft Access 2003. Two main types of GHG estimation methodologies are stored in this database, using different amounts of detailed information.

1.1 Methodologies involving simple algebraic formulas. (e.g., fuel combustion, clinker production, etc.)

In this case the formulas are stored as text strings in the database with the values for activity level and all other parameters involved in the formulas. The GHG estimates are recomputed in the database by a set of Visual Basic routines that parse the formula and query the database for the necessary data. The references for the origin of the formulas and the source of all data values are also stored in the database. Cases where data were not available and their values were estimated through interpolation, extrapolation or other methods are also documented in the data tables.

1.2 Methodologies requiring a complex model (e.g., land-use and forestry models, EMission FACtors (EMFAC) model, cattle enteric fermentation model, landfill emission model).

In this case, only the values for activity level and greenhouse gases estimates (model output) are stored in the database. The references for the origin of the models and the source of data values are also stored in the database. Cases where model input data were not available and their values were estimated through interpolation, extrapolation or other methods are not documented in the data tables (that information is available through the model reference however).

1.3 Cataloguing attributes

The various activities and their GHG estimates are catalogued using:

- Their IPCC category of emissions and removal (IPCC, 2006a). For instance, *1A3aii* : "Energy - Fuel Combustion Activities - Transport - Civil Aviation - Domestic Aviation"; or *2B2* : "Industrial Processes and Product Use - Chemical Industry - Nitric Acid Production"

- The activity name (e.g., fuel combustion, livestock population)
- The activity subset, if applicable, such as fuel type (e.g., coal, natural gas, gasoline) or livestock category (e.g., dairy cow, dairy heifer, market swine > 180 lbs)
- Up to four levels of economic sector information. For instance, "Electricity Generation (In State) -Utility Owned - Geothermal -" or, Industrial - Manufacturing - Metal Durables - Industrial Machinery & Equipment"

2. Inventory Web Pages

Information is extracted and summarized form the database to produce Inventory tables and documentation pages for dissemination through ARB's Climate Change web site.

2.1 Inventory tables

A set of queries and reports is used to summarize and tabulate the GHG estimates by IPCC category of emission and removal, by economic sector, by greenhouse gas and by year. The amounts of greenhouse gas are expressed in million of metric tones of CO_2 equivalent. The CO_2 equivalence calculations are based upon the IPCC Second Assessment Report's (IPCC, 1996) global warming potentials. This detailed inventory table is publicly available as a PDF document and as a MS Excel spreadsheet by following the corresponding links on the GHG Inventory and Documentation web page at: http://www.arb.ca.gov/cc/inventory/inventory.htm. Another, simplified, inventory table is generated in similar fashion. It summarizes GHG emissions by IPCC category and by year. This summary table is also available through the GHG Inventory web page. An interactive query tool is also available to select a subset of the inventory in a table, view it or download it to your computer, find out how each of the emissions values was estimated, and plot the data (http://www.arb.ca.gov/app/ghg/ghg_sector.php).

2.2 Documentation pages

Each of the emission values contained in the detailed inventory table discussed above has its own html documentation page. The goal of these pages is summarize all the information that was used by ARB staff to produce the particular emission value. With this information, members of the public may assess the methodology used to derive the GHG estimates and independently verify the estimates.

These pages are created by an automated set of queries extracting information from the GHG inventory database. Each of the html documentation pages features the following items:

- The date on which the page was last updated.
- The identification of the estimate: its IPCC category of emission and removal, economic sector classification, the greenhouse gas estimated and the year of the estimate.

- The estimated amount of emission or removal (both the mass of gas and its CO_2 equivalent), the units it is expressed in, the basis of the estimate (the algebraic formula or the name of the mathematical model), and the reference for the origin of the model or formula.
- The amount of activity that resulted in the GHG emission or removal (if applicable), the basis of the amount (data point, compilation of statistics, result from a calculation, mathematical model) and the reference for the source of the amount. In the case where the amount of activity is itself the result of a calculation, the formula and its source are given.
- The parameters and constants used in the calculation of the GHG estimate and/or the amount of activity. The value and units of these parameters and constants and the reference for their source is also listed.
- The calculated amount of greenhouse gas emitted per unit of activity.

The html documentation pages are publicly available on ARB's Climate Change website (http://www.arb.ca.gov/cc/inventory/doc/doc.htm) through a hierarchical index based on the same categorization as the detailed inventory table discussed above: IPCC category of emission and removal, economic sector, greenhouse gas and year. This index is located at: http://www.arb.ca.gov/cc/inventory/doc/doc_index.php.

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