California Environmental Protection Agency

Air Resources Board

2014 Edition

California's 2000-2012
Greenhouse Gas Emissions Inventory

Technical Support Document

State of California
Air Resources Board
Air Quality Planning and Science Division

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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) to determine the statewide 1990 greenhouse gas (GHG) 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, made ARB responsible to prepare, adopt, and update California's greenhouse gas inventory.

This technical support document presents a comprehensive and detailed discussion of the emissions estimation methods, equations, data sources, and references that ARB staff employed to develop ARB's 2014 edition of California's greenhouse gas (GHG) emission inventory, covering years 2000 to 2012. (http://www.arb.ca.gov/cc/inventory/inventory.htm)

The structure of the inventory and this report follows the categorization of GHG emissions to and removal from the atmosphere contained in the *2006 IPCC Guidelines for National Greenhouse Gas Inventories*. In developing the 2014 California GHG inventory, staff consulted with other State agencies and the U.S. Environmental Protection Agency (USEPA). Some methodologies and data from the *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2012*, published in April 2014 by the USEPA were also incorporated for use in developing California emissions estimates.

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, tables of intermediary results, etc. 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 preparation for each new edition of the GHG inventory, recalculations are made to correct errors, incorporate new methodologies or, most commonly, to reflect changes in statistical data supplied by other agencies. Emission and sink estimates are recalculated for all years in order to maintain a consistent time-series of estimates within the inventory. This approach follows the recommendation for developing GHG inventories discussed in Chapter 7 of the IPCC Good Practice Guidance document (IPCC, 2000): "In order to assess emission trends it is important that the entire time series of emissions, not just the most recent years, be calculated using the changed or refined methods. It is good practice to recalculate historic emissions when methods are changed or refined, when new source categories are included in the national inventory, or when errors in the estimates are identified and corrected." As a consequence, successive editions of the inventory may report a different amount of emissions/removal for an earlier year than earlier published inventories.

With each new edition of the California GHG inventory, staff makes improvements to methods or data sources. In developing ARB's first edition of California's GHG inventory in 2007, staff consulted with other State agencies, stakeholders and the public through a series of workshops and technical discussions. That public process resulted in major revisions to the inventory, including changes to the classification of emissions and sinks, selected emission estimation methods, GHG emission factors, and other parameters. ARB's second edition of California's GHG inventory, covering years 2000 to 2006, and its third edition (for years 2000 to 2008) saw a number of such changes to the data and methods used for the estimates. New data or methods were described in the online documentation published with these inventories on ARB's website. In the fourth edition, the major change was the integration of data collected under the Regulation for Mandatory Reporting of Greenhouse Gas Emissions (MRR), including information from: cement plants (for 2008 and 2009), refineries (2009), electricity generation and electricity imports (2009). In the sixth edition that covered years 2000-2011, a majority of the changes were related to the attribution of the substitutes of Ozone Depleting Substances (ODS) and off-road vehicles. A new emission source category named "off-road" was added in the transportation sector in 2011. It includes off-road vehicles such as construction equipment, lawn and garden equipment and recreational vehicles. The emissions from ODS substitutes, transmission and distribution losses and semiconductor manufacturing were not attributed to specific sectors in the fourth edition. These emissions are now attributed to specific sectors wherever applicable. In this technical support document, all changes in methodology and data since the first edition of the inventory are described and their impacts on emissions estimates are quantified.

SUMMARY OF DATA SOURCES AND ESTIMATION METHODS

A comprehensive inventory

The methods used to estimate greenhouse gas (GHG) emissions in this inventory generally follow both bottom-up and top down approaches. 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 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 various fuels combusted in California are used to estimate emissions.

With the implementation of ARB's Mandatory Greenhouse Gas Emissions Reporting Program, bottom-up GHG emissions data are becoming available for use in the statewide inventory. Mandatory reporting of GHG emissions began with year 2008 emissions. Emissions reported for every year are verified by independent verifiers, which greatly increased their accuracy and completeness. Only facilities emitting more than the regulation's thresholds are required to report their emissions. As a consequence, reported emissions represent the totality of emissions in sectors where all facilities are over the threshold (i.e. cement manufacturing and petroleum refining) but not in the other sectors, such as electricity generation. For this edition of California's GHG inventory, staff used bottom-up data from the Mandatory Reporting Program in two ways: exclusively in the case of cement plants and refineries, and as a complement to top-down sources for in-state electricity generation and imported electricity.

In the absence of a comprehensive GHG emissions reporting system, a top-down approach is usually followed. Aggregate levels of activity are in general 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. 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 are often 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 compiling the first edition of California's GHG inventory, California Air Resources Board (ARB) staff strived to be consistent with the new 2006 guidelines. However, because of time constraints, a few categories still followed the Revised 1996 guidelines. Estimation methods were updated in the second and third editions of California's GHG inventory. In this edition, all methods are consistent with the 2006 IPCC guidelines.

Built upon previous work

This version of the Technical Support Document builds on the previous versions and adds the updates and changes in the 2000-2012 statewide inventory. A major change of this edition of inventory is that the 2000-2012 emissions are based on the Global Warming Potentials (GWPs) in IPCC's Fourth Assessment Report (AR4) (IPCC, 2007). All the previous editions of the inventory were based on the GWPs in IPCC's Second Assessment Report (SAR) (IPCC, 1996).

ARB's first edition of California's Greenhouse Gas Inventory was a refinement of previous statewide inventory work. The CEC published the first multi-year inventory of California GHG emissions (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, 1995). 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 CEC's second inventory of California GHG emissions (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 CEC's third inventory of California GHG emissions extended the covered period through 2002 (CEC, 2005). This inventory initiated the inclusion 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 CEC's fourth inventory of California GHG emissions (CEC, 2006) covered the 1990-2004. 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, 2004) 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. 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 was another example for which national data was adjusted pro-rata to the population.

Since then ARB staff has continued to work closely with USEPA staff, adopting improved methods from the successive version of the national GHG inventory when appropriate.

An on-going improvement process

Staff has made many improvements to emissions estimates since ARB's previous editions of California's GHG inventory and the accompanying technical support document. The following points give an overview of updates made to the inventory over the years. More details are described in the sections related to the individual sectors.

- Emissions from the semiconductor manufacturing sector are now speciated by gas instead of a single emission value for all halogenated compounds, and nitrogen trifluoride (NF_3) was introduced as a new GHG compound in accord with the 4th IPCC Assessment report and California Senate Bill 104 passed in

2009. ARB also conducted a survey (for 2006 processes and emissions) in which data was collected from California Semiconductor manufacturing businesses. This survey result was used as a surrogate to quantify the annual changes to semiconductor emissions between 2000 and 2012.

- The inventory of emissions of substitutes to ozone depleting substances (ODS) previously relied upon USEPA's Vintaging Model which was modified periodically to incorporate changes in the assumptions used for a variety of refrigeration and air conditioning equipment types and end uses. The GHG calculation method for ODS Substitutes has been changed to utilize a new source of data. Numerous contracts for ARB were completed in which baseline surveys were conducted for the years 2002, 2007, 2008, and 2010. These surveys provided summary data of California-specific equipment types and processes which have the potential to emit ODS Substitute compounds. This time series profile was further delineated by end use sector and economic sector.
- In estimating emissions from in-state electricity production: the various types of coal have been combined into a single "coal" category; two types of non-combustion emissions were added —CO_2 from acid gas control devices and fugitive CH_4 from coal piles; data from ARB's Mandatory Reporting Program were also used in compiling 2009+ emissions. Fugitive CH_4 from coal piles was updated to now be based on amount of coal consumed, using an emission factor based on the average of MRR data for those years when it was required.
- In estimating emissions from fuel combustion in transportation and in the industrial, commercial, residential and agricultural sectors: gasoline-ethanol blends are no longer listed under the generic term of "gasoline" to allow for emissions from gasoline and ethanol to be analyzed separately; also, data on fuel use by petroleum refineries in 2009+, and cement plants in 2008+, were summarized from values reported to ARB's Mandatory Reporting Program. For the 2000-2012 version uses gasoline and ethanol data from MRR, instead of CEC's reported ethanol percentage mix.
- Two changes were made to the estimation of emissions from aviation: first, California jet fuel sales data were obtained from the Energy Information Administration State Energy Data System (EIA SEDS) rather than from previously cited non-SEDS EIA data or California Energy Balance; second, the methods used for the apportionment of aviation jet fuel among intrastate, interstate and international commercial flights were much improved by using specific fuel consumption rates for many aircraft types rather than simply the distance flown. For year 2012, the source of aviation data was changed from USEIA to California Board of Equalization (BOE).
- In the case of electricity imports: staff corrected an error carried over from the old CEC inventory in the source mix of unspecified imports from the PSW in 2000-2001; included two new specified plants located in Mexico and a geothermal plant in Nevada; integrated revisions to the table of "Total Production by Resource Type", published by the California Department of

Finance (CDOF) on the basis of data prepared by CEC; used data from CEC's Net System Power reports to directly calculate the unspecified imports emission factor for 2001-2008; and incorporated Mandatory Reporting regulation data for both specified and unspecified imports for 2009+.

- For emissions from oil and gas production: staff used data from the Division of Oil, Gas & Geothermal Resources of California's Department of Conservation for associated gas, and included a complete data set of fuel use by pipeline compressor stations from the EIA. In this version, the Mandatory Reporting data was used to obtain an average emission factor for geothermal emissions for 2000-2008.
- In the case of fugitive emissions from fuel and energy production: new categories were added, and changes were made to the methodology used for some of the other categories using data from ARB's Mandatory Reporting Program.
- For 2008+ emissions from clinker production, staff used data collected under ARB's GHG Mandatory Reporting regulation exclusively.
- Emissions of CO_2 from lime production were obtained from ARB's Mandatory Reporting Program, and include emissions from LKD by-product generation.
- For emissions from the non-energy use of fossil fuels: staff determined that several fuels that were thought to be used for non-energy purposes were actually used as refinery feedstock or as fuel blending agents, and removed them from this section; staff introduced evaporative emission estimates for solvent use as part of this section.
- In the case of nitric acid production: staff learned that all nitric acid plants in California are using non-selective catalytic reduction (NSCR) air pollution abatement devices since the 1980s and modified their N_2O emission factor accordingly. Beginning in 2010, staff used data collected under ARB's GHG Mandatory Reporting regulation exclusively.
- Emissions from carbon dioxide consumption: staff changed the ratio used to estimate California emissions by scaling down national emissions from the ratio of respective production capacities to that of populations.
- In the case of fuel consumption as feedstock for hydrogen production: staff used Mandatory Reporting data to estimate the proportion of natural gas and refinery gas for each year and made direct use of Mandatory Reporting data for 2009+.
- Emissions of methane from livestock enteric fermentation are based on USEPA models, changes included: adjustments to the population and typical weights of several classes of livestock; improvements to the inputs to the models used to predict methane production from cattle; and a change of method to estimate California's horse population. In this version, enteric emissions from bulls are now estimated using the CEFM like other categories of cattle. New categories of cattle, such as dairy calves and beef calves were added in the 2000-2012 version of the inventory.
- Major changes in data and methods used in the estimation of emissions from manure management include: addition of anaerobic digesters to the list of

waste management systems; changes in the distribution of some livestock classes among manure management systems; use of outputs from USEPA's Cattle Enteric Fermentation Model as inputs to the manure management emissions calculations —which increases the methodological consistency with the enteric fermentation modeling; revision of population numbers and manure characteristics of several classes of livestock; and reporting of emissions of CH_4 and N_2O by animal group *and* by manure management system.

- Staff made revisions to the type of crop data used to estimate emissions from agricultural residue burning. An improved emission factor was derived for rice cultivation for years 2000-2012, in collaboration with USEPA.
- For 2009-2011 version, fertilizer tonnage survey data were revised for 2009-on. Estimates of the amount of nitrogen in the un-managed manure for beef cattle were adjusted based on new data.
- Extensive changes to both the domestic and industrial wastewater emission equations occurred since the publication of the 1990-2004 edition of the GHG Inventory: four domestic wastewater treatment options are now considered each with a separate equation (septic systems, centrally treated aerobic systems, centrally treated anaerobic systems and anaerobic digesters); a distinction is made between plants with and without nitrification/denitrification; the per capita protein consumption factor was modified; methane emissions from the pulp and paper manufacturing industries are now included and the estimation of emissions from wastewater treatment facilities of petroleum refineries is based on a new approach; other data used in the calculations were updated. No changes have been made to these methods since 2009.

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.

GHG ESTIMATION METHODS AND SUPPORTING DATA SOURCES

I. Energy

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

1. Background

The sources of energy used for electricity generation are varied in nature and origin: fuel combustion, hydropower, nuclear, solar, wind, and geothermal. The dominant source of energy for electricity and heat production in California is fuel combustion, and greenhouse gases (GHG) are emitted during this process. With the exception of fugitive emissions of CO_2 released from geologic formations tapped for geothermal energy, other energy sources do not emit GHG in the energy conversion process. 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 associated with the distribution of electricity 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, etc.), liquid fuels (distillate, residual fuel oil, jet fuel, etc.), and solid fuels (coal, petroleum coke, etc.). Various biomass 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 biomass 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 total.

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 it a potentially more energy efficient means of generating electricity. Although Combined-Cycle Power Plants that use a combustion turbine (usually burning natural gas) followed by a heat-recovery steam generator to convert waste heat into steam for even more power generation, are a type of CHP, because they only produce power, they count as the first category and not as CHP. For CHP, 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). 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

2.1 Stationary combustion emissions

The method for estimating stationary combustion emissions follows IPCC 2006 guidelines (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 (higher heating value) 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, biomass, coal, crude oil, digester gas, distillate, jet fuel, kerosene, landfill gas, municipal solid waste, natural gas, 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 biomass fuels. These fuels are a mix of materials from biomass and fossil origins. Municipal solid waste (MSW) and used tires are two such fuels.

Equation 2: Variant for partially renewable fuels

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

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, Biomass]

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_00-12/annex_1a_electricity_and_heat_production_in_state.pdf

2.2 Other emissions

Non-combustion emissions from electricity and heat production include CO_2 from acid gas control devices and fugitive emissions of CH_4 from coal storage piles. Information about these sources of emissions first became available through the ARB Mandatory Reporting Regulation (MRR) (ARB, 2007).

To estimate emissions from these sources for years without MRR data, staff assumed that these emissions would scale with the amount of activity associated with each source. For acid gas control, the MRR data showed that only coal, coke, biomass and MSW fuels were associated with this process. Thus, emissions from this source were estimated for years 2000 to 2008 pro rata the total amount of heat (BTU) generated by these fuels in each of these years. A similar method was applied to scale the fugitive methane emissions from coal storage piles for 2000 to 2008 and for 2011 onwards (as MRR no longer required these emissions be reported), using only the amount of coal consumed for this purpose. That is:

Equation 3: Back-scaling of non-combustion emissions

$$E_{GHG,\ source,year} = \frac{E_{GHG,\ source,MRR}}{H_{source,MRR}} \bullet H_{source,\ year}$$

Where,

$E_{GHG,\ source,\ year}$ = Emissions of the given GHG from the particular sources in the given year (g of GHG)

$E_{GHG,\ source,\ MRR}$ = Emissions of the given GHG from the particular source in MRR (g of GHG)

$H_{\text{source, year}}$ = amount of combustion heat associated with the source in the given year (BTU) for acid gas, or amount of coal consumed (tons) for fugitive methane

$H_{\text{source, MRR}}$ = amount of combustion heat associated with the source in MRR (BTU) for acid gas, or amount of coal consumed (tons) for fugitive methane

With,

GHG = [CO_2 or CH_4]

Source = [Acid gas control device, Coal pile]

Year = [2000-2011]

3. Data Sources

Fuel-use data for 2000 was obtained through personal correspondence with the U.S. Energy Information Administration, the statistical arm of the U.S. Department of Energy (Schnapp, 2008). Fuel use data for 2001-2008 was downloaded from U.S. Energy Information Administration (EIA) databases published online (EIA, 2013a). These fuel-use datasets are available online in full detail starting with year 2001, but are not available at the same level of detail for previous years. Detailed data for these years are available from the EIA upon special request.

Heat content data for 2000-2008 also came from the U.S. Energy Information Administration (Schnapp, 2008; EIA, 2013a). CO_2, CH_4 and N_2O emissions factors come from ARB's Mandatory Reporting Program data (ARB, 2012).

The data source for 2009+ fuel-use, heat content, and emissions are primarily from ARB's Mandatory Reporting Program data (ARB, 2012). The threshold of reporting for power plants excludes plants with emissions less than 2,500 metric tons per year (10,000 metric tons in 2011 onwards), so for these plants (which amount to less than 2 percent of the emissions from in-state electricity generation) EIA data were used (EIA, 2013a).

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 apportion 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	OG (for EIA ID: 56090 only)
Biomass	AB, BLQ, OBL, OBS, ORW, SLW, WDL, WDS, WWW
Coal	BIT, LIG, SUB, SC, WC
Crude Oil	OTH
Digester Gas	OBG
Distillate	DFO

ARB GHG Inventory Fuel	EIA Fuel Code(s) Included
Geothermal	GEO
Jet Fuel	JF
Kerosene	KER
Landfill Gas	LFG, MLG
Municipal Solid Waste (MSW)	MSB, MSN, MSW
Natural Gas	NG
Petroleum Coke	PC
Propane	PG
Refinery Gas	BFG, 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” based on the EIA sector code in Table 2. For years 2009+ staff also used data from ARB’s Mandatory Reporting Program for CHP facilities reporting therein.

3.3 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 provided by Covanta Energy (Hahn, 2007) from the three power plants burning MSW in the state to estimate that, on a carbon basis, about 66 percent of the MSW burned in California for energy is from renewable biomass origin. These values serve as defaults when source specific data is not available.

For 2009+, staff used Mandatory Reporting data supplied updated values for these fuels where reported as based on source tests or other measurement methods done by each reporting facility.

4. Changes in Estimates

When compared with the 2000-2011 edition of the GHG inventory, only minor changes have been made to the estimates.

CHP total fuel use is divided into that used for electricity production and that used for UTO. Prior to MRR data, EIA data was used for this split. MRR data was then used once it was available (2009-2011). However, this data is of lower priority in the MRR, as it does not get used in Cap & Trade, and this combined with the changes made to the MRR over the past few years to make it compatible with EPA and improve reporting, resulted in inconsistent data in this area. This led to strange trends in the CHP fuel splits for 2009-2011 compared to the 2000-2008 time series when EIA data was used. It was decided to continue to use EIA data to split MRR fuel until the MRR could become stable and give at least 3 good years of consistent reporting. Thus for 2009-2012, EIA data was used to split out fuel for CHP, and this lead to some changes compared to previous estimates for 2009-2011.

All together these changes and updates made by data sources resulted in minor changes in emissions estimates for the categories included in this section: 3.6 percent on average for 2011 (the latest overlapping year) when compared with the estimates in the previous edition of ARB's GHG inventory.

5. Future Improvements

ARB's Mandatory Reporting Program includes detailed information related to cogeneration activities (amount of useful thermal output generated and amount of gross generation produced). This data will assist ARB staff in better allocating emissions between the electric power and UTO components of cogeneration plants. These data were first available for 2011 and will be incorporated into future GHG inventory editions once at least 3 years of consistent and stable data is reported.

B. Electricity Production - Imports (IPCC 1A1a)

1. Background

California's highly interconnected electricity system relies on imports as well as on electricity generated in state. 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" (I.B.3.1 below); emissions from all other imports are discussed in the "unspecified imports" (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. The specified imports consist of those listed in Table 3 below.

Two natural gas plants, La Rosita and Termoeléctrica de Mexicali are located in Mexico (MEX) and thus do not report to the EIA (and do not have an EIA ID). Data for these plants comes from the CEC's Quarterly Fuels and Energy Report (QFER) database (Nyberg, 2009). The CEC ID of these two facilities is included instead of the EIA ID. The Armstrong Woodwaste Cogeneration Plant and the Prince George Pulp & Paper Plant are biomass plants in Canada (CAN), and do not have EIA IDs; nor do they report to the CEC. The emission factors for these plants were estimated from data obtained through a survey of the two facilities. Bonneville Power Administration is an Asset Controlling Supplier and has no individual EIA ID. For 2011 they used a default assumption of 20% of the Unspecified Imports Emission Factor as their own. In 2012 and future years, they will develop their own emission factor based on their total system emissions and generation, available through MRR.

Table 3: Specified imports

Plant Name-Primary Fuel (EIA ID)	***State/Country (Import Region)***
Apache Station - Coal (160)	AZ (Pacific Southwest)
Apex Generating Station - Natural Gas (55514)	NV (Pacific Southwest)
Arlington Valley Energy Facility - Natural Gas (55282)	AZ (Pacific Southwest)
Armstrong Woodwaste Cogeneration - Biomass (NA)	CAN (Pacific Northwest)
Blundell - Geothermal (299)	UT (Pacific Southwest)
Boardman - Coal (6106)	OR (Pacific Northwest)
Bonanza - Coal (7790)	UT (Pacific Southwest)
Bonneville Power Administration - Hydropower (NA)	N/A (Pacific Northwest)
Caithness Dixie Valley - Geothermal (52015)	NV (Pacific Southwest)
Colstrip - Coal (6076)	MT (Pacific Northwest)
Desert View Power – Biomass (10300)	CA (Tribal Lands in CA)
El Dorado Energy - Natural Gas (55077)	NV (Pacific Southwest)
Four Corners - Coal (2442)	NM (Pacific Southwest)
Gila River Power Station - Natural Gas (55306)	AZ (Pacific Southwest)
Grays Harbor Energy Facility - Natural Gas (7999)	WA (Pacific Northwest)
Griffith Energy - Natural Gas (55124)	AZ (Pacific Southwest)
Hardin Generating Project - Coal (55749)	MT (Pacific Northwest)
Harquahala Generating Project - Natural Gas (55372)	AZ (Pacific Southwest)
Hermiston Power - Natural Gas (55328)	OR (Pacific Northwest)
Hunter - Coal (6165)	UT (Pacific Southwest)
Intermountain - Coal (6481)	UT (Pacific Southwest)
Kettle Falls - Biomass (550)	WA (Pacific Northwest)
Klamath Falls Cogen - Natural Gas (55103)	OR (Pacific Northwest)
Klamath Peaking - Natural Gas (55544)	OR (Pacific Northwest)
La Rosita - Natural Gas (G9787)	MEX (Pacific Southwest)
Mesquite Generating Station - Natural Gas (55481)	AZ (Pacific Southwest)
Mohave - Coal (2341)	NV (Pacific Southwest)
Navajo - Coal (4941)	AZ (Pacific Southwest)

Plant Name-Primary Fuel (EIA ID)	***State/Country (Import Region)***
Nebo Power Station - Natural Gas (56177)	UT (Pacific Southwest)
Prince George Pulp & Paper - Biomass (NA)	CAN (Pacific Northwest)
Red Hawk - Natural Gas (55455)	AZ (Pacific Southwest)
Reid Gardner - Coal (2324)	NV (Pacific Southwest)
Roosevelt Biogas – Biomass (7832)	WA (Pacific Northwest)
San Juan - Coal (2451)	NM (Pacific Southwest)
Sierra Pacific Burlington - Biomass (56406)	WA (Pacific Northwest)
Simpson - Biomass (57099)	WA (Pacific Northwest)
Southpoint Energy Center - Natural Gas (55177)	AZ (Pacific Southwest)
Termoeléctrica de Mexicali - Natural Gas (G9786)	MEX (Pacific Southwest)
Thermo No. 1 Raser - Geothermal (57353)	UT (Pacific Southwest)
Transalta Centralia Generation - Coal (3845)	WA (Pacific Northwest)
Trans-Jordan Generating Station - Biomass (56853)	UT (Pacific Southwest)
Weyerhaeuser Long View - Biomass/Coal/Natural Gas (50187)	WA (Pacific Northwest)
Yucca/Yuma Axis - Natural Gas (120 & 121)	AZ (Pacific Southwest)
Yuma Cogeneration Associates - Natural Gas (54694)	AZ (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. For years 2000 to 2008, a composite emission factor was developed, based on data provided by the CEC. For 2009+, staff used an emission factor developed by the Western Climate Initiative (WCI) (WCI, 2011). This change of method was motivated by two reasons: (a) the discontinuation in 2009+ of the CEC data reporting (Net System Power) on which the previous emission factors were based; and (b), to maintain consistency with the upcoming cap and trade program, which uses the WCI emission factor. The WCI has estimated unspecified imports emission factors for 2006 to 2008, and staff used the average of these 3 values as the 2009+ emission factor.

As electrical power is transmitted through power lines, losses occur primarily because of resistance. 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 for import into California at the plant of origin was known and thus there was no need for line loss corrections. In some cases (e.g. Colstrip, Bonanza and Hunter in 2000-2008) 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. In those cases, 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. For 2000-2008, staff used line loss factors of 7.5 percent for imports from Colstrip and Hunter, and 3 percent for imports from Bonanza. This last factor reflects the line loss estimates included in the contract for power purchased from the Bonanza plant by LADWP (Parsons, 2009). Line losses from the remaining two specified imports (Colstrip and Hunter) and all unspecified imports were estimated using the CEC suggested loss factor of 7.5 percent. For 2009+, Mandatory Reporting electricity imports data was used, which include line losses (defaulting to 2% if not known), eliminating the need for such a correction.

Statewide electricity imports are typically reported as net imports (gross imports – exports). However, accounting for all emissions resulting from the generation of electrical power for California requires estimating the gross import value. Actual export data was obtained from the California Department of Finance (CDOF) California Statistical Abstract – Table J-11 (CDOF, 2010) for 2001-2008. These export estimates were then added to the net import value to obtain the gross import number. For 2000, the average of the 2002-2004 exports were used as an estimate, and for 2009+, this procedure was no longer necessary as the Mandatory Reporting Program captured gross imports directly.

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 2000 were obtained through personal correspondence with Robert Schnapp of the U.S. Energy Information Administration (Schnapp, 2008). Data for 2001 to 2008 were downloaded from U.S. Energy Information Administration databases published online (EIA, 2013a). 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, 2009). Imported generation contract data was provided by LADWP (Parsons, 2009) for the Bonanza and Colstrip plants and by the City of Riverside (Mendez, 2009) for the Hunter plant. For 2009+, Mandatory Reporting data (ARB, 2012) was used to determine the amount of electricity (MWh) imported while the emission factors applied to these imports were estimated from EIA data (EIA, 2013a), CEC data (Nyberg, 2009), or informal surveys of fuel use of facilities that exist outside the USA (e.g. 2 facilities in Canada) for these plants.

Fuel CO_2, CH_4 and N_2O Emissions factors are from ARB's Mandatory Reporting Program data (ARB, 2012).

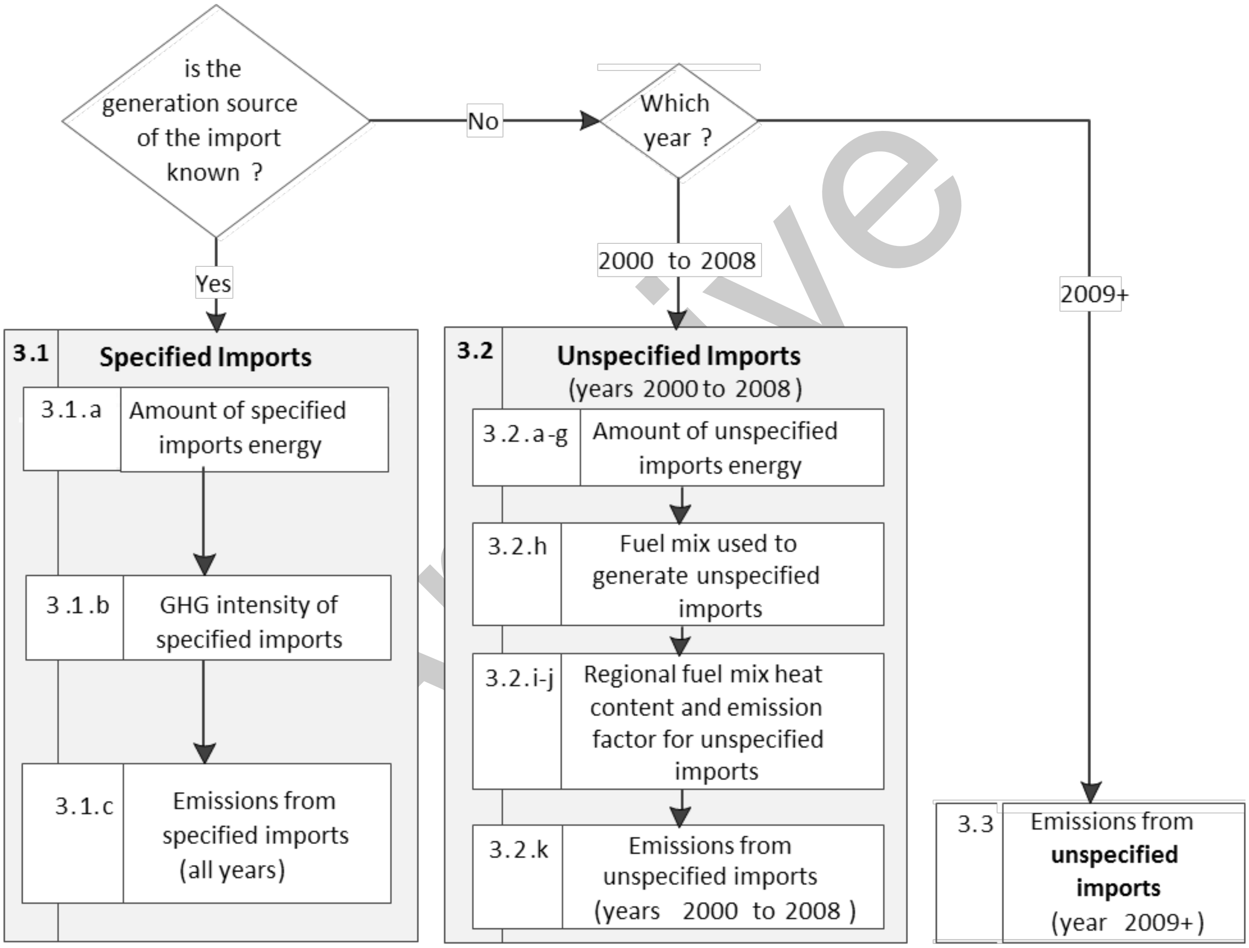
Net Imports data for 2000-2008 are from the California Department of Finance's (CDOF) California Statistical Abstract Table J-11 (CDOF, 2010). The CEC provided data on line losses, exports (Alvarado, 2007), ownership and entitlement shares (Griffin, 2007), and assumptions for the fuel mix of unspecified imports for 2000 and 2001 (CEC, 2000) and for 2002 to 2008

(CEC, 2002-08). The emission factor used for 2009+ unspecified imports comes from the Western Climate Initiative (WCI) (WCI, 2011), but are contained in ARB's Mandatory Reporting Program data (ARB, 2012).

3. Methodology

The methodological steps involved in estimating emissions from electricity imports depends upon whether the generation source of the imports is known or not and with the year of the estimate (see Figure 1).

Figure 1: Methodological steps involved in estimating emissions from electricity imports



3.1 Specified Imports

(a) Amount of specified imports energy

For 2000-2008, ownership, entitlement or contracted import amounts were provided by the CEC except for the Intermountain, Mohave, Navajo, Colstrip, and Bonanza plants, for which data were obtained from the LADWP (Parsons, 2009), and for the Hunter plant which information was provided by the City of

Riverside (Mendez, 2009). For Colstrip, Bonanza and Hunter, 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 or the City of Riverside 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 data allow one to calculate the percentage of a given plant's electricity generation imported into California that year. A subset of these percentages is shown in Table 4 below. Note that Hoover (hydropower) and Palo Verde (nuclear) are included below even though they are not shown in the inventory itself because they generate no emissions.

Table 4: Percent of plant electricity generation imported by California

Plant Name (State) – Fuel	***2000***	***2001***	***2002***	***2003***	***2004***	***2005***	***2006***	***2007***	***2008***
Boardman (OR) - Coal	27.29	23.50	23.50	23.50	23.50	23.50	23.50	23.50	23.50
Bonanza (UT) - Coal	7.49	5.59	5.24	5.80	5.79	5.76	5.42	5.61	5.61
Caithness Dixie Valley (NV) - Geothermal	97.83	95.10	96.02	96.89	100	98.04	99.44	97.79	99.46
Colstrip (MT) - Coal	0*	0*	0*	0*	0*	0*	0*	0*	0*
Four Corners (NM) - Coal	34.61	36.05	36.05	36.05	36.05	36.05	36.05	36.05	36.05
Hoover (AZ/NV) - Hydro	76.57	76.57	76.57	76.57	76.57	76.57	76.57	76.57	76.57
Hunter (UT) - Coal	2.42	2.78	2.29	2.15	2.28	2.31	2.24	2.09	2.15
Intermountain (UT) - Coal	99.11	96.83	96.38	97.08	93.75	94.76	93.79	89.59	88.57
La Rosita (MEX) - Natural Gas	0*	0*	0*	0*	0*	0*	0*	0*	52.38
Mohave (NV) - Coal	76.02	75.35	66.02	66.12	66.11	66.11	0*	0*	0*
Navajo (AZ) - Coal	21.19	21.18	21.37	21.40	20.74	19.70	20.41	20.83	20.97
Palo Verde (AZ) - Nuclear	27.41	27.41	27.41	27.41	27.41	27.41	27.41	27.41	27.41
Reid Gardner (NV) - Coal	29.22	28.88	28.88	28.88	28.88	28.88	28.88	28.88	28.88
San Juan (NM) - Coal	4.37	24.08	24.08	24.08	24.08	24.08	24.08	24.08	24.08
Termoeléctrica de Mexicali (MEX) - Natural Gas	0*	0*	0*	0*	0*	0*	0*	100	100
Yucca/Yuma Axis (AZ) - Natural Gas	42.61	42.61	42.61	42.61	42.61	42.61	42.61	42.61	42.61

*LADWP imported from Colstrip for years 1990-1999 (about 5.8 percent on average) and from Mohave for years 1990-2005. Termoeléctrica de Mexicali began exporting in 2007 and La Rosita began in 2008.

For 2009+, the amount of electricity imported into the state from each specified source was queried from ARB's Mandatory Reporting Program's database (ARB, 2012).

(b) GHG intensity of specified imports

Staff used fuel use and heat content data from EIA or CEC, and fuel specific emission factors to estimate the GHG intensity per MWh of electricity from each plant as follows:

Equation 4: GHG intensity of specified imports

$$\boxed{I_{GHG,\ plant} = \frac{\sum\limits_{fuel} Q_{fuel,plant} \bullet HC_{fuel,plant} \bullet EF_{GHG,\ fuel,plant}}{TG_{plant}}}$$

Where,

$I_{GHG,\ plant}$ = GHG intensity of electricity from the given plant, for the particular GHG (g of GHG per MWh)
$Q_{fuel,\ plant}$ = Amount of fuel combusted at the given plant (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 at the given plant (BTU / unit)
$EF_{GHG,\ fuel}$ = Emission factor of the particular GHG by combustion of the given fuel (g GHG / BTU)
TG_{plant} = Total net generation of electricity at the given plant (MWh)

With,

GHG = [CO_2, CH_4, N_2O]
Fuel = [biomass, coal, distillate, natural gas, residual fuel oil]
Plant = [the specified plant]

Some of the specified imports came from geothermal plants (e.g. Caithness Dixie Valley). GHG intensity was estimated by calculating emissions from those plants with the method described in section I.G below and dividing by the total net amount of electricity produced.

(c) Emissions from specified imports

Emissions from specified imports are then estimated using the following equation:

Equation 5: Emissions from specified imports

$$\boxed{E_{GHG,\ plant} = I_{GHG,plant} \bullet IG_{plant}}$$

Where,

$E_{GHG,\ plant}$ = Emissions of the particular GHG from the specified imports from the given plant (g)
$I_{GHG,\ plant}$ = GHG intensity of electricity from the given plant, for the particular GHG (g of GHG per MWh)
IG_{plant} = Imported amount of the net electricity generated by the given plant (MWh)

With,

GHG = [CO_2, CH_4, N_2O]
Plant = [the specified plant]

Values for the EIA or plant specific heat inputs and emission factors are available upon request. For a list of yearly activity and GHG intensities used in the emission estimation equation, please consult the online documentation annex at: http://www.arb.ca.gov/cc/inventory/doc/methods_00-12/annex_1b_electricity_production_imports.pdf

3.2 Unspecified Imports (years 2000 to 2008)

For years 2000 and 2001, the fuel mix used for unspecified imports and the resulting GHG emissions are based on CEC's *1999 Net System Power Calculation* (CEC, 2000), and on CEC's *Net System Power Reports* for years 2002 to 2008 (CEC, 2002-08). ARB staff relies on the expertise of CEC staff in this matter. Any future updates on these fuels used in the production of unspecified power will involve collaboration between staff of ARB and CEC. Detailed data used for all calculations are available upon request.

Electricity imported into California originates from two regions: the Pacific Northwest (PNW) and Pacific Southwest (PSW).

(a) Net electricity imports

Net imports data come from the California Department of Finance (CDOF) California Statistical Abstract – Table J-11 (CDOF, 2010). Table J-11 is based on data supplied to CDOF by the CEC.

Table 5: Net imports (GWh)

Region	2000	2001	2002	2003	2004	2005	2006	2007	2008
PNW	18,777	6,826	27,186	22,303	20,831	20,286	19,803	24,669	23,959
PSW	7,997	58,107	60,408	63,097	70,458	66,795	59,911	67,547	74,113

(b) Electricity exports - years with data

Known exports data for years 2001 to 2008 were also taken from CDOF's table J-11, values for year 2000 are not available:

Table 6: California exports (GWh)

Region	2000	2001	2002	2003	2004	2005	2006	2007	2008
PNW	Unknown	5,846	1,020	1,471	1,532	2,061	2,518	2,620	2,242
PSW	Unknown	9,007	5,514	4,555	3,292	3,623	2,539	2,966	2,822

(c) Electricity exports - estimation for years without data

First, staff used years 2002 to 2004 of data from Table 5 and Table 6 to determine the average ratio of exports to net imports in gigawatt-hours (GWh) for each region as follows:

Equation 6: Average ratio of exports to net imports of electricity

$$Ratio = \frac{\sum_{year=2002}^{2008} Exports_{year}}{\sum_{year=2002}^{2008} Net\_imports_{year}}$$

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 average export-to-import ratios were 6 percent (0.06) for the PNW and 7 percent (0.07) for the PSW.

These export-to-import ratios were then applied to the net imports for year 2000 from each of these regions to estimate the exports for that year.

Table 7: Estimate of California exports (GWh)

Region	***2000***	***2001-2008***
PNW	1,074	See Table 6
PSW	3,418	See Table 6

(d) Gross imports

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

Table 8: Gross imports (GWh)

Region	***2000***	***2001***	***2002***	***2003***	***2004***	***2005***	***2006***	***2007***	***2008***
PNW	19,851	12,672	28,206	23,774	22,363	22,347	22,321	27,289	26,201
PSW	11,415	67,114	65,922	67,652	73,750	70,418	62,450	70,513	76,935

(e) Amount of generation related to gross 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	**2000**	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**
PNW	21,461	13,699	30,493	25,702	24,176	24,159	24,131	29,502	28,325
PSW	12,341	72,556	71,267	73,137	79,730	76,128	67,514	76,230	83,173

(f) Amount of specified imports included in net imports data

To avoid double counting emissions, specified imports (see section 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 or entitlement generation prior to 2001. On the basis of this information, ARB staff determined that, before 2001, only contracted imports were included in table J-11 and needed to be removed. These include three plants: Bonanza, Colstrip and Hunter.

For 2000, only Bonanza, Colstrip and Hunter were removed. For years 2001 to 2008, all the specified imports were removed:

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

Region	2000	2001	2002	2003	2004	2005	2006	2007	2008
PNW	0	1,040	887	1,011	832	814	558	1,023	951
PSW	451	46,505	45,425	44,513	45,397	43,992	37,671	40,164	43,918

(g) Amount of unspecified imports energy

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

Table 11: Unspecified imports (GWh)

Region	2000	2001	2002	2003	2004	2005	2006	2007	2008
PNW	21,461	12,659	29,606	24,691	23,344	23,345	23,573	28,478	27,374
PSW	11,890	26,051	25,842	28,624	34,333	32,135	29,842	36,066	39,255

(h) Fuel Mix used to generate unspecified imports

The fuel mix of unspecified imports was based directly on the CEC's *1999 Net System Power Calculation* (CEC, 2000) for years 2000 and 2001 and through a reconciliation methodology with their *Net System Power Reports* (NSP) for years 2002 to 2008 (CEC, 2002-08). NSP was not used for 2001 due to the potential for aberrant values resulting from the California energy market crisis.

The methodology for determining the unspecified imports fuel mix for 2002-2008 using the NSP data is described briefly here.

First, the total gigawatt-hours (GWh) of imports by fuel type (Coal, Natural Gas, and Non-Emitting) and by region were compiled from the NSP reports for 2002-2008:

Table 12: Net System Power (GWh by fuel type and region)

Region	Fuel	2002	2003	2004	2005	2006	2007	2008
PNW	Coal	5,283	7,488	5,154	4,926	5,467	6,546	8,581
	Natural Gas	1,717	1,911	1,926	1,786	2,051	1,837	2,939
	Non-Emitting	20,186	12,904	10,346	13,574	12,286	16,286	12,425
PSW	Coal	21,582	24,306	20,760	24,796	23,195	39,275	43,271
	Natural Gas	6,865	7,738	8,400	10,812	13,207	16,363	15,060
	Non-Emitting	7,226	7,464	5,912	6,562	8,557	11,909	15,782

Second, these values, which represent the amount of electricity measured at the California border (and thus is missing the line losses), were increased to estimate the amount of electricity generated at the plant of origin, so a full reckoning (including line losses) could be developed. The values in Table 12 were divided by 0.925 to account for line losses using the CEC suggested line loss value of 7.5 percent (Alvarado, 2007).

Additionally, the amount of generation from two plants (Intermountain and Mohave) was added to the NSP report values for years 2002 to 2006 to stay consistent with CDOF's table J-11. This table includes all imports, whereas the NSP reports for 2002 to 2006 exclude the generation from those two plants, considering them as utility owned rather than imports. The NSP reports for 2007 and 2008 do include these two plants into the totals and future reports will continue to do so. Thus this adjustment is needed only for years 2002 to 2006. Table 13 below incorporates both the line loss adjustment and the addition of the two missing specified imports from Intermountain and Mohave:

Table 13: Net System Power (adjusted to account for missing specified imports & line losses)

Region	Fuel	2002	2003	2004	2005	2006	2007	2008
PNW	Coal	5,926	8,629	6,062	5,866	6,662	7,828	10,145
	Natural Gas	1,926	2,202	2,265	2,127	2,499	2,197	3,475
	Non-Emitting	22,641	14,870	12,168	16,165	14,971	19,476	14,690
PSW	Coal	46,598	48,915	44,852	49,023	40,046	44,324	48,561
	Natural Gas	8,569	9,330	9,933	12,693	15,084	18,466	16,901
	Non-Emitting	9,019	9,000	6,991	7,704	9,773	13,440	17,711

Third, the Specified Imports by fuel type for years 2002 to 2008 were determined. The values in Table 14 below match those of Table 10, except that the Table 14 values are shown in greater detail:

Table 14: Specified imports by fuel type and region (GWh)

Region	Fuel	2002	2003	2004	2005	2006	2007	2008
PNW	Coal	887	1,011	832	814	558	1,023	951
	Natural Gas	0	0	0	0	0	0	0
	Non-Emitting	0	0	0	0	0	0	0
PSW	Coal	32,782	33,125	34,121	33,586	27,460	26,057	25,769
	Natural Gas	171	99	109	105	126	3,417	6,881
	Non-Emitting	12,472	11,289	11,167	10,302	10,086	10,691	11,268

Fourth, Specified Imports (Table 14) were deducted from total imports (Table 13) to obtain the values of Unspecified Imports:

Table 15: Unspecified imports by fuel type and region (GWh)

Region	Fuel	2002	2003	2004	2005	2006	2007	2008
PNW	Coal	5,039	7,618	5,229	5,052	6,104	6,805	9,194
	Natural Gas	1,926	2,202	2,265	2,127	2,499	2,197	3,475
	Non-Emitting	22,641	14,870	12,168	16,165	14,971	19,476	14,690
	Total	29,606	24,691	19,663	23,345	23,574	28,478	27,359
PSW	Coal	13,816	15,790	10,731	15,437	12,586	18,267	22,792
	Natural Gas	8,398	9,231	9,824	12,588	14,958	15,050	10,020

Region	Fuel	2002	2003	2004	2005	2006	2007	2008
	Non-Emitting	0	0	0	0	161	2,749	6,443
	Total	**22,214**	**25,021**	**20,555**	**28,025**	**27,705**	**36,066**	**39,255**

Finally, taking the fuel and region specific values in Table 15 and dividing each by the total for that region produced the percentages in Table 16, which were used to calculate the emissions from Unspecified Imports for 2002 to 2008. The values for 2000 and 2001 were taken directly from the CEC's 1999 Net System Power Calculation (CEC, 2000) and required no additional calculations:

Table 16: Fuel-mix of unspecified imports (percentage)

Region	Fuel	2000	2001	2002	2003	2004	2005	2006	2007	2008
PNW	Coal	20%	20%	17%	31%	27%	22%	26%	24%	34%
	Natural Gas	0%	0%	7%	9%	12%	9%	11%	8%	13%
	Non-Emitting	80%	80%	76%	60%	62%	69%	64%	68%	54%
PSW	Coal	74%	74%	62%	63%	52%	55%	45%	51%	58%
	Natural Gas	26%	26%	38%	37%	48%	45%	54%	42%	26%
	Non-Emitting	0%	0%	0%	0%	0%	0%	1%	8%	16%

(i) Average heat content and emission factors for unspecified imports

(i.i) Weighted average heat content

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 7: Weighted average heat contents of fuels

$$WHC_{fuel} = \frac{\sum_{type,plant}(Q_{fuel,type,plant} \bullet HC_{fuel,type,plant})}{\sum_{type,plant} G_{fuel,type,plant}}$$

Where,

WHC_{fuel} = Weighted average heat content for the given fuel (btu per MWh)

$Q_{fuel,\ type,\ plant}$ = Quantity of the given fuel of the particular type combusted by the given plant (tons for coal, scf for natural gas)

$HC_{fuel,\ type,\ plant}$ = Heat content of the given fuel of the particular type combusted by the given plant (btu / ton for coal, btu / scf for natural gas)
$G_{fuel,\ type,\ plant}$ = Power generated with given fuel of the particular type by the given plant (MWh)

With,
fuel = [coal, natural gas]
type = [bituminous, lignite, etc.], applies only to coal
plant: power plants in either Pacific Northwest or Pacific Southwest region

(i.ii) Weighted average emission factor

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 8: Weighted average fuel emission factors of unspecified imports

$$\boxed{WEF_{GHG,fuel} = \frac{\sum_{plant}(Q_{fuel,plant} \bullet HC_{fuel,plant} \bullet EF_{GHG,fuel,plant})}{\sum_{plant}(Q_{fuel,plant} \bullet HC_{fuel,plant})}}$$

Where,
$WEF_{GHG,\ fuel}$ = Weighted average emission factor for one of the given GHG, for a given fuel (grams per btu)
$Q_{fuel,\ plant}$ = Amount of the given fuel combusted by the particular plant (tons for coal, scf for natural gas)
$HC_{fuel,\ plant}$ = Heat content of the given fuel combusted by the particular plant (btu / ton for coal, btu / scf for natural gas)
$EF_{GHG,\ fuel,\ plant}$ = Emission factor of a given GHG from the given fuel combusted by the particular plant (g of GHG per btu)

With,
fuel = [coal, natural gas]
GHG = [CO_2, CH_4, N_2O]
plant: 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 9: Combined-GHG emission factors of unspecified imports

$$CEF_{fuel} = \frac{\sum_{GHG}(WHC_{fuel} \bullet WEF_{GHG,fuel} \bullet GWP_{GHG})}{453.6}$$

Where,

CEF_{fuel} = Combined-GHG emission factor of the given fuel (lbs CO_2e per MWh)
WHC_{fuel} = Weighted average heat content for the given fuel (btu per MWh)
$WEF_{GHG,\ fuel}$ = Weighted average emission factor for the given GHG, for a given fuel (grams per btu)
GWP_{GHG} = Global Warming Potential of a given GHG (unitless)
453.6 = number of grams in a pound

With,

fuel = [coal, natural gas, non-emitting]
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 17: Fuel-specific combined-GHG emission factors for Unspecified Imports (lbs CO_2e / MWh)

Region	**Fuel**	**2000**	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**
PNW	Coal	2,169	2,268	2,339	2,301	2,316	2,310	2,344	2,316	2,301
	Natural Gas	1,024	1,014	947	923	838	838	852	857	835
	Non-Emitting	0	0	0	0	0	0	0	0	0
PSW	Coal	2,116	2,201	2,208	2,207	2,195	2,210	2,218	2,223	2,209
	Natural Gas	1,141	1,162	1,049	1,062	1,009	943	939	923	916
	Non-Emitting	0	0	0	0	0	0	0	0	0

(j) Regional fuel-mix heat content 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 16.

Equation 10: Regional fuel-mix heat contents for unspecified imports

$$RHC_{region} = \sum_{fuel} WHC_{fuel} \bullet P_{fuel,region}$$

Where,

RHC_{region} = Regional fuel-mix heat content for the particular region (btu per MWh)
WHC_{fuel} = Weighted average heat content for the given fuel (btu per MWh)
$P_{fuel,\ region}$ = Proportion of power generated in a particular region using the given fuel (percent)

With,
fuel = [coal, natural gas]
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.ii) above by the regional fuel mix values of Table 16.

Equation 11: Regional fuel-mix emission factors for unspecified imports

$$\boxed{REF_{GHG,region} = \sum_{fuel} WEF_{GHG,fuel} \bullet P_{fuel,region}}$$

Where,
$REF_{GHG,\ region}$ = Regional fuel-mix emission factor for the given GHG in the particular region (g GHG / btu)
$WEF_{GHG,\ fuel}$ = Weighted average emission factor for the given GHG for the given fuel (g GHG / btu)
$P_{fuel,\ region}$ = Proportion of power generated in a particular region using the given fuel (percent)

With,
fuel = [coal, natural gas, non-emitting]
GHG = [CO_2, CH_4, N_2O]
region = [PNW, PSW]

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 16) by the corresponding combined-GHG fuel-specific emissions factors (Table 17) and summing to arrive at a single factor for each region for each year. The Total Imports row in Table 18 shows the yearly system-wide average emission factors for California's unspecified imports.

Table 18: Regional emission factors for Unspecified Imports (lb CO_2e / MWh)

Region	**2000**	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**
PNW	434	454	460	792	713	576	697	620	879
PSW	1,862	1,931	1,770	1,785	1,628	1,641	1,514	1,511	1,517
Total Imports	**943**	**1,448**	**1,070**	**1,325**	**1,258**	**1,193**	**1,154**	**1,118**	**1,255**

(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 12: Emissions from unspecified imports

$$\boxed{E_{GHG,region} = UI_{region} \bullet RHC_{region} \bullet REF_{GHG,region}}$$

Where,

$E_{GHG,\ region}$ = Emissions of the given GHG for unspecified imports from the particular region (g of GHG)

UI_{region} = Amount of unspecified power imported from the particular region (MWh)

RHC_r = Regional fuel-mix heat content for the particular region (btu per MWh)

$REF_{g,r}$ = Regional fuel-mix emission factor for the given GHG in the particular region (g / btu)

With,

GHG = [CO_2, CH_4, N_2O]

region = [PNW, PSW]

3.3 Emissions from unspecified imports (year 2009+)

The above detailed method (used for 2000 to 2008) cannot be used 2009 and future years because the CEC no longer generates the Net System Power report required to use the previous methodology.

For 2009+, Mandatory Reporting data was used to determine the total amount of unspecified electricity imported into the state. These unspecified imports were converted into emissions using the unspecified emission factor originating from the Western Climate Initiative (WCI) (WCI, 2011), and now contained in ARB's Mandatory Reporting Program data (ARB, 2012).

For a list of yearly activity, heat content and emission factor values used in the inventory estimates, please consult the online documentation annex at: http://www.arb.ca.gov/cc/inventory/doc/methods_00-12/annex_1b_electricity_production_imports.pdf

4. Changes in Estimates

There are no changes in the current estimates of imported electricity emissions when compared with those made for the 2000-2011 edition of GHG Inventory.

5. Future Improvements

Future improvements will include the use of Open Access Technology International, Inc. (OATI) data. OATI collects data on E-Tags and how much power is imported into each state. This secondary source of data will help insure that all importers are reporting to the ARB's Mandatory Reporting Program, and doing so correctly.

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, 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 section I.D below.

Petroleum refineries used catalyst coke, distillate, LPG, natural gas, petroleum coke, refinery gas and residual fuel oil. Fuels used by manufacturing industries and construction include: biomass waste fuel, coal, distillate, ethanol, gasoline, kerosene, LPG, natural gas, petroleum & catalyst coke, residual fuel oil, tires, and wood. Fuels used in commercial, institutional and residential settings are: coal, distillate, ethanol, gasoline, kerosene, LPG, natural gas, residual fuel oil, and wood.

The inventory includes the emissions of CO_2, CH_4 and N_2O resulting from the combustion of fossil fuels. Some biomass 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 biomass 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 total. Other combustibles used as fuels, such as used tires, are made in part from biomass materials (e.g., natural rubber). In this case, two values for CO_2 emissions are estimated in proportion to the biomass and fossil components. Only the CO_2 from the fossil component is included in the inventory total.

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 13: Emissions from stationary combustion

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

Where,

$E_{GHG,\,fuel}$ = Emissions of the given GHG for the type of fuel (g of GHG)
Q_{fuel} = Quantity of the type 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, ethanol, gasoline, jet fuel, kerosene, LPG, natural gas, petroleum & catalyst coke, refinery gas, process 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 biomass and fossil origins. Used tires are such a fuel.

Equation 14: 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, Biomass]

3. Data Sources

The data sources for estimating emissions include CEC's Quarterly Fuels and Energy Report (QFER), CEC's Petroleum Industry Information Reporting Act (PIIRA), the Energy Information Administration State Energy Data System (EIA SEDS), the US Environmental Protection Agency, the Intergovernmental Panel on Climate Change (IPCC), ARB's Mandatory Reporting Program, and selected industry associations.

Fuel use data are primarily from the EIA and CEC. Data on fuel use by petroleum refineries were summarized from the PIIRA database (O'Brien, 2010) for 2000-2008, and from ARB's Mandatory Reporting Program (ARB, 2012) for 2009+. Natural gas use data were summarized from the QFER database

(Gough, 2013), except for natural gas use by natural gas pipeline compressor stations, which came from the EIA SEDS (EIA, 2013c).

Data for natural gas use by petroleum refineries, taken from PIIRA for 2000-2008, were adjusted to avoid double counting of the amounts that went to cogeneration and hydrogen production by refineries, as they are accounted for in other sections of this inventory. These adjustments were made by calculating the ratio of the amount of natural gas used for these purposes, as reported for 2009 in the Mandatory Reporting database by refineries, to the amount reported to PIIRA in 2009. That ratio was then used to adjust the natural gas use data from PIIRA for 2000 to 2008. Data on fuel use by California's cement plants were supplied by the Portland Cement Association (O'Hare, 2007) for years 2000 and 2005, and by an ARB survey (ARB, 2008) for year 2006. Data reported by cement plants to ARB Mandatory Reporting Program were used for 2008+, and fuel consumption for other years (2001-2004, and 2007) was interpolated between these data values. All other fuel use, except gasoline and ethanol, came from the EIA SEDS (EIA, 2013c).

Yearly data on the use of gasoline-ethanol blend came from the California State Board of Equalization (BOE, 2013). BOE data shows the total on-road amount of gasoline used and FWHA shows the amount of non-road use of gasoline. Together they make up the total gasoline use in the state. The CEC (O'Brien, 2010) provided the percent of ethanol in the blend for 2000-2010, while data on amounts of ethanol and gasoline for 2011+ come from ARB's Mandatory Reporting Program (ARB, 2012). The ethanol used in gasoline blends is actually a denatured ethanol which includes up to 5 percent of denaturant (natural gasoline, gasoline components or unleaded gasoline) which renders it undrinkable, in order to avoid alcohol taxes. Thus the percentages of denatured ethanol provided by the CEC or ARB's Mandatory Reporting Program were adjusted to calculate the amounts of pure ethanol blended in California "gasoline". This adjustment was based on ASTM D4806 Standard Specification for denatured fuel ethanol for blending with gasoline for use as automotive spark-ignition engine fuel. For 2000 to 2008 the minimum percent volume of pure ethanol in the denatured ethanol had to be 92.1 percent, allowing for up to 5 percent denaturant, 1 percent water, 0.5 percent methanol and 1.4 percent other. In 2009+ the percent denaturant was reduced to 2.5 percent, resulting in 94.6 percent pure ethanol in denatured ethanol.

Table 19: Proportion of ethanol in California's gasoline-ethanol blend: Proportion of ethanol in California's gasoline-ethanol blend

Year	**Percent denatured ethanol in the blend**	**Percent ethanol in denatured ethanol**	**Percent pure ethanol in blend**
2000	0.41%	92.10%	0.38%
2001	0.55%	92.10%	0.51%

Year	Percent denatured ethanol in the blend	Percent ethanol in denatured ethanol	Percent pure ethanol in blend
2002	0.64%	92.10%	0.59%
2003	3.75%	92.10%	3.46%
2004	5.65%	92.10%	5.21%
2005	6.00%	92.10%	5.53%
2006	6.01%	92.10%	5.54%
2007	6.02%	92.10%	5.55%
2008	6.63%	92.10%	6.11%
2009	6.57%	94.60%	6.21%
2010	10.05%	94.60%	9.50%
2011	10.90%	94.60%	10.31%
2012	10.13%	94.60%	9.58%

The BOE and FWHA “gasoline” consumption data include the blended ethanol, so the pure ethanol amounts were subtracted from the volumes provided to obtain the amounts of pure gasoline consumed in the state. Staff assumed that all inventory categories using “gasoline” did use a mix of gasoline and ethanol blended in the same proportions. Staff assumed that the small amount of methanol, water and other substances potentially contained in the denaturant-ethanol blend would just fall under gasoline for purposes of estimating emissions from it, given they amount to around 0.1% of the total fuel amount, which is much less than the error associated with the emission factor and heat content estimates.

Heat content values for natural gas are from EIA SEDS (EIA, 2013c). Heat content for the various other fuels, except fossil waste fuel, is from ARB’s Mandatory Reporting Program (ARB, 2012). Natural gas heat content in the Mandatory Reporting Program is a default value, the same for all sources, while the EIA SEDS is year specific, so for natural gas use not reported in the Mandatory Reporting Program, EIA SEDS is used.

Unable to locate an authoritative reference for the heat content of the fossil waste fuel used by the cement manufacturing sector, staff assumed that the heat content of an equal mixture of solid biomass and solid fossil fuels would be the best approximation. Thus the heat content for fossil waste fuel is simply the average of those of wood and petroleum coke.

CO_2 emission factor values for fossil waste fuel burned in cement plants are from PCA (O'Hare, 2007), from the Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2011 (USEPA, 2013e) for gasoline (with 2012 assumed to be the same as 2011) and from ARB’s Mandatory Reporting Program (ARB, 2012) for other fuels. CH_4 and N_2O emission factors for all fuels are from ARB’s Mandatory Reporting Program (ARB, 2012).

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_00-12/annex_1c_fuel_combustion_in_industrial_commercial_residential_agricultural_and_other_sectors.pdf

4. Changes in Estimates

Updates to hydrogen production data (which influences how much fuel is burned) and to the data made by data providers resulted in limited adjustments in emissions estimates for the categories included in this section: -6.0 percent on average for 2011 when compared with the estimates in the previous edition of ARB's GHG inventory.

5. Future Improvements

Future estimates will continue to make use of the data reported under the GHG Mandatory Reporting Program for petroleum refining and cement production. Also, total gasoline and ethanol reported in the GHG Mandatory Reporting Program starting in 2011 will be used in future updates, in place of the data from CEC and FWHA/BOE.

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 recommends 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 and typical aircraft fuel consumption. 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 motorhomes); 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 as reported by BOE and apportioned based on vehicle miles traveled and vehicle fuel consumption.

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. The first is based on the amount of fuel combusted and emission factors (consistent with the tier 2 IPCC methodology), and the second is based on emissions/activity modeling (consistent with the tier 3 IPCC methodology). On-road gasoline and diesel emissions were modeled, while fuel use water-borne navigation fuel use was modeled then emission factors were applied. The simpler methodology was used for other on-road vehicles emissions (e.g. natural gas vehicles) and 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 2011 EMission FACtors model (ARB, 2013c). Two EMFAC modules were used: EMFAC-HD for heavy duty and EMFAC-LDV for light duty vehicles. 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 for calculating 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 CH_4, and NO_x emissions. EMFAC outputs were then scaled so that EMFAC fuel combustion numbers would match fuel sales numbers obtained from the BOE.

The EMFAC model is a transportation emissions model developed by the ARB to quantify on-road vehicle emissions (THC, CH_4, CO, NO_x, particulate matter, lead, SO_x, 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 vehicle.

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 based on reported fuel sales. As mentioned above, staff decided to scale EMFAC outputs to match the fuel sales numbers reported by the BOE (and CEC) in order to maintain a consistent state-level energy balance. This was done by scaling EMFAC model outputs using the ratio of the reported 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 BOE.

Also, in both the EMFAC fuel consumption data and the BOE fuel sales data, “gasoline” is in fact a blend of gasoline and ethanol. The proportions of ethanol and pure gasoline in this blend have changed from year to year. In this version of the inventory, to allow for gasoline and ethanol to be analyzed separately, staff used data from the FHWA and CEC to compute the proportion of ethanol in the blend for each year. Reporting gasoline and ethanol separately led staff to change the method of estimation of CO_2 emissions from on-road vehicles. Since EMFAC does not model the two components of the gasoline-ethanol separately, staff opted to use the emission factors approach to estimate CO_2 emissions. The derivation of the pure gasoline heat content and the choice of appropriate emission factors are discussed in Section I.C.3 above.

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 gallons, and VMT). In order to convert from EMFAC’s average weekday outputs (i.e., an average of the five days of the week, excluding Saturday and Sunday) to a full year, staff multiplied EMFAC outputs by various annual conversion factors based on differences between weekday and weekend activity levels for each vehicle category (e.g. 347 for all passenger vehicle categories, 312 for most heavy vehicles, etc.). Once a number of “tons per year” was calculated, staff multiplied by 0.90718474 to convert from short tons (2000 pounds) to metric tonnes (1000 kilograms).

Equation 15: Conversion of emissions per weekday to emissions per year

$$Y = W \bullet C \bullet 0.90718474$$

Where,

Y = Emission value in tonnes per year

W = Emission value in short tons per average weekday

C = Annual conversion factor to convert from average weekday value to annual total for a given vehicle category (from Table 20)

0.90718474 = factor to convert short tons to metric tonnes

Table 20: Factors to convert each vehicle category's activity (weekday to annual)

Vehicle & Technology	***Annual Conversion Factor***	***Mapping to GHG Inventory Vehicle Categories***
All Other Buses - DSL	292	heavy duty
LDA - DSL	347	light duty vehicle- passenger car
LDA - GAS	347	light duty vehicle- passenger car
LDT1 - DSL	347	light duty vehicle- light duty (aka passenger) trucks/SUVs
LDT1 - GAS	347	light duty vehicle- light duty (aka passenger) trucks/SUVs
LDT2 - DSL	347	light duty vehicle- light duty (aka passenger) trucks/SUVs
LDT2 - GAS	347	light duty vehicle- light duty (aka passenger) trucks/SUVs
LHD1 - DSL	327	heavy duty
LHD1 - GAS	327	heavy duty
LHD2 - DSL	327	heavy duty
LHD2 - GAS	327	heavy duty
MCY - GAS	347	light duty vehicle- motorcycle
MDV - DSL	347	light duty vehicle- light duty (aka passenger) trucks/SUVs
MDV - GAS	347	light duty vehicle- light duty (aka passenger) trucks/SUVs
MH - DSL	327	heavy duty
MH - GAS	327	heavy duty
Motor Coach - DSL	292	heavy duty
OBUS - GAS	327	heavy duty
PTO - DSL	312	heavy duty
SBUS - DSL	327	heavy duty
SBUS - GAS	327	heavy duty
T6 Ag - DSL	312	heavy duty
T6 CAIRP heavy - DSL	312	heavy duty
T6 CAIRP small - DSL	312	heavy duty
T6 instate construction heavy - DSL	312	heavy duty
T6 instate construction small - DSL	312	heavy duty
T6 instate heavy - DSL	312	heavy duty
T6 instate small - DSL	312	heavy duty

Vehicle & Technology	***Annual Conversion Factor***	***Mapping to GHG Inventory Vehicle Categories***
T6 OOS heavy - DSL	312	heavy duty
T6 OOS small - DSL	312	heavy duty
T6 Public - DSL	312	heavy duty
T6 utility - DSL	312	heavy duty
T6TS - GAS	327	heavy duty
T7 Ag - DSL	312	heavy duty
T7 CAIRP - DSL	312	heavy duty
T7 CAIRP construction - DSL	312	heavy duty
T7 NNOOS - DSL	312	heavy duty
T7 NOOS - DSL	312	heavy duty
T7 other port - DSL	312	heavy duty
T7 POAK - DSL	312	heavy duty
T7 POLA - DSL	312	heavy duty
T7 Public - DSL	312	heavy duty
T7 Single - DSL	312	heavy duty
T7 single construction - DSL	312	heavy duty
T7 SWCV - DSL	312	heavy duty
T7 tractor - DSL	312	heavy duty
T7 tractor construction - DSL	312	heavy duty
T7 utility - DSL	312	heavy duty
T7IS - GAS	327	heavy duty
UBUS - DSL	327	heavy duty
UBUS - GAS	327	Heavy duty

(b) Scaling EMFAC outputs to match reported fuel sales

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

Equation 16: Ratio of EMFAC fuel combustion to reported fuel sales

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

Where,

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

$S_{\text{fuel, year}}$ = reported fuel 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-ethanol blend, Distillate]

Year = [2000 – 2012]

Table 21: Ratio of EMFAC modeled fuel combustion to reported fuel sales

Year	Fuel	Source	Reported (gal)	EMFAC (gal)	Ratio
2000	Gasoline-ethanol blend	BOE	14,760,642,277	14,340,998,790	1.029261803
2001	Gasoline-ethanol blend	BOE	14,873,287,328	14,077,336,357	1.056541305
2002	Gasoline-ethanol blend	BOE	15,497,850,137	14,358,660,799	1.079338133
2003	Gasoline-ethanol blend	BOE	15,660,106,873	14,857,971,976	1.053986836
2004	Gasoline-ethanol blend	BOE	15,882,228,670	15,101,293,037	1.051713163
2005	Gasoline-ethanol blend	BOE	15,912,767,049	15,439,992,817	1.030620107
2006	Gasoline-ethanol blend	BOE	15,802,491,301	15,736,227,912	1.004210881
2007	Gasoline-ethanol blend	BOE	15,644,532,462	15,985,487,740	0.978670949
2008	Gasoline-ethanol blend	BOE	15,007,122,838	16,146,287,517	0.929447269
2009	Gasoline-ethanol blend	BOE	14,791,632,891	16,362,248,006	0.904009821
2010	Gasoline-ethanol blend	BOE	14,851,505,738	16,479,115,372	0.901231978
2011	Gasoline-ethanol blend	BOE	14,583,411,578	16,626,744,104	0.877105673
2012	Gasoline-ethanol blend	BOE	14,487,897,816	16,754,951,074	0.864693532
2000	Distillate	BOE	2,632,760,095	2,360,565,407	1.115309107
2001	Distillate	BOE	2,627,365,783	2,407,107,756	1.091503185
2002	Distillate	BOE	2,700,122,539	2,452,986,528	1.100749029
2003	Distillate	BOE	2,667,933,637	2,597,869,326	1.026969913
2004	Distillate	BOE	2,842,332,046	2,737,099,042	1.038446911
2005	Distillate	BOE	2,963,733,672	2,883,274,692	1.027905416
2006	Distillate	BOE	2,994,049,134	2,994,952,957	0.999698218
2007	Distillate	BOE	3,082,740,281	2,999,112,529	1.027884166
2008	Distillate	BOE	2,827,526,205	2,736,654,998	1.033205211
2009	Distillate	BOE	2,580,139,949	2,543,717,279	1.014318679
2010	Distillate	BOE	2,590,655,088	2,625,532,853	0.986715929
2011	Distillate	BOE	2,622,534,125	2,737,045,030	0.958162579
2012	Distillate	BOE	2,603,545,631	2,855,725,922	0.911693104

EMFAC outputs can then be scaled to the reported fuel sales by using the ratios from Table 21 and the following equation:

Equation 17: Scaling of EMFAC outputs to reported fuel sales

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

Where,

$Z_{\text{type, fuel, year}}$ = Scaled EMFAC output value for a particular vehicle type using a given fuel in a given year

$Y_{\text{type, fuel, year}}$ = Modeled output value for a particular vehicle type using a given fuel in a given year

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

With,

Type = [passenger cars, light duty trucks, heavy-duty vehicles, motorcycles]

Fuel = [Gasoline-ethanol blend, Distillate]

Year = [2000 – 2012]

(c) Proportions of gasoline and ethanol in the gasoline-ethanol blend

In the case of "gasoline", both the EMFAC modeled fuel use and the BOE reported fuel sales data are in fact amounts of an unspecified gasoline-ethanol blend. To allow for the separate analysis of pure gasoline and ethanol, staff calculated the yearly proportions of pure ethanol in the blend in section I.C above (see Table 21) and the proportion of gasoline by difference.

Equation 18: Proportion of gasoline in the gasoline-ethanol blend

$$\boxed{P_{Gasoline,\ year} = 1 - P_{Ethanol,year}}$$

Where,

$P_{\text{Gasoline, year}}$ = Proportion of gasoline in the gasoline-ethanol blend for a given fuel in a given year

$P_{\text{Ethanol, year}}$ = Proportion of ethanol in the gasoline-ethanol blend for a given fuel in a given year (from Table 21)

With,

Year = [2000 – 2012]

The gasoline and ethanol contributions to emissions of the gasoline-ethanol blend can be un-mixed using their respective proportions in the blend.

Equation 19: Un-mixing of scaled EMFAC output values to each component of a fuel blend

$$\boxed{U_{type,fuel,year} = Z_{\text{type, blend, year}} \bullet P_{fuel,year}}$$

Where,

$U_{\text{fuel, year}}$ = Un-mixed value for a particular vehicle type using the given fuel in a given year

$Z_{\text{type, blend, year}}$ = Scaled EMFAC output value for a particular vehicle type using gasoline-ethanol blend in a given year (from Equation 17)

$P_{\text{fuel, year}}$ = Proportion of fuel in the blend (from Table 21and Equation 18)

With,

Type = [passenger cars, light duty trucks, heavy-duty vehicles, motorcycles]

Blend = [Gasoline-ethanol]

Fuel = [Gasoline, Ethanol]

Year = [2000 – 2012]

(d) Calculating CO_2 emissions

Emissions of CO_2 are estimated with the emissions factors method. The case of vehicles combusting a blend of gasoline and ethanol involves one extra factor to separate the emissions of each of these two fuels.

Equation 20: CO_2 emissions from on road transport (diesel vehicles)

$$E_{type,fuel,year} = (V_{type,fuel,year} \bullet R_{fuel,year}) \bullet HC_{fuel} \bullet EF_{CO2,fuel}$$

Where,

$E_{type, fuel, year}$ = CO_2 emissions of a particular vehicle type using the given fuel in the given year (g of CO_2)

$V_{type, fuel, year}$ = Amount of fuel combusted by the particular type of vehicle in a given year (gallons) as modeled with EMFAC

$R_{fuel, year}$ = Scaling factor for the given fuel in the given year (from Table 21)

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

$EF_{CO2, fuel}$ = CO_2 emission factor for given fuel (g CO_2 / BTU)

With,

Type = [passenger cars, light duty trucks, heavy-duty vehicles]

Fuel = [distillate]

Year = [2000 – 2012]

Equation 21: CO_2 emissions from on road transport (gasoline-ethanol vehicles)

$$E_{type,fuel,year} = (V_{type,blend,year} \bullet R_{blend,year}) \bullet P_{fuel,year} \bullet HC_{fuel} \bullet EF_{CO2,fuel}$$

Where,

$E_{type, fuel, year}$ = CO_2 emissions of a particular vehicle type using the given fuel in the given year (g of CO_2)

$V_{type, blend, year}$ = Amount of gasoline-ethanol blend combusted by the particular type of vehicle in a given year (gallons) as modeled with EMFAC

$R_{blend, year}$ = Scaling factor for the gasoline-ethanol blend in the given year (from Table 21)

$P_{fuel, year}$ = Proportion of the given fuel in the blend (from Table 21and Equation 18)

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

$EF_{CO2, fuel}$ = CO_2 emission factor for given fuel (g CO_2 / BTU)

With,

Type = [passenger cars, light duty trucks, heavy-duty vehicles, motorcycles]

Blend = [gasoline-ethanol]

Fuel = [ethanol, gasoline]

Year = [2000 – 2012]

(e) Calculating CH_4 emissions

The amount of CH_4 emitted is the EMFAC modeled output of CH_4 for a particular vehicle class scaled to the reported fuel sales with Equation 17. EMFAC-HD does not output CH_4 directly, so TOG outputs must be multiplied by 0.0408 to obtain CH_4 emissions (ARB, 2013d), then scale the outputs to the reported fuel sales with Equation 17.

In the case of gasoline-ethanol powered vehicles, the yearly proportions of gasoline and ethanol in the gasoline-ethanol blend are then used to separate the respective share of emissions from gasoline and ethanol (using Equation 19).

(f) Calculating N_2O emissions

We calculated N_2O emissions from gasoline vehicles by establishing a correlation between ARB tailpipe test measurements of NO_x and N_2O emissions. For every gram of NO_x emitted from gasoline vehicles, an average of 0.0416 grams of N_2O are emitted. That is:

Equation 22: Correlating N_2O emissions to NO_x emissions (gasoline vehicles)

$$\boxed{E_{N2O} = 0.0416 \bullet O_{NOx}}$$

Where,

E_{N2O} = N_2O emissions of gasoline vehicles (grams)
0.0416 = emission of N_2O for every unit of NO_x emitted
O_{NOx} = scaled EMFAC output for NO_x emitted by that category of vehicles (grams)

Equation 22 was calculated for each vehicle type and each year using the ratio of reported fuel sales from Equation 17. Then the respective share of N_2O emissions of gasoline and ethanol were estimated for each vehicle type using Equation 19.

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 thus computed by multiplying the emission factor by BOE diesel fuel sales, for each category of vehicles:

Equation 23: Transportation - on road N_2O emissions (diesel vehicles)

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

Where,

E_{N2O} = N_2O emissions of a type of diesel vehicles (grams)
V = Fuel consumption of that type of diesel vehicles (gallons) scaled to reported fuel sales with Equation 17
EF_{N2O} = Emission factor for diesel vehicles (0.3316 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 (those using natural gas as a fuel), as well as 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: staff did not estimate indirect emissions resulting from the energy consumed by 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 aviation fuel data

For the reasons discussed in section I.D.1 above, staff apportioned aviation fuel use among intrastate, interstate and international flights. Statistics from the US Department of Transportation are available for all commercial airlines' flights taking off and/or landing in California which allows for distinguishing intrastate flights from interstate and international ones. Such statistics were not available for military flights and general aviation flights. General aviation flights are private and commercial flights other than military, scheduled airline or regular cargo flights. This led staff to focus on the apportionment of jet fuel used by scheduled airlines which, as estimated in section I.D.2.2(a.i) below, constitutes approximately 90 percent of the jet fuel sold in California.

ARB staff retrieved data for total jet fuel sold within California from the Energy Information Administration (EIA, 2013b). Typically, aircrafts do not carry significant extra fuel, or fuel for a continuing flight, since that would add to the weight being transported, and thus to the fuel consumed and the costs incurred. Thus, the amount of aviation fuel sold within California should approximate the amount of fuel consumed on all flights originating in California.

(a.i) Commercial airlines versus general aviation and military aircrafts

The first step was to distribute the jet fuel sold in California between general aviation, military activity, and scheduled commercial flights. California's taxable general aviation jet fuel is reported by BOE. CEC only reports military jet fuel from 2004 onward so historical data was estimated by assuming that the amount of fuel obtained for 2004-2010 (O'Brien, 2010) fluctuated in proportion with the amount of fuel consumed by military aviation nationwide (i.e. USA military jet fuel Tbtu for each calendar year 2000-2003 was multiplied by scaling factor 1,298,720 to estimate the *scaled fuel). The amount of fuel used nationwide for military activity is reported in the USEPA annual greenhouse gas inventory (USEPA, 2012a). Staff then assigned the remainder of the aviation fuel to commercial airlines activity (Table 22).

Table 22: Estimation of California commercial jet fuel use (gallons)

Year	Total CA Jet Fuel (from EIA)	CA General Aviation	USA Military Jet Fuel (Tbtu)	CA Military jet fuel (*scaled)	CA commercial airlines jet fuel (by difference)
2000	4,326,042,000	121,428,020	292.5	*379,856,351	3,824,757,629
2001	4,083,072,000	128,008,285	318.5	*413,660,159	3,541,403,556
2002	4,315,752,000	125,254,189	284.9	*370,044,631	3,820,453,180
2003	4,188,282,000	126,076,880	286.6	*372,181,710	3,690,023,410
2004	4,427,136,000	141,395,642	294.8	339,343,349	3,946,397,009
2005	4,393,704,000	148,400,808	251.0	336,774,630	3,908,528,562
2006	4,468,926,000	147,011,420	226.2	305,384,496	4,016,530,084
2007	4,653,348,000	155,414,192	223.3	285,390,657	4,212,543,151
2008	4,235,112,000	141,712,863	224.7	272,713,681	3,820,685,456
2009	4,115,370,000	106,573,334	195.5	260,519,367	3,748,277,299
2010	4,031,496,000	119,296,386	173.0	262,755,664	3,649,443,950
2011	4,071,984,000	121,155,444	.	234,600,600	3,716,227,956
2012	3,967,908,000	128,434,645	.	292,165,000	3,547,308,355

(a.ii) Intrastate versus Interstate and International

In a second step, commercial airlines fuel consumption was subdivided among intrastate, interstate, and international flights. First, staff downloaded data regarding flight activity from the USDOT's Air Carrier Statistics database (USDOT, 2013). Based on the airports of departure and arrival, these flights were subdivided into three categories:

- (1) Flights originating and ending in California (intrastate)
- (2) Flights originating in California but ending in another state (interstate from CA)
- (3) Flights originating in California but ending in another country (international from CA)

These flight categories should all consume fuel purchased in CA —thus contributing to the amounts in the last column of Table 22. For example, in 2007, the database indicated that 402,758 intrastate flights occurred in California; 583,247 interstate flights originated in California; and 88,510 international flights originated in CA.

For each flight, the USDOT Air Carrier Statistics database also provides information on the type of aircraft and the length of the flight in miles. In the 2000-2004 edition of ARB's GHG Inventory staff had used distance to apportion fuel use into interstate, intrastate and international amounts. However, this approach introduces a bias because it does not account for the impact of the size of the airplane on fuel consumption and, since smaller airplanes are used on shorter distances, they are used for a higher proportion of intrastate flights than of interstate or international ones. In 2007, eighty five different types of airplanes were used by airlines operating in California with a wide range of maximum takeoff weight: from the 3.3 tonnes of the Cessna 208 Caravan to the 365 tonnes of the Airbus A340-600 and 405 tonnes of the Antonov 124 (a cargo plane).

For each of these aircrafts, ARB staff estimated a fuel consumption factor that could be applied to each flight as a function of distance. These fuel consumption factors were based on data from the European Environment Agency (EAA) 2007 EMEP/CORINAIR Air Pollutant Emissions Inventory Guidebook (EAA, 2007). The Guidebook contains fuel consumption, as a function of flight distance, for 26 main aircraft types. For each aircraft type, the fuel consumption is subdivided into the fuel associated with the landing/takeoff phase of the flight and the fuel consumed during the other phases (Figure 2). An example of the data from the Guidebook is shown in Table 23.

Figure 2: Standard flying cycles (from EMEP/CORINAIR Guidebook)

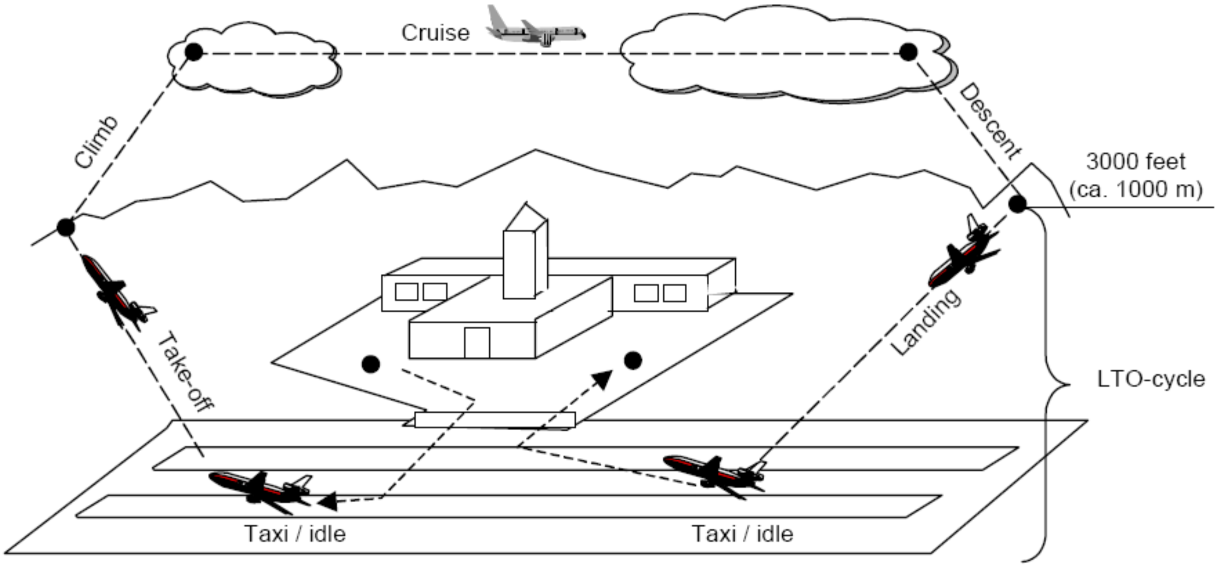


Table 23: Example of typical fuel consumption (from EMEP/CORINAIR Guidebook)

Aircraft Type: Boeing 737-400							
Standard flight distances (nautical miles) [1 nautical mile = 1.15078 statute mile]							
Climb / Cruise / Descent	125	250	500	750	1000	1500	2000
Corresponding fuel use (kilograms)							
Landing & Take Off (LTO)	825.4	825.4	825.4	825.4	825.4	825.4	825.4
Climb / Cruise / Descent	777.7	1442.6	2787.4	4134.9	5477.2	8362.3	11342.2
Flight total	**1603.1**	**2268**	**3612.8**	**4960.3**	**6302.6**	**9187.7**	**12167.6**

ARB staff used the EMEP/CORINAIR fuel consumption data to construct a linear formula that would estimate fuel consumption as a function of distance for each of the 26 aircraft. The coefficients for the resultant formulae are shown in Table 24.

Table 24: Fuel consumption factors estimated for aircraft listed in the EMEP EEA Inventory.

Aircraft IATA code	***Aircraft***	***Engine type***	***LTO Fuel (kg)***	***Cruise Fuel (kg/mi)***	***Max Takeoff Weight (kg)***
405	Beech 1900 A/B/C/D	Turboprop	59.9	0.78	7,688
416	Cessna 208 Caravan	Turboprop	28.8	0.49	3,310
442	Aerospatiale/Aeritalia Atr-72	Turboprop	135.9	1.49	22,000
449	Dornier 328	Turboprop	123.9	1.20	13,990
450	Fokker Friendship F-27/Fairchild F-27/A/B/F/J	Turboprop	158.2	1.58	20,410
456	Saab-Fairchild 340/B	Turboprop	74.9	1.19	13,155
482	Dehavilland Dhc8-400 Dash-8	Turboprop	180.9	2.64	27,330
556	Lockheed L100-30/L-382e	Turboprop	272.0	5.96	70,310
602	Fokker F28-4000/6000 Fellowship	Turbofan	666.1	3.89	33,110
603	Fokker 100	Turbofan	744.4	4.12	43,090
617	Boeing 737-400	Turbofan	825.4	4.87	62,820
620	Boeing 737-100/200	Turbofan	919.7	4.58	52,390
622	Boeing 757-200	Turbofan	1,253.0	6.19	108,860
626	Boeing 767-300/300er	Turbofan	1,617.1	8.49	181,890
627	Boeing 777-200/200lr/233lr	Turbofan	2,562.8	12.30	286,897
640	Mcdonnell Douglas Dc-9-30	Turbofan	876.1	4.95	64,885
656	Mcdonnell Douglas Md-90	Turbofan	1,003.1	5.59	67,800
692	Airbus Industrie A310-200c/F	Turbofan	1,540.5	7.81	150,000
694	Airbus Industrie A320-100/200	Turbofan	802.3	4.42	77,000
696	Airbus Industrie A330-200	Turbofan	2,231.5	10.43	230,000
715	Boeing 727-200/231a	Turbofan	1,412.8	7.17	95,030
730	Mcdonnell Douglas Dc-10-10	Turbofan	2,381.2	14.48	263,085
816	Boeing 747-100	Turbofan	3,413.9	19.20	340,195
819	Boeing 747-400	Turbofan	3,402.2	17.51	362,875
867	British Aerospace Bae-146-200	Turbofan	569.5	4.44	42,185
873	Airbus Industrie A340-200	Turbofan	2,019.9	11.34	260,000

For each aircraft, the fuel consumption is subdivided into the fuel associated with the landing/takeoff (LTO) of the aircraft and the fuel consumed during the climb, cruise and descent (“cruise”) phase. The fuel consumed during the landing and takeoff is assumed independent of the flight distance for all aircrafts. In EMEP/CORINAIR tables, the fuel consumed during the landing and takeoff of smaller aircraft is somewhat affected by flight distance – presumably because smaller aircraft travel at different elevations and project from the ground at different angles depending on flight distance. This factor was considered negligible in the context of the overall inventory and ignored for simplification sake. The EMEP/CORINAIR fuel consumptions associated with the cruise phase were linear for most aircraft and thus assumed linear for all aircrafts for estimation purposes.

For example, using Table 24, the fuel consumed during a 2,850 mile flight by a Boeing 737-400 would be approximated as 825 kg of fuel during the landing/takeoff phase and 4.87 kg of fuel for each mile flown between takeoff and landing (i.e. 825 + 4.87*2850) for a total of 14,704 kg of fuel. A 600-mile flight of a de Havilland Dhc8-400 Dash-8 would consume approximately (181 + 2.64*600 =) 1,765 kg of fuel.

In addition to the 26 aircraft types listed in the EMEP/CORINAIR guidebook, the flight activity originating in California between 2000 and 2008 comported approximately 80 other aircraft types. To estimate the fuel consumption associated with these aircraft, staff assumed that the fuel consumed by an aircraft during its flight cycle is largely proportional to its size. Because the exact size of an aircraft can vary between flights due to its payload, staff used the aircraft's maximum takeoff weight as representative of its size.

The equations to estimate fuel consumption of aircrafts based on their takeoff weight were fitted by least-square regression using the maximum takeoff weight values for each of the 26 EMEP aircraft types (shown in Table 24). Staff separated the aircrafts in 2 groups based on engine type (turboprop vs. turbofan) because doing so yielded better fitting equations. The equations are as follow:

Equation 24: Fuel consumption regressions for turboprop aircrafts

$$\boxed{\begin{aligned} F_{LTO} &= 0.58 + 0.0082 \bullet W - 6.2 \bullet 10^{-8} \bullet W^{2}) \\ F_{Cruise} &= 0.064 + 8.325 \bullet 10^{-5} \bullet W \end{aligned}}$$

Where,

F_{LTO} = Amount of fuel consumed in the Landing and Take-off phase of the flight (kg)

F_{Cruise} = Amount of fuel consumed during the climb/cruise/descent phase of the flight (kg/mile)

W = Maximum takeoff weight (kg)

Equation 25: Fuel consumption regressions for turbofan aircrafts

$$\boxed{\begin{aligned} F_{LTO} &= 546.49 + 0.0047 \bullet W - 8.86 \bullet 10^{-9} \bullet W^{2}) \\ F_{Cruise} &= 3.61 + 1.6 \bullet 10^{-5} \bullet W + 6.94 \bullet 10^{-11} \bullet W^{2} \end{aligned}}$$

Where,

F_{LTO} = Amount of fuel consumed in the Landing and Take-off phase of the flight (kg)

F_{Cruise} = Amount of fuel consumed during the climb/cruise/descent phase of the flight (kg/mile)

W = Maximum takeoff weight (kg)

The fuel consumption factors estimated with the regression model are shown in Table 25.

Table 25: Fuel consumption factors estimated for aircraft not listed in the EMEP EEA Inventory.

Aircraft Type	**Aircraft**	**LTO Fuel (kg)**	**Cruise fuel (kg/mile)**	**Max Takeoff Weight (kg)**
79	Piper Pa-32 (Cherokee 6)	13.86	0.20	1,633
110	Beechcraft Beech 18 C-185	36.29	0.44	4,490
430	Convair Cv-580	174.42	2.26	26,371
441	Aerospatiale/Aeritalia Atr-42	126.50	1.53	17,650
448	Dornier 228	52.02	0.61	6,575
461	Embraer Emb-120 Brasilia	87.02	1.02	11,500
464	Embraer Emb-110 Bandeirante	46.23	0.55	5,800
467	Swearingen Metro Iii	54.42	0.64	6,900
469	British Aerospace Jetstream 31	54.79	0.64	6,950
470	Gulfstream I	117.00	1.40	16,100
471	British Aerospace Jetstream 41	82.92	0.97	10,900
479	Pilatus Pc-12	38.20	0.46	4,740
483	Dehavilland Dhc8-100 Dash-8	114.18	1.37	15,650
484	Dehavilland Dhc8-300 Dash 8	137.46	1.69	19,500
485	Dehavilland Twin Otter Dhc-6	38.38	0.46	4,763
489	Shorts 360	90.24	1.06	11,975
491	Dehavilland Dhc8-200q Dash-8	119.26	1.43	16,465
507	Antonov 12	271.36	5.14	61,000
520	Canadair Cl-44d	220.55	7.99	95,250
550	Lockheed L-188a/C Electra	261.65	4.45	52,664
552	Lockheed L-382b	271.99	5.92	70,300
555	Lockheed L100-20 Hercules	271.99	5.92	70,310
560	Shorts Belfast Freighter-Sh5	208.59	2.89	34,000
601	Fokker F28-1000 Fellowship	691.31	4.13	29,000
604	Fokker 70	739.29	4.32	38,000
608	Boeing 717-200	818.97	4.64	52,390
609	Bombardier Bd-100-1a10 Challenger 300	632.60	3.91	17,600
612	Boeing 737-700/700lr	864.51	4.83	60,330
614	Boeing 737-800	924.68	5.08	70,535
616	Boeing 737-500	818.97	4.64	52,390
619	Boeing 737-300	843.78	4.74	56,740
621	Boeing 737-200c	818.97	4.64	52,390
623	Boeing 757-300	1259.47	6.61	122,470
624	Boeing 767-400/Er	1882.42	9.77	204,120
625	Boeing 767-200/Er/Em	1650.94	8.56	175,540
628	Canadair Rj-100/Rj-100er	652.55	3.99	21,523
629	Canadair Rj-200er /Rj-440	665.49	4.03	24,040

Aircraft Type	**Aircraft**	**LTO Fuel (kg)**	**Cruise fuel (kg/mile)**	**Max Takeoff Weight (kg)**
630	Mcdonnell Douglas Dc-9-10	756.14	4.38	41,100
631	Canadair Rj-700	711.84	4.21	32,885
632	Dornier 328-300	622.84	3.88	15,660
633	Boeing 737-600	840.94	4.73	56,245
634	Boeing 737-900	950.61	5.20	74,840
635	Mcdonnell Douglas Dc-9-15f	811.11	4.61	51,000
636	Cessna Citation Ii/ Bravo	579.35	3.72	6,850
637	Boeing 777-300/300er/333er	2405.68	12.62	263,080
638	Canadair Crj 900	731.27	4.29	36,514
639	Cessna Citationjet/Cj1/Cj2/Cj3	569.49	3.69	4,812
641	Gulfstream Aerospace G-Iii/G-Iv	713.52	4.22	33,200
642	Raytheon Beechcraft Hawker 400xp	581.54	3.73	7,300
643	1124a Westwind Ii	597.99	3.79	10,660
644	Airbus Industrie A-318	909.56	5.02	68,000
645	Mcdonnell Douglas Dc-9-40	833.16	4.70	54,885
646	Cessna Citation X Model 650/550b/550xl	626.43	3.89	16,375
647	Cessna Citation X Model Ce750 X	626.43	3.89	16,375
648	Gulfstream G200	624.95	3.89	16,080
650	Mcdonnell Douglas Dc-9-50	833.16	4.70	54,885
651	Gulfstream G150	603.82	3.81	11,840
652	Canadair CL-600 Challenger	642.48	3.95	19,550
654	Mcdonnell Douglas Dc9 Super 87	883.03	4.91	63,505
655	Mcdonnell Douglas Dc9 Super 80/Md81/82/83/88	883.03	4.91	63,505
657	Bombardier Crj 705	731.21	4.29	36,504
658	Bombardier Bd-700 Global Express	767.06	4.43	43,091
665	Hawker Siddeley 125	599.67	3.79	11,000
667	Gulfstream Iii/V/ G-V Exec/ G-5/550	752.16	4.37	40,370
668	Canadair (Bombardier) Challlenger 601	642.74	3.95	19,600
669	Bombardier Challenger 604/605	654.30	3.99	21,865
671	Gulfstream G450	715.23	4.22	33,520
673	Embraer ERJ-175	743.56	4.33	38,790
674	Embraer-135	639.69	3.94	19,000
675	Embraer-145	647.83	3.97	20,600
676	Embraer-140	650.38	3.98	21,100
677	Embraer 170	725.55	4.26	35,450
678	Embraer 190	788.64	4.51	46,990
679	Grumman G-1159 Gulfstream Ii/Iii	700.05	4.17	30,660
681	Dassault-Breguet Mystere-Falcon	588.64	3.76	8,755
682	Dassault Falcon 2000ex	637.66	3.93	18,600
683	Boeing B777-F	3265.37	17.57	347,800
684	Raytheon Beechcraft Hawker 800xp	608.08	3.82	12,700
686	Learjet45	590.62	3.76	9,160
687	Airbus A330-300	2148.80	11.20	235,000
689	Airbus Industrie A330-600st (Beluga)	1493.51	7.76	155,000

Aircraft Type	Aircraft	LTO Fuel (kg)	Cruise fuel (kg/mile)	Max Takeoff Weight (kg)
690	Airbus Industrie A300b/C/F-100/200	1018.81	5.50	85,910
691	Airbus Industrie A300-600/R/Cf/Rcf	1611.61	8.35	170,500
693	Airbus Industrie A310-300	1456.32	7.57	150,000
695	Airbus Industrie A300-B2	1397.73	7.28	142,000
697	Airbus Industrie A340	2518.95	13.26	275,000
698	Airbus Industrie A319	885.94	4.92	64,000
699	Airbus Industrie A321	1038.24	5.58	89,000
710	Boeing 727-100	936.90	5.14	72,570
711	Boeing 727-100c/Qc	936.90	5.14	72,570
732	Mcdonnell Douglas Dc-10-30	2405.73	12.62	263,085
733	Mcdonnell Douglas Dc-10-40	2371.69	12.43	259,450
735	Mcdonnell Douglas Dc-10-30cf	2405.73	12.62	263,085
740	Mcdonnell Douglas Md-11	2502.78	13.17	273,314
760	Lockheed L-1011-1/100/200	1943.48	10.09	211,375
765	Lockheed L-1011-500 Tristar	2116.25	11.02	231,330
770	Dassault Falcon 900	648.03	3.97	20,640
771	Dassault Falcon 50	632.60	3.91	17,600
775	Dassault Falcon 7x	703.57	4.18	31,325
780	Tupolev Tu-154	1115.27	5.93	101,000
800	Boeing 707-100	1219.24	6.42	116,600
806	Boeing 707-300	1465.94	7.62	151,300
808	Boeing 707-300b	1465.94	7.62	151,300
809	Boeing 707-300c	1465.94	7.62	151,300
817	Boeing 747-200/300	3306.19	17.81	351,535
818	Boeing 747c	3431.66	18.56	362,875
820	Boeing 747-400f	3431.66	18.56	362,875
822	Boeing 747sp	2943.45	15.69	317,515
840	Mcdonnell Douglas Dc-8-10	1268.67	6.65	123,800
848	Mcdonnell Douglas Dc-8-50	1354.54	7.07	136,000
850	Mcdonnell Douglas Dc-8-50f	1419.57	7.39	145,000
851	Mcdonnell Douglas Dc-8-61	1437.26	7.48	147,415
852	Mcdonnell Douglas Dc-8-63f	1521.77	7.90	158,760
854	Mcdonnell Douglas Dc-8-62	1470.77	7.64	151,950
856	Mcdonnell Douglas Dc-8-63	1521.77	7.90	158,760
860	Mcdonnell Douglas Dc-8-71	1546.51	8.02	162,025
862	McDonnell Douglas DC-8-72	1546.51	8.02	162,025
864	Mcdonnell Douglas Dc-8-73	1546.51	8.02	162,025
865	Mcdonnell Douglas Dc-8-73f	1546.51	8.02	162,025
866	British Aerospace Bae-146-100/Rj70	761.07	4.40	42,000
868	British Aerospace Bae-146-300	773.31	4.45	44,225
870	Lockheed Jetstar	643.98	3.95	19,844
871	Airbus Industrie A340-300	2376.82	12.46	260,000

Aircraft Type	Aircraft	LTO Fuel (kg)	Cruise fuel (kg/mile)	Max Takeoff Weight (kg)
872	Airbus Industrie A340-500	3455.43	18.70	365,000
874	Airbus Industrie A340-600	3455.43	18.70	365,000
876	Ilyushin 62	1569.22	8.14	165,000
877	Ilyushin 76/Td	1607.74	8.34	170,000
879	Ilyushin 96	2284.28	11.95	250,000
880	Antonov 124	3917.69	21.48	405,000
882	Airbus Industrai A380-800	5976.67	34.34	560,000
890	Antonov 225 (6 Engine)	7205.87	42.29	640,000

Staff then multiplied these aircraft-specific fuel consumption factors by the total number of flights and the total flight distance travelled by each aircraft type in each of the three categories of flights originating in California (intrastate, interstate, international) to estimate the total fuel consumed for flights originating in California. Table 26 shows examples of these estimates for three common aircraft types.

Table 26: Fuel consumption in flights originating in California for three common aircrafts in 2007

Aircraft Type	Aircraft	Flight Category	Number of flights originating in CA	Total Distance Travelled (miles)	LTO Fuel (kg)	Cruise Fuel (kg)
612	Boeing 737-700/700lr	International	4,680	5,918,964	4,045,971	28,595,314
612	Boeing 737-700/700lr	Interstate	81,757	75,399,452	70,680,869	364,264,933
612	Boeing 737-700/700lr	Intrastate	71,646	26,739,509	61,939,670	129,182,178
819	Boeing 747-400	International	18,573	115,324,611	63,188,306	2,019,197,081
819	Boeing 747-400	Interstate	1,453	4,817,124	4,943,338	84,342,125
819	Boeing 747-400	Intrastate	677	228,003	2,303,262	3,992,062
627	Boeing 777-200/200lr/233lr	International	7,301	42,494,441	18,711,295	522,883,132
627	Boeing 777-200/200lr/233lr	Interstate	3,322	6,417,767	8,513,754	78,968,967
627	Boeing 777-200/200lr/233lr	Intrastate	3	1,011	7,689	12,440

The share of total jet fuel consumption of each flight category within each calendar year is shown in Table 27.

Table 27: Share of total jet fuel consumption of each flight category.

Year	International	Interstate	Intrastate	Grand Total
2000	44.6%	48.8%	6.6%	100%

Year	International	Interstate	Intrastate	Grand Total
2001	43.6%	49.8%	6.5%	100%
2002	41.8%	51.7%	6.5%	100%
2003	40.1%	53.0%	6.9%	100%
2004	40.7%	52.5%	6.8%	100%
2005	42.1%	51.1%	6.8%	100%
2006	42.6%	50.5%	6.9%	100%
2007	42.3%	50.4%	7.2%	100%
2008	44.2%	48.6%	7.2%	100%
2009	44.7%	48.1%	7.2%	100%
2010	45.1%	48.2%	6.7%	100%
2011	47.0%	46.7%	6.3%	100%
2012	47.1%	46.6%	6.3%	100%

Note: Staff assumed that the share of each category in 2009 remained the same as in 2008.

Staff then applied the distribution of estimated fuel consumption in Table 27 to the estimated jet fuel sales to commercial airlines in California (last column of Table 22) to allocate California jet fuel sales to each of the three flight categories (Table 28).

Table 28: Apportionment of California's commercial aviation fuel sales, 2000-2012 (gallons)

Year	Intrastate	Interstate	International	Total
2000	254,262,902	1,866,203,760	1,704,290,967	3,946,185,649
2001	231,835,074	1,764,858,780	1,544,709,702	3,669,411,841
2002	247,604,073	1,976,547,037	1,596,302,070	3,945,707,369
2003	253,668,618	1,956,618,733	1,479,736,059	3,816,100,290
2004	268,561,848	2,073,606,111	1,604,229,050	4,087,792,651
2005	265,084,350	1,997,757,794	1,645,686,418	4,056,929,370
2006	276,467,791	2,029,035,215	1,711,027,078	4,163,541,504
2007	303,938,534	2,124,757,324	1,783,847,294	4,367,957,343
2008	275,544,797	1,855,484,120	1,689,656,539	3,962,398,319
2009	271,165,111	1,802,896,430	1,674,215,759	3,854,850,633
2010	243,554,343	1,758,550,879	1,647,338,727	3,768,740,336
2011	233,414,014	1,736,253,832	1,746,560,110	3,837,383,400
2012	223,007,900	1,652,392,718	1,671,907,737	3,675,743,000

In the final inventory allocation, staff assumed that all of California's general aviation jet fuel was consumed in the state and added it to the intrastate commercial jet fuel. Thus, the results from Table 22 and Table 28 can be combined to calculate the final apportionment of total jet fuel sales for California. Table 29 presents these results.

Table 29: Apportionment of California's jet fuel sales, summary for 2000 to 2012 (gallons)

Year	Intrastate (commercial + general aviation flights)	Interstate commercial flights	International commercial flights	CA Military flights	Total CA fuel sales (from EIA SEDS)
2000	375,690,922	1,866,203,760	1,704,290,967	379,856,351	4,326,042,000
2001	359,843,359	1,764,858,780	1,544,709,702	413,660,159	4,083,072,000
2002	372,858,262	1,976,547,037	1,596,302,070	370,044,631	4,315,752,000
2003	379,745,498	1,956,618,733	1,479,736,059	372,181,710	4,188,282,000
2004	409,957,490	2,073,606,111	1,604,229,050	339,343,349	4,427,136,000
2005	413,485,158	1,997,757,794	1,645,686,418	336,774,630	4,393,704,000
2006	423,479,211	2,029,035,215	1,711,027,078	305,384,496	4,468,926,000
2007	459,352,726	2,124,757,324	1,783,847,294	285,390,657	4,653,348,000
2008	417,257,660	1,855,484,120	1,689,656,539	272,713,681	4,235,112,000
2009	377,738,445	1,802,896,430	1,674,215,759	260,519,367	4,115,370,000
2010	362,850,729	1,758,550,879	1,647,338,727	262,755,664	4,031,496,000
2011	354,569,458	1,736,253,832	1,746,560,110	234,600,600	4,071,984,000
2012	351,442,545	1,652,392,718	1,671,907,737	292,165,000	3,967,908,000

(b) Apportionment of marine vessel fuel

Staff apportioned distillate and residual fuel oil used by marine vessels for port activities, harbor craft, transit (within 24 nautical miles from California's coast) and travel outside of California waters among intrastate, interstate and international activities using an ARB model based on geographically specific shipping activity data which was developed for the Goods Movement Plan (ARB, 2010b; ARB, 2011b).

(c) Rail distillate

Sales of rail distillate gallons in California were reported by EIA. Staff used those numbers without adulteration, so CO_2 calculations simply follow the methodology for calculating emissions from any source of distillate combustion.

(d) Off-Road mobile sources

Fuel use estimates of distillate (in gallons) from Off-Road mobile sources (airport ground support equipment, construction and mining equipment, industrial equipment, and oil drilling equipment) operated in California were obtained from ARB's Off-Road Model (ARB, 2011a). Staff used those numbers without adulteration, so CO_2 calculations simply follow the methodology for calculating emissions from any source of distillate combustion.

(e) Emission calculations

All CO_2 emissions (as well as the CH_4 and N_2O emissions from LPG and natural gas) were estimated using the fuel combustion equation based on heat content:

Equation 26: Emissions from mobile source combustion (case 1)

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

Where,

$E_{GHG,\ fuel}$ = Emissions of the given GHG for the type of fuel (g of GHG)
Q_{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 27: Emissions from mobile source combustion (case 2)

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

Where,

$E_{GHG,\ fuel}$ = Emissions of the given GHG for the type of fuel (g of GHG)
Q_{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 California State Board of Equalization (BOE, 2013, Covert, 2013). These numbers are also referenced in the Federal Highway Administration (FHWA) Highway Statistics annual reports (FHWA, various years). Data for jet fuel sold within California came from the Energy Information Administration (EIA, 2013b). Data regarding distillate fuel use for railroad activity (locomotives) were obtained from the Energy Information Administration (Walzer, 2011).

Heat content values for ethanol and gasoline are from ARB's Mandatory Reporting Program (ARB, 2012). Heat content of natural gas came from the EIA SEDS database (EIA, 2013c) and values for aviation gasoline, distillate, jet fuel, residual fuel oil and LPG from USEPA (USEPA, 2007d).

CO_2 emission factor values are for gasoline and ethanol are discussed in Section I.C.3. Other CO_2 emissions factors were from USEPA (USEPA, 2007d) for natural gas, aviation gasoline, and distillate and residual fuel oil used in international shipping; and from ARB's Goods Movement Plan (ARB, 2010b; ARB, 2011b) 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, 2007c; USEPA, 2013e) for distillate, aviation gasoline, jet fuel, and residual fuel oil used in international shipping; and from ARB's Goods Movement Plan (ARB, 2010b; ARB, 2011b) 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_00-12/annex_1d_transport.pdf

4. Changes in Estimates

In this edition of the inventory, all transportation categories received only minor updates such as updating fuel numbers to match the latest reported fuel data and improved data sources.

5. 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. Also, staff will ensure that EMFAC outputs are in line with fuel consumption data, such as fuel sales from BOE.

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, the processing and upgrading of natural gas, and the transport in pipelines. 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). Crude oil combustion occurred in California in the early 1990's but has since been discontinued.

When crude oil is first brought to the surface, it may contain a mixture of associated gas, 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. 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. Emissions from fuel combusted in pipelines compressor stations are included in this section, but the fugitive emissions from pipelines are reported in section I.F.

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 28: Emissions from oil and gas production

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

Where,

$E_{GHG,\ fuel}$ = Emissions of the given GHG for the type of fuel (g of GHG)
Q_{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, Distillate, Natural Gas, Residual fuel oil]

3. Data Sources

The data sources for estimating emissions include the CEC's Quarterly Fuels and Energy Report (QFER), the CA Department of Conservation Division of Oil, Gas & Geothermal Resources (DOGGR), the Energy Information Administration (EIA), 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 EIA (EIA, 2013b). The QFER (Gough, 2013) provided natural fuel use. The DOGGR (Winkler, 2013) provided data on associated gas fuel use.

Natural gas heat content values are from EIA SEDS (EIA, 2013c), associated gas values from WSPA (Wang, 2007) and other heat content values from ARB's Mandatory Reporting Program (ARB, 2012).

Emission factor values for CO_2 are from WSPA (Wang, 2007) for associated gas and from ARB's Mandatory Reporting Program (ARB, 2012) for other fuels. Emissions factor values for CH_4 and N_2O are from ARB's Mandatory Reporting Program (ARB, 2012).

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_00-12/annex_1e_oil_and_gas_production.pdf

4. Changes in Estimates

No changes were made for the categories included in this section when compared with the estimates in the previous edition of ARB's GHG inventory.

5. Future Improvements

A large amount of emissions in this category must be reported to ARB's Mandatory Reporting Program, the rest being emitted by facilities under the current emissions threshold of 10,000 tonnes of CO_2. Thus, the data sources currently in use provide the best comprehensive estimate of emissions from this sector. Future improvements may, however, come from better data on the composition and heating value of associated gas.

F. Fugitive Emissions from Fuels and Energy Production (IPCC 1B1, 1B2, and 1B4)

1. Background

This section discusses various emissions associated with fuels and energy production, other than combustion emissions, in several industrial sectors.

Methane emissions occur due to leaks arising from 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. These emissions are associated with 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. Fugitive emissions of methane also occur from the natural off-gassing of methane from petroleum gas seeps and coal storage piles.

Carbon dioxide emissions are generated by some processes used to control and eliminate acid gases in the exhaust of power plants. For example, limestone or lime is injected to react with acid gases and result in the release of carbon dioxide as a byproduct of the reaction.

Emissions of both methane and carbon dioxide arise from certain processes occurring in petroleum refineries. These emissions result from the purposeful venting of exhaust gases, rather than an unintended leakage from pipes or tanks. Sources of these process emissions include: asphalt blowing, coke drum vents, and sulfur recovery units.

Flaring at petroleum refineries is a process that burns various waste products for which a more useful purpose cannot be found. The composition of these waste streams can vary greatly and are usually not monitored in such a way as to allow a breakdown into their component parts. They are grouped here with the fugitive and process emissions even though they are a type of combustion emission. Flaring produces the usual gases associated with combustion: carbon dioxide, methane and nitrous oxide.

2. Methodology

For some of the categories, 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

Year 2009+ data from ARB's Mandatory Reporting Regulation (MRR) were used for some categories. Estimates for fugitive emissions from pipes, storage tanks and process losses in the oil & gas extraction, petroleum refining and cement manufacturing sectors, flaring in refineries (CO_2, CH_4 and N_2O), acid gas control devices (CO_2), refinery process such as asphalt blowing, coke drum vents, and sulfur recovery units (CO_2, CH_4), and fugitives from coal storage piles (CH_4) come from ARB's MRR. For MRR categories without any previous data source, MRR emissions for 2009 were obtained from the Mandatory Reporting database, and then scaled back in time —proportionally to the relevant level of activity— to estimate values for 2000-2008.

Equation 29: Scaling of some fugitive emissions back in time

$$E_{year} = \frac{E_{2009}}{H_{2009}} \bullet H_{year}$$

Where,

E_{year} = GHG emission estimate for a given economic subsector in a particular year (g of GHG)
E_{2009} = GHG emission reported by the given economic subsector in 2009 (g of GHG)
H_{2009} = Total amount of heat or fuel used by the facilities in the given subsector in 2009 (btu or tons)
H_{year} = Total amount of heat or fuel used by the facilities in the given subsector in the particular year (btu or tons)

With

Year = [2000 to 2008]

The scaling used PIIRA data on the total heat used by refineries to scale emissions from flaring, refinery process emissions and the refinery portion of acid gas control. Total fuel use for coal was used to scale methane emissions from coal storage piles not already addressed in the electricity sector.

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

Data from ARB's Mandatory Reporting Program (ARB, 2012) were used instead of CEIDARS data for some categories in 2009+ (e.g. fugitive emissions from refineries process losses and storage tanks). Data from the PIIRA database (O'Brien, 2010) and from EIA SEDS databases published online (EIA, 2013c) were used to scale 2009 emissions found only in the Mandatory Reporting database back in time to cover 2000-2008 (e.g. emissions from coal piles, flaring, or acid gas control devices).

4. Changes in Estimates

In this edition of the GHG inventory the use of updated and corrected Mandatory Reporting data resulted in a substantial decrease in emissions estimates for fugitives from natural gas pipelines and smaller changes to a few other categories included in this section: -35.6 percent on average for 2011 when compared with the estimates in the previous edition of ARB's GHG inventory.

5. Future Improvements

ARB staff will continue to use of Mandatory Reporting data for future editions of the GHG inventory. Staff is also considering the potential use of more comprehensive data on fugitive emissions from tanks and pipelines now being collected through year specific surveys of the Oil & Gas industry.

G. Carbon Dioxide from Geothermal Energy Production (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

2.1 Years 2000 to 2008

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 power plants and applied the CO_2 emission factor obtain by averaging the emission factors used by geothermal plants reporting to ARB's Mandatory Reporting Program. The emission factor is 0 for geothermal resources using Binary Turbines to generate electricity, as they prevent any escape of CO_2.

Equation 30: 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)

2.2 Year 2009+

Emissions data reported by individual power plants under ARB's Mandatory Reporting Program were used for 2009+. However, small plants emitting less than the Mandatory Reporting threshold of 2,500 metric tons of CO_2 (10,000 metric tons for 2011 onwards) do not report their emissions. For those plants staff used the same methodology as for years 2000 to 2008, see Equation 30 above.

3. Data Sources

Geothermal heat data was obtained from the U.S. Energy Information Administration (EIA). Data for 2000 was obtained through personal correspondence with Robert Schnapp of U.S. Energy Information Administration (Schnapp, 2008). Data for 2001-2008 data was downloaded from U.S. Energy Information Administration databases published online (EIA, 2013a). The emission factor for 2000-2008 is an average of those used by geothermal plants reporting to the ARB's Mandatory Reporting Program (ARB, 2012), while actual reporting data was used for 2009+ for plants reporting to ARB.

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_00-12/annex_1g_carbon_dioxide_from_geothermal_power.pdf

4. Changes in Estimates

No changes were made for the categories included in this section when compared with the estimates in the previous edition of ARB's GHG inventory.

5. Future Improvements

ARB's GHG Mandatory Reporting data for geothermal plants will continue to be included in future editions of the GHG inventory.

II. Industrial Processes and Product Use

A. Cement Production (IPCC 2A1)

1. Background

In cement manufacturing, 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 (predominantly 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 ARB statewide GHG 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

This GHG inventory for the cement industrial sector presents three calculation methods including a Tier 2 approach for years 2000 to 2007, followed by Tier 3 approach —based on facility level measurements— for years 2008 and 2009, and then a Tier 2 method for years 2010 through 2012.

2.1 Methodology for years 2000 through 2007

Staff 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 31: CO_2 emissions from cement production (equation 2.2 of the guidelines)

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

Where,

E_K = emissions of CO_2 from cement production in the clinker process (tonnes)

M_{cl} = weight (mass) of clinker produced (tonnes)

EF_{cl} = emission factor for clinker (tonnes CO_2/tonne clinker). This clinker emission factor (EF_{cl}) is not corrected for CKD.

CF_{ckd} = emissions correction factor for CKD, (dimensionless, see Equation 32)

Equation 32: 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 32 into Equation 31, one gets Equation 33.

Equation 33: Substituting for CF_{ckd} into Equation 31

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

And considering that ($C_d \bullet F_d \bullet EF_c$) constitutes EF_d the emission factor of the CKD, Equation 33 can be simply written as:

Equation 34: CO_2 emissions from cement production

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

2.2 Methodology for years 2008 and 2009

Years 2008 and 2009 CO_2 emissions were quantified by each cement manufacturing plant in California using the calculation methodology specified by the ARB GHG Mandatory Reporting regulation (ARB, 2007). This is a clinker-based method using the volume and composition of clinker produced and the amount of CKD discarded. A plant-specific clinker CO_2 emission factor and a CKD emission factor for CO_2 are also determined. The clinker emission factor is based on the actual percentage of lime (CaO) and magnesium oxide (MgO) content of the clinker. For any CKD which is not recycled back into the kiln, a plant-specific CKD calcination rate is determined. Further, each cement plant calculates the process related emissions resulting from the total organic carbon (TOC) content of the raw materials such as limestone, shale, or fly ash. This additional TOC factor was not included in the methodology used for years 2000 to 2007.

The plant-specific clinker emission factor is determined using the following equation:

Equation 35: Clinker emission factor

$$\boxed{EF_{cl} = (F_{CaO} \bullet 0.785) + (F_{MgO} \bullet 1.092)}$$

Where,

EF_{cl} = emission factor for clinker (tonnes CO_2/tonne clinker). This clinker emission factor is not corrected for CKD.

F_{CaO} = fraction content of CaO in the clinker by weight minus non-carbonate CaO in the clinker by weight (fraction)

0.785 = molecular weight ratio of CO_2/CaO (44g/56g), (dimensionless)

F_{MgO} = fraction content of MgO in the clinker by weight minus non-carbonate MgO in the clinker by weight (fraction)

1.092 = molecular weight ratio of CO_2/MgO (44g/40g), (dimensionless)

The plant-specific CKD emission factor is quantified for cement plants that generate CKD which is not recycled back to the kiln as follows:

Equation 36: Clinker kiln dust emission factor

$$\boxed{EF_{CKD} = \frac{\frac{EF_{cl}}{1+EF_{cl}} \bullet d}{1-\frac{EF_{cl}}{1+EF_{cl}} \bullet d}}$$

Where,

EF_{CKD} = emission factor for CKD (tonnes CO_2/tonne CKD)

EF_{cl} = emission factor for clinker (tonnes CO_2/tonne clinker). This clinker emission factor is not corrected for CKD.

d = plant-specific CKD calcination rate (dimensionless, see Equation 37)

Equation 37: Plant specific clinker kiln dust calcination rate

$$\boxed{d = 1-\frac{C_d \bullet (1-C_{RM})}{(1-C_d) \bullet C_{RM}}}$$

Where,

d = plant-specific CKD calcination rate (dimensionless)

C_d = fraction of original carbonate in the CKD (fraction)

C_{RM} = fraction of original carbonate in the raw material (fraction)

The CO_2 emissions from the clinker process for each cement plant are calculated using the following equation:

Equation 38: CO_2 emissions from clinker production

$$\boxed{E_{cl} = (M_{cl} \bullet EF_{cl}) + (M_{CKD} \bullet EF_{CKD})}$$

Where,

E_{cl} = emissions of CO_2 from clinker calcination process (tonnes)

M_{cl} = amount of clinker produced (tonnes)

EF_{cl} = emission factor for clinker (tonnes CO_2/tonne clinker).

M_{CKD} = amount of CKD not recycled to the kiln (tonnes)

EF_{CKD} = emission factor for CKD (tonnes CO_2/tonne CKD)

The estimation of CO_2 emissions from the combustion of the total organic carbon (TOC) in raw materials is calculated as follows (with a default value of 0.2 percent organic carbon):

Equation 39: CO_2 emissions from combustion of organic carbon in raw materials

$$\boxed{E_{TOC} = TOC \bullet C_{RM} \bullet 3.664}$$

Where,

E_{TOC} = emissions of CO_2 from the combustion of organic carbon (TOC) content in raw materials (tonnes)

TOC = total organic carbon content of raw material, default value = 0.002 (fraction)

C_{RM} = fraction of original carbonate in the raw material (fraction)

3.664 = molecular weight ratio of CO_2/C (44g/12g), (dimensionless)

The total CO_2 emissions from the calcination process for each plant are finally determined using the next equation; by summing the emissions from the clinker process and the emissions from the combustion of organic carbon in raw materials described above.

Equation 40: Total CO_2 emissions from cement production process

$$\boxed{E_{total} = E_{cl} + E_{TOC}}$$

Where,

E_{total} = total process emissions of CO_2 from cement production (tonnes)

E_{cl} = emissions of CO_2 from the clinker calcination process (tonnes)

E_{TOC} = emissions of CO_2 from the combustion of organic carbon in raw materials (tonnes)

Note that to satisfy the ARB GHG Mandatory Reporting regulation, cement plant operators also have the option to determine CO_2 emissions from installed Continuous Emission Monitoring Systems (CEMS) which comply with federal performance standards. The cement sector total in California is obtained by summation of all cement plants' emissions. Emissions for 2007 were determined by interpolation between 2006 and 2008 estimates.

2.3 Methodology for years 2010 through 2012

Years 2010 through 2012 CO_2 emissions were quantified using clinker amounts provided by each cement manufacturing plant in California as reported under the ARB GHG Mandatory Reporting program (ARB, 2013b).

Cement plant operators have the option to determine CO_2 emissions from installed Continuous Emission Monitoring Systems (CEMS) which comply with federal performance standards. The total emissions from the CEMS combine data from process emissions and fuel combustion sources. Cement process emissions were determined by adding emissions from clinker production to emissions assigned to CKD.

Equation 41: CO_2 emissions from clinker production and CKD

$$\boxed{E_{cl} = 1.02 \bullet (M_{cl} \bullet EF_{cl})}$$

Where,

E_{cl} = emissions of CO_2 from clinker calcination process (tonnes)
M_{cl} = amount of clinker produced (tonnes)
EF_{cl} = emission factor for clinker (tonnes CO_2/tonne clinker).

The emission factor for clinker is based on the average fraction of lime used in cement clinker and a constant reflecting the mass of CO2 released per unit of lime (IPCC, 2006a). The CKD emissions are estimated as two percent of the CO_2 emissions from clinker production (IPCC, 2006a).

3. Data Sources

The Portland Cement Association (PCA) provided clinker production data (M_{cl}) for all California Portland cement plants for years 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.

In 2008, ARB conducted a survey of California cement plants to obtain the 2006 annual production data which was utilized by ARB to calculate the 2006 CO_2 emissions (ARB, 2008). Cement plant emissions for 2007 were determined through interpolation of clinker production and CKD discarded amounts between the ARB survey for 2006 and the 2008 cement production reports submitted by facilities to ARB under the ARB GHG Mandatory Reporting regulation.

For years 2000 to 2007 and for years 2010 through 2012, the default emission factor values from the 2006 IPCC guidelines (IPCC, 2006a) were used for CO_2 emissions calculations, 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.

The 2008 and 2009 CO_2 emissions were calculated for all California cement manufacturing plants using the data reported by plant operators as required by the ARB GHG Mandatory Reporting regulation (ARB, 2012). Plant-specific emission factors for clinker and CKD are determined and then used to calculate CO_2 emissions per facility which are summed to present the total statewide GHG emissions for this industrial sector.

The 2010 through 2012 CO_2 emissions were quantified using clinker amounts reported by each cement manufacturing plant in California as required under the ARB GHG Mandatory Reporting program (ARB, 2013b) and using an estimated CKD calculation.

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_00-12/annex_2a_cement_production.pdf

4. Changes in Estimates

For the 2008 and 2009 emissions calculations, staff utilized data collected under the ARB GHG Mandatory Reporting regulation. This calculation methodology uses plant-specific data to determine emission factors, and also includes the CO_2 emissions from the combustion of the organic content of the raw materials such as limestone and shale. These plant-specific emission factors incorporate data on the mass and composition of calcium and magnesium carbonates. Further, the fraction of non-carbonate sources (e.g. steel slag, calcium silicates, or fly ash) is subtracted from the total amount of the CaO and MgO content of the clinker. The additional estimation of CO_2 emissions from the combustion of organic carbon contained in raw materials was not included for years 2000 through 2007.

For the 2010 through 2012 emissions data reports, cement plant operators have utilized the option of determining facility CO_2 emissions from installed Continuous Emission Monitoring Systems (CEMS). The total emissions from the CEMS combine data from process emissions and fuel combustion sources. In this case, cement process emissions were determined by calculating emissions resulting from clinker production along with emissions assigned to CKD by-product.

5. Future Improvements

ARB plans to continue to utilize plant-specific data submitted under the requirements of the ARB GHG Mandatory Reporting program for future state emission inventory calculations.

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 $CaCO_3$) or dolomitic limestone (higher Mg concentration) is heated in a kiln to produce lime (CaO), CO_2 emissions and lime kiln dust (LKD) as a by-product.

Equation 42: Calcination processes

$$\boxed{\begin{array}{l} CaCO_3 + \text{Heat} \rightarrow CaO + CO_2 \\ MgCO_3 + \text{Heat} \rightarrow MgO + CO_2 \end{array}}$$

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

2. Methodology

There are two types of lime material: high-calcium lime and dolomitic lime. Quicklime is the product which results from the calcination of limestone material. High-calcium quicklime is derived from limestone material containing less than 5 percent magnesium carbonate ($MgCO_3$). Dolomitic quicklime is produced from limestone material containing 35 to 46 percent $MgCO_3$. A plant-specific CO_2 emission factor for limestone calcination in a kiln can be developed through laboratory analysis of the actual percent CaO and percent magnesium oxide (MgO) in the input limestone material. Then, multiplying the quantity of lime produced annually at a plant by the derived CO_2 emission factor will provide the annual CO_2 emissions. This methodology is consistent with emission estimation methodology used by the USEPA Emission Inventory Improvement Program guidance (USEPA, 2004a), and with the Tier 3 method of the 2006 IPCC guidelines (IPCC, 2006a).

Equation 43: CO_2 emissions from lime calcination

$$\boxed{E_l = W_l \bullet (P_{CaO,l} \bullet 0.7848 + P_{MgO,l} \bullet 1.0918)}$$

Where,

E_l = CO_2 emissions from lime calcination process (tonnes)

W_l = Weight (mass) of lime produced (tonnes)

$P_{CaO,l}$ = Proportion of CaO in lime (fraction)

0.7848 = Molecular weight ratio of CO_2 to CaO (44g/56g), (dimensionless)
$P_{MgO, l}$ = Proportion of MgO in lime (fraction)
1.0918 = Molecular weight ratio of CO_2 to MgO (44g/40g), (dimensionless)

Equation 44: CO_2 emissions from LKD by-product

$$\boxed{E_{LKD} = W_{LKD} \bullet (P_{CaO,\, LKD} \bullet 0.7848 + P_{MgO,\, LKD} \bullet 1.0918)}$$

Where,
E_{LKD} = CO_2 emissions from LKD calcined by-product generation (tonnes)
W_{LKD} = Weight (mass) of LKD generated (tonnes)
$P_{CaO, LKD}$ = Proportion of CaO in LKD (fraction)
0.7848 = Molecular weight ratio of CO_2 to CaO (44g/56g), (dimensionless)
$P_{MgO, LKD}$ = Proportion of MgO in LKD (fraction)
1.0918 = Molecular weight ratio of CO_2 to MgO (44g/40g), (dimensionless)

Equation 45: Total CO_2 emissions from lime production

$$\boxed{E_{total} = E_l + E_{LKD}}$$

Where,
E_{total} = total process emissions of CO_2 from lime production (tonnes)
E_l = CO_2 emissions from lime production (tonnes)
E_{LKD} = CO_2 emissions from LKD calcined by-product generation (tonnes)

3. Data Sources

The National Lime Association (NLA) provided CO_2 emission estimates from lime production operations in California for years 2002 through 2009 using plant-specific CO_2 emission factors and actual material throughput for both limestone calcination and LKD by-product generation (Lime Producers, 2011). The limestone material is generally mined on-site and mineral characteristics for CaO and MgO concentrations are determined monthly by laboratory analysis. The molecular weight ratio of CO_2 to CaO (0.7848) and CO_2 to MgO (1.0918) are derived from molecular weight data published by the International Union of Pure and Applied Chemistry (IUPAC, 2006).

The NLA provided CO_2 emission estimates for California lime plants for years 2002 to 2009 (rounded to the nearest thousand tonne). Material throughput amounts presented in the inventory were back-calculated for 2000 and 2001, based on the 2002 to 2008 CO_2 emissions and using the data for lime material composition and LKD ratios provided for 2007. GHG emissions data for 2000 and 2001 were determined through extrapolation from the values for years 2002 to 2008.

Years 2010 through 2012 CO_2 emissions were quantified using facility process emissions and then subtracting the annual amount of CO_2 captured on-site as provided by each lime manufacturing plant in California and reported under the ARB GHG Mandatory Reporting program (ARB, 2013b). The CO_2 captured on-site is recovered by facilities for use in sugar refining and precipitated calcium carbonite production.

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_00-12/annex_2b_lime_production.pdf

4. Changes in Estimates

The1990-2004 edition of the California GHG inventory used annual material production data provided by the California Department of Conservation. This previous inventory calculation method assumed a CO_2 emission factor for high-calcium lime only and did not account for CO_2 emissions from LKD by-product generation. This edition of the GHG inventory relies upon industry calculations based on plant-specific emission factors and including the CO_2 emissions from LKD by-product generation.

The current estimates should be more accurate and have resulted in significantly lower GHG emissions for this category.

5. Future Improvements

ARB staff will continue to utilize plant-specific data submitted under the requirements of the ARB GHG Mandatory Reporting program for future state emission inventory calculations from this sector.

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 use as feedstock for the chemical industry (IPCC category 2B) for the manufacture of plastics, rubber, synthetic fibers and other materials. Other consumptive uses of fossil fuels involve non-energy products such as lubricants, waxes, asphalt, and the evaporation of solvents (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 feedstock or they may occur during the product's lifetime, for instance some of the lubricant in motors will end up being burned and evaporated solvents are eventually oxidized in the atmosphere. However, emissions from 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.

In California, the only known activities of this kind are the consumption of lubricants and evaporation of solvents. Hydrogen production which also consumes fuels, is discussed in a later section (IPCC 2H3)

2. Methodology

2.1 Consumption of lubricants

Staff used a simple methodology consistent with that used by USEPA for the national GHG inventory (USEPA, 2012a). 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 refinery gas used for hydrogen production.

Staff determined that, in the case of California, only lubricants consumed incidentally in internal combustion engines make up this category, as no data could be found for consumptive use of other fossil fuels resulting in their partial oxidation.

Equation 46: CO_2 emissions from non-energy uses of fossil fuels

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

Where,

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

Q_{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 = [lubricants]

2.2 Solvent evaporation

Solvent evaporation data was retrieved from ARB's CEIDARS database. Emissions of Reactive Organic Compounds (ROG), which do not include methane, are converted into the amount of CO_2 that would result from the oxidation of all carbon atoms in the ROG compounds into CO_2. To do that, staff assumed that each ROG compound can be approximated as a hydrocarbon, where each carbon is bonded to 2 other carbon atoms and to 2 hydrogen atoms.

Equation 47: Assumed oxidation of reactive organic compounds

$$\boxed{C_nH_{2n} + nO_2 \rightarrow nCO_2 + nH_2O}$$

Thus each CH_2 chain in the ROG molecules is converted into a molecule of CO_2. CH_2 has an approximate molar mass of 14 grams/mole, while CO_2 has a molar mass of approximately 44 grams/mole. Thus, multiplying by 44/14 converts the amount of evaporated ROG the resulting amount of CO_2 emissions.

3. Data sources

Lubricant consumption data came from EIA SEDS (EIA, 2013c). The proportion of carbon stored came from USEPA inventory annex 2 (USEPA, 2007b). The heat content and emission factor for CO_2 are from ARB's Mandatory Reporting Program (ARB, 2012). Solvent evaporation data comes from the CEIDARS database (ARB, 2013a).

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_00-12/annex_2c_non-energy_uses_of_fossil_fuels.pdf

4. Changes in Estimates

No changes were made from the previous methodology for the categories included in this section.

5. Future Improvements

ARB staff will seek to obtain more detailed data about the non-energy use of fuel in California, to determine if any other fuel use as feedstock should be included in this section.

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. Nitric acid is manufactured by the catalytic oxidation of ammonia. California nitric acid manufacturing plants have emissions control devices that reduce the amount of N_2O released to the atmosphere.

2. Methodology

ARB staff utilized annual HNO_3 production data and emissions from California facilities as collected under the ARB GHG Mandatory Reporting program (ARB, 2013b). This methodology is consistent with the Tier 3 method of the 2006 IPCC guidelines (IPCC, 2006a).

The previous statewide inventory time series had utilized the estimation method suggested by USEPA Emission Inventory Improvement Program guidance (USEPA, 2004a). This previous approach estimated California production by scaling the national production of nitric acid by the ratio of California's nitric acid production capacity to the national production capacity, since actual plant production amounts were not available.

Emissions of N_2O are can be determined using the following equation.

Equation 48: 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

CO_2 emissions were provided by each nitric acid plant in California for 2011 and reported under the ARB GHG Mandatory Reporting program (ARB, 2013b). The average of emissions reported for 2011 and 2012 from California plants were used as a constant value for the 2000 through 2010 time series.

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_00-12/annex_2d_nitric_acid_production.pdf

4. Changes in Estimates

Staff learned that all nitric acid plants in California are using non-selective catalytic reduction (NSCR) air pollution abatement devices since the 1980s (Toledo, 2011). The N_2O emission factor for nitric acid plants with NSCR is 2 kg N_2O/tonne HNO_3 while plants with only selective catalytic reduction (SCR) release 9.5 kg N_2O/tonne HNO_3 produced (USEPA, 2004a). In the 1990-2004 edition of the Inventory staff had used a weighted average N_2O emission factor of 8 kg N_2O/tonne HNO_3 from the USEPA Emission Inventory Improvement Program guidance (USEPA, 2004b) which is based on a national survey of abatement devices on nitric acid manufacturing facilities that found that 80 percent of US plants had SCR technology while 20 percent had NSCR installations. This edition of the GHG inventory relies upon industry reported data for N_2O emissions.

5. Future Improvements

ARB staff will continue to use plant-specific emissions data submitted under the requirements of the ARB GHG Mandatory Reporting program for future state emission inventory calculations from this sector.

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. Un-dissociated 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, then the process-generated gases will also be released into the atmosphere.

2. Methodology

ARB conducted a 2006 survey in which data was collected from California Semiconductor manufacturing businesses (ARB, 2009). The time series for 2000 through 2012 data years for California emissions from this sector was updated to utilize the 2006 survey data. ARB calculated emissions from the 2006 survey were used to apportion the remaining years from this data point. The ratio was determined using the USEPA annual GHG Semiconductor emissions as a surrogate to measure the yearly change in emissions for California.

The USEPA has estimates of the national GHG emissions from semiconductor manufacture based upon information reported under their GHG Reporting Program, participants in its PFC Reduction/Climate Partnership for the Semiconductor Industry, and USEPA's PFC Vintage Model. ARB staff estimated California's emissions for years 2000 through 2005 and 2007 through 2012 by apportioning USEPA's estimates of U.S. semiconductor manufacture emissions to the ratio of California survey results to U.S. emissions for 2006. For the 2006 data point, this methodology is consistent with the Tier 3 method of the 2006 IPCC guidelines (IPCC, 2006a). ARB staff assumed that emissions of individual fluorinated gas from semiconductor manufacturing facilities in California were proportional to emissions of these gases at the national level. The fluorinated gases included in the USEPA GHG inventory are: CF_4, C_2F_6, C_3F_8, C_4F_8, HFC-23 (CHF_3), SF_6, and NF_3.

Equation 49: Emissions from semiconductor manufacturing

$$\boxed{E_{CA,\,GHG} = E_{US,\,GHG} \bullet \left(\frac{S_{CA,2006}}{E_{US,2006}} \right)}$$

Where,

$E_{CA,\,GHG}$ = Emissions of a particular fluorinated gas from semiconductor manufacturing in California (g)
$E_{US,\,GHG}$ = Emissions of the particular fluorinated gas from semiconductor manufacturing in the entire US (g)
$S_{CA,2006}$ = 2006 survey of emissions of a particular fluorinated gas from semiconductor manufacturing in California (g)
$E_{US,2006}$ = 2006 emissions of the particular fluorinated gas from semiconductor manufacturing in the entire US (g)
GHG = [CF_4, C_2F_6, C_3F_8, C_4F_8, HFC-23 (CHF_3), SF_6, NF_3]

3. Data Sources

Data sources include the ARB 2006 survey information (ARB, 2009), a ratio of 2006 California emissions to 2006 national emissions for each compound, and USEPA emissions estimates (USEPA, 2014b).

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_00-12/annex_2e_semiconductor_manufacturing.pdf

4. Changes in Estimates

In this edition of the inventory for the semiconductor manufacturing sector, emissions are now speciated by gas (including NF_3) instead of a single emission value for all halogenated compounds, expressed in CO_2 equivalent. Nitrogen trifluoride (NF_3) was introduced as a new GHG compound by the IPCC 4th Assessment report with a Global Warming Potential (GWP) value of 17,200. In 2009, California Senate Bill 104 amended the California Health & Safety code (Section 38505) to include NF_3 as a defined GHG. The USEPA presents NF_3 emissions from semiconductor manufacturing in their annual national inventory; however, they do not include it in the aggregated total of halogenated compounds for this sector since NF_3 is not a specified Kyoto gas and is therefore not reported under UNFCCC guidelines. It is anticipated that NF_3 will be added to future UNFCCC standards.

In the previous version of the statewide inventory, estimates of emissions from semiconductor manufacturing for California utilized national level US Environmental Protection Agency data (USEPA, 2011) along with semiconductor shipment data for the United States and California from the US Census Bureau economic data surveys (USCB, various years b). This Census is only revised every 5 years so the data accuracy is limited since previous values had been held constant until a new Census is published.

The revised methodology for semiconductor manufacturing resulted in a reduction to previous estimates which had been determined based on the Census Bureau economic data calculation.

5. Future Improvements

ARB enacted a 2010 Regulation to achieve GHG emissions reductions from semiconductor manufacturing and related devices. This rule provides standards for manufacturing operations and emission abatement devices as well as annual reporting of GHG emissions for 2010 and thereafter. California GHG emissions from this sector may decrease based on a combination of rule standards and continued manufacturing of product components in other countries. ARB is trying to obtain this annual data which is being collected at the Air District level, and this could be a future data source.

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 significantly 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 equipment lifetime. ARB has implemented detailed inventory estimations for the 2000 through 2012 inventory years based on comprehensive research completed by ARB and by private consulting companies under contract with ARB. The time series of net consumption of each chemical compound was performed at a detailed product and equipment level to establish the basis for emissions profile calculations. The estimation of emissions used activity data and resulting emission bank (equipment quantity) calculations along with emission factors that reflect the individual characteristics of the various equipment types, processes, and products. This methodology is consistent with the Tier 2a method of the 2006 IPCC guidelines (IPCC, 2006a)

The previous methodology of the statewide emissions inventory for ODS substitutes utilized a USEPA “vintaging” model of ODS-containing equipment and products in order to estimate the actual (versus potential) emissions of various ODS substitutes, including HFCs and PFCs. Similar to the new ARB methodology, the USEPA 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.

In the previous version of the GHG inventory for this sector, ARB staff estimated California’s share of ODS substitute emissions by apportioning national emissions numbers on the basis of population for each compound as provided by USEPA.

The revised inventory methodology completed by ARB for this industrial sector further speciates each compound into the following emission categories:

- Refrigeration and Air Conditioning
- Aerosol Propellants
- Insulating Foams
- Solvents
- Fire Protection

Next, the above emission categories are further delineated into the below economic sectors:

- Commercial
- Industrial
- Residential
- Transportation

The calculation of mass emissions is determined for each category of equipment type through using known charge amounts of each GHG compound and average loss rate for equipment reaching end-of-life. This method is used for simple calculations such as Refrigeration and Air Conditioning equipment with known refrigerant charge and leak rates (ARB, 2014).

Equation 50: Emissions of ODS substitutes using Simple Calculation Inputs

$$\boxed{E_{CA,GHG,EQUIPMENT} = [N_{units} \bullet C_{unit} \bullet L_{rate}] + [N_{EOL} \bullet C_{EOL} \bullet L_{EOL}]}$$

Where,

$E_{CA,\,GHG,\,EQUIPMENT}$ = Estimate of the given GHG (ODS substitute) emissions in California for each Equipment Type or Emissions sub-sector (g)

N_{units} = Number of units (equipment) in use (dimensionless)

C_{unit} = Average chemical charge rate per unit (g/unit)

L_{rate} = Average annual leak or loss rate (dimensionless)

N_{EOL} = Number of units reaching end-of-life (dimensionless)

C_{EOL} = Average chemical charge at end-of-life (g/unit)

L_{EOL} = Average loss rate at end-of-life (dimensionless)

With,

GHG = [CF_4, 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, C_4F_{10} 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}.

Mass emissions for more complex equipment varieties employed several calculation sources such as vehicle emissions models or information obtained from ARB research projects. The more complex emission profiles included the following categories: Mobile Vehicle Air Conditioning (ARB, 2013c); Marine Vessel Ships; Aircraft Air Conditioning; Metered Dose Inhaler Aerosol Propellant; Aerosol Propellants from products (consumer, commercial, and industrial); Fire Suppressants; Insulating Foam; Solvents; and Medical Sterilants.

3. Data Sources

In the previous methodology of the GHG inventory for this sector, ARB staff estimated California's share of ODS substitute emissions by apportioning national emissions numbers provided by USEPA on the basis of population. These past emission estimates for ODS substitutes for the United States were provided by the US Environmental Protection Agency (Godwin, 2009 and

USEPA, 2014b). Population estimates for the United States and California were from the US Census Bureau (USCB, various years a) and from the California Department of Finance (CDOF, 2013).

ARB developed the 2000 through 2012 time series for ODS substitutes for this inventory. After sectors were delineated by equipment category and economic sector, distinct emission profiles were ascertained. Then, mass emission rates were calculated for each sub-sector by year and for each applicable GHG compound. Internal ARB research, ARB-funded consultant surveys, and ARB emission model output were utilized to form the basis of the various parameters such as equipment types, number of units, GHG compounds specific to equipment types, mass charge rates, transition to different GHG compounds over time, and end-of-life profiles (ARB, 2014).

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_00-12/annex_2f_use_of_ods_substitutes.pdf

4. Changes in Estimates

Since the publication of the 1990-2004 edition of California's GHG inventory, ARB has developed a bottom up inventory calculation for ODS substitutes. The revised time series resulted in a decrease of California's current estimates of emissions of ODS substitute compounds over the 2000 to 2007 time period and then an increase in emissions between 2009 and 2012. The decrease in emissions from 2000 through 2007 as compared to scaled USEPA Vintage model output was determined to result from a decrease in the assumed leak rate used for motor vehicle air conditioning and for transport refrigeration units. The increase seen for 2009 through 2012 emissions from this industrial sector as compared to scaled USEPA Vintage model output was based on a change in the assumption of when residential air conditioning units approach their end-of-life.

5. Future Improvements

ARB staff will continue to track further updates of information sources to periodically revise the time series.

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, 2008). As of 2011, through the Regulation for Reducing Sulfur Hexafluoride Emissions from Gas Insulated Switchgear (GIS), ARB staff now obtains California specific SF_6 emissions data directly reported to them. For 2011 onwards, the SF_6 emissions reported through the GIS regulation are used. To obtain previous year emissions (2000-2010), staff corrected the estimates produced using the previous method, by multiplying each estimate by the ratio of the 2011 GIS reported emissions to the 2011 previously estimated emissions.

The previous method apportioned 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, 2004a).

Equation 51: Previous method to estimate 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 (watt-hours)
G_{IMP}	= Electricity generation imported into California (watt-hours)
G_{US}	= National electricity generation (watt-hours)

The new method corrects each previous year (2000-2010) estimate using the GIS data reported to ARB in 2011.

Equation 52: New method to update SF_6 emissions from use of electrical equipment for 2000-2010

$$\boxed{E_{New,Year} = E_{Previous,Year} \bullet \frac{E_{GIS,2011}}{E_{Previous,2011}}}$$

Where,

$E_{New,Year}$	= Updated California SF_6 emissions (grams) for each year (2000-2010)
$E_{Previous,Year}$	= Previously estimated SF_6 emissions (grams) for each year (2000-2010)
$E_{GIS,2011}$	= GIS reported SF_6 emissions (grams) in 2011
$E_{Previous,2011}$	= Previously estimated SF_6 emissions (grams) for 2011

The new and updated SF_6 emissions are finally apportioned to either in-state generation or imported power based on the share of total generation in that sector.

Equation 53: Method to apportion SF_6 emissions to in-state or imported power sectors

$$E_{in-state} = E_{total} \bullet \frac{G_{in-state}}{G_{total}}$$

$$E_{imports} = E_{total} \bullet \frac{G_{imports}}{G_{total}}$$

Where,

$E_{\text{in-state}}$ = SF_6 emissions (grams) apportioned to in-state generation
E_{imports} = SF_6 emissions (grams) apportioned to imported generation
E_{total} = Total SF_6 emissions (grams)
$G_{\text{in-state}}$ = Electricity generation produced in California (watt-hours)
G_{imports} = Electricity generation imported into California (watt-hours)
G_{total} = Total California electricity generation (watt-hours)

3. Data sources

Estimates of the national SF_6 emissions are from the 1990-2011 USEPA greenhouse gas inventory (USEPA, 2013c), national and California electricity generation data are from the Energy Information administration. California in-state electricity generation is from data discussed in section I.A. California electricity generation imports are from data discussed in section I.B.

4. Changes in Estimates

No changes were made for the categories included in this section when compared with the estimates in the previous edition of ARB's GHG inventory.

5. Future Improvements

Staff will continue to use California specific data from ARB's Mandatory GHG Reporting Program for inventory purposes.

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 find any source of data to assess California's CO_2 consumption. USEPA publishes CO_2 consumption emission estimates for the entire US. California emissions were estimated by scaling the national emissions from CO_2 consumption by the ratio of California population to the US population.

Equation 54: Emissions from CO_2 consumption

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

Where,

E_{CA} = California emissions from CO_2 consumption (g)
E_{US} = US emissions from CO_2 consumption (g)
Rpop = Ratio of the population of California to the population of the entire US (dimensionless)

3. Data sources

Data for US emissions from CO_2 consumption are from the USEPA national GHG inventory (USEPA, 2013a;USEPA, 2013d). Data for California and US population estimates were from the US Census Bureau (USCB, various years a).

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_00-12/annex_2h_carbon_dioxide_consumption.pdf

4. Changes in Estimates

Staff changed the ratio used to estimate California emissions by scaling down national emissions. In the 1990-2004 edition of the inventory, the ratio of California's CO_2 production capacity to US CO_2 production capacity was used instead of the ratio of population. Staff decided to change from production to population because CO_2 is widely used throughout society —in chemical production, food processing, carbonated beverages, refrigeration— and emissions occur wherever it is released to the atmosphere. Moreover, since only the CO_2 extracted from naturally occurring CO_2 reservoirs is to be accounted for in this section (see Background section above) using the ratio of state to national production has very little relevance.

5. 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), 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 (USGS, various years a). 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 – Emission Inventory Improvement Program guidance of 2004 (USEPA, 2004a).

Equation 55: 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, 2013a;USEPA, 2014a). Data for California's consumption of limestone and dolomite is from the US Geological Survey (USGS, various years a), and national consumption data came from the US Geological Survey (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_00-12/annex_2i_limestone_and_dolomite_consumption.pdf

4. Changes in Estimates

The US Geological Survey periodically revises some of their estimates of limestone and dolomite consumption. In addition, USEPA revised their estimates of national CO_2 emissions from limestone and dolomite consumption for the entire time series based on changes for the subcategory of "unspecified uses" identified by US Geological Survey. These changes resulted in somewhat lower emissions for this sector.

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, 2013a). 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 Emission Inventory Improvement Program guidance (USEPA, 2004a). 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 56: 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 IPCC 2006 Guidelines (IPCC, 2006c).

Equation 57: 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, various years c), and population estimates for the United States and California come from the US Census Bureau (USCB, various years a). The emission factor for soda ash consumption is from the 2006 IPCC Guidelines (IPCC, 2006c).

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_00-12/annex_2j_soda_ash_consumption.pdf

4. Changes in Estimates

There were no changes for this category.

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

Yearly hydrogen production data from the Oil and Gas Journal's "Historical Worldwide Refinery Survey" database were provided to staff by the Western States Petroleum Association (Shires, 2009). This database indicates that two basic types of H_2 production processes are used by California refineries: steam-methane reforming and partial-oxidation. Staff assumed that steam-methane reforming used either natural gas or refinery gas as the methane feedstock source and that partial-oxidation used various hydrocarbons as feedstocks. In the Oil and Gas Journal's database hydrogen gas production rates were reported in million cubic feet per day (MMCFd) capacity, and staff converted these capacity values into estimated production rates of million cubic feet per year (MMCF) by multiplying the original capacity value by 365 days per year. Staff assumed that these were standard cubic feet measured at 60° F and 1 atmosphere of pressure. In the absence of yearly data on the capacity factor (the amount of full capacity actually used), staff used the average capacity factor from ARB's Mandatory Reporting Program in 2009 (84.4 percent) and also used the respective amounts of refinery gas and natural gas used as feedstock in the same 2009 Mandatory Reporting data (42.1 percent refinery gas and 57.9 percent natural gas) and applied these to all previous years (2000-2008). For 2009+, actual Mandatory Reporting data was used for both hydrogen production and feedstock composition.

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 steam-methane reforming process was assumed to generate 1 mole of CO_2 for every 4 moles of H_2 produced (when Natural Gas was the feedstock) or 1 mole of CO_2 for every 3.5 moles of H_2 produced (when Refinery Gas was the feedstock):

Equation 58: Steam-Methane reforming process: natural gas feedstock

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

Equation 59: Steam-Methane reforming process: refinery gas feedstock

$$\boxed{CH_3 + 2H_2O \rightarrow CO_2 + 3.5H_2}$$

The partial oxidation method was assumed to generate 1 mole of CO_2 for every 3 moles of H_2 produced. This molar ratio is based on the assumption that each carbon in the longer chain carbon molecules was bonded to 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 60: Partial oxidation stoichiometric assumption

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

Based on these assumptions, CO_2 emissions associated with the use of feedstocks in the hydrogen production process (as separate from the fuel burned to produce the steam and heat for the process) can be derived from the volume of hydrogen produced in a given year:

Equation 61: 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 feedstocks used in 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^{o} 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 (natural gas), 1/3.5 for steam-methane (refinery gas) and 1/3 for partial oxidation

44 = molecular weight of CO_2 (grams per mole)

With,

Process = [steam-methane, partial oxidation]

2.2 Fuel consumed as feedstock

Staff estimated the amount of fuel consumed as feedstock by the hydrogen 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, and various petroleum feedstocks for partial oxidation.

Equation 62: Amount of fuel consumed as feedstock for hydrogen production

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

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 feedstocks used in 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, partial oxidation]

Fuel = [natural gas, refinery gas, petroleum feedstock]

3. Data Sources

For years 2000 to 2008, data on hydrogen production capacity from the Oil and Gas Journal's "Historical Worldwide Refinery Survey" database were provided to staff by the Western States Petroleum Association (Shires, 2009). Estimates of the respective capacity factors and amounts of refinery gas and natural gas used in the steam-methane reforming process were made using data from the Mandatory Reporting Program (ARB, 2012). For 2009+, hydrogen production and feedstocks used came from the Mandatory Reporting Program.

For all years, heat content data and CO_2 emissions factors are from the Mandatory Reporting Program (ARB, 2012).

4. Changes in Estimates

Corrections to Mandatory Reporting data for 2011 (reporters misunderstood how to report) was the only change that occurred, resulted in an increase in emissions estimates in 2011 for the categories included in this section: 44.1 percent on average for 2011 when compared with the estimates in the previous edition of ARB's GHG inventory.

5. Future Improvements

ARB's GHG Mandatory Reporting data for hydrogen plants will continue to be included in future editions of the GHG inventory.

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, and 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 has developed methods based on the 2006 IPCC guidelines to estimate the greenhouse gas emissions from enteric fermentation for the national GHG inventory (USEPA, 2013a). 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 (USEPA, 2014c).

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 (USEPA, 2014c).

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 for cattle, the Cattle Enteric Fermentation Model (CEFM), which tracks cattle sub-populations at different growth and production stages. The methane production is then derived from the gross energy contained in each sub-population’s feed intake and the methane conversion rate associated with its diet composition.

The CEFM is an implementation of the Tier 2 methodology of the IPCC guidelines, with the added refinement that cattle sub-populations are modeled on a monthly basis instead of a yearly basis. The steps involved in the CEFM are as follows:

(a) Characterization of cattle populations

The amount of methane emitted by cattle at different stages of their lifecycle varies greatly because of changes in size, growth rate or lactation. Also, while the emissions are reported on a yearly basis, some of these stages may last less than a year (e.g., calves become stockers; stockers enter a feedlot, etc.). USEPA uses a population transition matrix to simulate each stage of the cattle lifecycle on a per month basis to estimate the number of individuals in each cattle sub-population from birth to slaughter. The model disaggregates dairy and beef cattle populations into the categories of Table 30, based upon cattle population data from the U.S. Department of Agriculture statistics (USDA, 2013a), calving rates, average weights and weight gains, feedlot placement statistics, pregnancy and lactation, and death rates.

Table 30: Cattle population categories based on life-cycle

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

*Bulls for dairy and beef cattle are combined in a single category

The cattle population numbers from this monthly lifecycle modeling may differ from the annual livestock population data published by the U.S. Department of Agriculture (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 Population transition matrix 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 values for dairy cows were estimated from results of a literature search. Y_m values for dairy cows were estimated using mechanistic models of the digestive processes occurring in cattle: AAMOLLY (Donovan and Baldwin, 1999) and COWPOLL described in Kebreab et al. 2008. 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 for 1990 were taken from the literature. DE and Y_m values for 2000 onwards were estimated using the MOLLY model as described in Kebreab et al. 2008. Values for 1991 through 1999 were linearly extrapolated based on values for 1990 and 2000.

(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 63: 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)

NE_p = 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 daily emissions

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

Equation 64: Daily CH4 emission factor for a cattle population category

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

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 65: Yearly CH4 emissions of a cattle population category

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

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 66: 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 (USDA, 2013a) or California Department of Food and Agriculture (CDFA, 2012). California horse population numbers are derived from the United Nations' Food and Agriculture Organization (FAO) FAOSTAT database (FAO, 2012) and from an American Horse Council Report (AHC, 2005). California's horse population is estimated as follows:

Equation 67: Estimation of California's horse population

$$\boxed{H_{CA,year} = H_{US,year} \bullet R}$$

Where,

$H_{CA,\,year}$ = California's horse population for a given year (head)
$H_{US,\,year}$ = National horse population for a given year (head) from FAOSTAT
R = Ratio of California horse population to US horse population from AHC

Default methane emission factors for these livestock, shown in Table 31 below, are from IPCC Guidelines (IPCC, 2006d).

Table 31: Methane emission factors for bulls and other livestock (kg/animal/year)

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

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, 2013, from the

California Department of Food and Agriculture annual directories (CDFA, 2012), the U.S. Department of Agriculture (USDA, 2013a), the United Nations Food and Agriculture Organization (FAO, 2012), the American Horse Council (AHC, 2005) 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_00-12/annex_3a_enteric_fermentation.pdf

4. Changes in Estimates

The only changes in data and methods used in the current estimation of enteric fermentation emissions when compared with those used for the 2000-2011 edition of GHG Inventory are:

- For the first time the CEFM in this edition of the inventory the CEFM was used to estimate emissions from calves below 6 months of ages, for both dairy and beef breeds. Emissions from calves amount to about 3.4 percent of total cattle emissions.
- Population numbers for some categories of livestock were updated

Together these methodology changes and updates to data sources resulted in minor adjustments in emissions estimates for the categories included in this section: +3.3 percent on average over the years 2000 to 2011 when compared with the estimates in the 2000-2011 edition of ARB's GHG inventory.

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 microbial 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.F.

2. Methodology

The USEPA developed methods to estimate the CH_4 and N_2O emissions from manure management for the national GHG inventory (USEPA, 2013a). ARB staff extracted California specific information from a detailed set of data and parameters obtained from the USEPA Climate Change Division (Wirth, 2013) 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 (USEPA, 2014d).

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 32). Annual animal population data for cattle are from USEPA's Cattle Enteric Fermentation Model (CEFM) population transition matrix (see section III.A.2.1(a)). Other species population data are from the U.S. Department of Agriculture (USDA) National Agricultural Statistics Service (NASS) (USDA, 2013a) except for horses. Horse population data were derived from the FAOSTAT database (FAO, 2012) and an American Horse Council Report (AHC, 2005) as described in section III.A.2.2. 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, 2014d).

Table 32: Livestock groups used for manure management emissions estimates

Dairy Cattle	***Beef Cattle***	***Swine***	***Poultry***	***Others***
▪ Dairy Cows ▪ Dairy Heifers	▪ Beef Cows ▪ Bulls >500 lbs ▪ Calves <500 lbs ▪ Heifers >500 lbs ▪ Steers >500 lbs ▪ Feedlot Heifers ▪ Feedlot Steers	▪ Breeding ▪ Market <50 lbs ▪ Market 50-119 lbs ▪ Market 120-179 lbs ▪ Market 180+ lbs	▪ Layer Hens >1 yr ▪ Layers – Pullets ▪ Layers – Chickens ▪ Broilers ▪ Turkeys	▪ Sheep ▪ Goats ▪ Horses

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 kg per year. 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 cattle, it is calculated by the enteric fermentation model of Section III.A above. For other species values are based on measurements from the literature and are adjusted for the typical animal mass of animals in the group.
- Maximum methane producing capacity (B_0) of excreted volatile solids (m^3 of CH_4 per kg 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 year (g of N per year). For cattle, it is calculated by the enteric fermentation model of Section III.A above. The values used for other species are based on measurements made on manure of each of the livestock groups.

For further information about how to calculate VS for cattle, swine and poultry, as well as the sources of data for the VS, TAM and B_0 parameters see USEPA, 2014d.

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 33 and Table 34 show the distribution of livestock manure among waste management systems in California. Note that the manure that is directly deposited on pasture, range or paddocks, or spread daily does not actually enter a "waste management system". This un-managed manure is listed here for completeness of the animal waste distribution. Estimates of nitrogen inputs from both managed and un-managed manure will be used in the Nitrous Oxide from Agricultural Soil Management Section of the inventory (see III.F below).

Table 33: Waste distribution of cattle, goats, horses and sheep manure in California

Waste System	***Beef cattle (not on feed)***	***Feedlot heifers and steers***	***Dairy Cows***	***Dairy Heifers***	***Goats***	***Horses***	***Sheep***
Anaerobic digester			✓				
Anaerobic lagoon			✓				
Daily spread*			✓	✓			
Deep pit			✓				
Dry lot		✓		✓	✓	✓	✓
Liquid / slurry		✓	✓	✓			
Pasture*	✓		✓	✓	✓	✓	✓

Waste System	Beef cattle (not on feed)	Feedlot heifers and steers	Dairy Cows	Dairy Heifers	Goats	Horses	Sheep
Solid Storage			✓				

* Un-managed manure: manure that is directly deposited on pasture, rangeland, or paddock, or is spread daily on agricultural land.

Table 34: Waste distribution of swine and poultry manure in California

Waste System	Poultry - Layers	Poultry - Pullets	Poultry - Chickens	Poultry - Broilers	Poultry - Turkeys	Swine - Market	Swine - Breeding
Anaerobic digester						✓	✓
Anaerobic lagoon	✓	✓	✓			✓	✓
Deep pit						✓	✓
Liquid / slurry	✓	✓	✓			✓	✓
Pasture*				✓	✓	✓	✓
Poultry with bedding				✓	✓		
Poultry without bedding	✓	✓	✓				
Solid Storage	✓	✓	✓			✓	✓

* Un-managed manure: manure that is directly deposited on pasture, rangeland, or paddock.

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 MCFs that reflects the seasonal changes in temperatures, and also accounts for long-term retention time. State-specific MCF values are derived using monthly weighted-average temperatures for the state, calculated using the population estimates and average monthly temperature in each county. For lagoon systems MCF values also account for a variety of factors that may affect methane production in lagoon systems.

In the particular case of anaerobic digesters, the MCF reflects the proportion of methane actually released to the atmosphere. To estimate it, USEPA assumed that anaerobic digester systems produce 90 percent of the maximum CH_4 producing capacity; have a collection efficiency of 75 percent in the case of covered lagoon systems and 99 percent for complete mix and plug flow systems; and that the methane destruction efficiency from flaring or burning in an engine was 98 percent.

2.5 Estimation of methane emissions

Methane emissions of each combination of the livestock group and waste management system are then calculated using the following equations:

Equation 68: CH_4 emissions in in each animal group and manure management system

$$E_{group,system} = P_{group} \bullet WMS_{group,system} \bullet VS_{group} \bullet MCF_{group,system} \bullet B_{0,group} \bullet 662$$

Where,

$E_{group,\ system}$	= CH_4 emissions of the given livestock group in the particular waste management system (grams per year)
P_{group}	= Number of animals in the livestock group (heads)
$WMS_{group,\ system}$	= Proportion of animals in the group whose manure is managed in the particular waste management system (fraction)
VS_{group}	= Volatile Solids Production rate of livestock group (kg per head per year)
$MCF_{group,\ system}$	= Methane conversion factor for the given group in the particular waste management system (fraction)
$B_{o,\ group}$	= Maximum methane producing capacity of the VS in manure of the given animal group (m^3 per kg)
662	= Density of methane (g / m^3), at 22°C and 1 atm.

With,

Group	= livestock group from Table 32
System	= waste management system from Table 33 and Table 34.

Equation 69: Total CH_4 emissions from manure management

$$E = \sum_{group,system} E_{group,system}$$

Where,

E	= CH_4 emissions from manure management (grams per year)
$E_{group,\ system}$	= CH_4 emissions of the given livestock group in the particular waste management system (grams per year)

With,

Group	= livestock group from Table 32
System	= waste management system from Table 33 and Table 34.

2.6 Nitrous oxide emission factors

Direct N_2O emission factors for manure management systems (g N_2O-N/g excreted N) were taken from the most recent default IPCC factors (IPCC, 2006d) and are presented below.

Table 35: Direct N_2O emission factors

Management system	Direct N as N2O EF
Anaerobic digester	0

Management system	**Direct N as N2O EF**
Anaerobic lagoon	0
Daily spread	0
Deep pit	0.002
Dry lot	0.02
Liquid/slurry	0.005
Pasture	0
Poultry with bedding	0.001
Poultry without bedding	0.001
Solid storage	0.005

Indirect N_2O emission factors account for two fractions of nitrogen losses: volatilization of ammonia (NH_3) and NO_X (volatilized fraction) and runoff/leaching (runoff fraction). IPCC default indirect N_2O emission factors were used. These factors are 0.010 g N_2O-N/g N for volatilization and 0.0075 g N_2O-N/g N for runoff and leaching.

USEPA has developed region-specific estimates of nitrogen losses for the volatilized fraction and the runoff/leaching fraction for the U.S using available data. Nitrogen losses from leaching are believed to be small in comparison to the runoff losses; therefore, the runoff/leaching fraction was set equal to the runoff loss factor. Values for individual combinations of animal group and waste management system are available in the online annexes to this document and in USEPA, 2014d.

2.7 Estimation of nitrous oxide emissions

Nitrous oxide emissions of each combination of livestock group and waste management system are then calculated using the following equation:

Equation 70: N_2O emissions in each animal group and manure management system

$$E_{group,system} = P_{group} \bullet WMS_{group,system} \bullet NER_{group} \bullet \left[\begin{array}{l} DEF_{system} + (VF_{group,system} \bullet VEF) \\ + (RF_{group,system} \bullet REF) \end{array} \right] \bullet 1.5711$$

Where,

$E_{group,system}$ = N_2O emissions of the given livestock group in the particular management system (grams)

P_{group} = Number of animals in the livestock group (heads)

$WMS_{group,system}$ = Proportion of animals in the group whose manure is managed in the particular waste management system (fraction)

NER_{group} = Nitrogen excretion rate of animals in the group (g per year)

DEF_{system} = Direct N as N_2O emission factor for the particular management system (g N_2O-N per g N)

$VF_{group, system}$ = Volatilization fraction of N for the given animal group in the particular management system (fraction)
VEF = Indirect N as N_2O emission factor for re-deposited volatilized N (g N_2O-N per g N)
$RF_{group, system}$ = Runoff fraction of N for the given animal group in the particular management system (fraction)
REF = Indirect N as N_2O emission factor for runoff N (g N_2O-N per g N)
1.5711 = Molecular weight ratio of N_2O to N_2

With,
Group = livestock group from Table 32
System = waste management system from Table 33 and Table 34

Equation 71: Total N_2O emissions from manure management

$$\boxed{E = \sum_{group,system} E_{group,system}}$$

Where,
E = N_2O emissions from manure management (grams per year)
$E_{group, system}$ = N_2O emissions of the given livestock group in the particular waste management system (grams per year)

With,
Group = livestock group from Table 32
System = waste management system from Table 33 and Table 34

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 (USEPA, 2014d), and from the IPCC guidelines (IPCC, 2006d).

For a complete 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_00-12/annex_3b_manure_management.pdf

4. Changes in Estimates

Only minor changes in data were made in the current estimation of emissions from manure management when compared with those used for the 2000-2011 edition of GHG Inventory. They included:

- Changes to the population numbers of some categories of livestock, in particular swine and poultry in 2011.

These updates to data sources resulted in negligible adjustments in emissions estimates for the categories included in this section over the years 2000 to 2011 when compared with the estimates in the 2000-2011 edition of ARB's GHG inventory.

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

1. Background

Current forest sector emissions and sequestration estimates in the ARB's GHG inventory are based on a 2004 California Energy Commission study (CEC, 2004) which quantified carbon stock in forests and rangelands. The study focused on a time period from 1994 to 2000 and was geographically limited to the northern part of the State. Results from the study were extrapolated to include the entire state and to other years. The study was limited in geographic and temporal scope and afforded few options for updating. Updated methods for regular periodic quantification of greenhouse gas fluxes on forest, range, and other natural lands are in development.

2. Future Improvements

In 2011, ARB contracted with researchers from University of California (UC) Berkeley to develop a new data-driven methodology for assessing carbon stock changes for all land in California except agricultural and urban areas. The new methods use California specific land based data sets and satellite remote sensing data. The covered ecosystems include forests, woodlands, shrub lands, grasslands, and wetlands. Data sources for the new method include Forest Inventory and Analysis (FIA) ground-based data (vegetation type, tree species and dimensions, percent canopy cover, etc.) from the USDA-Forest Service, remote sensing products from NASA's MODIS sensor, geospatial vegetation data (vegetation community type, canopy height, percent canopy cover) from the federal Landscape Fire and Resource Management Planning Tools Project (Landfire), geospatial fire and harvest occurrence data from CalFIRE, and ancillary data on shrub lands and grasslands.

The method enables analysts to retrospectively assess ecosystem carbon stock changes resulting from fire, human activities, and other processes. It will enable monitoring of changes on the land over time and periodic quantification of the GHG flux associated with changes in ecosystem carbon stocks. The research has generated a wealth of new data to support a planned update to the GHG inventory.

Additional work is needed to evaluate the data provided by the UC Berkeley research, to incorporate additional new data, and to identify further research needed to expand use of these tools. The sources and methods for quantifying ecosystem carbon and GHG flux in this sector are complex. Continued refinements will advance carbon quantification, attribution of GHG flux by disturbance process, and reduce uncertainty.

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 72: GHG emissions from residue burning

$$\boxed{E_{GHG,crop} = A_{crop} \bullet 0.404685642 \bullet FB_{crop} \bullet MR_{crop} \bullet EF_{GHG,crop}}$$

Where,

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

A_{crop} = Harvested area of the given crop (acres)

0.404685642 = Acres to hectares conversion factor

FB_{crop} = Fraction of harvested area on which crop residues are burned (unitless)

MR_{crop} = Mass of the given crop's residue (g dry matter per ha)

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

With,

GHG = [CO_2, CH_4, N_2O]

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

3. Data Sources

Areas harvested of 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, 2013b; USDA, 2013c; USDA, 2013d). The fractions of crop acreage on which residues are burned, and the mass of residue burned are taken from survey data gathered and published by B.M. Jenkins (Jenkins et al. 1992) and assumed to have remained constant since, 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 until 2002. For later years, the percent of rice acres burned was based upon data compiled by Les Fife, Sacramento Valley Basinwide Air Pollution Control Council Burn Coordinator. Given that more than 96 percent of rice grown in California is grown in the Sacramento Valley, staff used the percent of rice acreage burned in the Sacramento Valley as the value for the rest of the state acreage. 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_00-12/annex_3d_agricultural_residue_burning.pdf

4. Changes in Estimates

The only change in data sources or methodology made to the estimation of emissions from this category since the 2000-2011 version of ARB's GHG inventory was a revision of the percent of rice acreage burned for 2004 to 2011. This change resulted in a minor adjustment in emissions from this section: +0.3 percent in 2010 and -0.8 percent in 2011 when compared with the estimates in the 2000-2011 edition of ARB's GHG inventory.

5. 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 in 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, 2006a). Total CO_2 emissions from liming are estimated as follows:

Equation 73: 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 74: Mass of limestone applied to soils

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

Equation 75: 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). Limestone and dolomite sold or used in California are reported in the *Minerals Yearbook* by the U.S. Geological Survey (USGS, various years a). Limestone and dolomite emission factors are from the 2006 IPCC Guidelines (IPCC, 2006e).

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_00-12/annex_3e_carbon_dioxide_from_liming.pdf

4. Changes in Estimates

No change was made to the methods or data used for these estimates.

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; 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, 2006e).

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 N2O emissions (IPCC category 3C4)

Direct N_2O emissions are calculated with the following equation:

Equation 76: Direct N_2O emissions from managed soils

$$\boxed{E_{direct} = \begin{Bmatrix} [N_{SF} + N_{OF} + N_{MM} + N_{CR}] \bullet EF_1 \\ + N_{UM,CPP} \bullet EF_{2,CPP} + N_{UM,SGH} \bullet EF_{2,SGH} \\ + A_{OS} \bullet EF_3 \end{Bmatrix} \bullet 1.5711}$$

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_{MM} = Amount of N from managed manure spread on soils (kg N)
N_{CR} = Amount of N in crop residues that is returned to soils (kg N)
$N_{UM,\ CPP}$ = Amount of N from un-managed manure from grazing cattle, poultry and pigs (kg N)
$N_{UM,\ SGH}$ = Amount of N from the un-managed manure from grazing sheep, goats and horses (kg N)
A_{OS} = Area of drained organic soil (histosols) (ha)
EF_1 = Emission factor: proportion of N applied to agricultural soils that is emitted as N_2O
$EF_{2,\ CPP}$ = Emission factor: proportion of N from cattle, poultry and pigs un-managed manure that is emitted as N_2O
$EF_{2,\ SGH}$ = Emission factor: proportion of N from sheep, goats and horses un-managed manure 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 N2O emissions (IPCC category 3C5)

Indirect N_2O emissions are calculated with the following equations:

Equation 77: 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 78: Indirect N_2O emissions from volatilization

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

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_{MM} = Amount of N from managed manure applied to soils (kg N)
N_{UM} = Amount of N from un-managed manure [$N_{UM,\ CPP} + N_{UM,\ SGH}$] (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 79: Indirect N_2O emissions from N lost to leaching and runoff

$$\boxed{E_{LR} = [N_{SF} + N_{OF} + N_{MM} + N_{UM}] \bullet L \bullet EF_5 \bullet 1.5711}$$

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_{MM} = Amount of N from managed manure applied to soils (kg N)
N_{UM} = Amount of N from un-managed manure [$N_{UM,\ CPP} + N_{UM,\ SGH}$] (kg N)
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 36.

Table 36: Factors for the estimation of N_2O emissions from agricultural soil management

Emission factor	Description	Default Value
EF1	Proportion of N applied to agricultural soils that is emitted as N_2O	0.01
EF2, CPP	proportion of N deposited on pastures, rangelands, and paddocks by cattle, poultry and pigs [PRP–CPP] that is emitted as N_2O	0.02
EF2, SGH	proportion of N deposited on pastures, rangelands, and paddocks by sheep, goats, horses [PRP–SGH] that is emitted as N_2O	0.01
EF3	N emitted as N_2O per unit area of drained organic soils (kg N per ha)	8
EF4	Proportion of N volatilized and re-deposited on soils that is emitted as N_2O	0.01
EF5	Proportion of N lost to leaching and runoff that is emitted as N_2O	0.0075
V1	Fraction of synthetic fertilizer N that volatilizes	0.1
V2	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, 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 in animal manure is estimated in the manure management section (see III.B above). The amount of N in managed manure (N_{MM}) is calculated as the total N excreted by animal groups in manure management systems minus the amount of nitrogen lost to volatilization, runoff and direct N_2O emissions during the manure management phase. The amount of N in un-managed manure is equal to the total N excreted by animal groups depositing their urine and dung directly on the land (i.e. pasture, rangeland and paddocks) and animal groups whose manure is spread daily. Unmanaged manure N is grouped in two categories: manure N from cattle, poultry and pigs ($N_{UM, CPP}$); and that from sheep, goats and horses ($N_{UM, SGH}$) (see Table 32 and Table 33).

(c) Crop residues nitrogen

The amount of nitrogen from crop residues (N_{CR}) comprises above-ground and below-ground residues N and includes N-fixing crops. The nitrogen is returned to the soil as the crop is renewed. Crops are generally renewed on an annual basis, with some exceptions such as alfalfa which is typically renewed every four years. Since the combustion of residue causes most of its nitrogen to be volatilized, an adjustment must be made for burning of crop residue. N_{CR} is calculated using the following equations, the variables and regression parameters used in the equations are from the IPCC guidelines (Table 11.2 in IPCC, 2006e) unless the source is noted otherwise:

Equation 80: Amount of nitrogen input from crop residues

$$\boxed{N_{CR} = \sum_{crop} \left(N_{AGR,crop} + N_{BGR,crop}\right)}$$

Where,

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

$N_{AGR,\ crop}$ = Amount of N in the above-ground residues of the given crop (kg)

$N_{BGR,\ crop}$ = Amount of N in the below-ground residues of the given crop (kg)

With,

Crop = crops listed in Table 38.

The amount of nitrogen in the above-ground residues of a given crop ($N_{AGR,\ crop}$) is calculated as follows:

Equation 81: Amount of nitrogen in the above-ground residues of a crop

$$\boxed{N_{AGR,crop} = A_{NBR,crop} \bullet M_{AGR,crop} \bullet NC_{AGR,crop}}$$

Where,

$N_{AGR,\ crop}$ = Amount of N in a given crop above-ground residues that is returned to soils (kg)

$A_{NBR,\ crop}$ = Area of the given crop that is not burned after harvest and is renewed (kg)

$M_{AGR,\ crop}$ = Mass of above-ground residue left after harvest of the given crop (kg dry matter per ha)

$NC_{AGR,\ crop}$ = Nitrogen content of above-ground residues of the given crop (fraction)

With,

Crop = crops listed in Table 38.

The amount of above-ground residue of a given crop ($M_{AGR,\ crop}$) can be estimated from its harvested yield using:

Equation 82: Amount above-ground residues of a crop

$$\boxed{M_{AGR,crop} = \beta_{0,crop} + \beta_{1,crop} \bullet M_{Yield,crop}}$$

Where,

$M_{AGR,\ crop}$ = Mass of above-ground residue left after harvest of the given crop (kg dry matter per ha)
$\beta_{0,crop}$ = Intercept of linear regression of the given crop's above-ground residue on its yield
$M_{Yield,\ crop}$ = Mass harvested yield of the given crop (kg dry matter per ha)
$\beta_{1,\ crop}$ = Slope of linear regression of the given crop's above-ground residue on its yield

With,

Crop = crops listed in Table 38.

The amount of nitrogen in the below-ground residues of a given crop ($N_{BGR,\ crop}$) is calculated as follows:

Equation 83: Amount of nitrogen in the below-ground residues of a crop

$$\boxed{N_{BGR,crop} = A_{NBR,crop} \bullet \left(M_{Yield,crop} + M_{AGR,crop}\right) \bullet R_{BA,crop} \bullet NC_{BGR,crop}}$$

Where,

$N_{BGR,\ crop}$ = Amount of N in a given crop below-ground residues that is returned to soils (kg)
$A_{NBR,\ crop}$ = Area of the given crop that is not burned after harvest and is renewed (ha)
$M_{Yield,\ crop}$ = Mass of harvested yield of the given crop (kg dry matter per ha)
$M_{AGR,\ crop}$ = Mass of above-ground residue left after harvest of the given crop (kg dry matter per ha)
$R_{BA,\ crop}$ = Ratio of below-ground residue to above-ground biomass of the given crop
$NC_{BGR,\ crop}$ = Nitrogen content of below-ground residues of the given crop (fraction)

With,

Crop = crops listed in Table 38.

The area of a given crop that is not burned in the given year and is renewed ($A_{NBR,\ crop}$) is calculated as follows:

Equation 84: Area of the given crop that is not burned and is renewed

$$A_{NBR,crop} = A_{H,crop} \bullet \left(1 - (F_{AB,crop} \bullet F_{RC,crop}\right) \bullet F_{AR,crop}$$

Where,

$A_{NBR,\ crop}$ = Area of the given crop that is not burned after harvest and is renewed (ha)

$A_{H,\ crop}$ = Area of the given crop that is harvested (ha)

$F_{AB,\ crop}$ = Fraction of the given crop harvested area on which residues are burned (see Agricultural Residue Burning section III.D)

$F_{RC,\ crop}$ = Fraction of the residue combusted when crop residues are burned

$F_{AR,\ crop}$ = Fraction of the given crop area that is renewed each year

With,

Crop = crops listed in Table 38.

Table 37: Fraction of crop area renewed each year ($F_{AR,\ crop}$) and fraction of residue combusted when crop residues are burned ($F_{RC,\ crop}$)

Crop	FAR, crop	FRC, crop
Alfalfa hay	0.25	0
Other hay	0.5	0
Corn for grain	1	0.8
Corn for silage	1	0
Wheat winter	1	0.9
Wheat durum	1	0.9
Barley	1	0.9
Sorghum for grain	1	0
Sorghum for silage	1	0
Oats	1	0
Rice	1	0.8
Potatoes	1	0
Dry Edible Beans	1	0

Crop renewal data from cost studies of the UC Davis Agricultural Economics department, and assuming half of non-legume hay crop is annual; residue combusted data from IPCC 2006 Volume 4 Chapter 2 Table 2.6 and assuming Barley same as wheat.

The nitrogen input to soils from crop residues ($N_{CR,\ crop}$) are shown in Table 38.

Table 38: Amount of nitrogen input to soils from crop residues (metric tons)

Crop	2000	2005	2006	2007	2008	2009	2010	2011	2012
Alfalfa hay	25,700	25,829	26,923	25,656	26,456	26,067	23,565	22,546	24,231
Other hay	6,150	8,574	9,123	9,689	9,309	7,071	8,363	8,058	9,123
Corn for grain	7,368	4,728	3,843	7,589	6,963	6,071	7,372	5,842	7,011

Crop	2000	2005	2006	2007	2008	2009	2010	2011	2012
Corn for silage	6,765	8,713	8,622	9,474	9,953	7,893	8,880	9,737	8,880
Wheat winter	9,433	7,454	5,061	6,594	14,277	11,236	9,891	12,229	9,027
Wheat durum	3,216	2,178	2,134	2,368	4,120	4,561	3,449	4,139	4,689
Barley	1,732	1,023	988	655	912	825	1,191	1,279	1,216
Sorghum for grain	153	221	250	243	207	207	0	0	0
Sorghum for silage	46	221	321	300	495	495	0	0	0
Oats	315	252	280	297	330	491	377	235	362
Rice	15,639	15,780	17,034	17,382	17,802	19,651	18,663	20,203	18,929
Potatoes	1,242	1,154	1,152	1,139	1,090	1,078	997	1,095	1,144
Dry Edible Beans	887	562	518	496	412	604	575	460	518
Total (NCR)	**78,645**	**76,689**	**76,248**	**81,882**	**92,326**	**86,251**	**83,327**	**85,829**	**85,130**

(d) Area of drained organic soil (AOS)

In California, the Sacramento-San Joaquin Delta was once a 540 square mile tidal marsh where peat soils (termed organic soils or histosols) accreted for thousands of years. Peat is made of partially decayed organic matter that accumulates under waterlogged —and thus anaerobic— conditions. The layer of peat in the Delta is up to 50 feet thick. In the late 1800's Delta land was "reclaimed" with levees and since then it has been drained and used for crops and as pasture land. Drainage exposes peat to oxygen and triggers rapid microbial oxidation which results in the continuous release of large amounts of the stored carbon to the atmosphere as CO_2. Peat oxidation is the principal cause of land subsidence in the Delta, some "islands" are now down to 25 feet below mean sea level. Subsidence continues at a rate of 1 to 3 inches per year. As organic soils oxidize, the N-rich organic matter mineralizes thereby increasing N_2O emissions from these soils.

The area of drained organic soils in the Sacramento-San Joaquin Delta was determined with a Geographic Information System (GIS) using the following steps:

- Download the Soil Survey Geographic (SSURGO) database from U.S. Department of Agriculture, Natural Resources Conservation Service website for counties comprising the Delta (Contra Costa, Sacramento, San Joaquin, Solano and Yolo).
- Use the NRCS soil classification and attributes to identify all organic soils.
- Overlay the organic soils with the 2001 National Land Cover Data (NLCD 2001) downloaded from the USGS website to identify all areas of organic soils that are drained (i.e. developed, grassland/pasture, cultivated).
- Calculate the sum of area in ha of drained organic soils.

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 yield and acreage harvested data were taken from CDFA Agriculture Resources Directories (CDFA, 2012). The amount of manure returned to soils as fertilizer is estimated in section III.B above. Variables and regression parameters for the crop residues estimates are from the IPCC guidelines (Table 11.2 in IPCC, 2006e). The data for the fraction of crop area renewed each year are from cost studies of the UC Davis Agricultural Economics department, and assume half of non-legume hay crop is annual. The fraction of crop harvested area on which residues are burned is discussed in the Agricultural Residue Burning section (III.D). Residue combusted data are from IPCC 2006 Guidelines Volume 4 Chapter 2 Table 2.6 and assume barley values are the same as wheat's values. Drained organic soils area was estimated based on the Soil Survey Geographic (SSURGO) database from U.S. Department of Agriculture, Natural Resources Conservation Service and the 2001 National Land Cover Data (NLCD 2001) downloaded from the USGS website. 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_00-12/annex_3f_nitrous_oxide_from_agricultural_soil_management.pdf

4. Changes in Estimates

The only change made to the data or methodology used in the current estimation of emissions of N_2O from agricultural soil management, when compared with those used for the 2000-2011 edition of GHG Inventory, was a small update in the amount of managed manure as discussed in section III.B above.

This data update resulted in negligible adjustments in emissions estimates for the categories included in this section over the years 2000 to 2011 when compared with the estimates in the 2000-2011 edition of ARB's GHG inventory.

5. Future Improvements

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. USEPA started using the DAYCENT model in 2005 to calculate N_2O emissions from major agricultural crops (USEPA, 2007a). The ARB has sponsored a study to explore the possibility of using the DNDC model to estimate GHG emissions from California agricultural systems. The data necessary to parameterize and validate such models for agricultural crops grown in California is currently being developed.

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 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, residue management practices, amendments).

California state legislation passed in 1991 mandated a phased reduction of rice straw burning in the Central Valley, to reduce air pollution. While 99 percent of rice acreage was burned in 1990, rice straw burning was down to 15 percent of harvested acreage in 2001 and has been below 10 percent in 2011 and 2012 (cf. section III.D). Agronomic studies (Bird et. al., 2002) have shown that alternatives to burning such as straw incorporation into the soil, rolling, or baling and removing the straw did not reduced grain yields. However there was an increase in weeds when straw was incorporated, and in particular when the fields were not winter flooded. Since a market for rice straw did not develop, most growers either incorporate or roll the straw in contact with the soil and about 60 percent of rice fields are flooded in the winter. A positive outcome of this change in management practices is that waterfowl on the Pacific Flyway benefit significantly from the wetlands created when fields are flooded during the winter. The downside of winter flooding is that methane is produced under anaerobic conditions of the winter-flooded fields, with significantly more methane produced when the residue is incorporated or rolled compared to burned or baled (Bossio et. al. 1999).

To reflect these practices, ARB staff has done a literature review seeking published measurement of methane emissions from rice fields in California with treatments including incorporation or rolling of straw with and without winter flooding. Staff retained 5 treatments without winter flooding and 6 treatments with winter flooding from Bossio et. al. 1999; Fitzgerald et. al. 2000 and McMillan et. al. 2007. Averaging over the treatments provided yearly methane emission factors of 139.6 kg CH_4/ha without winter flooding (EF_{wowf}) and 265.5 kg CH_4/ha with winter flooding (EF_{wwf}).

The emissions computation is:

Equation 85: CH_4 emissions from rice cultivation

$$\boxed{E = A \bullet 0.6 \bullet EF_{wwf} + A \bullet 0.4 \bullet EF_{wowf}}$$

Where,

E = Amount of CH_4 emitted by rice cultivation (g)
A = Harvested rice area (ha)
EF_{wwf} = California specific CH_4 emission factor with winter flooding (g/ha)
EF_{wowf} = California specific CH_4 emission factor without winter flooding (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, 2013b). The California-specific emission factor is from literature review cited in methodology section

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_00-12/annex_3g_rice_cultivations.pdf

4. Changes in Estimates

For this edition of the GHG inventory, staff researched and calculated new emission factors for rice cultivation that distinguish and better reflect the main management practices currently used by rice growers in California. This new approach is the same as that used by USEPA in their current edition of the National GHG Inventory. These changes resulted in a substantial reassessment of emissions estimates for this category: +75.4 percent on average over the years 2000 to 2011 when compared with the estimates in the 2000-2011 edition of ARB's 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 Department of Resources Recycling and Recovery (CalRecycle) —previously known as California Integrated Waste Management Board or CIWMB— has identified 372 such landfills in the State. Most of the waste contained in these landfills (95 percent) is currently under a control system that reduces the emissions of methane, the principal GHG pollutant generated by landfills, by combustion of the gas.

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 86: Anaerobic biodegradation process

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

A large fraction (49 percent to 62 percent) of the carbon in the waste will not degrade under these anaerobic conditions and 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 95 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, of which the 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 about half of the landfilled waste (e.g., approximately 52 percent in 2006, the latest data year reported in the surveys to ARB). In 2013, The Department of Resources Recycling and Recovery (CalRecycle) conducted another survey and shared the results with ARB, increasing the amount of data collected (even if only for 1 additional year, 2010). Finally, the USEPA Mandatory Reporting Program now provides similar data for the larger landfills (about 82% of the waste received in 2012), starting in 2012 and continuing each year thereafter. The combined datasets represent about 90 percent of the landfilled waste. Therefore, to fill in the missing landfills and the missing years, staff opted to use a model to estimate landfill emissions for all sites, and used the survey data to supplement and enhance 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, 2006f). 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 a 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 86).

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 of Equation 87 below. The inputs for calculating *ANDOC* are therefore important determinants of landfill emissions estimates.

(a) Anaerobically Degradable Organic Carbon (ANDOC)

Equation 87: 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)

CalRecycle 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+ for those landfills still receiving waste after 1990. CalRecycle staff also furnished the amounts of green waste and sludge used as daily cover by each landfill from 1995+. CalRecycle staff provided data on 377 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 WIP data from their survey and used them to update the CalRecycle data.

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 required 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). ARB staff inquired about the opening and closure dates for all landfills, required data to estimate annual disposal amounts, giving the range of years over which the waste should be distributed. CalRecycle staff had closure dates for all 377 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 CalRecycle and the USEPA. The CalRecycle studies were conducted in 1999, 2004 and 2008; the 1999 study was used to characterize waste for 1996 to 2002, the 2004 study for 2003 to 2006 and the 2008 study for 2007 and beyond, as suggested by CalRecycle's 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, 1990 and

1995. Staff used the waste profiles from those studies as follows: up to 1964 (1960 survey), 1965-1974 (1970 survey), 1975-1984 (1980 survey), 1985-1992 (1990 survey) and 1993-1995 (1995 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 39.

Table 39: Waste characterization – Percentage of each component in the overall waste in place

Waste Component	**Up to 1964**	**1965 - 1974**	**1975 - 1984**	**1985 - 1992**	**1993 - 1995**	**1996 - 2002**	**2003 - 2006**	**2007 +**
Newspaper	6.4%	6.4%	5.9%	4.8%	3.9%	4.3%	2.2%	1.7%
Office Paper	10.7%	11.3%	12.0%	13.1%	15.0%	4.4%	2.0%	1.8%
Corrugated Boxes	10.8%	13.5%	11.5%	10.5%	10.3%	4.6%	5.7%	4.8%
Coated Paper	2.2%	2.0%	2.4%	2.1%	1.8%	16.9%	11.1%	9.0%
Food	14.8%	11.3%	9.5%	12.1%	13.4%	15.7%	14.6%	15.5%
Grass	12.1%	10.3%	10.1%	9.0%	6.6%	5.3%	2.8%	1.9%
Leaves	6.1%	5.1%	5.0%	4.5%	3.3%	2.6%	1.4%	3.2%
Branches	6.1%	5.1%	5.0%	4.5%	3.3%	2.4%	2.6%	2.0%
Lumber	3.7%	3.3%	5.1%	7.0%	7.3%	4.9%	9.6%	14.5%
Textiles	2.1%	1.8%	1.7%	3.3%	4.5%	2.1%	4.4%	5.5%
Diapers	0.1%	0.3%	1.4%	1.6%	1.9%	6.9%	4.4%	4.3%
Construction/Demolition	2.6%	2.5%	3.5%	3.9%	4.5%	6.7%	12.1%	5.5%
Medical Waste	-	-	-	-	-	0.0%	0.0%	0.0%
Sludge/Manure	-	-	-	-	-	0.1%	0.1%	0.1%

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

The amounts of green waste and sludge used as daily cover were included with the landfill WIP. Green waste was split based on USEPA studies (Table 40).

Table 40: Waste characterization of daily green waste cover material

Daily Cover Waste Component	**Assumed Content Percentage**
Grass	50%
Leaves	25%
Branches	25%

(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 41.

Table 41: Degradable Organic Carbon (DOC) content of different MSW components

Waste Component	DOC Fraction (Mg DOC / Mg wet waste)	Source
Newspaper	0.471	USEPA
Office Paper	0.385	USEPA
Corrugated Boxes	0.448	USEPA
Coated Paper	0.330	USEPA
Food	0.148	USEPA
Grass	0.133	USEPA
Leaves	0.291	USEPA
Branches	0.442	USEPA
Lumber	0.430	CEC
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 42: Decomposable anaerobic fraction (DANF) of the DOC of different MSW components

Waste Component	Decomposable Anaerobic Fraction	Source
Newspaper	0.150	USEPA
Office Paper	0.870	USEPA
Corrugated Boxes	0.442	USEPA
Coated Paper	0.243	USEPA
Food	0.865	USEPA
Grass	0.474	USEPA
Leaves	0.073	USEPA
Branches	0.231	USEPA
Lumber	0.233	CEC
Textiles	0.500	IPCC
Diapers	0.500	IPCC
Construction/Demolition	0.500	IPCC
Medical Waste	0.500	IPCC

Waste Component	***Decomposable Anaerobic Fraction***	***Source***
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 43). 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 43: 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 - 1992***	***1993 - 1995***	***1996 - 2002***	***2003 - 2006***	***2007 +***
1. Biodegradable Carbon	23.16%	22.90%	22.86%	23.32%	22.95%	20.77%	18.87%	19.78%
a. Decomposable	10.45%	10.44%	10.34%	11.02%	11.62%	8.42%	7.45%	7.52%
b. Sequestered	12.71%	12.46%	12.52%	12.30%	11.33%	12.35%	11.42%	12.25%
2. Other Materials	76.84%	77.10%	77.14%	76.68%	77.05%	79.23%	81.13%	80.22%

Most of the waste in landfills is non-biodegradable. Of that portion that is biodegradable (19 percent to 23 percent) most (49 percent to 62 percent) will not decompose in a landfill environment and instead will remain permanently sequestered.

(b) Change in ANDOC

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 88: Change in anaerobically degradable organic carbon in landfills

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

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 44).

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

Table 44: 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 89: 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 44).

(d) Emissions Estimates

Equation 90: 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)

CalRecycle 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 CalRecycle numbers. For years where CalRecycle 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 may be possible to adjust the first year of the collection efficiency to account for how much of that first year it was actually in operation.

CalRecycle 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. These defaults were used if specific landfill survey data detailing any of these was not available.

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 (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 377 landfills of interest in California.

ARB and CalRecycle staff also surveyed landfill operators and some landfills report to the USEPA's Mandatory Reporting Program, these data provided site-specific landfill gas collection data for certain years of operations (136 of the 377 landfills submitted site specific survey data, while 107 report to the USEPA). These data were used either to replace or to improve the model's estimates for that landfill.

When staff received landfill gas collection data for a particular year, it used the information in place of the model estimate. However, this 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 gas collection 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 N_2O 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 CalRecycle data indicating which landfills burn their captured gas.

Equation 91: N_2O emissions from landfill gas combustion

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

Where,

EN_2O = N_2O emissions from landfill gas combustion (grams)
LFG = Landfill gas captured and burned (standard cubic feet)
FCH_4 = CH_4 fraction of landfill gas (unitless)
$HCCH_4$ = Heat content of CH_4 (BTU / standard cubic foot)
$EFCH_4$ = 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, 2006a). Waste characterization data was obtained from studies made by the Department of Resources Recycling and Recovery (CalRecycle, 2009) and by the USEPA (USEPA, 2007e). Degradable Organic Carbon (DOC) content and values for Decomposable Anaerobic Fraction (DANF) were taken from USEPA (USEPA, 2010b). DANF data for lumber comes from the California Energy Commission (CEC, 2006). 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, 2006a). 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 CalRecycle 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). USEPA Mandatory Reporting Program (USEPA, 2012b) provided data on landfill gas collection for 107 landfills reporting to them.

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_00-12/annex_4a_landfills.pdf

4. Changes in Estimates

Since the publication of the previous edition of the GHG Inventory, staff obtained USEPA Mandatory Reporting data. While the model remained the same, inclusion of this new data resulted in a limited change in emission estimates: -1.2 percent on average for 2011 when compared with the estimates in the previous edition of ARB's GHG inventory.

5. Future Improvements

Staff will continue to follow ongoing research and data developments to help improve estimates of landfill gas emissions. ARB's Landfill Methane Control Measure and USEPA's Mandatory Reporting Program will provide more comprehensive, California-specific data on landfill gas collection and composition, as well as information on the types of cover used by landfills. USEPA's Mandatory Reporting Program also provides alterative collection efficiency estimates based on cover types (replacing the 75% default) which staff will consider using in future versions of the inventory.

B. Composting of Organic Waste (IPCC 4B)

1. Background

Composting of organic waste such as food scraps, yard trimmings, branches, leaves, grass and organic municipal solid waste, is common in California as a way to divert such waste from landfills. Over the last 20 years, the amount of organic waste composted in California has increased over 3-fold (CalRecycle, various years). Composting is a controlled decomposition process that destroys pathogens in the waste material, reduces its volume greatly and yields a stable organic-rich soil-like mixture called compost. This section is concerned with emissions from industrial-scale composting facilities and does not include small-scale backyard composting. These industrial facilities predominantly use a process called windrow composting in which large amounts of organic waste undergo decomposition in long rows. The windrows are actively managed (e.g. shredding, aeration, watering, etc.) to maximize the aerobic decomposition of the organic feedstock. During the composting process a large fraction of the degradable organic carbon (DOC) in the waste material is converted into carbon dioxide. However, studies have indicated that some anaerobic pockets occur in the piles where methanogenic bacteria produce some methane, and some nitrous oxide is emitted as the byproduct of nitrifying or denitrifying bacteria (ARB, 2010a).

2. Methodology

The methodology staff used to calculate the CH_4 and N_2O emissions from industrial composting is similar to that used for the Inventory of U.S Greenhouse Gas Emissions and Sinks (USEPA, 2010a). These methodologies are consistent with Tier-1 and Tier-2 methods of the IPCC Guidelines (IPCC, 2006g), and incorporates California-specific data when available.

2.1 Methane Emissions

Emissions of CH_4 and N_2O were estimated by multiplying the amount of composting feedstock processed in California by an appropriate emission factor.

Equation 92: GHG emissions from composting

$$\boxed{E_{GHG} = Q * EF_{GHG} * 907.2}$$

Where,

E_{GHG} = emissions of the given GHG during the composting process (g)

Q = amount of organic waste feedstock composted (ton)

EF_{GHG} = emission factor for methane emissions during the composting process (g/kg)

907.2 = factor to convert tons into kilograms (kg/ton)

With,

GHG = [CH_4, N_2O]

The amount of composting feedstock processed in California was obtained from CalRecycle's *California Compost -and Mulch- Producing Infrastructure Studies* (CalRecycle, various years). These reports published in 2001, 2004 and 2010 estimated amount of composting feedstock that was processed in California during the years 2000, 2003 and 2008 respectively. Using these three data points for 2000, 2003 and 2008, a linear regression was calculated ($R^2 = 0.71$). The best fit equation was used along with details on percentage of product by product type and bulk densities to estimate feedstock tonnages of compost only for each of the years 1990+. Specific details of the method used are available upon request.

Staff used a methane emission factor of 4.1 g/kg and a nitrous oxide emission factor of 0.09 g/kg which are based on the studies used to determine IPCC and USEPA emissions factors as well as more up-to-date compost emission studies. (ARB, 2010a).

3. Data Sources

The estimates for composting feedstock were obtained from three CalRecycle reports (CalRecycle, various years). The emission factors for methane and nitrous oxide were obtained from a study that was used to support the generation of a lifecycle compost emission factor (ARB, 2010a).

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_00-12/annex_4b_composting_of_organic_waste.pdf

4. Changes in Estimates

Since the publication of the previous edition of the GHG Inventory, staff discovered an error in the calculations used (bulk density was reported in the data source with units of cubic years/ton while staff mistakenly thought it was tons/cubic yard). While the method remained the same, correction of this error resulted in a substantial change in emission estimates: 59.9 percent on average for 2011 when compared with the estimates in the previous edition of ARB's GHG inventory. Fortunately the absolute emissions are small from this category so the absolute error was less than 0.2 $MMTCO_2e$.

5. Future Improvements

In the future, the composting fugitive emission factors for both methane and nitrous oxide need to be improved. The current factors are more representative of a global average (and consistent with IPCC and USEPA values); however, future emission factors would ideally be California-specific.

C. 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 receive 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 methodologies and updated parameter values from the Inventory of U.S Greenhouse Gas Emissions and Sinks: 1990-2012 (USEPA, 2014e). These methodologies are 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.

For the previous edition, ARB staff adopted the method refinements introduced by the USEPA for their 2000-2012 GHG inventory (USEPA, 2014e). Instead of using a single general equation to estimate CH_4 emissions, four wastewater treatment options were considered each with a separate equation: septic systems, centrally treated aerobic systems, centrally treated anaerobic systems and anaerobic digesters. Finally, the population component of Equation 106 was modified to subtract out the population served by biological denitrification. The estimation of N_2O emissions was also improved by distinguishing the contributions of plants with nitrification/denitrification and plants without nitrification/denitrification. Additionally, the per capita protein consumption factor was modified to include only the amount of protein consumed, not the total protein available for consumption (USEPA, 2014e).

Since the previous edition, the methane emissions from the pulp and paper manufacturing industries are included in the industrial wastewater emissions section and are calculated by population-weighting the pulp and paper production data compiled by the United States Environmental Protection Agency (USEPA, 2014e). The estimation of CH_4 emissions from wastewater treatment facilities of petroleum refineries is now based on Equation 100. The new equation for petroleum refining is more consistent with ARB's Greenhouse Gas Mandatory Reporting Program. In addition, the industrial fruits processing data was modified by subtracting out the influence of nut production.

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 centrally treated (aerobic or anaerobic systems), anaerobically digested or treated in septic systems. 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 from the quantity of product it manufactured or processed.

(a) Methane emissions from domestic wastewater

Methane emissions from the treatment of domestic wastewater are estimated using the following equations:

Equation 93: Total CH_4 emissions from domestic wastewater treatment

$$E_{Domestic,CH4} = E_{Septic,CH4} + E_{Aerobic,CH4} + E_{Anaerobic,CH4} + E_{Digester,CH4}$$

Equation 94: CH_4 emissions from Septic Systems

$$E_{Septic,CH4} = P \bullet R_{BOD5} \bullet 365.2425 \bullet f_{Septic} \bullet B_o \bullet MCF_{Septic}$$

Equation 95: CH_4 emissions from Centrally Treated Aerobic Systems

$$E_{Aerobic,CH4} = \left\{ \begin{matrix} P \bullet R_{BOD5} \bullet 365.2425 \bullet f_{central} \bullet f_{aerobic} \bullet \\ (f_{aerobic,woPT} + (f_{aerobic,wPT} \bullet (1 - f_{BOD}))) \bullet f_{NWM} \bullet B_o \bullet MCF_{aerobic,NWM} \end{matrix} \right\}$$

Equation 96:CH_4 emission from Centrally Treated Anaerobic Systems

$$E_{Anaerobic,CH4} = \left\{ \begin{matrix} P \bullet R_{BOD5} \bullet 365.2425 \bullet f_{central} \bullet f_{anaerobic} \bullet \\ (f_{anaerobic,woPT} + (f_{anaerobic,wPT} \bullet (1 - f_{BOD}))) \bullet B_o \bullet MCF_{anaerobic} \end{matrix} \right\}$$

Equation 97:CH_4 emissions from Anaerobic Digesters

$$E_{Digester,CH4} = V_{biogas} \bullet f_{CH4} \bullet 0.02831 \bullet 662 \bullet (1 - D_{CH4})$$

Equation 98: Volume of biogas produced in anaerobic digesters

$$\boxed{V_{biogas} = W_{Digester} \bullet \frac{R_{biogas}}{R_{wastewater}} \bullet 365.2425}$$

Where,

$E_{Domestic,\ CH4}$ = Emissions of methane from domestic wastewater treatment (gram)

$E_{Septic,\ CH4}$ = Emissions of methane from Septic Systems (gram)

$E_{Aerobic,\ CH4}$ = Emissions of methane from Centrally Treated Aerobic Systems (gram)

$E_{Anaerobic,\ CH4}$ = Emissions of methane from Centrally Treated Anaerobic Systems (gram)

$E_{Digester,\ CH4}$ = Emissions from Anaerobic Digesters (gram)

P = California population (person)

R_{BOD5} = Rate of per capita biological organic demand (BOD_5) production (gram / person / day)

0.02831 = Average number of days per year (day)

f_{septic} = Fraction of California wastewater treated in septic systems (unitless)

B_o = Maximum methane production capacity (g CH_4/g BOD_5)

MCF_{septic} = Methane correction factor for septic systems (unitless)

$f_{central}$ = Fraction of wastewater centrally treated in California (unitless)

$f_{aerobic}$ = Fraction of wastewater treated aerobically in California (unitless)

$f_{aerobic,\ woPT}$ = Fraction of aerobic systems that do not employ primary treatment (unitless)

$f_{aerobic,\ wPT}$ = Fraction of aerobic systems that employ primary treatment (unitless)

f_{BOD} = Fraction of BOD removed during primary treatment (unitless)

f_{NWM} = Fraction of aerobic systems that are not well managed and in which some anaerobic degradation occurs (unitless). *Currently, it is assumed that all aerobic systems are well managed and produce no* CH_4.

$MCF_{aerobic,\ NWM}$ = Methane correction factor for aerobic systems that are not well managed (unitless)

$f_{anaerobic}$ = Fraction of wastewater treated anaerobically in California (unitless)

$f_{anaerobic,\ woPT}$ = Fraction of anaerobic systems that do not employ primary treatment (unitless)

$f_{anaerobic,\ wPT}$ = Fraction of anaerobic systems that employ primary treatment

$MCF_{anaerobic}$ = Methane correction factor for anaerobic systems

V_{biogas} = Volume of biogas produced (ft^3)

f_{CH4} = Fraction of methane in biogas (unitless)
0.02831 = Factor used to convert between m^3 and ft^3 (m^3/ft^3)
662 = Density of methane (g/m^3)
D_{CH4} = Methane destruction efficiency from flaring or burning in engine (unitless)
$W_{Digester}$ = Total wastewater flow to treatment plants that have anaerobic digesters (gal)
R_{biogas} = Rate of per capita digester gas production (ft^3/person/day)
$R_{wastewater}$ = Rate of per capita wastewater production (gal/person/day)
365.2425 = Average number of days produced per year (USNO, 2004)

(b) Methane emissions from industrial wastewater

(b.i) Processing of pulp and paper, fruits, vegetables, red meat and poultry

For each of the type of product processed in industrial wastewater treatment plants, the CH_4 emissions are estimated using the following equation:

Equation 99: CH_4 emissions from industrial wastewater treatment

$$E_{CH4,product} = Q_{product} \bullet W_{product} \bullet COD_{product} \bullet f_{COD,product} \bullet B_o \bullet MCF$$

Where,
$E_{CH4,\ product}$ = Emissions of methane from the treatment of wastewater associated with processing the given product (gram)
$Q_{product}$ = Quantity of the given product processed (tonne)
$W_{product}$ = Wastewater outflow associated with processing the given product (liter / tonne)
$COD_{product}$ = Chemical Oxygen Demand (COD) of the wastewater associated with the processing of the given product (gram / liter)
$f_{COD,\ product}$ = Proportion of COD anaerobically degraded by the treatment of the wastewater associated with the processing of the given product (unitless)
B_o = Maximum methane producing potential of industrial wastewater (g CH_4/ g COD)
MCF = Methane correction factor, indicating the extent to which the organic content (measured as COD) degrades anaerobically (unitless)

With,
Product = [Pulp and Paper, Red meat, Poultry, Potatoes, Other vegetables, Apples, Citrus Fruits, Non-citrus fruits, and Wine grapes]

(b.ii) Petroleum refining

For petroleum refining emissions associated with wastewater treatment systems, the following equation was used:

Equation 100:CH_4 Emissions from petroleum refineries wastewater treatment systems

$$\boxed{E_{CH4} = W \bullet COD \bullet B_o \bullet MCF}$$

Equation 101: Wastewater flow from petroleum refineries

$$\boxed{W = V \bullet 35}$$

Where,

E_{CH4} = Methane emissions from wastewater treatment systems at petroleum refining facilities (gram)

W = Wastewater flow (m^3)

COD = COD loading in wastewater entering anaerobic treatment system (g/m^3)

B_o = Maximum methane production capacity (g CH_4/ g COD)

MCF = Methane conversion factor (unitless)

V = Volume of petroleum finished product produced by California's refineries (barrel)

35 = wastewater flow generation rate of petroleum refineries (gal/barrel)

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).

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

Equation 102: N_2O emissions from wastewater treatment

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

Where,

E_{N2O} = Total N_2O emissions from wastewater treatment (gram)

$E_{N2O,\ plant}$ = N_2O emissions from centralized wastewater treatment plants (gram)

$E_{N2O,\ effluent}$ = N_2O emissions from wastewater effluent discharged into aquatic environments (gram)

(a) Emissions at the wastewater treatment plants

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

Equation 103: N_2O emissions at the water treatment plant

$$\boxed{E_{N2O,plant} = E_{N2O,wNDN} + E_{N2O,woNDN}}$$

Equation 104: N_2O emissions from centralized wastewater treatment plant with nitrification/denitrification

$$\boxed{E_{N2O,wNDN} = P_{NDN} \bullet EF_{wNDN} \bullet F_{IC}}$$

Equation 105: N_2O emissions from centralized wastewater treatment plant without nitrification/denitrification

$$\boxed{E_{N2O,woNDN} = [(P \bullet f_{central}) - P_{ND}] \bullet EF_{woNDN} \bullet F_{IC}}$$

Where,

$E_{N2O,\ plant}$ = Total N_2O emissions from centralized wastewater treatment plants (gram)

$E_{N2O,\ wNDN}$ = N_2O emissions from centralized wastewater treatment plants with nitrification/denitrification (gram)

$E_{N2O,\ woNDN}$ = N_2O emissions from centralized wastewater treatment plants without nitrification/denitrification (gram)

P_{NDN} = California population served by biological denitrification (person)

EF_{wNDN} = Emission factor for with nitrification/denitrification (gram/person)

F_{IC} = Factor for industrial and commercial co-discharged nitrogen into the sewer system (unitless)

P = California population (person)

$F_{\ central}$ = Fraction of population using centralized wastewater treatments plants as opposed to septic systems (unitless)

EF_{woNDN} = Emission factor for without nitrification/denitrification (gram/person)

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

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

Equation 106: N_2O emissions from wastewater effluent

$$\boxed{E_{N2O,Effluent} = \{[(P - (P_{NDN} \bullet 0.9)) \bullet R_{protein} \bullet f_N \bullet F_{NCN} \bullet F_{IC}] - N_{sludge}\} \bullet EF_{effluent} \bullet 1.5711}$$

Where,

$E_{N2O,\ Effluent}$ = Effluent N_2O emissions (gram)
P = California population (person)
P_{NDN} = California population served by biological denitrification (person)
0.9 = Factor to scale the population served by biological denitrification to reflect the amount of N removed by denitrification (unitless)
$R_{protein}$ = Rate of per capita protein consumption (gram/person/year)
f_N = fraction of N in protein (gram N/gram protein)
F_{NCN} = Factor for non-consumed protein added to wastewater (unitless)
F_{IC} = Factor for industrial and commercial codischarged protein into the sewer system (unitless)
N_{sludge} = Sewage sludge N not entering aquatic environment (gram N/year)
$EF_{Effluent}$ = Emission factor for effluent water (g N_2O-N/ gram sewage N produced)
1.5711 = Molecular weight ratio of N_2O to N_2 (unitless)

3. Data Sources

State population numbers came from the California Department of Finance (CDOF, 2013). The fraction of Californians using centrally treated facilities and septic systems was obtained from the California Wastewater Training and Research Center (CWTRC, 2003). The proportions of wastewater treated aerobically or anaerobically, and with or without primary treatment are derived from USEPA's Clean Watershed Needs Surveys (USEPA, various years). The production data for fruits and vegetables, red meat, and poultry are from the California Department of Food and Agriculture (CDFA) and USDA National Agriculture Statistics Services (USDA, 2013a). The volume of petroleum finished product produced by California's refineries was obtained from the CEC Weekly Fuel Watch Reports (CEC, various years). The rate of wastewater flow of refineries was determined to be 35 gallons per barrel of petroleum finished product based on a CEC report (O'Brien, 2010) and on a study of water use and wastewater treatment alternatives for oil refineries in New Mexico (Timm, 1985). Other factors used in the equations are from USEPA 1990-2012 GHG Inventory (USEPA, 2014e). The fraction of California's population served by biological denitrification was estimated to the same as that of the US population (CDOF and US Census).

Table 45: California population served by biological denitrification.

Year	US Population served by biological denitrification (Millions)	CA to US population ratio	CA population served by biological denitrification
2000	2.636668	0.120500937	317,721
2001	2.58346	0.121110533	312,884
2002	2.530252	0.121471592	307,354
2003	2.477044	0.121985385	302,163
2004	2.423836	0.122104228	295,961
2005	2.370628	0.121771779	288,676
2006	2.31742	0.121478761	281,517
2007	2.264212	0.121343766	274,748
2008	2.211004	0.12120011	267,974
2009	2.157796	0.120862598	260,797
2010	2.104588	0.120614998	253,845
2011	2.05138	0.120576945	247,349
2012	3.00	0.120498465	361,495

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_00-12/annex_4c_wastewater_treatment_and_discharge.pdf

4. Changes in Estimates

The parameters estimated in both the domestic and industrial wastewater emission equations since the publication of the 2000-2011 edition of the GHG Inventory changed in the 2000-2012 inventory. Since the publication of the previous edition of the GHG Inventory, staff obtained updated data from the data sources. While the method remained the same, inclusion of this new data resulted in minor changes in emission estimates.

4.1 Domestic wastewater

Since the 2000-2011 inventory publication, emissions from domestic wastewater increased by 3.2 percent that correlates to increased population of California. No method changes were introduced for this edition.

4.2 Industrial wastewater

Since the 2000-2011 inventory publication, the industrial wastewater emissions changed by 3.4 percent. Some of the data parameters such as production of various fruit and vegetables, pulp and paper were updated as a time series, to represent the latest available data from the sources. No method changes were introduced for this edition.

5. Future Improvements

ARB staff is working on obtaining data to include wastewater treatment emissions from ethanol production facilities. Currently, the data set is incomplete, making it difficult for staff to estimate the emissions. Additionally, staff is working with USEPA to obtain a California-specific assessment for the fraction of centralized wastewater facilities that use aerobic or anaerobic treatment. 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 software. 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, wastewater treatment, 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., 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 from 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 categories defined in the scoping plan, by IPCC category of emission and removal, by economic sector, by greenhouse gas and by year. The amounts of greenhouse gas are expressed in millions of metric tonnes of CO_2 equivalent. The CO_2 equivalence calculations are based upon the IPCC Fourth Assessment Report’s (IPCC, 2007) global warming potentials. Detailed inventory tables are publicly available as PDF documents and as MS Excel spreadsheets by following the corresponding links on the GHG Inventory and Documentation website at: http://www.arb.ca.gov/cc/inventory/inventory.htm. Other, simplified, inventory tables are generated in similar fashion, summarizing the inventory by categories and by year. These summary tables are also available through the GHG Inventory web site. 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/2000_2012/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. The documentation pages are also available within the interactive query tool by clicking on emissions values in the query result table.

REFERENCES

AHC, 2005 American Horse Council. National Economic Impact of the U.S. Horse Industry. Report available at: http://horsecouncil.org/

Alvarado, 2007 Personal communication between Larry Hunsaker of the CA Air Resources Board and Al Alvarado of the California Energy Commission. Summer 2007.

ARB, 2003 Progress Report on Phase-Down of Rice Straw Burning in the Sacramento Valley Air Basin, California Air Resources Board, December 2003. Available online at: http://www.arb.ca.gov/smp/rice/phsdown/phsdown.htm

ARB, 2007 Regulation for the Mandatory Reporting of Greenhouse Gas Emissions. Subchapter 10, Article 2, sections 95100 to 95133, title 17, California Code of Regulations. Available online at: http://www.arb.ca.gov/regact/2007/ghg2007/frofinoal.pdf

ARB, 2008 Unpublished Survey of Cement Manufacturers for 2006. California Air Resources Board, Stationary Source Division, April 2008.

ARB, 2009 Initial Statement of Reasons for Proposed Regulation to Reduce Greenhouse Gas Emissions from Semiconductor Operations. California Air Resources Board, Stationary Source Division, January 2009. http://www.arb.ca.gov/regact/2009/semi2009/semi2009.htm

ARB, 2010a Proposed Method for Estimating Greenhouse Gas Emission Reductions from Compost from Commercial Organic Waste, California Air Resources Board, Planning and Technical Support Division. Available online at: http://www.calrecycle.ca.gov/Actions/PublicNoticeDetail.aspx?id=248&aiid=248

ARB, 2010b Updates on the Emissions Inventory for Commercial Harbor Craft Operating in California. Document available online at: http://www.arb.ca.gov/regact/2010/chc10/appc.pdf

ARB, 2011a OSM and Summary of Off-road Emissions Inventory Update - Emissions Inventory Development for In-use Off-road Equipment. Document available online at: http://www.arb.ca.gov/regact/2010/offroadlsi10/offroadappd.pdf

ARB, 2011b Emissions Estimation Methodology for Ocean-Going Vessels. Document available online at: http://www.arb.ca.gov/regact/2011/ogv11/ogv11appd.pdf

ARB, 2012 Summary of 2008 to 2011 data from California's Greenhouse Gas Mandatory Reporting Program. Reported emissions are available at: http://www.arb.ca.gov/cc/reporting/ghg-rep/ghg-rep.htm

ARB, 2013a California Emission Inventory Development and Reporting System Database (CEIDARS). CA Air Resources Board Staff queried CEIDARS for

Total Organic Gases (TOG) emissions, and then speciated the results. California Air Resources Board. Spring 2013. http://www.arb.ca.gov/ei/general.htm

ARB, 2013b Summary of 2008 to 2012 data from California's Greenhouse Gas Mandatory Reporting Program. Reported emissions are available at: http://www.arb.ca.gov/cc/reporting/ghg-rep/ghg-rep.htm

ARB, 2013c The California Air Resources Board's Emission FACtors (EMFAC) model available online at: http://www.arb.ca.gov/msei/modeling.htm

ARB, 2013d. The California Air Resources Board's Emission FACtors (EMFAC) model's Frequently Asked Questions (FAQ) section documents factors for calculating CH4 and N2O emissions. Documentation is available at: http://www.arb.ca.gov/msei/emfac2011-faq.htmemfac2011_web_db_qstn07

ARB, 2014 Gallagher, G.; Zhan, T.; Hsu, Y-K.; Gupta, P.; Pederson, J.; Croes, B.; Blake, D. R.; Barletta, B.; Meinardi, S.; Ashford, P.; Vetter, A.; Saba, S.; Slim, R.; Palandre, L.; Clodic, D.; Mathis, P.; Wagner, M.; Forgie, J.; Dwyer, H.; Wolf, K. High-global Warming Potential F-gas Emissions in California: Comparison of Ambient-based versus Inventory-based Emission Estimates, and Implications of Refined Estimates. *Environ Sci. Technol.* 2014, 48, 1084-1093. http://pubs.acs.org/doi/suppl/10.1021/es403447v

Bird et. al., 2002 Bird J., Eagle A., Horwath W., Hair M., Zilbert E., van Kessel C. 2002. Long-term studies find benefits, challenges in alternative rice straw management. California Agriculture 56(2):69-75.

BOE, 2013 California State Board of Equalization. Fuel Taxes Division Statistics & Reports - Motor Vehicle Fuel. Accessed online at: http://www.boe.ca.gov/sptaxprog/spftrpts.htm

Bossio et. al. 1999 Bossio D.A., Horwath W.R., Mutters R.G., van Kessel C. 1999. Methane pool and flux dynamics in a rice field following straw incorporation. Soil Biology & Biochemistry, 31:22.

CalRecycle, 2009 Solid Waste Characterization Database, California Department of Resources Recycling and Recovery, Sacramento. Accessed online, fall 2009, at: http://www.calrecycle.ca.gov/WasteChar/

CalRecycle, various years CalRecycle (2010, 2003, 2001) Assessment of California's Compost and Mulch-Producing Infrastructure - Management Practices and Market Conditions. Infrastructure Surveys, 1st, 2nd and 3rd versions. CalRecycle. Sacramento. CA. Accessed online at: http://www.calrecycle.ca.gov/Organics/Processors/

CDFA, 2012 California Agricultural Resource Directory 2011-2012, California Department of Food and Agriculture, Sacramento. http://www.cdfa.ca.gov/statistics/

CDFA, various years Fertilizing Materials Tonnage Report, (published bi-annually). California Department of Food and Agriculture. http://www.cdfa.ca.gov/is/ffldrs/Fertilizer_Tonnage.html

CDOF and US Census Current population estimates from the California Department of Finance (for California) and from the U.S. Census Bureau (for the entire US) were used to compute a ratio of California to US population. This ratio is used to scale down some national statistics to California.

CDOF, 2010 California Department of Finance, California Statistical Abstract, (Table J-11) Electrical Energy Generation: Total Production by Resource Type, California. Accessed online at: http://www.dof.ca.gov/HTML/FS_DATA/STAT-ABS/documents/J11.xls

CDOF, 2013 State of California, Department of Finance, E-6 Population Estimates for Cities, Counties and the State, with 2010 Benchmark. Sacramento, California. Accessed January 2013 http://www.dof.ca.gov/research/demographic/reports/view.php

CEC, 1990 1988 Inventory of California Greenhouse Gas Emissions, Final Staff Report, October 1990. California Energy Commission, Sacramento, CA.

CEC, 1997 California's Greenhouse Gas Emissions Inventory 1990. Publication P500-97-004, March 1997. California Energy Commission, Sacramento, CA.

CEC, 1998 1997 Global Climate Change Report: Greenhouse Gas Emissions Reduction Strategies for California. Appendix A – Historical and Forecasted Greenhouse Gas Emissions Inventories for California. Publication # 500-98-001V3, January 1998. California Energy Commission, Sacramento, CA. Available online at: http://www.energyarchive.ca.gov/global_climate_change/1997_ghg_report/P500-98-001V3.PDF

CEC, 2000 1999 Net System Power Calculation, (1999 California Power Mix). Adopted by the full Commission at the April 5, 2000 Business Meeting. California Energy Commission publication # 300-00-004. Available online at: http://www.energy.ca.gov/sb1305/documents/

CEC, 2002 Inventory of California Greenhouse Gas Emissions and Sinks: 1990-1999. Publication #600-02-001F. November 2002. California Energy Commission, Sacramento. http://www.energy.ca.gov//reports/600-02-001F/2002-09-14_600-02-001F.PDF

CEC, 2002-08 Net System Power Reports, 2002 to 2008 editions, California Energy Commission. Accessed online, summer 2011, at: http://energyalmanac.ca.gov/electricity/system_power/

CEC, 2004 Baseline Greenhouse Gas Emissions for Forest, Range, and Agricultural Lands in California. PIER Final Project Report CEC-500-04-

069F. California Energy Commission. http://www.energy.ca.gov/pier/project_reports/500-04-069.html

CEC, 2005C Inventory of California Greenhouse Gas Emissions and Sinks: 1990 to 2002 Update. CEC Publication CEC-600-2005-025. Available online at http://www.energy.ca.gov/2005publications/CEC-600-2005-025/CEC-600-2005-025.PDF

CEC, 2006 Inventory of California Greenhouse Gas Emissions and Sinks: 1990 to 2004. CEC Publication CEC-600-2006-013-SF. Available online: http://www.energy.ca.gov/2006publications/CEC-600-2006-013/CEC-600-2006-013-SF.PDF

CEC, various years Weekly Fuel Watch Reports. Yearly compilations of weekly refinery production and stocks levels in California. California Energy Commission. Available online in tabular form at http://energyalmanac.ca.gov/petroleum/fuels_watch/index.php

Covert, 2013. Personal communication between Kevin Eslinger of CA Air Resources Board and Theresa Covert, California State Board of Equalization, April 2013.

CWTRC, 2003 Status Report: Onsite Wastewater Treatment Systems in California. Jointly presented by: California Wastewater Training & Research Center, California State University Chico and USEPA Region 9 Ground Water Office. August 2003. http://www.csuchico.edu/cwtrc/Pages/InfoandReoprtspage.htm

Donovan and Baldwin, 1999 Donovan, K. and L. Baldwin (1999). Results of the AAMOLLY model runs for the Enteric Fermentation Model. University of California, Davis.

EAA, 2007 EMEP/CORINAIR Air Pollutant Emissions Inventory Guidebook – 2007. European Environment Agency Technical report No 16/2007. Available online at: http://www.eea.europa.eu/publications/EMEPCORINAIR5

EIA, 2013a Energy Information Administration. Form EIA-906/920/923: Monthly Utility Power Plant Database. Accessed online at: http://www.eia.gov/cneaf/electricity/page/eia906_920.html

EIA, 2013b Energy Information Administration. Petroleum Navigator. Topics for Petroleum Consumption/Sales. Accessed online at: http://tonto.eia.doe.gov/dnav/pet/pet_cons_top.asp

EIA, 2013c Energy Information Administration. State Energy Consumption, Price, and Expenditure Estimates (SEDS). Available online at: http://www.eia.gov/beta/state/seds/?sid=CA

FAO, 2012 FAOSTAT Statistical Database. Food and Agriculture Organization of the United Nations. Available online at: http://faostat.fao.org

FHWA, various years US Department of Transportation, Federal Highway Administration - Highway Statistics Series. Motor Fuel. Data accessed online at: http://www.fhwa.dot.gov/policy/ohpi/qffuel.cfm

Fitzgerald et. al. 2000 Fitzgerald, G. J., K. M. Scow, and J. E. Hill (2000), Fallow season straw and water management effects on methane emissions in California rice, Global Biogeochemical Cycles, 14(3), 767– 776.

Godwin, 2009 Personal communication between Karen Lutter of CA Air Resources Board and Dave Godwin, Stratospheric Protection Division Source Lead, US Environmental Protection Agency, Summer 2009.

Gough, 2013 Personal communication (data from the CEC's Quarterly Fuels and Energy Report) between Larry Hunsaker of the CA Air Resources Board and Andrea Gough of the California Energy Commission. March 2013.

Griffin, 2007 Personal communication between Larry Hunsaker of the CA Air Resources Board and Karen Griffin of the California Energy Commission. Summer 2007.

Hahn, 2007 Personal communication (source test data) between Larry Hunsaker of the CA Air Resources Board and Jeffrey L. Hahn, environmental director of Covanta Energy. Summer 2007.

IPCC, 1996 Second Assessment Report. Climate Change 1995: WG I - The Science of Climate Change. Intergovernmental Panel on Climate Change; J.T. Houghton, L.G. Meira Filho, B.A. Callander, N. Harris, A. Kattenberg, and K. Maskell (eds.); Cambridge University Press. Cambridge, U.K.

IPCC, 1997 Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories (Revised Guidelines). Intergovernmental Panel on Climate Change. Published: IGES, Japan. http://www.ipcc-nggip.iges.or.jp/public/gl/invs1.htm

IPCC, 2000 Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Inventories. Penman J., Kruger D., Galbally I., Hiraishi T., Nyenzi B., Emmanuel S., Buendia L., Hoppaus R., Martinsen T., Meijer J., Miwa K., and Tanabe K. (Eds). IPCC/OECD/IEA/IGES, Hayama, Japan. Available online at http://www.ipcc-nggip.iges.or.jp/public/gp/english/index.html

IPCC, 2003 Good Practice Guidance for Land Use, Land-Use Change and Forestry. Intergovernmental Panel on Climate Change. IPCC National Greenhouse Gas Inventories Programme. IGES, Kanagawa, Japan. Available on-line at http://www.ipcc-nggip.iges.or.jp/public/gpglulucf/gpglulucf.html

IPCC, 2006a 2006 IPCC Guidelines for National Greenhouse Gas Inventories, Prepared by the National Greenhouse Gas Inventories Programme, Eggleston H.S., Buendia L., Miwa K., Ngara T., and Tanabe K. (eds).

Volume 2, Chapter 2: Stationary Combustion. Published: IGES, Japan. #http://www.ipcc-nggip.iges.or.jp/public/2006gl/pdf/5_Volume5/V5_3_Ch3_SWDS.pdf#

IPCC, 2006b 2006 IPCC Guidelines for National Greenhouse Gas Inventories, Prepared by the National Greenhouse Gas Inventories Programme, Eggleston H.S., Buendia L., Miwa K., Ngara T., and Tanabe K. (eds). Volume 2, Chapter 2: Energy. http://www.ipcc-nggip.iges.or.jp/public/2006gl/pdf/2_Volume2/V2_2_Ch2_Stationary_Combustion.pdf

IPCC, 2006c 2006 IPCC Guidelines for National Greenhouse Gas Inventories, Prepared by the National Greenhouse Gas Inventories Programme, Eggleston H.S., Buendia L., Miwa K., Ngara T., and Tanabe K. (eds). Volume 3, Chapter 2: Mineral Industries Emissions. Published: IGES, Japan. http://www.ipcc-nggip.iges.or.jp/public/2006gl/pdf/3_Volume3/V3_2_Ch2_Mineral_Industry.pdf

IPCC, 2006d 2006 IPCC Guidelines for National Greenhouse Gas Inventories, Prepared by the National Greenhouse Gas Inventories Programme, Eggleston HAS., Biennia L., Miwa K., Negara T. and Tanabe K. (eds). Volume 4, Chapter 10: Emissions from Livestock and Manure Management. Published: IGES, Japan. http://www.ipcc-nggip.iges.or.jp/public/2006gl/pdf/4_Volume4/V4_10_Ch10_Livestock.pdf

IPCC, 2006e 2006 IPCC Guidelines for National Greenhouse Gas Inventories, Prepared by the National Greenhouse Gas Inventories Programme, Eggleston HAS., Biennia L., Miwa K., Negara T. and Tanabe K. (eds). Volume 4, Chapter 11: N_2O Emissions from Managed Soils, And CO_2 Emissions from Lime and Urea Application. Published: IGES, Japan. http://www.ipcc-nggip.iges.or.jp/public/2006gl/pdf/4_Volume4/V4_11_Ch11_N2O&CO2.pdf

IPCC, 2006f IPCC (2006). 2006 IPCC Guidelines for National Greenhouse Gas Inventories, Eggleston H.S., Buendia L., Miwa K., Ngara T., and Tanabe K. (eds). Vol.5, Chap. 3: Solid Waste Disposal. Published: IGES, Japan. http://www.ipcc-nggip.iges.or.jp/public/2006gl/pdf/5_Volume5/V5_3_Ch3_SWDS.pdf

IPCC, 2006g 2006 IPCC Guidelines for National Greenhouse Gas Inventories, Eggleston H.S., Buendia L., Miwa K., Ngara T., and Tanabe K. (eds). Vol.5, Chap. 4: Biological Treatment of Solid Waste. Published: IGES, Japan. Accessed online at: http://www.ipcc-nggip.iges.or.jp/public/2006gl/pdf/5_Volume5/V5_4_Ch4_Bio_Treat.pdf

IPCC, 2007 Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change, Solomon S., Qin D., Manning M., Chen Z., Marquis M., Averyt K.B., Tignor M., and Miller H.L. (eds.).

Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA. Chapter 2, Table 2.14.

IUPAC, 2006 Atomic Weights of the Elements 2005 (IUPAC Technical Report). Pure Appl. Chem., Vol. 78, No. 11, pp. 2051–2066, 2006.

Jenkins et al. 1992 Jenkins, B.M., Turn, S.Q., and Williams, R.B. (1992) Atmospheric Emissions from Agricultural Burning in California: Determination of Burn Fractions, Distribution Factors, and Crop-specific Contributions. Agriculture, Ecosystems and Environment, 38: 313-330.

Jenkins et al. 1996 Atmospheric Pollutant Emission Factors from Open Burning of Agricultural and Forest Biomass by Wind Tunnel Simulation. California Air Resources Board, A932-126, April 1996. (see in particular Tables 4.1.1 - 4.1.8). http://www.arb.ca.gov/research/single-project.php?row_id=55021

Kebreab et al. 2008 Kebreab, E. and Johnson, KA and Archibeque, SL and Pape, D. and Wirth, T. (2008). Model for estimating enteric methane emissions from United States dairy and feedlot cattle. Journal of animal science 86(10): 2738.

Lime Producers, 2011 Personal communication between Karen Lutter of CA Air Resources Board and representatives of the Lime Producers of California, April 2011.

McMillan et. al. 2007 McMillan, A. M. S., Goulden M. L., and S. C. Tyler. 2007. Stoichiometry of CH4 and CO2 flux in a California rice paddy, Journal of Geophysical Research, 112.

Mendez, 2009 Personal communication between Larry Hunsaker, CA Air Resources Board and Atoya Mendez, City of Riverside. Summer 2009.

Murtishaw et al. 2005 Murtishaw S., De La Rue du Can, S,. Price, L., Masanet, E., and Simcich, M. CALEB: California Energy Balance Database, September 12, 2005. Lawrence Berkeley National Laboratory, Berkeley, CA.

NRCS, 2007 Map of Average precipitation data for California, US Department of Agriculture National Resources Conservation Service's Geospatial Data Gateway. Accessed online, Fall 2007, at: http://datagateway.nrcs.usda.gov/

Nyberg, 2009 Personal communication (data from the CEC's Quarterly Fuels and Energy Report) between Larry Hunsaker of the CA Air Resources Board and Michael Nyberg of the California Energy Commission. Fall 2009.

O'Brien, 2010 Personal communication (data from the Petroleum Industry Information Reporting Act [PIIRA] M-13 Survey Form and volumes of ethanol used in on-road gasoline in California) between Larry Hunsaker of the CA Air Resources Board and Keith O'Brien of the California Energy Commission. Fall 2010.

O'Hare, 2007 Personal communication between CA Air Resources Board Staff and Andrew T. O'Hare of the Portland Cement Association, Washington, DC. http://www.cement.org/

Parsons, 2009 Personal communication (EIA form 767 data submittal & Plant Specific Data Reports) between Larry Hunsaker of CA Air Resources Board and Cindy Parsons, Los Angeles Department of Water & Power. Summer 2009.

RMA, 2007 Rubber Manufacturers Association website. Scrap tires characteristics. Accessed online at: http://www.rma.org/scrap_tires/scrap_tire_markets/scrap_tire_characteristics/

Schnapp, 2008 Personal communication (data submittal) between Larry Hunsaker of CA Air Resources Board and Robert Schnapp of the Energy Information Administration. Summer 2008.

Shires, 2009 Personal communication between Larry Hunsaker of CA Air Resources Board and Terri Shires of URS Corporation (Austin, TX) who provided printed excerpt from the Oil and Gas Journal's "Historical Worldwide Refinery Survey" (Prod No. E1181C) database, for refineries in California for the years 1990 to 2008.

Timm, 1985 Timm, C.M. (1985). Water use, conservation and wastewater treatment alternatives for oil refineries in New Mexico. NMERDI-2-72-4628. NMERDI, Suite M., 457 Washington SE, Albuquerque, NM 87108

Toledo, 2011 Personal communication between CA Air Resources Board Staff and Rene Toledo of the Yolo-Solano Air Quality Management District. Davis, CA. Summer 2011.

USCB, various years a U.S. Census Bureau, Population Estimates for the United States and California. Accessed online at: http://www.census.gov

USCB, various years b U.S. Census Bureau's Economic Census data. Accessed online at: (Information is listed by NAICS Code Number, NAICS Code for Semiconductor Manufacturing = #334413). http://www.census.gov/econ/census02/

USDA, 2013a U.S. Department of Agriculture, National Agriculture Statistics Service, California Statistics. Accessed Spring 2013. Available online at: http://www.nass.usda.gov/Statistics_by_State/California/index.asp

USDA, 2013b U.S. Department of Agriculture, National Agricultural Statistics Service, California Publications. Field Crops. Accessed Fall 2013. Available online at: http://www.nass.usda.gov/Statistics_by_State/California/Publications/index.asp

USDA, 2013c U.S. Department of Agriculture, National Agricultural Statistics Service, Crop Production Summary. Accessed March 2013. Available online at:

USDA, 2013d. U.S. Department of Agriculture, National Agricultural Statistics Service, California Publications. Fruit and Nuts. Accessed fall 2013. Available online at: http://www.nass.usda.gov/Statistics_by_State/California/Publications/index.asp

USDOT, 2013 U.S. Department of Transportation, Research and Innovative Technology Administration, Bureau of Transportation Statistics, Air Carrier Statistics database (T100 databank). Accessed online at: http://www.transtats.bts.gov/Fields.asp?Table_ID=293

USEPA, 1995 State Workbook, Methodologies for Estimating Greenhouse Gas Emissions, January 1995. U.S. EPA, Office of Policy, Planning and Evaluation, State and Local Reach Program.

USEPA, 1999 Emission Inventory Improvement Program. Technical Report Series, Volume 8: Estimating Greenhouse Gas Emissions. October 1999. US Environmental Protection Agency. Washington DC.

USEPA, 2001 Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-1999. EPA 236-R-01-001, April 2001. U.S. Environmental Protection Agency. Washington DC.

USEPA, 2004a Emission Inventory Improvement Program. Technical Report Series, Volume 8: Estimating Greenhouse Gas Emissions, Chapter 6: Industrial Processes. US Environmental Protection Agency. Washington DC. http://www.epa.gov/ttn/chief/eiip/techreport/volume08/index.html

USEPA, 2004b Emission Inventory Improvement Program. Technical Report Series, Volume 8: Estimating Greenhouse Gas Emissions, Chapter 10: Agricultural Soil Management. US Environmental Protection Agency. Washington DC. http://www.epa.gov/ttn/chief/eiip/techreport/volume08/index.html

USEPA, 2007a Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2005. United States Environmental Protection Agency. EPA 430-R-07-002. April 15, 2007. Washington DC. http://www.epa.gov/climatechange/emissions/usgginv_archive.html

USEPA, 2007b Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2010. United States Environmental Protection Agency. EPA 430-R-12-001. Annex 2.1 (Tables A-31, A-32, A-35, and A-36). April 15, 2007. Washington DC.

USEPA, 2007c Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2010. United States Environmental Protection Agency. EPA 430-R-12-001. Annex 3.2. Methodology for Estimating Emissions of CH_4, N_2O, and Indirect Greenhouse Gases from Mobile Combustion. April 15, 2012. Washington DC.

USEPA, 2007d Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2005. United States Environmental Protection Agency. EPA 430-R-07-002. Annex 6: Additional Information. April 15, 2007. Washington DC. http://www.epa.gov/climatechange/emissions/usgginv_archive.html

USEPA, 2007e Municipal Solid Waste Characterization Reports (various years), US Environmental Protection Agency. Accessed online, fall 2007, at: http://www.epa.gov/epawaste/inforesources/pubs/municipal_sw.htm

USEPA, 2008 SF_6 Emission Reduction Partnership for Electric Power Systems. 2007 Annual Report, December 2008. United States Environmental Protection Agency. Washington DC. http://www.epa.gov/electricpower-sf6/documents/sf6_2007_ann_report.pdf

USEPA, 2010a Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2008. United States Environmental Protection Agency. EPA 430-R-10-006. April 15, 2010. Washington DC. http://www.epa.gov/climatechange/emissions/usgginv_archive.html

USEPA, 2010b Solid Waste Management and Greenhouse Gases. Documentation for Greenhouse Gas Emission and Energy Factors Used in the Waste Reduction Model (WARM). Landfilling Chapter, exhibits 6 & 12. United States Environmental Protection Agency. October 28, 2010. http://www.epa.gov/climatechange/wycd/waste/SWMGHGreport.html

USEPA, 2011 Inventory of U.S. Greenhouse Gas Emissions and Sinks (April 2011), Table 4-88, U.S. Environmental Protection Agency EPA 430-R-11-005. http://www.epa.gov/climatechange/emissions/usinventoryreport.html

USEPA, 2012a Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2010. United States Environmental Protection Agency. USEPA 430-R-12-001. April 15, 2012. Washington DC.

USEPA, 2012b Mandatory Reporting of Greenhouse Gas Regulation http://www.epa.gov/ghgreporting/

USEPA, 2013a Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2010. United States Environmental Protection Agency. USEPA 430-R-13-001. Washington DC.

USEPA, 2013b Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2011. United States Environmental Protection Agency. Annex 2.3. EPA 430-R-13-001. April 12, 2013. Washington DC. http://www.epa.gov/climatechange/ghgemissions/usinventoryreport.html

USEPA, 2013c Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2011. United States Environmental Protection Agency. EPA 430-R-13-001. Table 4-98. SF_6 Emissions from electric power systems and electrical equipment manufacturers. April 12, 2013. Washington DC. http://www.epa.gov/climatechange/emissions/usgginv_archive.html

USEPA, 2013d Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2010. United States Environmental Protection Agency. USEPA 430-R-13-001. Table 4-48. April 12, 2013. Washington DC. http://www.epa.gov/climatechange/emissions/usinventoryreport.html

USEPA, 2013e Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2011. United States Environmental Protection Agency. EPA 430-R-13-001. Annex 3.2. Methodology for Estimating Emissions of CH_4, N_2O, and Indirect Greenhouse Gases from Mobile Combustion. April 12, 2013. Washington DC. http://www.epa.gov/climatechange/emissions/usgginv_archive.html

USEPA, 2014a Draft Inventory of U.S. Greenhouse Gas Emissions and Sinks, Table 4-11, U.S. Environmental Protection Agency EPA 430-R-14-001. http://www.epa.gov/climatechange/emissions/usinventoryreport.html

USEPA, 2014b DRAFT Inventory of U.S. Greenhouse Gas Emissions and Sinks, Table 4-96, U.S. Environmental Protection Agency EPA 430-R-13-001. http://www.epa.gov/climatechange/emissions/usinventoryreport.html

USEPA, 2014c Draft Inventory of U.S. Greenhouse Gas Emissions and Sinks, U.S. Environmental Protection Agency EPA 430-R-14-001. Annex 3.9: Methodology for Estimating CH4 Emissions from Enteric Fermentation. http://www.epa.gov/climatechange/emissions/usgginv_archive. html

USEPA, 2014d Draft Inventory of U.S. Greenhouse Gas Emissions and Sinks, U.S. Environmental Protection Agency EPA 430-R-14-001. Annex 3.10: Methodology for Estimating CH_4 and N_2O Emissions from Manure Management. http://www.epa.gov/climatechange/emissions/usgginv_archive.html

USEPA, 2014e Draft Inventory of U.S. Greenhouse Gas Emissions and Sinks, U.S. Environmental Protection Agency EPA 430-R-14-001. Chapter 8: Waste. April 12, 2013. Washington DC. http://www.epa.gov/climatechange/emissions/usgginv_archive.html

USEPA, various years Clean Watershed Needs Surveys for 2000 2004, 2008 and 2012. Data have been extrapolated for years not covered in the surveys. Accessed online at: http://www.epa.gov/cwns/

USGS, various years a Minerals Yearbook: The Mineral Industry of California. California Dept. of Conservation, California Geological Survey/U.S. Geological Survey. (See: Crushed Stone). Accessed online at: http://minerals.usgs.gov/minerals/pubs/state/ca.html

USGS, various years b U.S. Geological Survey, Crushed Stone Statistics and Information, Mineral Yearbooks (Various Years), Stone (Crushed) Accessed online at: http://minerals.usgs.gov/minerals/pubs/commodity/stone_crushed/

USGS, various years c U.S. Geological Survey, Mineral Industry Surveys, Soda Ash. Accessed online at: http://minerals.usgs.gov/minerals/pubs/commodity/soda_ash/

USNO, 2004 U.S. Naval Observatory, Astronomical Applications Department, Leap Years. Accessed online at: http://www.usno.navy.mil/USNO/astronomicalapplications/astronomical-information-center/leap-years

Walker, 2007 Personal communication (Collection, Lat/Lon, and Control Data for Landfills) between Larry Hunsaker of CA Air Resources Board and Scott Walker, California Integrated Waste Management Board. Fall 2007.

Walzer, 2011 Personal communication between Webster Tasat, CA Air Resources Board and Dan Walzer, U.S. Energy Information Administration. July 18, 2011.

Wang, 2007 Personal communication between Larry Hunsaker, CA Air Resources Board and Michael D. Wang, Senior Advisor, Western States Petroleum Association. Summer 2007.

WCI, 2011 Western Climate Initiative, 2006, 2007 and 2008 Default Emission Factor Calculators. Queried in June 2011. Available online at: http://www.westernclimateinitiative.org/document-archives/Electricity-Team-Documents/Default-Emission-Factor-Calculators/

Weitz, 2007 Personal communication between Larry Hunsaker of CA Air Resources Board and Melissa Weitz, US Environmental Protection Agency. Fall 2007.

Winkler, 2013 Personal communication between Larry Hunsaker of CA Air Resources Board and Bill Winkler of the CA Department of Conservation, Division of Oil, Gas & Geothermal Resources. Summer 2013. http://www.conservation.ca.gov/DOG/Pages/Index.aspx

Wirth, 2013 Personal communication between Marc Vayssières of CA Air Resources Board and Tom Wirth, Greenhouse Gas Inventory Source Lead, US Environmental Protection Agency, December 2013.

LIST OF TABLES & FIGURES

LIST OF EQUATIONS

LIST OF ACRONYMS

A

AB: Assembly Bill
AHC: American Horse Council
ANDOC: Anaerobically Degradable Organic Carbon
ARB: Air Resources Board
ASTM: American Society for Testing and Materials

B

BOD: Biochemical Oxygen Demand
BOE: California State Board of Equalization
BTU: British Thermal Unit

C

CALEB: California Energy Balance
CalFire: California Department of Forestry and Fire Protection
CalRecycle: California Department of Resources Recycling and Recovery
CDFA: California Department of Food and Agriculture
CDOF: California Department of Finance
CEC: California Energy Commission
CEFM: Cattle Enteric Fermentation Model (USEPA)
CEIDARS: California Emission Inventory Development and Reporting System (ARB)
CEMS: Continuous Emission Monitoring System
CH_4: Methane
CHP: Combined Heat and Power
CKD: Cement Kiln Dust
CO: Carbon Monoxide
CO_2: Carbon Dioxide
COD: Chemical Oxygen Demand
CORINAIR: CORe INventory AIR emissions (EEA)

D

DANF: Decomposable Anaerobic Fraction
DBH: Diameter at Breast Height
DE: Digestible Energy
DOC: Degradable Organic Carbon
DOGGR: Division of Oil, Gas & Geothermal Resources (CA Department of Conservation)

E

EEA: European Environment Agency
EF: Emission Factor
EIA: Energy Information Administration
EIIP: Emission Inventory Improvement Program (USEPA)

EMEP: European Monitoring and Evaluation Programme (EEA)
EMFAC: EMission FACtors model (ARB).
EOR: Enhanced Oil Recovery

F

FAO: United Nations Food and Agriculture Organization
FAOSTAT: Statistics Division of the FAO
FHWA: Federal Highway Administration
FIA: Forest Inventory and Analysis program (USDA-FS)
FOD: First Order Decay model (IPCC)
FRAP: Fire and Resource Assessment Program (CalFire)

G

GE: Gross Energy
GHG: Greenhouse Gas
GIS: Geographic Information System
GPP: Gross Primary Production
GWP: Global Warming Potential

H

HC: Heat Content
HFC: Hydrofluorocarbon
HWP: Harvested Wood Products

I

IPCC: International Panel on Climate Change (UN)
IUPAC: International Union of Pure and Applied Chemistry

L

LADWP: Los Angeles Department of Water and Power
LFG: Landfill Gas
LKD: Lime Kiln Dust
LPG: Liquefied Petroleum Gas

M

MCF: Methane Conversion Factor
MSW: Municipal Solid Waste
MW: Mega Watt
MWh: Mega Watt hour

N

N: Nitrogen
N_2O: Nitrous Oxide
NASS: National Agricultural Statistics Service (USDA)
NE: Net Energy
NEP: Net Ecosystem Production
NLA: National Lime Association

NLCD: National Land Cover Data (USGS)
NO_x: Nitrogen oxides
NPP: Net Primary Production
NRCS: Natural Resources Conservation Service (USDA)
NSCR: Non-Selective Catalytic Reduction
NSP: Net System Power report (CEC)

O

ODS: Ozone Depleting Substance

P

PCA: Portland Cement Association
PFC: Perfluorocarbon
PFPE: Perfluoropolyether
PIER: Public Interest Energy Research (CEC)
PIIRA: Petroleum Industry Information Reporting Act (CEC)
PM: Particulate Matter
PNW: Pacific Northwest
PSW: Pacific Southwest

Q

QFER: Quarterly Fuels and Energy Report (CEC)

R

ROG: Reactive Organic Compound

S

SCR: Selective Catalytic Reduction
SEDS: State Energy Data System (EIA)
SIP: State Implementation Plan (USEPA)
SOC: Soil Organic Carbon
SSURGO: Soil Survey Geographic database (USDA-NRCS)

T

TDOC: Total Degradable Organic Carbon
THC: Total Hydrocarbon
TOC: Total Organic Carbon
TOG: Total Organic Gases

U

UC: University of California
UNFCCC: United Nations Framework Convention on Climate Change
USCB: United States Census Bureau
USDA: United States Department of Agriculture
USDA-FS: United States Department of Agriculture – Forest Service
USDOT: United States Department of Transportation
USEPA: United States Environmental Protection Agency

USGS: United States Geological Survey
UTO: Useful Thermal Output

V

VMT: Vehicle Miles Traveled
VS: Volatile Solids

W

WCI: Western Climate Initiative
WIP: Waste in Place
WMS: Waste Management System
WSPA: Western States Petroleum Association