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Inventory of California Greenhouse Gas Emissions and Sinks: 1990-1999

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Executive Summary

In September 2000, the California Legislature passed Senate Bill 1771, Senator Sher (Chapter 1018, Statutes of 2000), requiring the California Energy Commission (Commission), in consultation with other state agencies, to update California's inventory of greenhouse gas emissions in January 2002 and every five years thereafter. The inventory update is to include all emission sources in the State that were identified in the Commission's 1998 report, *Historical and Forecasted Greenhouse Gas Emissions Inventories for California*.

This report, *Inventory of California Greenhouse Gas Emissions and Sinks: 1990-1999*, presents the Commission's preliminary estimates of emissions and carbon sinks from 1990 to 1999. As Senate Bill 1771 requires, the report includes emissions of greenhouse gases and compares California's emissions with the emissions from other states and nations. Limited information was available to allow a complete and thorough analysis and discussion of the impact of air quality and energy policies and programs on greenhouse gas emissions.

Current research has largely supported earlier scientific findings that emissions of greenhouse gases from human activities have been steadily increasing since the industrial revolution. In addition, the United Nations-sanctioned technical body, Intergovernmental Panel on Climate Change reported that: "There is new and stronger evidence that most of the warming observed over the last 50 years is attributable to human activities."

In response to early scientific findings related to the impact of human activities on climate, the United Nations General Assembly established the Intergovernmental Negotiating Committee for a Framework Convention on Climate Change in 1990. At the United Nations Framework Convention on Climate Change held in 1992 in Rio de Janeiro, Brazil, over 180 nations adopted the agreement to reduce greenhouse gas emissions. The agreement was ratified by the United States the same year. At the 1997 Conference of the Parties in Kyoto, Japan, a protocol (Kyoto Protocol) was adopted to meet specific greenhouse gas emission goals.

Currently 84 countries, including the United States, have signed the Kyoto Protocol. If ratified, this Protocol would mandate the United States to reduce its greenhouse gas emissions by seven percent below the 1990 levels. Although the Kyoto Protocol has not been ratified by the United States or become the official basis for state climate change policy, 1990 emissions reduction targets can be used as a comparative between emissions trends of California and those of the United States.

This inventory was developed using new guidelines adopted by the Intergovernmental Panel on Climate Change, and is consistent with methods used to conduct the national inventory prepared by the U.S. Environmental Protection Agency.

For purposes of this report, greenhouse gases include carbon dioxide, methane, nitrous oxide, hydrofluorocarbons, perfluorocarbons, and sulfur hexafluoride. Although the first three gases are also emitted from natural sources, this report primarily focuses on emissions due to human activities (anthropogenic emissions).

The California Context

California has seen a modest increase in greenhouse gas emissions in California over the last decade. This increase is the consequence of several divergent forces within California: some lead to increases in greenhouse gas emissions, while others negate those increases. These are described below.

California has a large growing population and a robust economy, which ranks fifth after the United States, Japan, Germany, and the United Kingdom. Several key California industries emit only moderate amounts of carbon dioxide. With a relatively temperate climate, California uses relatively less heating and cooling energy than other states. As a leader in implementing aggressive efficiency and environmental programs, California has been able to reduce carbon dioxide emission rates in all sectors, as well as reducing energy demand and air pollution emissions. However, California leads the nation in vehicle miles traveled; as a result, CO_2 emissions from the transportation sector are increasing.

California uses fossil fuels differently than the United States as a whole (Figure ES-1, Figure ES-2, Figure ES-3). Compared to most other states, California uses less fossil energy to generate electricity. This lower reliance on fossil fuels is due to the availability of hydroelectric and nuclear power, and the continuing and growing use of renewable energy. As a fraction of its total fossil fuel use, California uses more fossil fuels (primarily gasoline) in the transportation sector.

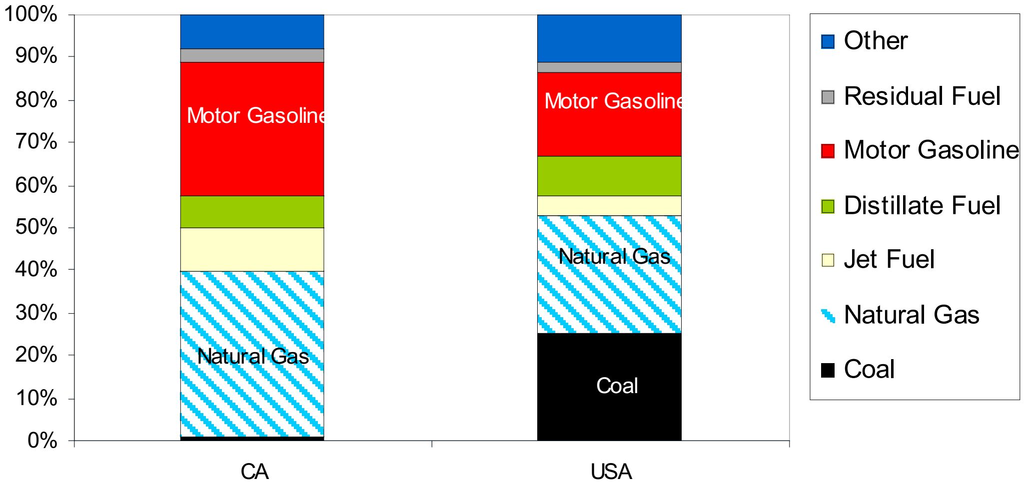


Figure ES-1: Distribution of Fossil Fuel Consumption in California and United States in 1999

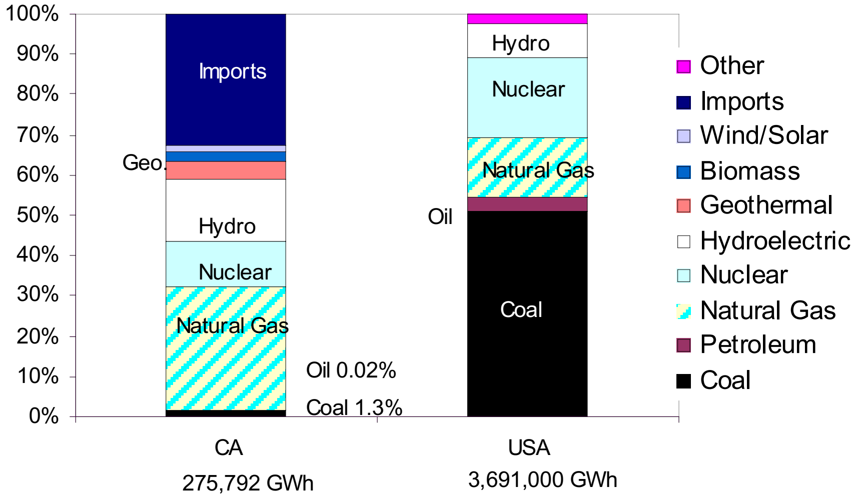


Figure ES- 2: Distribution of Electric Generation Sources in California and United States in 1999

As shown in Figure ES-3, California's electricity use per capita has remained flat compared to national per capita use, which increased by approximately 1.5 percent per year. On the demand side, reduced electricity consumption results from California programs such as energy efficiency in building and appliance standards. These programs have resulted in increased electricity conservation, which was particularly pronounced during the sharp electricity supply shortages experienced in California from 2000 to 2001. Preliminary data suggest that per capita electricity use dropped by 7 percent from 2000 levels in 2001.

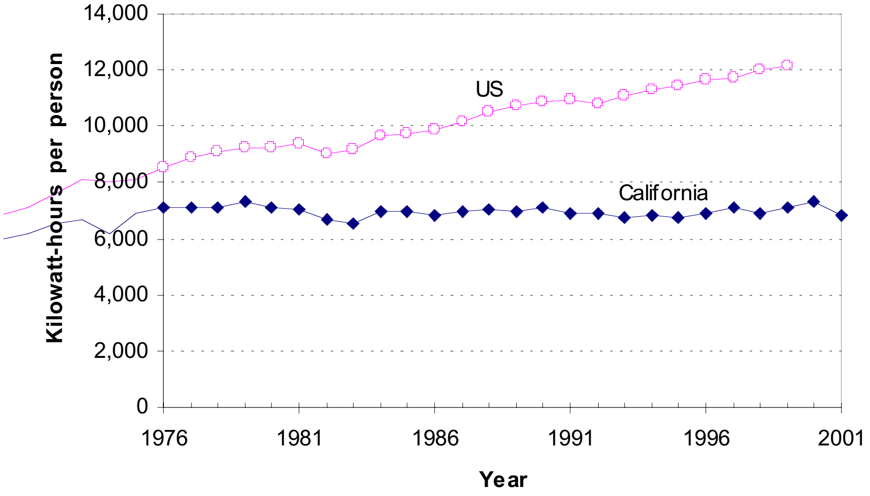


Figure ES-3: California and United States Electricity Use per Capita Trends since 1976

Trends in California Emissions Levels

Figure ES-4 depicts overall trends in gross emissions in California and the United States as a whole. Gross emissions include emissions from all the in-state and United States sources normalized to 1990 levels to allow a comparison between emissions in California and the United States (i.e., gross emissions in each year are presented as a ratio of gross emissions in 1990).

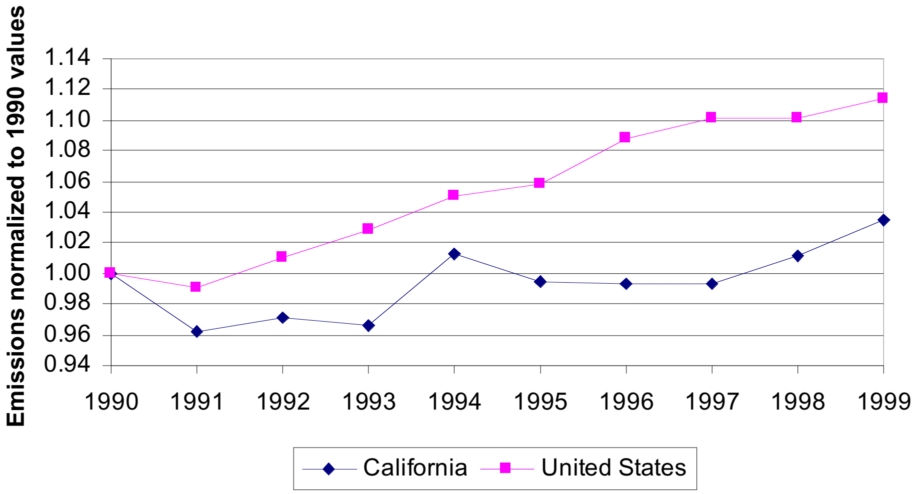


Figure ES-4: 1990-1999 Relative Gross Greenhouse Gas Emissions (excluding marine bunker fuels)

Economic activity explains in large measure California's changing greenhouse gas emission levels. The emissions decline in California in 1991 and 1992 is primarily the result of the economic recession experienced during those years. In 1994, emissions were relatively high because: 1) a recovering economy resulted in increased industrial activity and 2) low rainfall reduced availability of hydroelectric power (Figure ES-9), which in turn resulted in increased emissions from fossil-fueled electricity generation. Although moderated by available hydroelectric power, emissions from 1995 to 1999 increased from a strong expansion in the economy.

Changes in California's economy have contributed to the reduction in emissions per unit of gross state product (GSP). Emissions per dollar of GSP have fallen, as shown in Figure ES-5. For the period 1990 to 1999, five sectors and subsectors of the state economy accounted for 74 percent of the State's economic growth. This economic growth, however, occurred primarily during the 1995 to 1999 period. These sectors and subsectors of the California economy have lower than average energy intensities and include manufacturing of electronic equipment and computers and related equipment, wholesale trade, finance, insurance, and real-estate, and services.

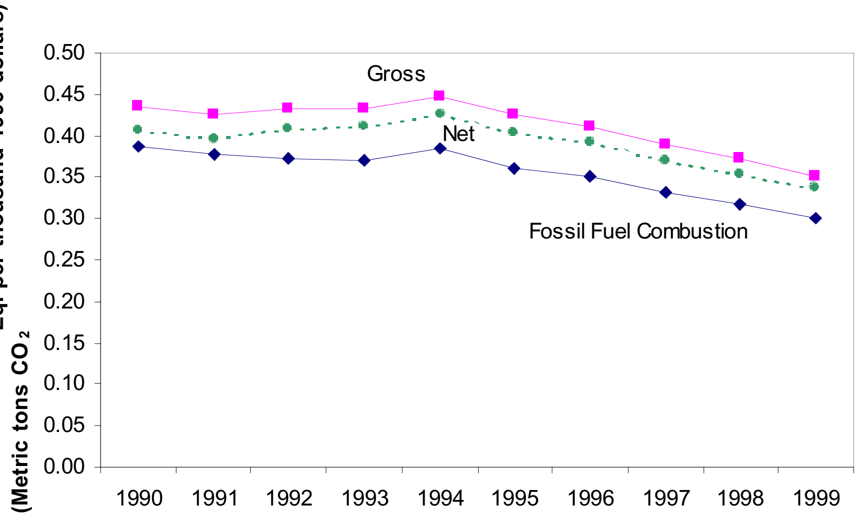
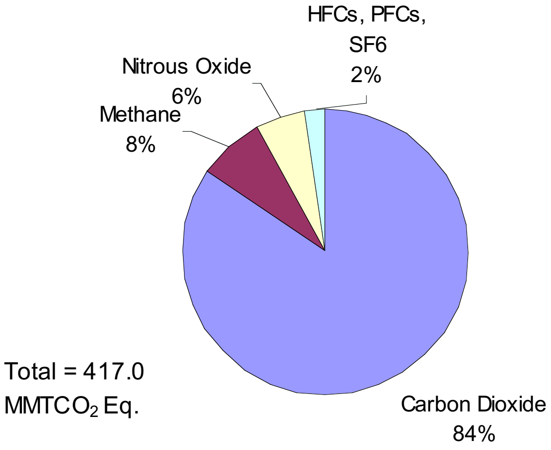


Figure ES-5: California Emissions per Dollar of Gross State Product (excluding marine bunker fuels)

Figure ES-6 shows the distribution of emissions by greenhouse gas type. Each gas differs in its atmospheric warming properties; for example methane has 21 times the warming potential of carbon dioxide. As a result, the relative contribution of each gas is shown on a carbon dioxide equivalent basis. At 84 percent of the total, carbon dioxide is the largest single contributor to emissions from in-state sources.



HFCs, PFCs, and SF_6 = Hydrofluorocarbons, perfluorocarbons, and sulfur hexafluoride

Figure ES-6: Distribution of California Greenhouse Gas Emissions by Gas in 1999 (excluding marine bunker fuels)

Table ES-1 presents a summary of the emissions and sinks in California for 1990 and 1999. To compare the gases on a common atmospheric warming potential basis, all the emissions are represented in million metric tons of carbon dioxide equivalent ($MMTCO_2$ Eq.), using the Intergovernmental Panel on Climate Change approved conversion factors.

Table ES-1: Trend in California Greenhouse Gas Emissions and Sinks (including and excluding marine bunker fuels) ($MMTCO_2$ Eq.)

	1990	1999	% change
Carbon Dioxide	363.8	362.8	
Fossil Fuel Combustion Other	358.2 5.6	356.3 6.5	
Methane	34.6	31.6	
Nitrous Oxide	24.6	23.5	
HFCs, PFCs, SF_6	2.1	9.7	
Gross Emissions	**425.1**	**427.7**	**0.6%**
Soils and Forest (Sink)	-25.6	-18.8	
Net Emissions	**399.5**	**408.9**	**2.4%**
Marine Bunker Fuels	22.0	10.7	
Gross Emissions Minus Marine Bunkers	**403.1**	**417.0**	**3.5%**
Net Emissions Minus Marine Bunkers	**377.5**	**398.2**	**5.5%**

Natural processes, such as photosynthesis, can remove carbon from the atmosphere, thereby offsetting greenhouse gas emissions. Land use and forestry activities have significant impacts on carbon storage as they affect the availability of carbon reservoirs (e.g., trees, soils). Carbon sequestration in California decreased from more than 25 million metric tons of carbon dioxide equivalent ($MMTCO_2$ Eq.) in 1990 to less than 19 $MMTCO_2$ Eq. in 1999. This decrease was primarily due to decreasing carbon storage in wood products, landfilled wood, and landfilled yard trimmings.

Greenhouse gas emissions from the bunker fuel category affect the quantity of emissions in the California inventory. “Bunker” fuel in Table ES-1 is fuel used for marine international transport. Under the United Nations Framework Convention on Climate Change and the U.S. Environmental Protection Agency inventory guidelines, marine and aviation bunker fuel emissions should, if possible, be estimated and subtracted from total carbon dioxide emissions. Under the accounting guidelines, however, if the data cannot be disaggregated sufficiently to estimate these emissions, total emissions (i.e., including bunker fuel) should be reported in the inventory as part of in-state emissions.

Including marine bunker fuels has a significant and possibly misleading impact on overall trends presented in this inventory. A state bunker fuel sales tax imposed in 1991 for marine fuels caused major declines in the state marine bunker fuel market. Even though this tax was repealed in 1993, the sales of marine bunker fuel have remained low, as sales of bunker fuel have been shifted out of California. As opposed to an actual decrease in marine transport or the associated emissions, the emission reductions are the result of this shift. To most accurately represent actual emissions, the results reported in this summary exclude marine bunker fuel from both 1990 and 1999.

Net emissions are those that are released into the atmosphere and contribute to the total greenhouse gas emissions burden on the global environment. Net emissions are estimated by subtracting the amount of carbon dioxide absorbed by sinks from the gross emissions. Gross and net emissions in California (not including marine bunker fuel) increased by 3.5 percent and 5.5 percent, respectively, from 1990 through 1999. These figures are relatively low when compared to a 12 percent and 16 percent increase for the United States overall.

Figure ES-7 presents carbon dioxide emissions by fuel type. The combustion of fossil fuels contributes about 98 percent of the total carbon dioxide emissions. Natural gas and motor gasoline consumption dominate emissions in California. The consumption of coal is minimal in the State.

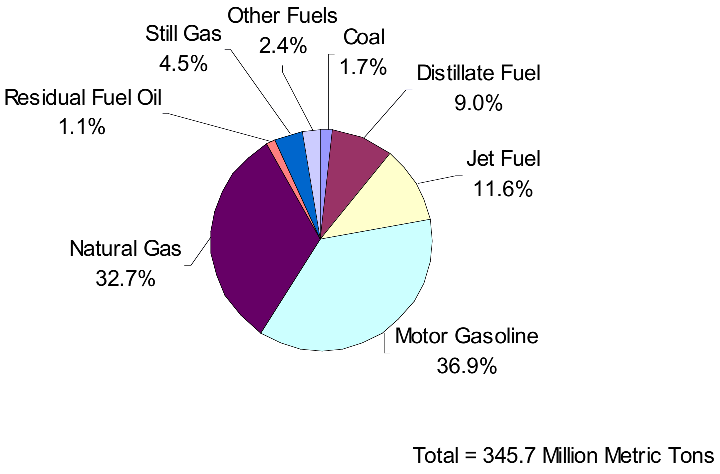


Figure ES-7: Carbon Dioxide Emissions by Fossil Fuel Type for 1999 (excluding marine bunker fuels)

Figure ES-8 shows the contribution of carbon dioxide emissions by sector, with the transportation sector contributing more than half of the emissions. Figure ES-8 also breaks this sector down by fuel type.

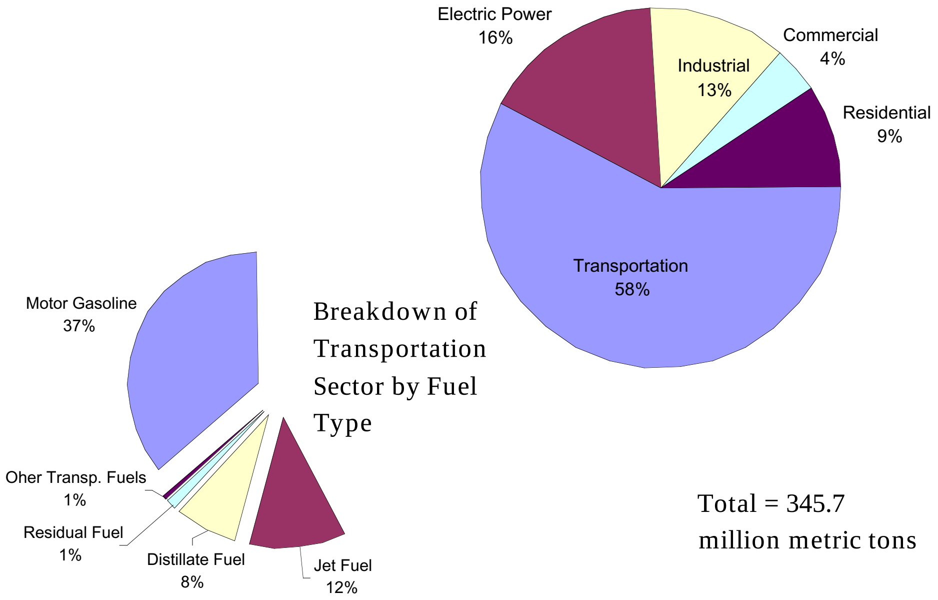


Figure ES-8: Carbon Dioxide Emissions from the Combustion of Fossil Fuels by Sector for 1999 (excluding marine bunker fuels)

Fuel Mix in the Electric Power Sector: In-state power plants contribute about 16 percent of the carbon dioxide emissions from the combustion of fossil fuels. This relatively low fraction is due in part to the mix of energy resources available to the State (at the national level, power generation contributes about one-third of the total carbon dioxide emissions from the combustion of fossil fuels). California imports a substantial amount of electricity from out-of-state power plants—a mix of hydro, nuclear, and coal—which contributes to the relatively low percentage contribution from this sector to in-state emissions.

For illustrative purposes, if carbon dioxide emissions from out-of-state power plants serving California were included, emissions would increase by about 5.5 million metric tons and the rate of increase of gross (minus marine bunker fuel) greenhouse gas emissions in the 1990 to 1999 period would have been about four percent. These emissions are not included for California in compliance with international and national protocols.

Emissions of carbon dioxide in the electric power sector are strongly influenced by available hydropower. The State experienced a five-year drought from 1987 to 1991, which reduced precipitation from 40 to 70 percent from normal levels during this period. As shown in Figure ES-9, because of the drought, hydroelectric generation in 1990 was reduced significantly. This reduction was accompanied by an increase in generation from fossil fuel burning power plants and higher carbon dioxide emissions. Late in the decade, the increased hydropower helped moderate what would have been more significant increases in greenhouse gas emissions from the production of electricity in California.

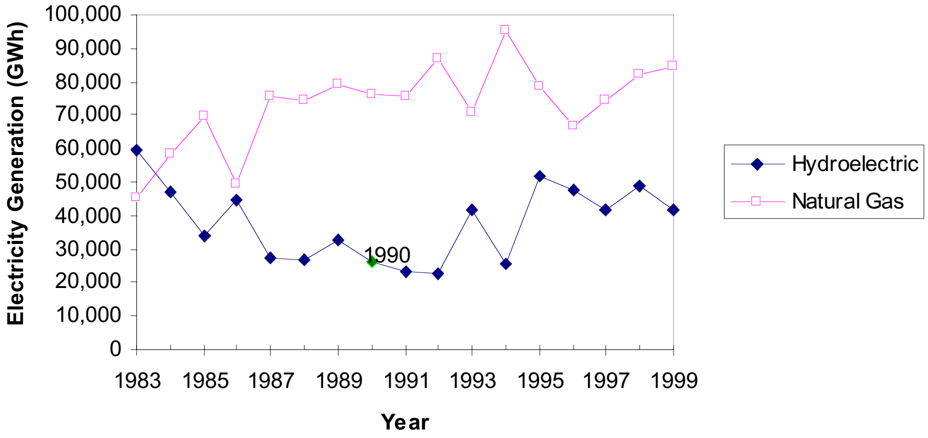


Figure ES-9: Generation from In-State Hydro and Natural Gas Power Plants: 1983-1999

Fuel Demand in the Transportation Sector: Emissions from distillate (diesel), jet fuel, and motor gasoline in the transportation sector increased in the 1990 to 1999 period (Figure ES-10). Emissions from distillate, jet fuel (for commercial and military transport), and motor gasoline consumption increased by 14.3, 4.5, and 9.4 percent, respectively.

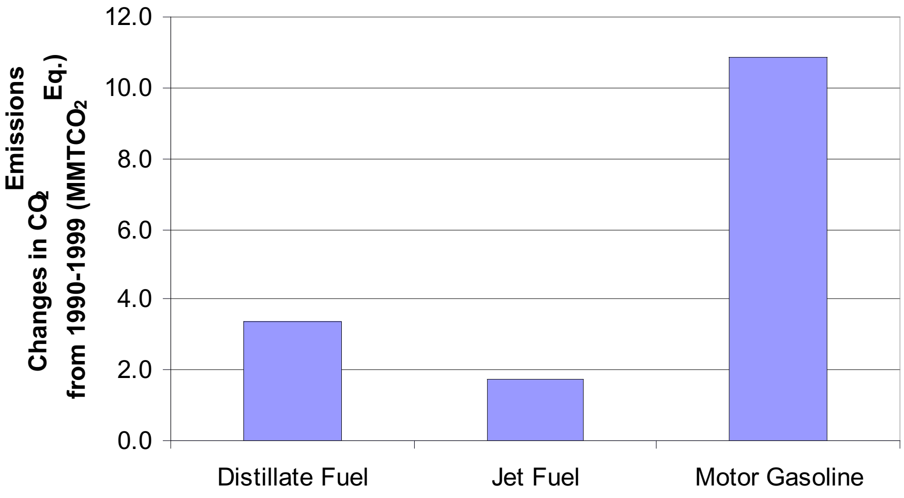


Figure ES-10: Changes in Carbon Dioxide Emissions from Distillate, Jet Fuel, and Motor Gasoline Consumption in the Transportation Sector: 1990-1999 (excluding marine bunker fuels)

Fuel Switching in the Commercial, Industrial, Electric Power and Transportation Sectors: During the 1990 to 1999 period, the switch from distillate and residual fuel oils to natural gas resulted in a decrease in emissions because natural gas produces less carbon dioxide than the other fossil fuels. The reductions of fuel oil consumption occurred for distillate in commercial and industrial boilers and for residual in power plants and domestic marine transport. The switch from residual fuel oil to natural gas in power plants started in the mid-1970s, but some residual fuel oil was still burned in power plants in 1990. These fuel oil reductions were accompanied by substantial increases in the amount of natural gas burned in California as shown in Figure ES-11. Note that the estimate for distillate included in Figure ES-11 excludes distillate fuel used for transportation (which is included in Figure ES-10).

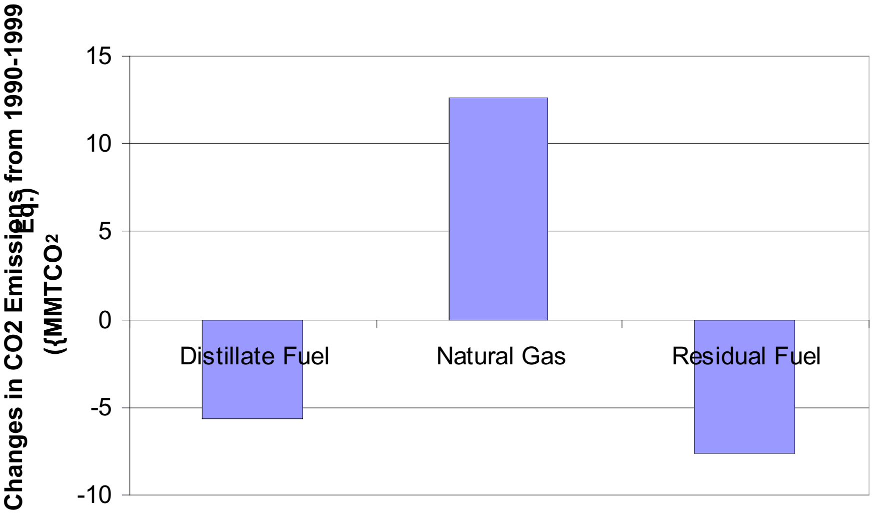


Figure ES-11: Changes in CO2 Emissions from Distillate and Residual Fuel Oils and Natural Gas: 1990-1999 (excluding marine bunker fuels)

Air quality regulations in the mid-1990s required a more stringent level of control of nitrogen oxides, and because of cost considerations, many facilities shifted from fuel oils to natural gas in commercial and industrial boilers. In addition, California refineries processed less crude oil (about nine percent) during the 1990 to 1999 period, which resulted in a decrease in the production and consumption of still gas and other gases used during the processing of crude oil. This change in crude oil processing and the modernization of the state refineries substantially reduced the availability of residual fuel oil, which is a low value fuel, in California.

Comparison of California Emissions with Selected States and Countries

California is characterized by a moderate climate, industries that emit relatively moderate levels of carbon dioxide, and active energy and air quality programs capable of indirectly reducing greenhouse gas emissions. As shown in Figure ES-12, California's emissions per capita and emissions per dollar of state product are low compared with other states.

The rate of emissions growth in the State is relatively modest compared to increases elsewhere in the United States. These comparatively modest increases are the result of: fuel switching to natural gas; relatively low hydropower production in 1990 that was compensated for by burning fossil fuels in power plants; the continuing effect of energy efficiency policies and standards; and, an increase of electricity imports. Without these factors, gross emissions in 1999 would have been about eight percent higher in 1999 than in 1990. Even though California's rate of emission growth has been modest, its total carbon dioxide emissions are very high, second only to Texas among the states.

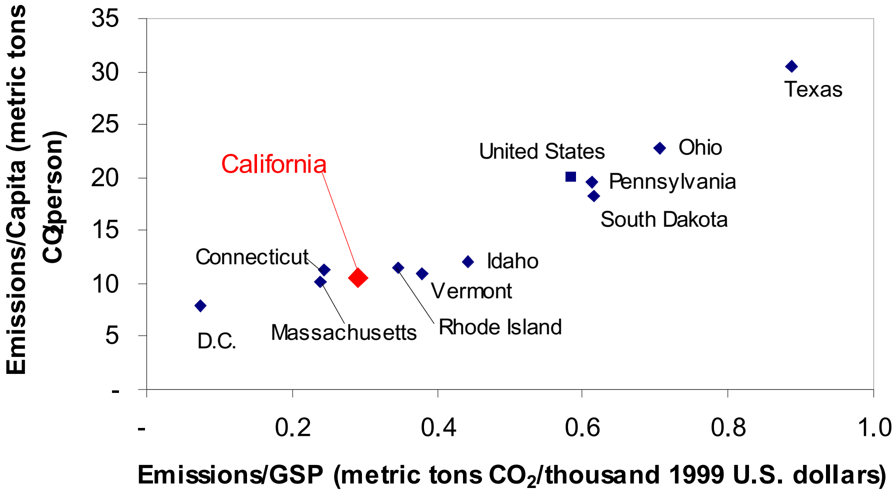


Figure ES-12: 1999 Carbon Intensity from the Combustion of Fossil Fuels for California and Selected States

In the international arena, California emissions from fossil fuel combustion per dollar of gross state product are much lower than U.S. emissions from fossil fuel combustion per dollar of gross domestic product, but as shown in Figure ES-13, comparable with several western European countries.

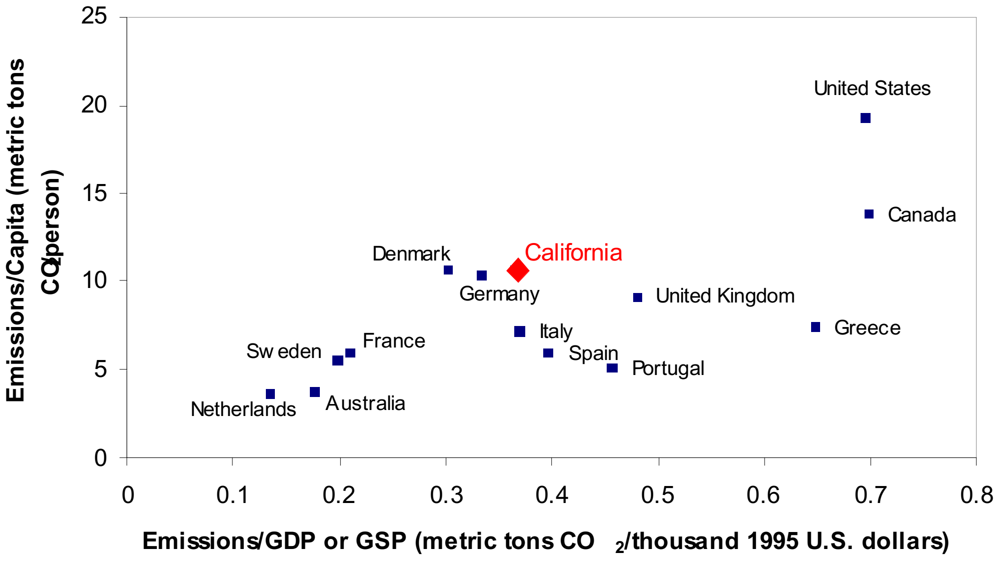


Figure ES-13: 1995 Carbon Intensities for California and Selected Countries Fossil Fuel Combustion

Future Emission Levels

The Commission staff forecasts significant increases in natural gas, motor gasoline, diesel fuel, and jet fuel consumption. For example, fuel use in California's transportation sector, representing nearly 60 percent of carbon dioxide emissions from fuel combustion, is forecast to increase from 1990 levels by 60 percent through 2020.

The data needed to estimate emissions in 2020 for sectors other than transportation are currently unavailable. It is possible, however, to forecast gross emissions for all sectors through the year 2010. Using existing forecasts and assuming consumption of all other fuels remains constant, carbon dioxide emissions from the combustion of fossil fuels in California will increase by about 20 percent from 1990 levels by 2010. Since consumption of other fuels is also likely to increase, this level represents the minimum expected increase in greenhouse gas emissions by the year 2010.

Refinement of Inventory Methods

The emission estimates presented in this inventory represent the best data and methods available, given time and resource constraints. The development of the current inventory has raised issues concerning data quality. Data quality concerns also arise from the current methodologies and protocols designed to disaggregate the data. In particular, there are data quality concerns regarding protocols used to develop emissions data for international marine and aviation bunker fuel.

Although this report does not address the significant uncertainties associated with estimating greenhouse gas emissions, this subject is addressed in a forthcoming report developed through the Commission's Public Interest Energy Research (PIER) Program. In future greenhouse gas inventories, the Commission plans to refine the state greenhouse gas emission estimates further by:

- Incorporating improved data and methods planned and under development;
- Updating emissions estimates to the most recent year;
- Presenting a discussion of the uncertainty in emissions estimates from key sources;
- Improving emissions estimates (e.g., emissions associated with international bunker fuels) and estimating emissions for sources not currently in the inventory.

Summary

Overall, California has done well in comparison to national trends. Over the ten-year period from 1990 to 1999, California's gross state product has increased by 28 percent and its population has grown by 10 percent, while its total greenhouse gas emissions have only increased 3.5 percent. By comparison, the U.S. has experienced an 11.7 percent increase in greenhouse gas emissions over the same ten-year period.

California has been able to reduce its per capita carbon dioxide emission rate by 8.6 percent, from 13.2 tons of carbon dioxide equivalent per person in 1990 down to 12.4 tons of carbon dioxide equivalent per person in 1999. In terms of per dollar of gross state product, the state lowered its "greenhouse gas intensity" by 19 percent, from 0.96 lbs. of carbon dioxide equivalent per dollar of gross state product in 1990 down to 0.77 lbs. of carbon dioxide equivalent per dollar of gross state product in 1999.

This analysis concludes that carbon dioxide emissions from the combustion of fossil fuels remained more or less constant for combined electricity generation and industrial use, primarily due to fuel switching and abundant non-fossil fuel choices (renewable, hydro, and nuclear) for electricity generation. These modest increases throughout the 1990s are also due to aggressive state control of criteria air pollutants, which can lead to a reduction of carbon dioxide emissions.

Carbon dioxide emissions have grown substantially in the transportation sector, which more closely mirrors national growth trends. This growth is especially true for gasoline-based emissions in the transportation sector, which have increased by 9.4 percent over the decade.

CHAPTER 1 – OVERVIEW

1.0 Overview

The potential risks of climate change have led over 180 nations, including the United States, to ratify the United Nations Framework Convention on Climate Change (UNFCCC), a landmark agreement to reduce the threat of climate change. In ratifying (i.e., formally sanctioning) the framework convention, nations agree to certain reporting requirements. In particular, each nation is required to prepare and periodically report: (1) the magnitude and sources of greenhouse gas emissions and sinks; (2) any ongoing activities to reduce emissions and enhance sinks; and (3) other activities related to adaptation, research, and education. Under the UNFCCC, national inventories are to be based on the methodologies and reporting structure of the Intergovernmental Panel on Climate Change (IPCC), and are to include estimates of emissions of six greenhouse gases: carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), hydrofluorocarbons (HFCs), perfluorocarbons (PFCs), and sulfur hexafluoride (SF_6).

California Senate Bill 1771, chaptered in September of 2000, requires the California Energy Commission, in consultation with other state agencies, to update the greenhouse gas emission estimates "for all sources located in the state as identified in the Commission's 1998 report entitled *Appendix A: Historical and Forecasted Greenhouse Gas Emissions Inventories for California*." Since the 1998 inventory was prepared, state-of-the art methods for estimating greenhouse gas emissions have been improved. In particular, the IPCC developed revised guidance, including new categories of greenhouse gas sources and improved methods for estimating emissions. The 2002 California emission inventory follows the latest IPCC guidelines, is consistent with the national inventory, and at the same time, uses California-specific data and methods when they result in better estimates of in-state emissions.

The scope of the *Inventory of California Greenhouse Gas Emissions and Sinks: 1990-1999* can be described as follows:

Statewide: The inventory includes estimates of emissions across the state of California.

Sectors: The inventory estimates emissions from five major sectors – Energy, Industrial Processes, Agriculture, Forestry, and Waste.

Thirty Greenhouse Gas Sources: The inventory provides emissions from thirty sources of emissions and sinks. There are several sources for which data were not available at the state level; however, estimates of emissions from some of these sources may be improved in subsequent inventories as data become available.

Six Greenhouse Gases: The inventory captures emissions of six greenhouse gases: CO_2, CH_4, N_2O, PFCs, HFCs, and SF_6. These six greenhouse gases were chosen because the UNFCCC requires that emissions from these gases be included in national inventories.

Time Series: The inventory includes emissions over a ten-year period, starting in 1990 and ending in 1999. Due to data constraints, estimates for 2000 were not included in the inventory.

The methods used to develop estimates for this inventory are consistent with the *Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories* and with the *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-1999*. Where possible, data from state agencies were used to develop emission estimates. In cases where state agencies were unable to provide the necessary data, estimates reflect state-level data that was collected by states but reported at a national level.

While this study meets the requirements of the California Legislature, due to time constraints and data availability, the Commission plans to further refine estimates of state greenhouse gas emissions. This revised inventory, when completed, will (1) incorporate improved data and methods planned and under development; (2) include estimates of greenhouse gas emissions through the year 2000; (3) present a discussion of the uncertainty in estimates of emissions from key sources; and (4) estimate emissions for sources not currently included in the inventory.

Climate change refers to long-term fluctuations in the climate system including, but not limited to, changes in temperature, precipitation, and wind. Changes in climate are driven by changes in the amount of radiation present in the Earth's atmosphere. The Earth's surface absorbs radiation from the sun and this energy is then redistributed by the atmospheric and oceanic circulations and radiated back to space. In general, incoming solar radiation is approximately balanced by outgoing terrestrial radiation. Any factor altering the distribution of radiative energy is likely to affect climate. According to the IPCC Third Assessment Report, radiative forcing describes a change to the net radiative energy available to the global Earth-atmosphere system. Radiative forcing may be positive--warming the Earth's surface and lower atmosphere--or negative--cooling the Earth's surface and lower atmosphere.

Increased concentrations of greenhouse gases inhibit the Earth's ability to radiate energy back to space. Greenhouse gases in the Earth's atmosphere absorb outgoing terrestrial radiation, causing less heat to escape and creating an enhanced "greenhouse effect." The greenhouse effect has taken place for billions of years, due to the presence of naturally occurring greenhouse gases in the Earth's atmosphere. However, over the last 50 years, anthropogenic greenhouse gas emissions (i.e., human-induced emissions) are believed to be responsible for most of the observed warming.

Naturally occurring greenhouse gases, such as water vapor, CO_2, CH_4, N_2O, and ozone (O_3), are emitted as part of the Earth's hydrological, geological, and biological cycles. Certain synthetic compounds, including chlorofluorocarbons (CFCs), HFCs, partially halogenated chlorofluorocarbons (HCFCs), SF_6, and PFCs, can also behave as greenhouse gases. Additionally, gases referred to as "ozone precursors" can *indirectly* influence the formation and destruction of ozone, which itself has a direct radiative force. Carbon monoxide (CO), oxides of nitrogen (NO_x), and nonmethane volatile organic compounds (NMVOCs) are such indirect contributors to the greenhouse effect.

The aforementioned greenhouse gases have different effects on the Earth's radiative energy balance. To allow scientists to normalize the effects of emissions of the different gases, Global Warming Potential (GWP) was created to compare the abilities of greenhouse gases to trap heat in the atmosphere relative to a reference gas, CO_2. The GWP is measured as the ratio of the radiative forcing of one unit mass of a gas relative to that capability of one unit mass of carbon dioxide over a specified time period. State and national inventory guidance recommends using the 100-year time horizon; thus, this study uses 100-year GWPs, listed in Table 1.

Table 1: Global Warming Potential for Greenhouse Gases

Gas	100-Year GWP
CO_2	1
CH_4	21
N_2O	310
HFC-143a	1,300
HFC-23	11,700
HFC-152a	140
SF_6	23,900

Source: EPA 2001

Greenhouse gas emissions can be expressed either on a mass basis of the gas (for example, 1 million metric ton of methane), or normalized by weighting the emissions by the GWP of the gas (continuing the example, 21 million metric ton of carbon dioxide, which has an equivalent radiative forcing). In the remainder of this report, units of million metric ton of carbon dioxide equivalent ($MMTCO_2$ Eq.) are used.

Aerosols (i.e., liquid or solid particles suspended in the air) are responsible for both directly and indirectly influencing the amount of radiation leaving the Earth's atmosphere. Aerosols scatter and absorb radiation in the atmosphere, directly influencing the greenhouse effect. Aerosols can also indirectly affect the amount of energy radiated to space by altering cloud formation processes. According to the IPCC, aerosols have most likely had a negative (cooling) effect on radiative forcing. Due to their short atmospheric lifetimes; however, aerosols do not represent a long-term offset to the warming influence of greenhouse gases.

1.1. Greenhouse Gas Emissions in California

Gross greenhouse gas emissions in California (i.e., emissions from all sources, irrespective of sinks) increased approximately one percent from 425 $MMTCO_2$ Eq. to 428 $MMTCO_2$ Eq. from 1990 to 1999. Carbon dioxide emissions from the combustion of fossil fuels, accounted for the majority (more than 80 percent) of emissions throughout the period. Emissions from landfills and agricultural soil management each represented roughly three percent of annual emissions and were responsible for the majority of state methane and nitrous oxide emissions, respectively. Substitutes for ozone-depleting substances were the fastest growing source of emissions, increasing from roughly 0.1 $MMTCO_2$ Eq. in 1990 to 7.0 $MMTCO_2$ Eq. in 1999. This dramatic increase was due to the penetration of substitutes to ozone-depleting chemicals in the middle to late 1990s in response to the terms of the Montreal Protocol, an international treaty to reduce the emissions of ozone-depleting chemicals.

Land-use change and forestry activities in California resulted in net carbon sequestration from this sector. However, sequestration in the state decreased from more than 25 MMTCO$_2$ Eq. in 1990 to slightly less than 19 MMTCO$_2$ Eq. in 1999, offsetting 6 and 4 percent of gross greenhouse gas emissions, respectively.

Net greenhouse gas emissions in California (i.e., emissions minus sequestration) increased approximately 2 percent from 399 MMTCO$_2$ Eq. in 1990 to 409 MMTCO$_2$ Eq. in 1999 (Table 2). Although emissions of greenhouse gases are increasing in California, the increase in state emissions is far more gradual than the trend in national emissions. Gross and net emissions in California increased 1 percent and 2 percent over the ten-year period, respectively, as compared to 12 percent and 16 percent for the entire country.

The gradual trend in emissions from 1990 through 1999 is a reflection of several underlying factors, all of which are described in more detail in Chapter 7. Factors influencing emissions during the 1990s include the continued benefits of energy efficiency and conservation programs, the switch from fuel oils to natural gas in industrial boilers, reduced production of residual fuel oil in California, and imports from out-of-state power plants. Of these factors, electricity imports have the largest impact on annual emissions; however, these emissions have a relatively minor impact on the *trend* in total emissions during the 1990s (less than 2 percent). In addition to these factors, relatively high emissions in 1990 may have masked more significant growth in emissions during the 1990s, as emissions were higher in 1990 than in the surrounding years. The peak in 1990 was likely driven by (1) the strength of the economy; and (2) increased fossil fuel combustion at state-owned power plants to compensate for reduced availability of water for hydropower.

Carbon dioxide emissions from fossil fuel combustion, cement production, and other sources dominated the emission profile in California throughout the ten-year period, accounting for 85 percent of gross emissions in 1999. Methane and nitrous oxide accounted for approximately 7 and 6 percent of gross 1999 emissions, respectively. HFCs, PFCs and SF$_6$ accounted for the remaining 2 percent of gross 1999 emissions.

Table 2: California Greenhouse Gas Emissions and Sinks: 1990-1999 (MMTCO$_2$ Eq.)

GAS/SOURCE	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999
Carbon Dioxide (CO_2)	363.76	350.47	342.79	338.56	355.64	346.17	346.83	348.19	355.49	362.82
Fossil Fuel Combustion	358.16	345.27	337.80	333.51	350.00	340.39	340.87	342.09	349.33	356.28
Cement Production	4.62	4.26	4.07	4.18	4.75	4.81	4.97	5.12	5.19	5.55
Lime Production	0.25	0.22	0.20	0.15	0.16	0.18	0.16	0.16	0.15	0.14
Limestone and Dolomite Consumption	0.14	0.13	0.12	0.11	0.12	0.16	0.18	0.18	0.19	0.20
Soda Ash Production and Consumption	0.22	0.21	0.21	0.21	0.21	0.22	0.21	0.22	0.22	0.21
Carbon Dioxide Consumption	0.07	0.08	0.08	0.08	0.08	0.09	0.11	0.12	0.12	0.13
Waste Combustion	0.30	0.30	0.31	0.31	0.32	0.32	0.32	0.31	0.30	0.31
Soils and Forests (Sink)	*-25.58*	*-25.21*	*-20.97*	*-20.68*	*-20.29*	*-19.88*	*-19.61*	*-19.26*	*-19.13*	*-18.79*
Methane (CH_4)	34.63	34.87	35.47	34.35	34.84	34.79	32.75	32.17	29.99	31.65
Oil System	0.40	0.40	0.39	0.39	0.39	0.39	0.39	0.38	0.38	0.36
Natural Gas System	3.34	3.24	3.19	3.05	2.94	3.00	2.91	2.91	2.87	2.90
Coal Mining	0.18	0.19	0.34	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Landfills	16.95	17.02	17.26	17.32	17.06	16.58	15.09	14.24	12.27	13.17
Enteric Fermentation	7.53	7.25	7.37	6.59	7.14	7.25	6.77	6.88	6.84	7.08
Manure Management	3.29	3.87	3.93	4.03	4.30	4.55	4.55	4.88	4.80	5.21
Flooded Rice Fields	0.41	0.36	0.41	0.45	0.50	0.48	0.52	0.54	0.50	0.52
Burning Agricultural Residues	0.03	0.03	0.03	0.04	0.04	0.04	0.04	0.04	0.04	0.04
Wastewater	1.27	1.28	1.30	1.32	1.33	1.33	1.34	1.36	1.37	1.39
Mobile Source Combustion	0.54	0.52	0.51	0.49	0.48	0.46	0.44	0.43	0.42	0.41
Stationary Source Combustion	0.69	0.71	0.73	0.67	0.67	0.69	0.69	0.52	0.52	0.56
Nitrous Oxide (N_2O)	24.60	23.09	23.52	24.41	23.56	25.40	24.57	23.00	23.28	23.55
Nitric Acid Production	0.53	0.52	0.56	0.38	0.38	0.49	0.30	0.30	0.28	0.28
Waste Combustion	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02
Agricultural Soils	14.93	13.35	13.68	14.69	14.04	15.93	15.51	14.10	14.45	14.74
Manure Management	0.81	0.76	0.74	0.72	0.70	0.72	0.70	0.70	0.70	0.71
Burning Agricultural Residues	0.09	0.08	0.09	0.10	0.11	0.11	0.11	0.11	0.11	0.12
Human Sewage	0.93	0.87	0.85	0.94	0.86	0.93	0.91	1.00	1.04	1.05
Mobile Source Combustion	6.82	7.06	7.15	7.14	7.02	6.81	6.63	6.39	6.32	6.24
Stationary Source Combustion	0.46	0.43	0.44	0.41	0.42	0.40	0.39	0.36	0.35	0.39
HFCs, PFCs, and SF_6	2.07	2.09	2.29	2.84	3.54	5.43	6.81	7.87	8.73	9.70
Substitution of Ozone Depleting Substances	0.12	0.10	0.19	0.65	1.23	2.94	4.15	5.15	6.10	7.00
Semiconductor Manufacture	0.36	0.36	0.36	0.46	0.52	0.67	0.86	0.86	0.84	0.84
Electric Utilities	1.60	1.63	1.74	1.74	1.80	1.81	1.81	1.87	1.80	1.87
Gross Emissions	425.05	410.52	404.08	400.16	417.59	411.79	410.95	411.23	417.49	427.72
Total Sinks	*-25.58*	*-25.21*	*-20.97*	*-20.68*	*-20.29*	*-19.88*	*-19.61*	*-19.26*	*-19.13*	*-18.79*
Net Emissions	399.47	385.31	383.11	379.48	397.30	391.91	391.34	391.97	398.37	408.93

Note: emission totals in the “Carbon Dioxide” row exclude soils and forests.

1.1.1 Greenhouse Gas Emissions in California, Excluding Emissions from Bunker Fuels

According to the guidance for national- and state-level inventories provided by the UNFCC and U.S. Environmental Protection Agency, emissions from bunker fuels (i.e., fuels used in international transportation activities, primarily in aviation and shipping), are to be estimated but not attributed to the national- or state-level totals. However, as described in Chapter 2, Section 2.7 (International Bunker Fuels), bunker fuel data for the aviation sector were not available, and bunker fuel data obtained for marine vessels appeared to be inconsistent with statewide fuel consumption data. Thus, it was difficult to reliably estimate the effect of bunker fuels, and CEC chose to report statewide levels both with and without emissions from bunker fuels.

The inclusion of bunker fuels emissions in state totals has a significant and possibly misleading effect on overall trends, however. To explain the nature and likely magnitude of this effect, this section presents California greenhouse gas emissions from 1990 through 1999, *excluding* emissions from marine bunker fuels. The effect of aviation bunkers is unknown, and is not addressed in this section.

Greenhouse gas emissions from marine bunker fuels attributed to California totaled 10.7 $MMTCO_2$ Eq. in 1999. These emissions consisted primarily of CO_2 (10.6 $MMTCO_2$ Eq.), but also included CH_4 (0.02 $MMTCO_2$ Eq.) and N_2O (0.08 $MMTCO_2$ Eq.). Emissions from marine bunker fuels in California in 1999 represented about 17.1 percent of national emissions from this source.

Table 3 demonstrates the impact that marine bunker fuel emissions could have on overall emissions in 1990 and 1999. Exclusion of bunker fuel emissions would result in a 5.2 percent decrease in gross 1990 state emissions, and a 2.5 percent decrease in gross 1999 state emissions. When bunkers are subtracted from state totals, 1999 gross emissions would represent a 3.5 percent increase over emissions in 1990. As reported elsewhere in the inventory, when bunker fuels are not excluded from the totals, 1999 gross emissions are just 0.6 percent higher than 1990 emissions.

Table 3: Trend in California Greenhouse Gas Emissions and Sinks (including and excluding marine bunker fuels) (MMTCO$_2$ Eq.)

	1990	1999	% change
Carbon Dioxide	363.8	362.8	
Fossil Fuel Combustion	358.2	356.3	
Other	5.6	6.5	
Methane	34.6	31.6	
Nitrous Oxide	24.6	23.5	
HFCs, PFCs, SF$_6$	2.1	9.7	
Gross Emissions	**425.1**	**427.7**	**0.6%**
Soils and Forest (Sink)	-25.6	-18.8	
Net Emissions	**399.5**	**408.9**	**2.4%**
Marine Bunker Fuels	22.0	10.7	
Gross Emissions Minus Marine Bunkers	**403.1**	**417.0**	**3.5%**
Net Emissions Minus Marine Bunkers	**377.5**	**398.2**	**5.5%**

Marine bunker fuel emissions, whether included or excluded from totals, have very little impact on the distribution of state emissions by type of greenhouse gas. As shown in Figure 1, when bunker fuels are excluded, CO_2, N_2O, and CH_4 account for 84.5, 7.6, and 5.6 percent of gross emissions (as compared to 84.8, 7.4, and 5.5 percent if bunker fuel emissions are included).

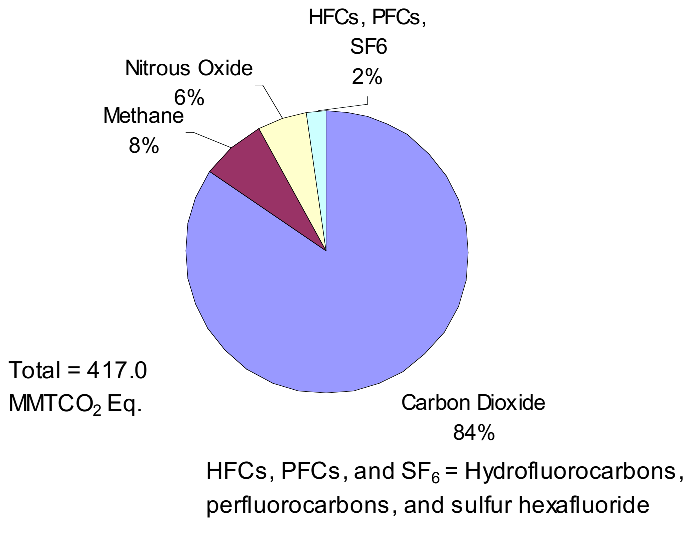


Figure 1: 1999 Distribution of California Greenhouse Gas Emissions by Gas (excluding marine bunker fuels)

The treatment of bunker fuels in the California Inventory is particularly important when the results of the inventory are used to understand trends in consumption of specific fuel types. The effects of a state bunker fuel sales tax imposed in 1991 led to major declines in state marine bunker fuel consumption and associated emissions, as shown in Figure 2. This tax was repealed after 1993, yet sales of marine bunker fuel have remained low. Another possible factor underlying the decrease in emissions from bunker fuels could be the reduced production of residual fuel oil at California refineries. During the 1990s, residual fuel oil production in California dropped by 56 percent.

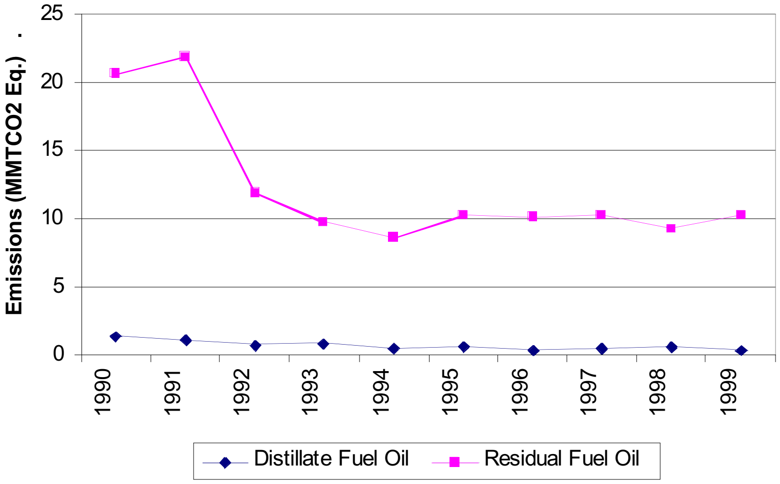


Figure 2: CO_2 Emissions from Residual Bunker Fuel Consumption in California: 1990-1999

Figure 3 shows the difference in the trend in California greenhouse gas emissions when marine bunker fuels are excluded from state totals. As mentioned above, gross emissions increase by 3.5 percent from 1990 to 1999, higher than the 0.6 percent increase when bunkers are included. The change in the two trends is a result of the sharp decrease in bunker fuel consumption in 1992. As bunker fuel purchases have remained fairly constant since 1992, the overall trend in emissions excluding bunker fuels mirrors emissions including bunker fuels from 1992 through 1999.

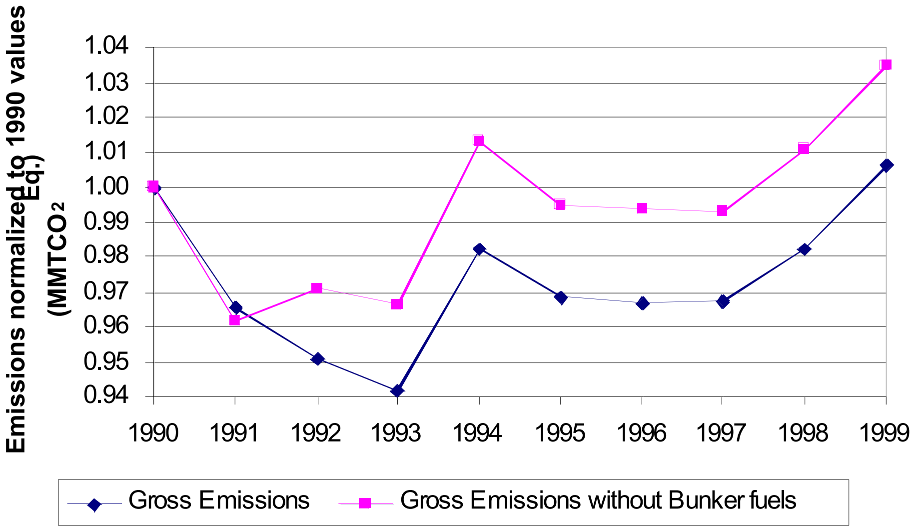


Figure 3: Relative Gross Greenhouse Gas Emissions, Including and Excluding Bunkers: 1990-1999

Figure 4 presents the trends in gross greenhouse gas emissions (excluding bunker fuel emissions) in California and the United States. As in Figure 3, gross emissions are normalized to 1990 levels (i.e., the numbers in the graph reflect gross emissions in each year divided by gross emissions in 1990) to facilitate comparison of state and national emissions.

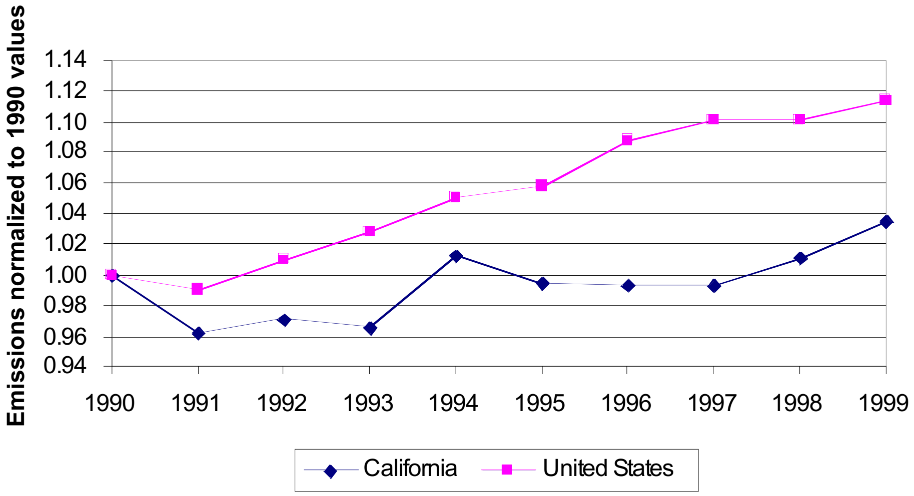


Figure 4: Relative Gross Greenhouse Gas Emissions: 1990-1999

The decline in emissions in the early 1990s shown in Figure 4 is because of the economic recession in California. In 1994, emissions were relatively high due to a recovering economy combined with low rainfall, which led to reduced availability of hydroelectric power.

Even when marine bunker fuels are excluded from California's totals, the state's 3.5 percent increase for the 1990 through 1999 period is lower than the 11.7 percent increase for the nation as a whole.

1.2 California Greenhouse Gas Emissions in Context

Chapter 7 of this report discusses the anthropogenic greenhouse gas emissions (i.e., emissions caused by human activities) estimated in Chapters 2 through 6 as they relate to natural greenhouse gas emissions and emissions from other states and countries.

Atmospheric concentrations of carbon dioxide, methane, and nitrous oxide have increased significantly since the industrial revolution. Although all three gases are produced by natural sources, the rapid increase in atmospheric concentrations of these gases is believed to be a result of anthropogenic sources. Preliminary analyses of natural emissions of greenhouse gases in California support this hypothesis.

California has a very large population and a healthy economy; as a result, California's emissions are very high, second only to Texas. California is also characterized by a moderate climate, industries that are relatively moderate carbon dioxide emitters, and active energy and air quality programs capable of indirectly reducing greenhouse gas emissions. For these reasons, California's emissions per capita and emissions per gross state product are actually quite low compared to other states.

In the international arena, California emissions per gross state product are much lower than U.S. emissions per gross domestic product, but comparable with several modern European countries. California emissions per capita are also lower than national emissions but higher than emissions from most European countries as shown in Figure 5.

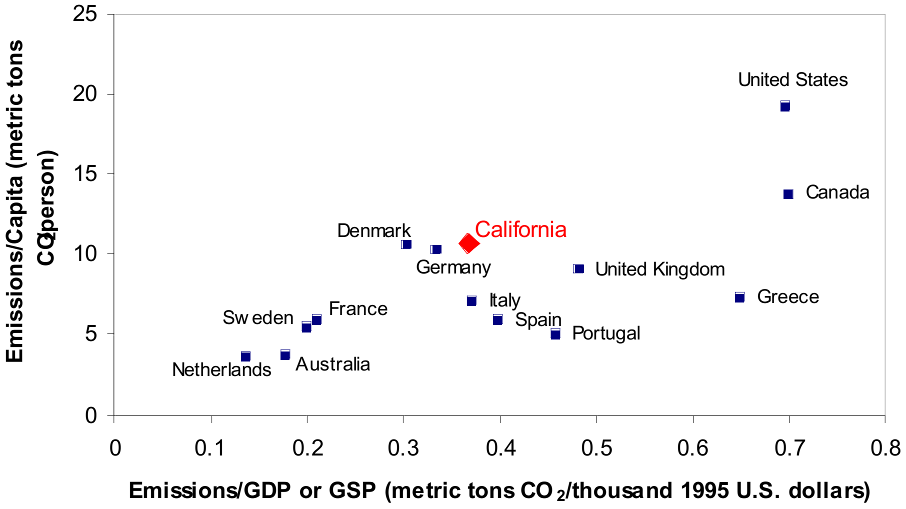


Figure 5: 1995 Carbon Intensities for California and Selected Countries

1.3 Emissions and Sinks by Gas

The remainder of this chapter includes summaries of emissions by gas, beginning with CO_2. As Table 2 shows, CO_2 dominated the emission profile in California over the entire period from 1990 through 1999. This is consistent with trends in other states and the United States as a whole.

1.3.1 Carbon Dioxide Emissions and Sinks

Carbon is naturally cycled between various atmospheric, oceanic, land biotic, marine biotic, and mineral reservoirs. Some of the largest carbon fluxes occur between the atmospheric and land biotic reservoirs. In the atmosphere, carbon generally exists in its oxidized form--as CO_2.

Increased CO_2 concentrations in the atmosphere have been primarily linked to increased combustion of fossil fuels. Fossil fuel combustion in California accounted for 98 percent of gross California CO_2 emissions (Table 4). Other sources of CO_2 emissions in California include non-energy production processes and waste combustion. Carbon sinks in California brought about by land-use change and forestry practices offset roughly 5 percent of gross state CO_2 emissions (Figure 6).

Table 4: CO_2 Emissions: 1990-1999 (MMTCO$_2$ Eq.)

Sector/Source	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999
Energy	**358.16**	**345.27**	**337.80**	**333.51**	**350.00**	**340.39**	**340.87**	**342.09**	**349.33**	**356.28**
Fossil Fuel Combustion	358.16	345.27	337.80	333.51	350.00	340.39	340.87	342.09	349.33	356.28
Industrial Processes	**5.30**	**4.90**	**4.69**	**4.74**	**5.32**	**5.46**	**5.64**	**5.79**	**5.86**	**6.24**
Cement Production	4.62	4.26	4.07	4.18	4.75	4.81	4.97	5.12	5.19	5.55
Lime Production	0.25	0.22	0.20	0.15	0.16	0.18	0.16	0.16	0.15	0.14
Limestone and Dolomite Consumption	0.14	0.13	0.12	0.11	0.12	0.16	0.18	0.18	0.19	0.20
Soda Ash Production and Consumption	0.22	0.21	0.21	0.21	0.21	0.22	0.21	0.22	0.22	0.21
Carbon Dioxide Consumption	0.07	0.08	0.08	0.08	0.08	0.09	0.11	0.12	0.12	0.13
Land-Use Change and Forestry	**-25.58**	**-25.21**	**-20.97**	**-20.68**	**-20.29**	**-19.88**	**-19.61**	**-19.26**	**-19.13**	**-18.79**
Forests and Soils	-10.10	-10.07	-9.72	-9.75	-9.67	-9.55	-9.55	-9.47	-9.58	-9.50
Harvested Wood	-15.49	-15.14	-11.25	-10.93	-10.62	-10.33	-10.05	-9.78	-9.55	-9.30
Waste	**0.30**	**0.30**	**0.31**	**0.31**	**0.32**	**0.32**	**0.32**	**0.31**	**0.30**	**0.31**
Waste Combustion	0.30	0.30	0.31	0.31	0.32	0.32	0.32	0.31	0.30	0.31
Gross Total	**363.76**	**350.47**	**342.79**	**338.56**	**355.64**	**346.17**	**346.83**	**348.19**	**355.49**	**362.82**
Net Total	**338.18**	**325.26**	**321.83**	**317.88**	**335.35**	**326.29**	**327.22**	**328.93**	**336.37**	**344.03**

Note: Totals may not sum due to independent rounding.

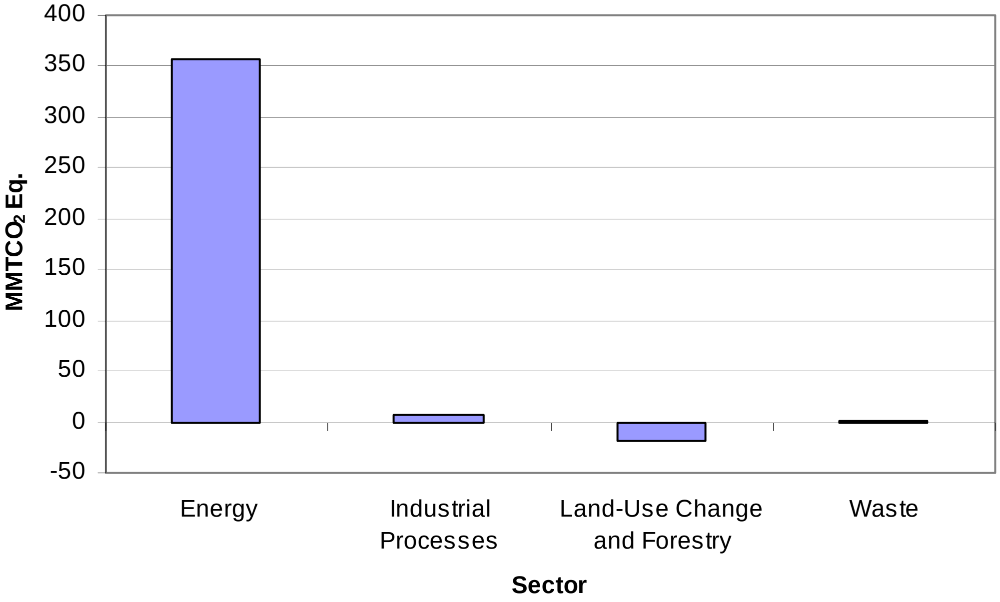


Figure 6: 1999 CO_2 Emissions in California by Sector

1.3.1.1 Energy

Following the IPCC guidelines, GHG emissions from energy-related activities include emissions from fuel combustion; and emissions released during the production, transmission, storage, and distribution of fuels. For example, nitrous oxide emissions from wood combustion in industrial boilers to produce steam are included in the energy sector.

Total CO_2 emissions from fossil fuel combustion in California in 1999 were 356.3 MMTCO$_2$ Eq., which accounts for approximately 7 percent of the U.S. emissions from this source. As shown in Table 4, total emissions from fossil fuel combustion were at their highest in 1990, underwent a rise and fall in 1994 and 1995, respectively, and then rose again from 1996 through 1999. Carbon dioxide emissions from petroleum accounted for the majority (about 67 percent) of total CO_2 emissions from fossil fuel combustion in California. Consumption of petroleum occurred mostly in the industrial and transportation sectors, while over half of the natural gas consumed was in the industrial sector. Natural gas consumption in the industrial sector increased approximately 97 percent from 1990. Emissions from coal in the utility sector and in other sectors were minor, especially compared to the rest of the United States.

The transportation sector accounted for the largest portion of emissions, averaging 59 percent of the total CO_2 emissions from fossil fuel combustion in California between 1990 and 1999. Transportation-related fossil fuel combustion did not fluctuate significantly during the 1990s, remaining around 200 MMTCO$_2$ Eq. Within the transportation sector, motor gasoline consumption accounted for the greatest portion of emissions, with 36 percent of CO_2 emissions from fossil fuel combustion in 1999. Jet fuel, distillate fuel, and residual fuel consumption in the transportation sector contributed roughly 11 percent, 8 percent, and 4 percent of total carbon dioxide emissions from fossil fuel combustion, respectively.

Energy use in the industrial sector ranked second to transportation in terms of total CO_2 emissions from fossil fuel combustion in California (about 26 percent in 1999). Emissions from the residential and commercial sectors accounted for nine and four percent of total emissions from fossil fuel combustion in 1999, respectively.

Electric utilities accounted for only about two percent of CO_2 emissions from fossil fuel combustion in 1999. Carbon dioxide emissions from the electric utilities dropped 73 percent from 28.5 $MMTCO_2$ Eq. in 1990 to 7.7 $MMTCO_2$ Eq. by 1999, as ownership of many utilities has transferred to the private sector and is now designated as industrial.

Total carbon dioxide emissions from the electric power sector (utilities plus non-utilities) totaled 56.7 $MMTCO_2$ in 1999. For an explanation of how estimates were compiled for this sector in 1999, please see Box 2 in Chapter 2.

Figure 7 presents the contribution of each sector to carbon dioxide emissions from fossil fuel combustion in 1999. Transportation sector emissions are disaggregated by fuel type in the small pie chart shown to the left of Figure 7.

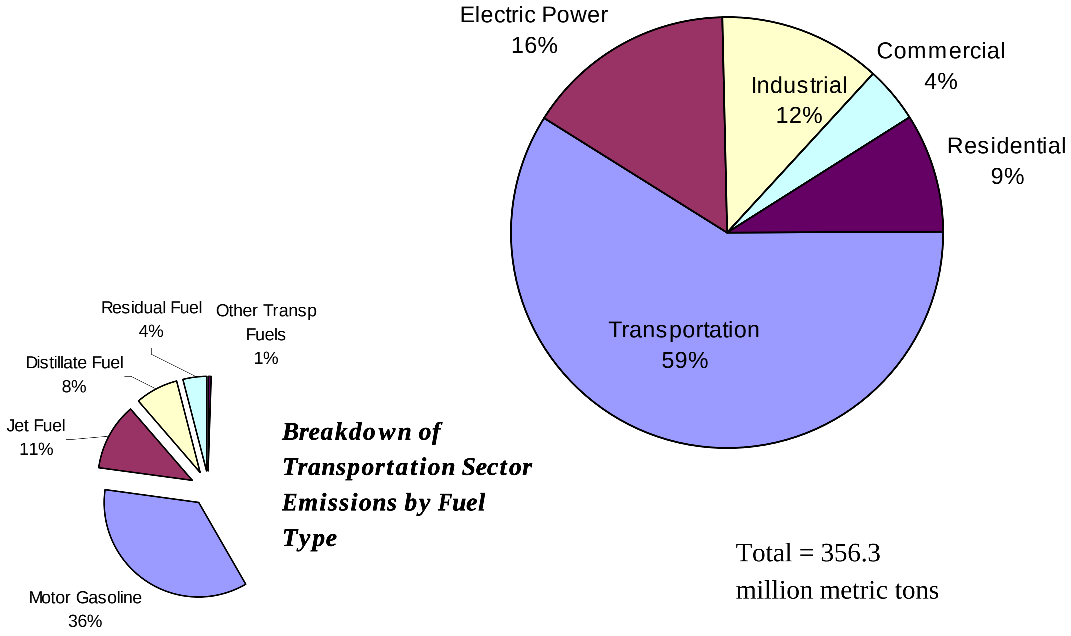


Figure 7: 1999 CO_2 Emissions from Fossil Fuel Combustion by Sector

Carbon dioxide emissions from the electric power sector reflect fossil fuel combusted to produce electricity for electricity end-use sectors (residential, commercial, industrial, and transportation). Figure 8 presents emissions by electricity end-use sector, with electric power sector emissions allocated to the various end-use sectors and included in sector emission totals. Electric power sector emissions were distributed using electricity consumption statistics. After redistributing electricity-related emissions, the contribution of the transportation sector remained unchanged. However, emissions from the industrial, residential, and commercial sectors increased significantly.

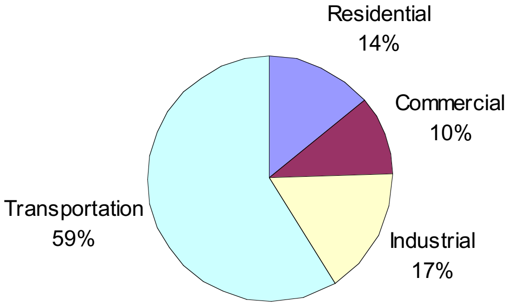


Figure 8: 1999 CO_2 Emissions from Fossil Fuel Combusion by End-Use Sectors

1.3.1.2 Industrial Processes

In addition to being emitted during the combustion of fossil fuels, carbon dioxide is emitted as a by-product of various industrial processes. For example, in the cement production process, carbon dioxide is released from limestone during its calcinations in the cement kiln. The carbon dioxide emissions associated with the combustion of fossil fuels in these kilns are reported in the energy sector.

Carbon dioxide emissions from industrial processes in 1999 were 6.2 MMTCO$_2$ Eq. The majority of these emissions, nearly 90 percent, were generated from the cement production sector (Figure 9). Other industrial sources of CO$_2$ emissions included lime production, limestone and dolomite consumption, soda ash consumption, and carbon dioxide manufacture.

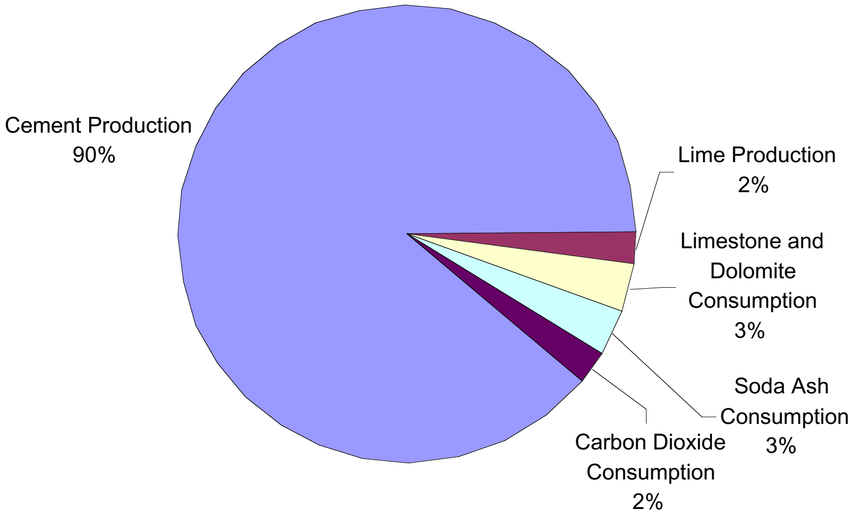


Figure 9: 1999 CO$_2$ Emissions from Industrial Processes by Source

1.3.1.3 Land-Use Change and Forestry

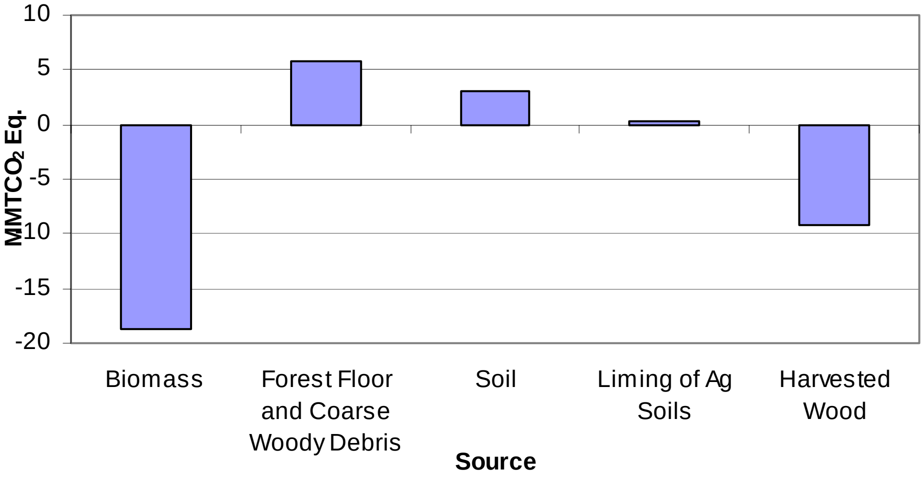
Estimates of emissions and sinks from land-use change and forestry include (1) changes in forest carbon stocks; (2) changes in agricultural soil carbon stocks; and (3) changes in yard trimming carbon stocks in landfills. Estimated total annual net CO_2 flux from land-use change and forestry in 1999 was 18.8 MMTCO$_2$ Eq. (Table 5). Sequestration offset 6 percent and 4 percent of gross state CO_2 emissions in 1990 and 1999, respectively. Over the ten-year period from 1990 to 1999, net sequestration decreased by 27 percent. This decline is primarily due to decreasing carbon flux from wood products, landfilled wood, and landfilled yard trimmings.

Table 5: Net Carbon Flux from Land-Use Change and Forestry (MMTCO$_2$ Eq.)

Description	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999
Forests and Soils	**-10.10**	**-10.07**	**-9.72**	**-9.75**	**-9.67**	**-9.55**	**-9.55**	**-9.47**	**-9.58**	**-9.50**
Biomass	-18.48	-18.48	-18.66	-18.66	-18.66	-18.66	-18.66	-18.66	-18.66	-18.66
Forest Floor and Coarse Woody Debris	5.21	5.21	5.79	5.79	5.79	5.79	5.79	5.79	5.79	5.79
Soil	3.12	3.12	3.04	3.04	3.04	3.04	3.04	3.04	3.04	3.04
Liming of Ag Soils	0.06	0.09	0.11	0.07	0.16	0.27	0.27	0.35	0.25	0.33
Harvested Wood	**-15.49**	**-15.14**	**-11.25**	**-10.93**	**-10.62**	**-10.33**	**-10.05**	**-9.78**	**-9.55**	**-9.30**
Wood Products and Landfilled Wood	-11.00	-11.00	-7.44	-7.44	-7.44	-7.44	-7.44	-7.44	-7.44	-7.44
Landfilled Yard Trimmings	-4.49	-4.14	-3.81	-3.49	-3.18	-2.89	-2.61	-2.34	-2.11	-1.85
Total Net Flux	**-25.58**	**-25.21**	**-20.97**	**-20.68**	**-20.29**	**-19.88**	**-19.61**	**-19.26**	**-19.13**	**-18.79**

Note: Negative value indicates net sequestration. Totals may not sum due to independent rounding.

As Figure 10 demonstrates, net negative fluxes—sequestration—in forests and soils were complemented by carbon storage in harvested wood products and landfills.



Note: Harvested wood includes wood products and landfilled wood and landfilled yard trimmings.

Figure 10: 1999 CO_2 Emissions and Sinks from Land-Use Change and Forestry by Source

1.3.1.4 Waste

During combustion of municipal solid waste (MSW), organic materials are converted to CO_2. Carbon dioxide emitted from combustion of organic wastes that are of biogenic origin (i.e., paper, food scraps, yard trimmings) is considered part of the natural carbon cycle. Therefore, these emissions are excluded from this report.

Carbon dioxide emissions from combustion of non-biogenic wastes were essentially constant, starting the decade at 0.30 $MMTCO_2$ Eq. in 1990 and ending at 0.31 $MMTCO_2$ Eq. in 1999. In 1999, these emissions accounted for approximately 0.08 percent of gross state CO_2 emissions.

1.3.2 Methane Emissions

Methane accounted for more than 7 percent of gross 1999 emissions in California, down from 8 percent of gross emissions in 1990. Table 6 shows emissions by sector and source category.

Table 6: CH_4 Emissions: 1990-1999 (MMTCO_2 Eq.)

Source	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999
Energy	**5.15**	**5.06**	**5.16**	**4.60**	**4.47**	**4.54**	**4.44**	**4.24**	**4.18**	**4.23**
Petroleum Systems	0.40	0.40	0.39	0.39	0.39	0.39	0.39	0.38	0.38	0.36
Natural Gas Systems	3.34	3.24	3.19	3.05	2.94	3.00	2.91	2.91	2.87	2.90
Coal Mining	0.18	0.19	0.34	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Mobile Source Combustion	0.54	0.52	0.51	0.49	0.48	0.46	0.44	0.43	0.42	0.41
Stationary Source Combustion	0.69	0.71	0.73	0.67	0.67	0.69	0.69	0.52	0.52	0.56
Agriculture	**11.26**	**11.51**	**11.74**	**11.11**	**11.98**	**12.33**	**11.87**	**12.34**	**12.17**	**12.85**
Enteric Fermentation	7.53	7.25	7.37	6.59	7.14	7.25	6.77	6.88	6.84	7.08
Manure Management	3.29	3.87	3.93	4.03	4.30	4.55	4.55	4.88	4.80	5.21
Flooded Rice Fields	0.41	0.36	0.41	0.45	0.50	0.48	0.52	0.54	0.50	0.52
Burning Agricultural Residues	0.03	0.03	0.03	0.04	0.04	0.04	0.04	0.04	0.04	0.04
Waste	**18.21**	**18.30**	**18.57**	**18.64**	**18.39**	**17.92**	**16.43**	**15.60**	**13.64**	**14.56**
Landfills	16.95	17.02	17.26	17.32	17.06	16.58	15.09	14.24	12.27	13.17
Wastewater Treatment	1.27	1.28	1.30	1.32	1.33	1.33	1.34	1.36	1.37	1.39
Total	**34.63**	**34.87**	**35.47**	**34.35**	**34.84**	**34.79**	**32.75**	**32.17**	**29.99**	**31.65**

Note: Totals may not sum due to independent rounding.

Methane is produced during anaerobic decomposition of organic matter in biological systems. Decomposition occurring in landfills accounts for the majority of anthropogenic methane emissions in California and in the United States as a whole. The decline in landfill methane emissions between 1990 and 1999 is primarily due to an increase in the prevalence of landfill gas controls. Agricultural processes such as enteric fermentation, manure management, and rice cultivation are also significant sources of methane in California.

Smaller quantities of methane are emitted during the production and distribution of natural gas and petroleum and as a by-product of coal mining and incomplete fossil fuel combustion (Figure 11).

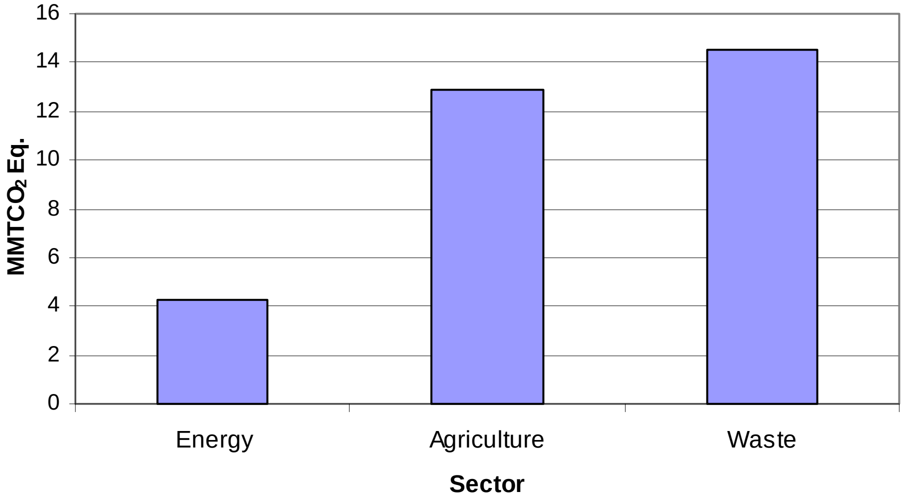


Figure 11: 1999 CH_4 Emissions in California by Sector

1.3.2.1 Energy

Energy-related methane emissions in California accounted for 4.2 MMTCO$_2$ Eq. in 1999, nearly 69 percent of which were attributable to natural gas systems in the state (Figure 12). Emissions from coal mining, responsible for nearly 10 percent of U.S. CH$_4$ emissions in 1999, were zero in 1999 and negligible for the entire ten-year period. Methane emissions from petroleum systems, stationary source combustion, and mobile source combustion decreased slightly between 1990 and 1999, in line with national trends.

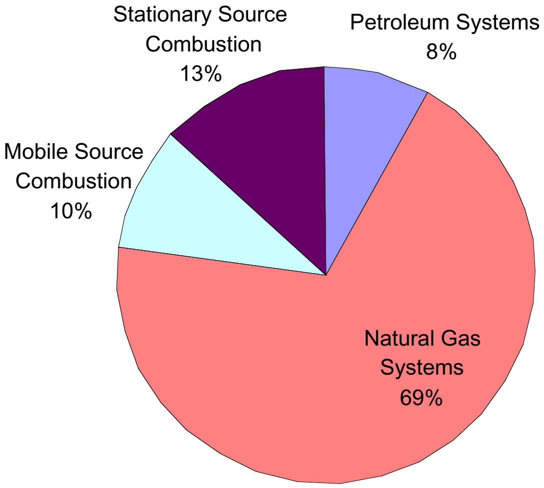


Figure 12: 1999 CH$_4$ Emissions from Energy by Source

1.3.2.2 Agriculture

Methane emissions from agriculture were driven by enteric fermentation and manure management, which represented 55 and 41 percent of 1999 agricultural CH_4 emissions, respectively (Figure 13).

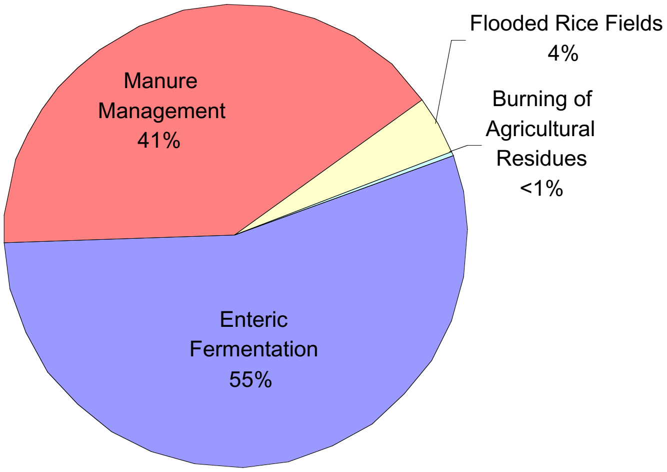


Figure 13: 1999 CH_4 Emissions from Agriculture by Source

Methane produced through the process of enteric fermentation accounted for emissions of 7.5 $MMTCO_2$ Eq. in 1990 and 7.1 $MMTCO_2$ Eq. in 1999. Overall, emissions from this source decreased by 6 percent between 1990 and 1999. The main driver for this decrease was the declining beef cattle population in California.

Methane emissions from manure management in 1999 were 5.2 $MMTCO_2$ Eq. Dairy cattle accounted for the majority of CH_4 emissions from manure management, followed by poultry, beef cattle, swine, horses, sheep, and goats.

Rice cultivation and agricultural residue burning were smaller sources of CH_4 emissions in California. In 1999, CH_4 emissions from these sources totaled approximately 0.56 $MMTCO_2$ Eq., roughly 4 percent of agricultural CH_4 emissions.

1.3.2.3 Waste

The waste sector was responsible for the majority of CH_4 emissions in California, with landfills accounting for 42 percent and wastewater accounting for roughly 4 percent of 1999 CH_4 emissions. As mentioned above, anaerobic decomposition in landfills is also the greatest source of anthropogenic CH_4 emissions in the United States, accounting for 35 percent of national CH_4 emissions.

Landfills dominated waste sector CH_4 emissions, representing more than 90 percent of sectoral emissions. Two key factors influencing landfill CH_4 emissions include the quantity of solid waste in landfills (waste-in-place) that is less than thirty years old and the quantity of CH_4 recovered for energy projects or flared. The total amount of waste-in-place in California landfills increased from 760 million tons in 1990 to 932 million tons in 1999, a gain of 23 percent. This increase resulted in an increase in CH_4 generation from 27.1 $MMTCO_2$ Eq. in 1990 to 31.8 $MMTCO_2$ Eq. in 1999. The amount of CH_4 recovered, meanwhile, increased from 7.6 $MMTCO_2$ Eq. to 15.7 $MMTCO_2$ Eq. during this period.

The net effect of these two trends--the relatively modest increase in CH_4 generation coupled with the large increase in recovery--was a 22 percent decrease in net landfill emissions over the ten-year period.

1.3.3 Nitrous Oxide Emissions

Nitrous oxide emissions accounted for nearly six percent of gross 1999 emissions in California. The primary sources of anthropogenic nitrous oxide emissions in California are agricultural soil management and fossil fuel combustion in mobile sources (Figure 14 and Table 7). Other, smaller sources include stationary source combustion, nitric acid production, manure management, agricultural residue burning, waste combustion, and human sewage.

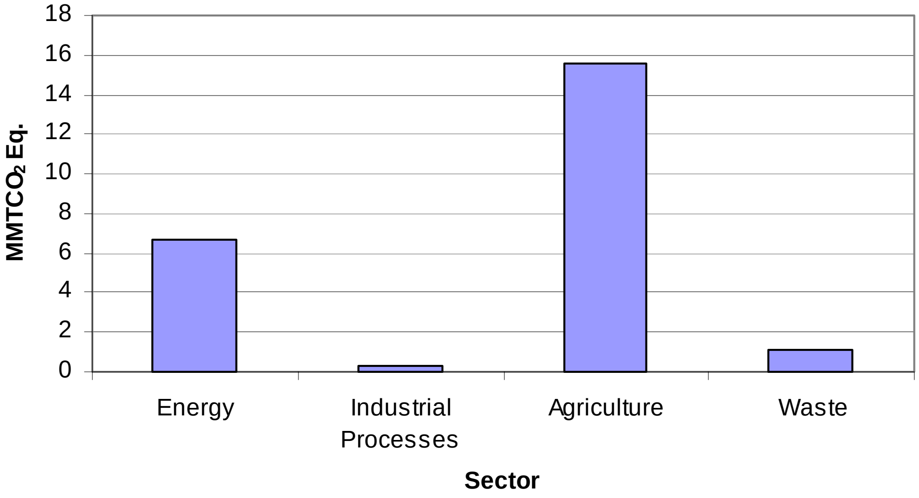


Figure 14: 1999 N_2O Emissions in California by Sector

Table 7: N_2O Emissions by Sector: 1990-1999 ($MMTCO_2$ Eq.)

	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999
Energy	**7.28**	**7.49**	**7.59**	**7.55**	**7.44**	**7.20**	**7.02**	**6.75**	**6.67**	**6.63**
Mobile Source Combustion	6.82	7.06	7.15	7.14	7.02	6.81	6.63	6.39	6.32	6.24
Stationary Source Combustion	0.46	0.43	0.44	0.41	0.42	0.40	0.39	0.36	0.35	0.39
Industrial Processes	**0.53**	**0.52**	**0.56**	**0.38**	**0.38**	**0.49**	**0.30**	**0.30**	**0.28**	**0.28**
Nitric Acid Production	0.53	0.52	0.56	0.38	0.38	0.49	0.30	0.30	0.28	0.28
Agriculture	**15.82**	**14.19**	**14.50**	**15.51**	**14.86**	**16.76**	**16.32**	**14.92**	**15.26**	**15.57**
Agricultural Soils	14.93	13.35	13.68	14.69	14.04	15.93	15.51	14.10	14.45	14.74
Manure Management	0.81	0.76	0.74	0.72	0.70	0.72	0.70	0.70	0.70	0.71
Burning Agricultural Residues	0.09	0.08	0.09	0.10	0.11	0.11	0.11	0.11	0.11	0.12
Waste	**0.96**	**0.89**	**0.88**	**0.96**	**0.89**	**0.96**	**0.93**	**1.03**	**1.06**	**1.08**
Waste Combustion	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02
Human Sewage	0.93	0.87	0.85	0.94	0.86	0.93	0.91	1.00	1.04	1.05
Total	**24.60**	**23.09**	**23.52**	**24.41**	**23.56**	**25.40**	**24.57**	**23.00**	**23.28**	**23.55**

Note: Totals may not sum due to independent rounding.

1.3.3.1 Energy

Nitrous oxide emissions from mobile source combustion were responsible for the majority (94 percent) of energy sector N_2O emissions, with emissions from stationary source combustion representing the remainder.

In 1999, N_2O emissions from mobile source combustion were 6.2 $MMTCO_2$ Eq., representing more than 26 percent of state N_2O emissions. From 1990 to 1999, emissions of N_2O from mobile sources decreased by 9 percent. Decreased emissions were attributable to reductions in emissions from gasoline passenger cars and gasoline light-duty trucks, which constitute the majority of emissions in California.

1.3.3.2 Industrial Processes

Nitric acid production was the only industrial source of N_2O emissions in California, accounting for roughly 1 percent of state N_2O emissions.

1.3.3.3 Agriculture

Agriculture soil management dominated agricultural emissions of N_2O, representing 95 percent of emissions from this sector. Emissions from agricultural soils accounted for 14.7 $MMTCO_2$ Eq. in 1999, representing roughly 63 percent of state N_2O emissions. Direct emissions from agricultural soils decreased by 3.5 percent, while indirect emissions remained relatively constant throughout the ten-year period. Nitrous oxide emissions from the sector as a whole decreased by just over 1 percent from 1990 through 1999, mainly as a result of a slight decline in fertilizer consumption.

Smaller sources of N_2O emissions from agriculture included manure management and agricultural residue burning, which accounted for 3 percent and 0.5 percent of state N_2O emissions in 1999, respectively.

1.3.3.4 Waste

Sources of N_2O emissions from the waste sector included human sewage and waste combustion. Human sewage was the third largest source of N_2O emissions in the state, accounting for more than 1 $MMTCO_2$ Eq. in 1999. Emissions from waste combustion were relatively minor, accounting for 0.02 $MMTCO_2$ Eq. in 1999.

1.3.4 Hydrofluorocarbon, Perfluorocarbon, and Sulfur Hexafluoride Emissions

Hydrofluorocarbons (HFCs), perfluorocarbons (PFCs), and sulfur hexafluoride (SF_6) are powerful greenhouse gases. HFCs are primarily used as substitutes for ozone-depleting substances (ODS) regulated under the Montreal Protocol. PFCs and SF_6 are generally emitted from various industrial processes including aluminum smelting, semiconductor manufacturing, electric power transmission and distribution, and magnesium casting. There is no aluminum production or magnesium production in California; therefore these sources of high GWP gases are excluded from this report.

All high GWP gas emissions are estimated in the Industrial Process chapter of the inventory (Table 8).

Table 8: High GWP Gas Emissions by Sector: 1990-1999 ($MMTCO_2$ Eq.)

	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999
Industrial Processes	**2.07**	**2.09**	**2.29**	**2.84**	**3.54**	**5.43**	**6.81**	**7.87**	**8.73**	**9.70**
Substitution of Ozone Depleting Substances	0.12	0.10	0.19	0.65	1.23	2.94	4.15	5.15	6.10	7.00
Semiconductor Manufacture	0.36	0.36	0.36	0.46	0.52	0.67	0.86	0.86	0.84	0.84
Electric Utilities	1.60	1.63	1.74	1.74	1.80	1.81	1.81	1.87	1.80	1.87
Total	**2.07**	**2.09**	**2.29**	**2.84**	**3.54**	**5.43**	**6.81**	**7.87**	**8.73**	**9.70**

Note: Totals may not add due to rounding.

1.3.4.1 Industrial Processes

Emissions from ODS substitutes were responsible for 72 percent of emissions of HFCs, PFCs, and SF_6 in 1999 (Figure 15).

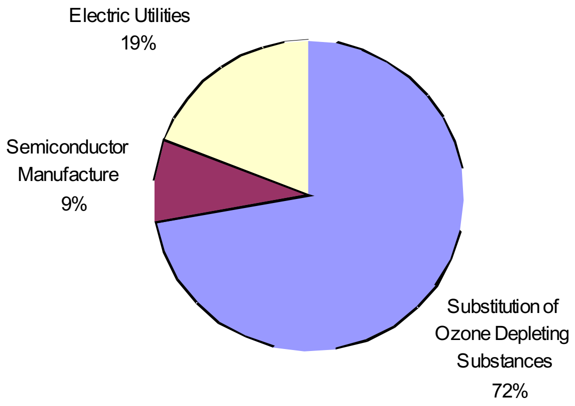


Figure 15: 1999 High GWP Gas Emissions by Industrial Processes Sub-Sector

The use and subsequent emissions of HFCs and PFCs as ODS substitutes has been increasing from small amounts in 1990 to 7.0 $MMTCO_2$ Eq. in 1999. Although the absolute magnitude of emissions from ODS substitutes is relatively small (2 percent of gross California emissions in 1999), its growth has been faster than any other sector. The increase has been driven by efforts to phase out ODS in the United States and the trends of ODS substitute emissions in California echo the trends that have been seen on a national level. In the early 1990s, ODS substitute emissions primarily consisted of HFC-134a from refrigeration and motor vehicle air conditioning end-uses. By the mid-1990s, other end-uses, such as foam blowing, aerosol propellants, solvents and sterilization, began using a larger variety of high-GWP substitutes. By 1995, ODS substitutes for halons entered widespread use in the United States as halon production was phased-out.

Semiconductor manufacture and electric utilities were responsible for 28 percent of high GWP gas emissions in 1999. Emissions from semiconductor manufacturing grew from 0.4 $MMTCO_2$ Eq. in 1990 to 0.8 $MMTCO_2$ Eq. in 1999, representing an increase of over 130 percent. This rapid growth is the result of not only the rapid growth in the semiconductor industry, but also the increasing complexity of semiconductor products, which leads to greater use of PFCs per semiconductor chip. Emissions from electric utilities increased more modestly (by approximately 17 percent), reflecting an increase in electricity consumption in the state.

1.4 Report Organization

The remainder of the report is organized as follows:

Chapter 2: Energy
Chapter 3: Industrial Processes
Chapter 4: Agriculture
Chapter 5: Land-Use Change and Forestry
Chapter 6: Waste
Chapter 7: California Emissions in Context
Chapter 8: Glossary, Abbreviations, and Chemical Names
Chapter 9: References

CHAPTER 2 – ENERGY

2.0 Energy

The majority of California's anthropogenic greenhouse gas emissions come from energy-related activities. This chapter addresses carbon dioxide (CO_2) emissions from fossil fuel combustion; methane (CH_4) and nitrous oxide (N_2O) emissions from stationary source combustion and mobile source combustion; CH_4 emissions from coal mining, natural gas systems, and petroleum systems; and discusses emissions from international bunker fuels.

Table 9 presents a summary of energy-related emissions in California. Fossil fuel combustion is the largest source of greenhouse gas emissions in the state, comprising 99 percent of California's energy-related emissions and 83 percent of gross emissions in 1999. Overall, energy emissions in California totaled 367 million metric tons of carbon dioxide equivalent ($MMTCO_2$ Eq.) in 1999. These emissions account for approximately 6 percent of total U.S. energy emissions. It is important to indicate that all the reported emissions in Table 9 and in sections 2.1 through 2.7 include the emissions associated with international transport (i.e., bunker fuels), which, as indicated below, should not be included in state and national inventories to the extent feasible.

Due to the importance of bunker fuels in California, this chapter provides a discussion of energy sector emissions excluding bunker fuel emissions. Although the bunker emission estimates are preliminary, they provide some insight into how trends in consumption of bunker fuels may have affected state emissions.

Table 9: Emissions from Energy ($MMTCO_2$ Eq.)

Gas/Source	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999
CO_2	**358.16**	**345.27**	**337.80**	**333.51**	**350.00**	**340.39**	**340.87**	**342.09**	**349.33**	**356.28**
Fossil Fuel Combustion	358.16	345.27	337.80	333.51	350.00	340.39	340.87	342.09	349.33	356.28
Int. Bunker Fuels	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
CH_4	**5.15**	**5.06**	**5.16**	**4.60**	**4.47**	**4.54**	**4.44**	**4.24**	**4.18**	**4.23**
Natural Gas Systems	3.34	3.24	3.19	3.05	2.94	3.00	2.91	2.91	2.87	2.90
Coal Mining	0.18	0.19	0.34	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Petroleum Systems	0.40	0.40	0.39	0.39	0.39	0.39	0.39	0.38	0.38	0.36
Stationary Sources	0.69	0.71	0.73	0.67	0.67	0.69	0.69	0.52	0.52	0.56
Mobile Sources	0.54	0.52	0.51	0.49	0.48	0.46	0.44	0.43	0.42	0.41
Int. Bunker Fuels	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
N_2O	**7.28**	**7.49**	**7.59**	**7.55**	**7.44**	**7.20**	**7.02**	**6.75**	**6.67**	**6.63**
Stationary Sources	0.46	0.43	0.44	0.41	0.42	0.40	0.39	0.36	0.35	0.39
Mobile Sources	6.82	7.06	7.15	7.14	7.02	6.81	6.63	6.39	6.32	6.24
Int. Bunker Fuels	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Total	**370.60**	**357.83**	**350.55**	**345.67**	**361.91**	**352.14**	**352.32**	**353.08**	**360.18**	**367.14**

Note: Totals may not sum due to independent rounding.

2.1. Energy-Related Emissions from California Excluding Bunker Fuels

According to the guidance for national- and state-level inventories provided by the United Nations Framework Convention on Climate Change and U.S. Environmental Protection Agency, emissions from bunker fuels (i.e. fuels used in international transportation activities, primarily in aviation and shipping), are to be estimated but not attributed to the national- or state-level totals. However, as described in Chapter 2, Section 2.7 (International Bunker Fuels), bunker fuel data for the aviation sector were not available, and bunker fuel data obtained for marine vessels appeared to be inconsistent with state-wide fuel consumption data. Thus, it was difficult to reliably estimate the effect of bunker fuels, and CEC chose to report state-wide levels throughout this inventory both with and without emissions from bunker fuels.

The inclusion of bunker fuels emissions in state totals has a significant and possibly misleading effect on overall trends, however. To explain the nature and likely magnitude of this effect, this section presents California greenhouse gas emissions from 1990 through 1999, *excluding* emissions from marine bunker fuels. The effect of aviation bunkers is unknown, and is not addressed in this section.

Greenhouse gas emissions from international bunker fuels attributed to California totaled 10.7 MMTCO_2 Eq. in 1999. These emissions consisted primarily of CO_2 (10.6 MMTCO_2 Eq.), but also included emissions of CH_4 (0.02 MMTCO_2 Eq.) and N_2O (0.08 MMTCO_2 Eq.). Emissions from marine bunker fuels in California in 1999 represented about 17.1 percent of national emissions from this source.

Table 10 provides an approximation of the impact that bunker fuels could have on emissions from the energy sector. Bunker fuel emissions are excluded by subtracting CO_2 emissions from bunker fuels from the row labeled "Fossil Fuel Combustion" and subtracting CH_4 and N_2O emissions from bunker fuels from the rows labeled "Mobile Sources." Exclusion of these emissions would result in a 5.9 percent decrease in gross 1990 emissions from the energy sector, and a 2.9 percent decrease in gross 1999 emissions from the energy sector. When bunkers are excluded, 1999 emissions from the energy sector would be 2.2 percent higher than 1990 emissions (as compared to a 0.9 percent decrease over the period when bunkers are not excluded).

Table 10: Trend in Greenhouse Gas Emissions and Sinks from the Energy Sector, Including and Excluding Marine Bunker Fuels (MMTCO$_2$ Eq.)

	1990	1999	% change
CO$_2$	**358.2**	**356.3**	
Fossil Fuel Combustion	358.2	356.3	
CH$_4$	**5.2**	**4.2**	
Natural Gas Systems	3.3	2.9	
Coal Mining	0.2	0.0	
Petroleum Systems	0.4	0.4	
Stationary Sources	0.7	0.6	
Mobile Sources	0.5	0.4	
N$_2$O	**7.3**	**6.6**	
Stationary Sources	0.5	0.4	
Mobile Sources	6.8	6.2	
Gross Emissions	**370.6**	**367.1**	**-0.9%**
CO$_2$ from Marine Bunker Fuels	21.8	10.6	
CH$_4$ from Marine Bunker Fuels	0.0	0.0	
N$_2$O from Marine Bunker Fuels	0.2	0.1	
Gross Emissions Excluding Marine Bunkers	**348.6**	**356.5**	**2.2%**

Excluding bunker fuels has a slight impact on the relative distribution of emissions by fuel type. Motor gasoline, natural gas, and jet fuel--which account for the majority of emissions from fossil fuel combustion--comprise 36.9, 32.7, and 11.6 percent of CO$_2$ emissions when bunker fuels are excluded, respectively (Figure 16). When included, these fuels comprise 35.8, 31.8, and 11.2 percent of emissions from fuel combustion, respectively. Unless otherwise specified, all figures in this section exclude bunker fuels.

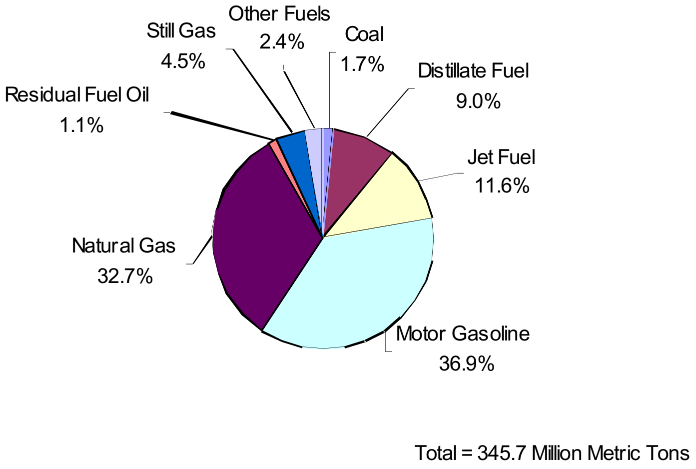


Figure 16: 1999 CO$_2$ Emissions from Fossil Fuel Combustion by Fuel (excluding marine bunker fuels) (MMTCO$_2$)

When preliminary estimates of marine bunker fuel emissions are subtracted from estimates of total CO_2 emissions from fossil fuel combustion, the transportation sector comprises 57.6 percent of emissions from this source (as opposed to 58.9 percent when bunker fuels are included). Emissions from this sector are due to the combustion of motor gasoline (36.7 percent), jet fuel (11.6 percent), distillate fuel oil (7.7 percent), residual fuel oil (1.0 percent), and other fuels (0.7 percent) (Figure 17). When bunker fuels are not subtracted from total emissions from this source, residual fuel oil accounts for 3.8 percent of transportation-related emissions and motor gasoline, jet fuel, distillate, and other fuels account for 35.6, 11.2, 7.6, and 0.6 percent, respectively.

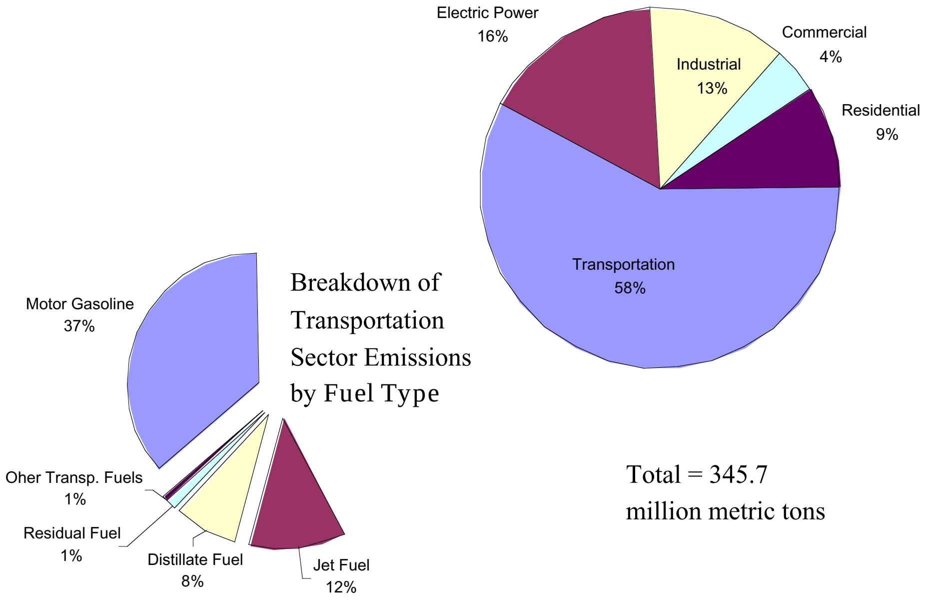


Figure 17: 1999 CO_2 Emissions from the Combustion of Fossil Fuels by Sector (excluding marine bunker fuels)

As demand for transportation has increased since 1990, emissions from distillate, jet fuel, and motor gasoline in the transportation sector have increased by 3, 2, and 11 MMTCO$_2$ Eq., respectively (Figure 18).

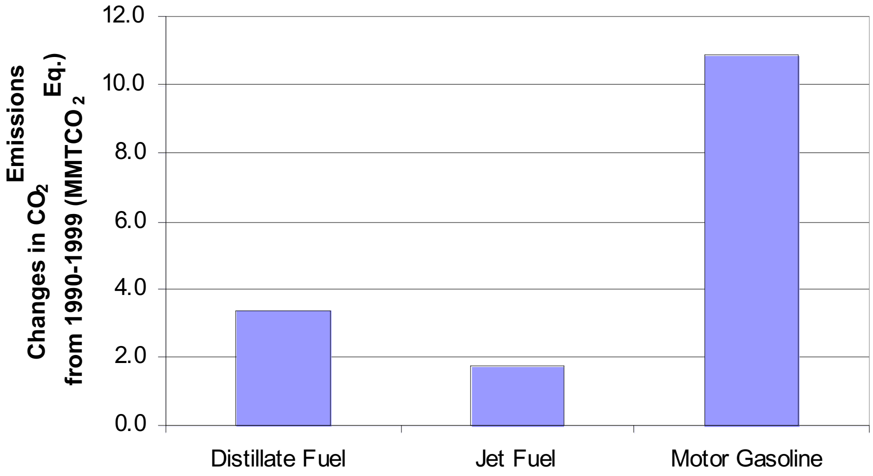


Figure 18: Changes in CO$_2$ Emissions from Distillate, Jet Fuel, and Motor Gasoline Consumption in the Transportation Sector, 1990-1999 (excluding marine bunker fuels)

Increasing emissions from transportation fuels have been partially offset by emission reductions from stationary sources. Air quality regulations in the mid 1990s required a more stringent level of control of nitrogen oxides from existing boilers, resulting in a shift from fuel oils to natural gas in commercial and industrial boilers. These regulations were the primary reason for decreased consumption of distillate and residual fuel oils, accounting for a 6 MMTCO$_2$ Eq. and a 5 MMTCO$_2$ Eq. decrease in emissions from these fuels, respectively. These shifts are illustrated in Figure 19, where changes in CO$_2$ emissions from increased natural gas consumption are presented next to changes in emissions from consumption of residual fuel oil and distillate fuel oil. Note that distillate emissions do not include transportation-related uses, which are included in Figure 18.

Decreased consumption of distillate and residual fuel oil led to increases in the consumption of natural gas and associated CO_2 emissions (Figure 1). Although increases in natural gas consumption exceeded decreases in distillate and residual fuel oil consumption, emissions were lower because natural gas is a lower-emitting fuel. In addition, consumption of still gas, petroleum coke, and other fuels lessened the overall extent of increase in emissions between 1990 and 1999.

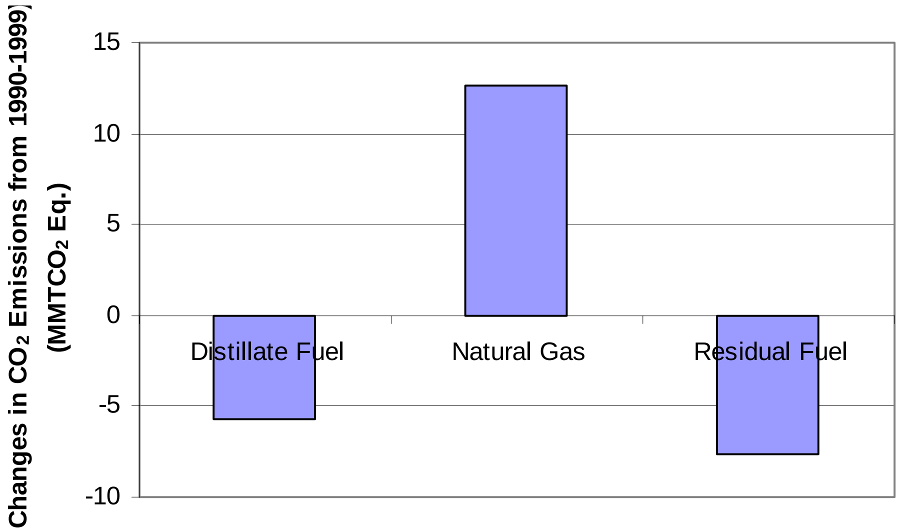


Figure 1: Changes in CO_2 Emissions from Distillate and Residual Fuel Oils, and Natural Gas: 1990-1999 (excluding marine bunker fuels)

2.2. Carbon Dioxide from Fossil Fuel Combustion

Emissions from the combustion of fossil fuels account for the majority of greenhouse gases emitted in California, as in the United States as a whole. When these fuels are burned to produce energy, the majority of the carbon they contain is released to the atmosphere as CO_2. This section quantifies CO_2 emissions from fossil fuel combustion for California. Smaller quantities of CH_4 and N_2O are also released during combustion; emissions of these gases are estimated later in this chapter under Stationary Source Combustion and Mobile Source Combustion.

Fossil fuels combusted for energy include coal, petroleum, and natural gas. In order to analyze patterns of energy use and related CO_2 emissions, the discussion of fossil fuel combustion is divided into five sectors: residential, commercial, industrial, transportation, and electric utilities. Note that for this emissions analysis, total energy consumption was adjusted to remove consumption of fuels for non-energy purposes. Non-energy uses primarily consist of the manufacturing of certain fossil fuels into consumer products, which allows for storage of carbon for long periods of time. As mentioned above, emissions attributable to bunker fuels were not excluded from the reported totals for this inventory. The estimates that include contributions from bunker fuels are CO_2 from fossil fuel combustion and CH_4 and N_2O from mobile sources.

Total CO_2 emissions from fossil fuel combustion in California in 1999 were 356.3 MMTCO$_2$ Eq., which accounts for approximately six percent of the U.S. emissions from this source. As seen in Table 11, total emissions from fossil fuel combustion were at their highest in 1990, underwent a rise and fall in 1994 and 1995, respectively, and then rose again from 1996 through 1999. Carbon dioxide emissions from petroleum accounted for the majority (about 67 percent) of total CO_2 emissions from fossil fuel combustion in California (Figure 20). Consumption of petroleum occurred mostly in the industrial and transportation sectors, while over half of the natural gas consumed was in the industrial sector. Note in Table 11 that natural gas consumption in the industrial sector increased approximately 97 percent from 1990. Emissions from coal from electric utilities and other sectors were minor, especially compared to the rest of the U.S. Chapter 7 presents a discussion of the factors affecting the trend in CO_2 emissions from fossil fuel combustion (e.g., fuel switching, electricity imports) that are not captured in greenhouse gas accounting methods.

The transportation sector accounted for the largest portion of emissions, averaging 59 percent of the total CO_2 emissions from fossil fuel combustion in California between 1990 and 1999. Transportation fossil fuel combustion was relatively steady during the 1990s, remaining around 200 $MMTCO_2$ Eq. Petroleum products accounted for nearly all of the consumption in this sector. The decrease in emissions from 1990 to 1993 (Table 11) can be attributed to the downturn in the economy, evidenced by the decline in gross state product (GSP) over the same period. This trend is described in further detail in Chapter 7.

Given the importance of the transportation sector on overall emissions from fossil fuel combustion, the portion of state carbon dioxide emissions from the various transportation fuels is significant (Figure 20) Motor gasoline accounted for 36 percent of CO_2 emissions from fossil fuel combustion in 1990. Jet fuel, distillate fuel oil, and residual fuel oil are responsible are responsible for 11 percent, 8 percent, and 4 percent of emissions from this source category. Box 1 includes a discussion of emissions from the consumption of gasoline and diesel in the transportation sector.

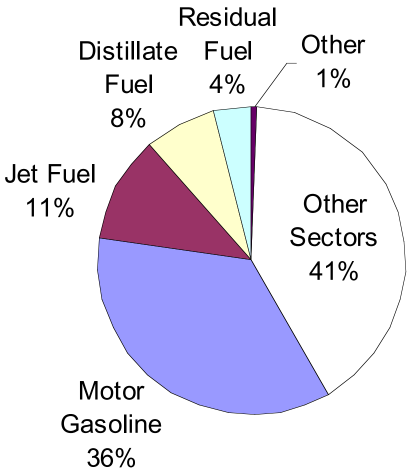


Figure 20: 1999 CO_2 Emissions from Transportation Fuels as a Percent of Total Fuel Combustion

Box 1: Greenhouse Gas Emissions from the Combustion of Gasoline and Diesel in the Transportation Sector

Emissions from motor vehicles account for the majority of emissions from transportation, primarily through the consumption of motor gasoline and diesel fuel. In 1999, CO_2 emissions from these fuels comprised 73 percent of total CO_2 emissions from transportation, and 43 percent of total CO_2 emissions from fossil fuel combustion. While emissions of CO_2 from motor gasoline increase nine percent from 1990 to 1999 due to increased fuel consumption, emissions of both CH_4 and N_2O decreased over the period (see table below) due to the implementation of stricter regulations that require the use of more advanced pollution control technologies (emissions of CH_4 and N_2O are discussed in more detail in Section 2.3, CH_4 and N_2O from Mobile Source Combustion). Vehicles that comply with Tier 1 and low emission vehicle (LEV) standards have been phased in more quickly in California than in any other U.S. State.[a]

The increased CO_2 emissions from diesel consumption (10 percent) is due to an increase in diesel consumed not only by trucks and other highway vehicles, but also by ships, trains, and other non-highway vehicles (all of which are included in CO_2 emission estimates).[b]

Greenhouse Gas Emissions from Gasoline and Diesel Consumption
in the Transportation Sector

	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999
Gasoline										
CO_2 (MMTCO$_2$ Eq.)	116.0	114.1	113.4	115.3	115.8	116.7	119.1	121.6	122.6	126.8
CH_4 (MMTCO$_2$ Eq.)	0.5	0.5	0.5	0.4	0.4	0.4	0.4	0.4	0.4	0.4
N_2O (MMTCO$_2$ Eq.)	6.2	6.5	6.6	6.6	6.4	6.2	6.0	5.8	5.7	5.6
Diesel										
CO_2 (MMTCO$_2$ Eq.)	24.7	23.8	22.7	20.4	22.8	24.3	24.2	26.3	27.1	27.0
CH_4 (MMTCO$_2$ Eq.)	+	+	+	+	+	+	+	+	+	+
N_2O (MMTCO$_2$ Eq.)	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
Total Emissions (MMTCO$_2$ Eq.)	**147.6**	**145.1**	**143.4**	**143.0**	**145.7**	**147.9**	**149.9**	**154.4**	**156.0**	**160.1**

+ Does not exceed 0.05

Note: CO_2 emissions include emissions from non-highway vehicles (which are a small proportion of total emissions). CH_4 and N_2O emissions are only from highway vehicles.

[a] The Tier 1 emission standard requires the use of more advanced catalysts, and applies to both light- and heavy-duty gasoline vehicles. It includes electronically controlled fuel injections and ignition timing, exhaust gas recirculation (EGR), and air injection. LEV standards require "the development and use of advanced emission control technology, coupled with fuels that burn "cleaner" than conventional gasoline. A low emission vehicle is defined as a vehicle that has been certified by ARB to meet one of four sets of exhaust emission standards. In order of increasing stringency, the emission standards pertain to transitional low emission vehicles (TLEVs), low emission vehicles (LEVs), ultra low emission vehicles (ULEVs), and zero emission vehicles (ZEVs)," (ARB 1997).

[b] Nationally, non-highway vehicles represent 24% of diesel fuel consumption but only 3% of motor gasoline consumption (DOE 2001).

Carbon dioxide emissions from fossil fuel combustion in the industrial sector (manufacturing, construction, mining, agriculture, and non-utility electricity generation) ranked second to emissions in the transportation sector in 1999. Industrial sector CO_2 emissions remained relatively constant from 1990 to 1995, then increased sharply through 1999. Overall CO_2 emissions from this sector have increased 28 percent since 1990. Decreases in petroleum consumption were overshadowed by steep growth in natural gas consumption in the industrial sector. Currently, the industrial sector estimates include consumption from non-utility electricity generation, which represents a significant portion of emissions. The sharp increase in emissions in 1998 and 1999 are due mostly to the sale of power plants by utilities to non-utilities in these two years.

In 1999, the residential and commercial sectors accounted for 9 and 4 percent of total emissions from fossil fuel combustion in California, respectively. Energy use in the residential sector stayed relatively constant around 29 $MMTCO_2$ Eq. during the 1990s, while commercial energy use decreased 25 percent over the same period. This could be attributable mainly to the effect of California's Title 24 Building Energy Efficiency Standards for New Residential and Nonresidential Buildings and Title 20 Appliance and Equipment Standards, which have served to offset the increase of energy usage and energy demand growth due to new buildings constructed during that time. It is estimated that the Building and Appliance Standards have avoided, on a cumulative basis for the study period, 16,579 GWh of electric energy, 5,095 MW of electric demand, and 2,410 million therms of natural gas usage, for new residential and commercial buildings (CEC 2001).

However, in 1998 both sectors witnessed a noticeable rise in fuel consumption and consequent emissions (Table 11). Natural gas and petroleum were consumed in these sectors for heating and cooking; coal use was negligible.

Table 11: Emissions of CO$_2$ from Fossil Fuel Combustion (MMTCO$_2$ Eq.)

Sector/Fuel Type	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999
Residential	**29.5**	**29.3**	**27.2**	**28.8**	**29.4**	**26.8**	**27.0**	**26.8**	**32.1**	**32.0**
Coal	0.0	0.0	0.0	0.1	0.1	0.1	0.1	0.1	0.1	0.0
Petroleum	1.4	1.7	1.2	1.2	1.2	1.2	1.0	0.9	1.5	1.4
Natural Gas	28.0	27.6	26.0	27.5	28.1	25.5	25.8	25.7	30.5	30.6
Commercial	**18.9**	**18.8**	**17.1**	**14.9**	**15.3**	**16.4**	**14.1**	**14.9**	**17.3**	**14.2**
Coal	0.0	0.1	0.0	0.2	0.2	0.2	0.3	0.2	0.2	0.0
Petroleum	3.4	3.2	1.6	1.0	0.9	1.3	1.0	1.1	1.4	1.0
Natural Gas	15.5	15.6	15.5	13.7	14.1	14.9	12.8	13.6	15.7	13.2
Industrial	**72.5**	**74.8**	**73.1**	**72.7**	**71.3**	**71.2**	**74.7**	**76.7**	**81.7**	**92.5**
Coal	6.0	5.8	5.9	4.9	5.0	5.3	4.6	4.3	5.7	5.8
Petroleum	35.6	31.9	30.9	28.0	28.5	26.8	29.8	30.1	27.6	25.6
Natural Gas	31.0	37.1	36.3	39.8	37.8	39.1	40.3	42.2	48.4	61.1
Transportation	**208.8**	**197.5**	**189.4**	**190.2**	**199.9**	**204.2**	**207.4**	**203.4**	**203.6**	**209.9**
Coal	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Petroleum	207.7	196.5	188.6	189.5	199.2	203.2	206.3	202.0	203.0	209.2
Natural Gas	1.1	1.0	0.8	0.7	0.7	1.1	1.1	1.3	0.6	0.7
Electric Utilities	**28.5**	**24.9**	**31.1**	**27.0**	**34.1**	**21.8**	**17.8**	**20.5**	**14.7**	**7.7**
Coal	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Petroleum	3.6	0.5	0.3	1.6	1.4	0.4	0.5	0.1	0.1	0.1
Natural Gas	24.9	24.4	30.8	25.3	32.7	21.4	17.2	20.3	14.6	7.7
Total	**358.2**	**345.3**	**337.8**	**333.5**	**350.0**	**340.4**	**340.9**	**342.1**	**349.3**	**356.3**
Coal	6.0	5.9	5.9	5.2	5.3	5.6	4.9	4.5	5.9	5.9
Petroleum	251.7	233.8	222.5	221.3	231.3	232.8	238.7	234.3	233.6	237.3
Natural Gas	100.5	105.6	109.3	107.0	113.4	102.0	97.2	103.3	109.8	113.1

Note: Totals may not sum due to independent rounding.

On average, electric utility generation accounted for roughly 7 percent of total CO$_2$ emissions. Carbon dioxide emissions from the electric utilities dropped 73 percent from 28.5 MMTCO$_2$ Eq. in 1990 to 7.7 MMTCO$_2$ Eq. by 1999. This was due to the requirement for utilities to sell most of their fossil fuel based power plants to non-utilities in 1998 and 1999. As mentioned above, estimates of CO$_2$ emissions from fossil fuel combustion by non-utility generators are included in the industrial sector, as non-utility consumption data were not available for the entire time series. The Energy Information Administration (EIA) maintains a database of power plants with a capacity of at least 1 MW covering the entire nation. EIA has only released the databases for 1998 and 1999. EIA is following quality assurance and quality control procedures to ensure the quality of the data before 1997 prior to their release. Future updates of this inventory will contain information for non-utility power plants from 1990 to 1999. In this inventory, Box 2 presents a discussion of these emissions for 1998 and 1999.

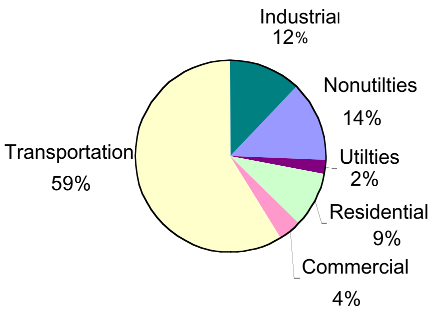
Box 2: Electricity Generation by Utilities and Non-Utilities

The electric utility sector includes only regulated utilities. Fuel use by non-utility generators of electricity (e.g., independent power producers, cogenerators, and other small power producers) is currently included in the industrial sector. These non-utility generators produce electricity for their own use, sell it to large consumers, or sell it in the open market. As California continues to deregulate utilities, and as ownership of electric generating stations is transferred to non-utilities, CO_2 emissions from utilities have decreased 73 percent since 1990. The sectoral definition obscures the actual trend in CO_2 emissions from electricity generation. However, some information is available to indicate the magnitude and trend in total electricity generation emissions.

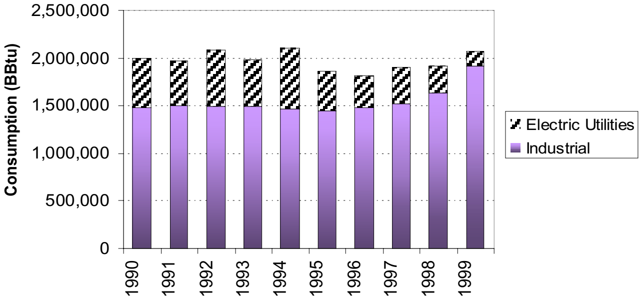
The Energy Information Administration (EIA) has released the data for non-utility generation for 1998 and 1999. EIA is reviewing the data for prior years to ensure the quality of the data before its released to the public and other state and federal agencies. For this reason, only non-utility data for 1998 and 1999 is presented in the below table. Electricity generation by non-utilities contributed about 14 percent of the CO_2 emissions from the combustion of fossil fuels in 1999, while the electricity generation sector (utility and non-utility generators) contributed about 16 percent.

Box Figure 2 presents total energy consumption from fossil fuels by electric utilities and the industrial sector. As seen below, the rapid increase in emissions in 1998 and 1999 was due to the reporting of fuel consumption data by power plants previously owned by electric utilities in the industrial sector. Even before 1998 the contribution by non-utilities to total generation in California has been substantial. In fact, most of the growth in generation capacity in California after 1986 occurred in the non-utility sector (Chapter 7).

Box Figure 1: 1999 Electricity Generation in the Context of Total Fossil Fuel Emissions



Box Figure 2: Fossil Fuel Energy Consumption in the Industrial and the Electric Utilities Sector



CO_2 Emissions from Electricity Generation at Utilities and Non-utilities, 1998 and 1999 ($MMTCO_2$ Eq.)

	1998	1999
Utilities	**14.7**	**7.7**
Coal	0.0	0.0
Petroleum	0.1	0.1
Natural Gas	14.6	7.7
Non-utilities (industry sector)	**38.4**	**49.0**
Coal	3.5	3.8
Petroleum	4.4	3.1
Natural Gas	30.5	42.1
Total Electricity Generation	**53.1**	**56.7**
Coal	3.5	3.8
Petroleum	4.5	3.1
Natural Gas	45.0	49.7

Electric power sector emissions comprise emissions at utilities and non-utilities associated with producing electricity for four end-use sectors: residential, commercial, industrial, and transportation. Emissions associated with electricity generation may be allocated to each of the end-use sectors based on electricity consumption statistics. Figure 21 presents total carbon dioxide emissions associated with fossil fuel combustion by electricity end-use sector. Reallocation of electricity-related emissions had no impact on the contribution of the transportation sector to overall emissions; however, relative emissions from the industrial, residential, and commercial sectors increased to 17 percent, 14 percent, and 10 percent, respectively.

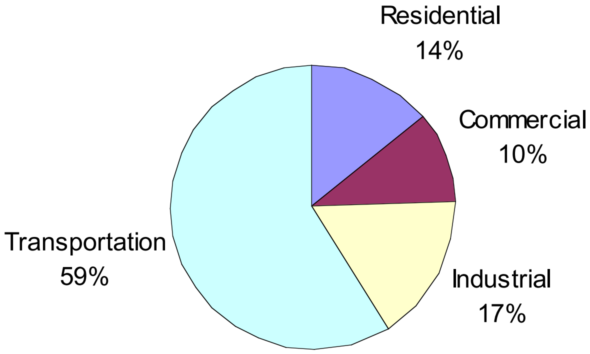


Figure 21: 1999 CO_2 Emissions from Fossil Fuel Combustion Allocated to Electricity End-Use Sectors

Figure 22 presents the contribution of fossil fuel types to total CO_2 emissions in California in 1999. As expected, petroleum based fuels are the main source of CO_2 emissions.

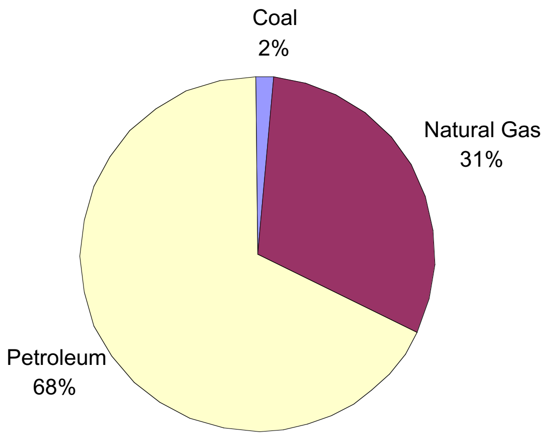


Figure 22: Fuel Type Contribution to CO_2 Emissions from Fossil Fuel Combustion

2.2.1. Methodology

The methodology for estimating CO_2 emissions from fossil fuel combustion is data-intensive, but produces emission estimates that are thought to be among the most accurate in the entire inventory. The methods used for this analysis are taken from the *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-1999* (EPA 2001) and the *Emission Inventory Improvement Program (EIIP)* guidance (EIIP 1999). These methods were developed to conform to internationally approved methods provided in the IPCC guidelines (IPCC / UNEP / OECD / IEA 1997).

The following steps characterize the methodology used to estimate CO_2 from fossil fuel combustion in California:

Step 1: Obtain Data on Fuel Consumption by Fuel Type and Sector.

California energy consumption data from each sector (i.e., residential, commercial, industrial, transportation, and electric utilities) were collected by primary fuel type (e.g., coal, petroleum, gas) and secondary fuel type (e.g., motor gasoline, distillate fuel oil). Table 12 shows all sectors and fuel types included, and Table 13 presents combustion by sector and fuel type.

Table 12: Fuel Types by Sector for Estimating CO_2 Emissions from Fossil Fuel Combustion

Residential	Commercial	Industrial	Transportation	Electric Utilities
Coal	Coal	Coking Coal Other Coal	Coal	Coal
Natural Gas	Natural Gas	Natural Gas	Natural Gas	Natural Gas
Petroleum: Distillate Fuel Kerosene LPG	Petroleum: Distillate Fuel Kerosene LPG Motor Gasoline Residual Fuel	Petroleum: Distillate Fuel Kerosene LPG Motor Gasoline Residual Fuel Lubricants Asphalt & Road Oil Crude Oil Feedstocks Misc. Petroleum Products Petroleum Coke Pentanes Plus Still Gas Special Naphthas Unfinished Oils Waxes Aviation Gasoline Blending Components Motor Gasoline Blending Components	Petroleum: Distillate Fuel LPG Motor Gasoline Residual Fuel Lubricants Aviation Gasoline Jet Fuel, Kerosene Jet Fuel, Naphtha	Petroleum: Distillate Fuel Residual Fuel Petroleum Coke

Source: EIA 1999, EPA 2001

Table 13: Energy Consumption for California (TBtu)

Sector/Fuel Type	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999
Residential	**554**	**549**	**511**	**541**	**552**	**504**	**506**	**503**	**603**	**601**
Coal	0	0	0	1	1	1	1	1	1	0
Natural Gas	531	522	493	520	532	484	489	487	578	579
Petroleum	23	27	19	19	19	19	16	15	24	22
Commercial	**341**	**340**	**316**	**276**	**283**	**303**	**260**	**275**	**319**	**264**
Coal	0	1	0	2	3	2	3	2	2	0
Natural Gas	294	295	293	260	267	282	243	258	297	249
Petroleum	47	44	23	14	13	18	14	15	20	15
Industrial	**1,284**	**1,330**	**1,305**	**1,318**	**1,295**	**1,286**	**1,331**	**1,366**	**1,480**	**1,740**
Coal	65	63	65	54	54	58	50	47	62	63
Natural Gas	607	726	706	775	741	764	787	826	947	1,196
Petroleum	677	604	599	543	553	522	544	540	534	544
Transportation	**2,896**	**2,747**	**2,638**	**2,648**	**2,780**	**2,839**	**2,887**	**2,841**	**2,843**	**2,926**
Coal	0	0	0	0	0	0	0	0	0	0
Natural Gas	21	19	15	13	13	20	20	25	12	13
Petroleum	2,875	2,728	2,623	2,636	2,767	2,819	2,867	2,816	2,831	2,913
Electric Utilities	**518**	**468**	**587**	**501**	**637**	**411**	**333**	**387**	**278**	**146**
Coal	0	0	0	0	0	0	0	0	0	0
Natural Gas	471	462	583	480	619	405	326	385	276	146
Petroleum	46	6	4	21	19	5	7	2	2	1
Total	**5,592**	**5,434**	**5,356**	**5,284**	**5,548**	**5,342**	**5,318**	**5,373**	**5,523**	**5,677**
Coal	65	64	65	57	58	61	54	49	64	64
Natural Gas	1,924	2,024	2,089	2,048	2,172	1,956	1,865	1,982	2,110	2,182
Petroleum	3,668	3,409	3,267	3,233	3,372	3,383	3,449	3,388	3,411	3,494

Source: EIA 1999, BOE 2001, PIIRA 2001
Note: Totals may not sum due to independent rounding.

Step 2: Determine the Total Carbon Content of Fuels Consumed.

Carbon content coefficients, which reflect the amount of carbon in each fuel type, were multiplied by energy consumption to yield potential carbon emissions. This estimate defines the maximum amount of carbon that could be released to the atmosphere if all of the carbon in each fuel were converted to CO_2.

Table 14 provides a list of carbon contents used in this analysis. The carbon content of some fuel types varies annually, due to fluctuations in fuel quality specific to California; Table 15 presents the carbon contents for these fuel types.

Step 3: Subtract the Total Carbon Stored in Products.

Some or all of the carbon from certain fuels can be stored for a long period of time through non-energy uses. These end-uses sequester varying amounts of carbon. For example, asphalt, an end product of petroleum, can sequester almost 100 percent of its carbon over a significant period of time, while lubricants lose or emit some carbon when they are used. To correct for this, a fuel-specific storage factor was multiplied by the amount consumed for non-energy purposes and the product (stored carbon) was subtracted from potential carbon emission estimates. Table 14 provides the fuel-specific storage factors.

Step 4: Subtract the Carbon Content of Bunker Fuels Consumed.

Emissions from international transportation activities, or bunker fuels, should be excluded from the total California emission estimates in accordance with the IPCC guidelines (IPCC / UNEP / OECD / IEA 1997). Although California has both aviation and marine fuels that fall under this category, only marine fuels were estimated due to data limitations. The total carbon in distillate and residual marine fuels consumed was subtracted from the total potential carbon emissions. To calculate carbon content of bunker fuels, a similar methodology was used, as described in the section entitled “International Bunker Fuels.”

The quality and availability of data on international bunker fuel consumption was not adequate to develop complete estimates of emissions from this source. Therefore, California’s emissions from fossil fuel combustion are not adjusted to reflect emissions from bunker fuels. For more information on bunker fuels, consult the section of this chapter on International Bunker Fuels.

Step 5: Adjust for Carbon that Does Not Oxidize During Combustion.

A small amount of the carbon in fuels is not emitted to the atmosphere because of inefficiencies in the combustion processes, remaining behind as soot. To account for this unoxidized carbon, the net carbon content for each fuel was multiplied by one percent for petroleum and coal and 0.5 percent for natural gas, which are assumed to represent the amount of unoxidized carbon during combustion (Table 14).

Table 14: Carbon Content Coefficients, Storage Factors, and Fraction Oxidized

Fuel Type	Carbon Content Coefficient (lbs C/MMBtu)[a]	Storage Factor (for Non-Energy Uses)	Fraction Oxidized
Coal			
Residential Coal	[b]		99.0%
Commercial Coal	[b]		99.0%
Industrial Coking Coal	[b]	75%	99.0%
Industrial Other Coal	[b]		99.0%
Utility Coal	[b]		99.0%
Natural Gas	31.9	91%	99.5%
Petroleum			99.0%
Asphalt and Road Oil	45.5	100%	99.0%
Aviation Gasoline	41.6		99.0%
Distillate Fuel	44.0	50%	99.0%
Jet Fuel, Kerosene	43.5		99.0%
Jet Fuel, Naphtha	44.0		99.0%
Kerosene	43.5		99.0%
Liquefied Petroleum Gas (LPG)	37.8	91%	99.0%
Lubricants	44.6	9%	99.0%
Motor Gasoline	42.8		99.0%
Residual Fuel	47.4	50%	99.0%
Misc. Petroleum Products	44.7	100%	99.0%
Naphtha	40.0	91%	99.0%
Other Oil	44.0	91%	99.0%
Pentanes Plus	40.2	91%	99.0%
Petroleum Coke	61.4	50%	99.0%
Still Gas	38.6	80%	99.0%
Special Naphtha	43.8	0%	99.0%
Unfinished Oils	44.6		99.0%
Waxes	43.7	100%	99.0%
Crude Oil[c]	44.6		99.0%
Aviation Gasoline Blending Components[d]	41.6		99.0%
Motor Gasoline Blending Components[d]	42.8		99.0%

Source: All carbon content values from EIIP 1999, except crude oil, aviation gasoline blending components, and motor gasoline blending components, which are taken from EPA 2001, and jet fuel, kerosene and jet fuel, naphtha which are taken from EIA 1994. Storage factors are taken from IPCC/UNEP/OECD/IEA 1997 and EPA 2001. Estimates of the fraction of carbon oxidized for various fuel types were taken from EPA 2001.

[a] Carbon contents reflect higher heating values.

[b] These coefficients vary annually due to fluctuations in fuel quality (Table 15).

[c] Used the average of the 1990-1999 carbon content for crude oil in Tg C/QBtu and converted to lbs C/million Btu.

[d] Carbon loads of blending components equal those of the gasolines they add to.

Table 15: Annually Variable Carbon Contents for California

Fuel Type	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999
Residential Coal	55.66	55.69	55.66	55.66	55.66	55.66	55.66	55.66	55.67	55.66
Commercial Coal	55.66	55.69	55.66	55.66	55.66	55.66	55.66	55.66	55.67	55.66
Industrial Coking Coal	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Industrial Other Coal	55.80	55.80	55.69	55.66	55.66	55.66	55.66	55.71	55.79	55.80
Utility Coal	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Source: EIA 1999

Step 6: Convert Carbon Emissions to CO_2 Emissions.

Carbon emissions from energy consumption were then converted to metric tons by multiplying by 0.0004536 metric tons per pound. This product is then multiplied by the molecular weight ratio of CO_2 to carbon to obtain metric tons of CO_2 equivalent.

The methodology above can be summarized by the following equation:

$$CO_2 \text{ emissions} = \varphi\,[(FC_i \times CC_i) - SC_i - BF_i] \times FO_i \times \frac{0.0004536 \text{ MTC}}{\text{lb C}} \times \frac{44\ CO_2}{12\ C}$$

Where:

φ indicates the sum across all fuel types
FC_i = fuel combusted for fuel i (million Btu)
CC_i = carbon content coefficient for fuel i (lbs C/million Btu)
SC_i = stored carbon for fuel i (lbs C)
BF_i = carbon in bunker fuels for fuel i (lbs C)
FO_i = fraction oxidized for fuel i (percent)

2.2.2. Data Sources

The following data were obtained for the estimation of CO_2 emissions from fossil fuel combustion:

- fossil fuel energy consumption by sector and energy type
- carbon content coefficients
- fraction of carbon oxidized
- marine bunker fuel consumption
- carbon storage factors

California energy consumption data from 1990 to 1999 were obtained almost entirely from the *State Energy Data Report (SEDR), 1999* published by the U.S. Department of Energy's Energy Information Administration (EIA 1999). Industrial still gas data were taken from the *Petroleum Industry Information Reporting Act*, which receives this information directly from the California refineries – allowing for a more accurate reflection of the actual data (PIIRA 2001). Table 13 provides the consumption activity data by sector and fuel type used to estimate emissions of CO_2 from fossil fuel combustion. Motor gasoline consumption data was obtained from the California Board of Equalization (BOE 2001). This information was based on collection of taxes on the sale of gasoline. Aviation gasoline included in the BOE data was subtracted out using aviation gasoline consumption data provided by the SEDR (EIA 1999). Consumption data reported by BOE for California's fiscal years were adjusted to calendar year data. To convert from fiscal years to calendar years, it was assumed that motor gasoline consumption is equally distributed throughout the entire year. For a fiscal year, half the consumption occurs between January 1 and June 30, and half between July 1 and December 31. Using this assumption, two consecutive fiscal years were averaged together to obtain data for the calendar year common to both fiscal years.

Carbon content coefficients were taken primarily from Chapter 1 of the EIIP guidance (EIIP 1999) (Table 14). The carbon content coefficient for crude oil was taken from the U.S. Inventory (EPA 2001). These values are consistent with EIA's national carbon factors. The fraction of carbon oxidized during combustion for each fuel is also consistent with the values used in the national inventory and in IPCC guidance (EPA 2001, IPCC / UNEP / OECD / IEA 1997) (Table 11). The variable carbon contents were taken from the *SEDR* (EIA 1999) (Table 15). Data sources used to estimate international bunker fuel emissions are discussed in the section "International Bunker Fuels." Non-energy use fuel carbon storage factors were obtained from both IPCC and the U.S. Inventory (IPCC / UNEP / OECD / IEA 1997, EPA 2001) (Table 14).

2.3. Methane and Nitrous Oxide from Stationary Source Combustion

Stationary source combustion includes all fuel combustion activities except transportation (i.e. mobile source combustion). Only methane (CH_4) and nitrous oxide (N_2O) emissions from the residential, industrial, commercial/institutional, and utility sectors are described here, as CO_2 emissions from stationary sources are covered earlier in this chapter. Non-CO_2 emissions originate from the combustion of coal, petroleum, natural gas, and wood, and are dependent on a variety of factors including: fuel characteristics, type and age of the technology, environmental surroundings, and the use of pollution control devices. Note the addition of wood in this section. Combustion of wood is not included in estimates of CO_2 emissions from fossil fuel combustion because it is a biogenic source.

Stationary source combustion in 1999 resulted in the emission of 0.56 MMTCO_2 Eq. of CH_4 and 0.39 MMTCO_2 Eq. of N_2O, for a total of 0.95 MMTCO_2 Eq. of non-CO_2 emissions. California contributed approximately seven percent of the nation's CH_4 emissions and two percent of the N_2O emissions from this source category (Table 16 and Table 17).

Methane emissions remained approximately constant from 1990 to 1996 and then dropped 19 percent from 1996 to 1999. The recent decrease in CH_4 emissions is principally due to a decline in wood consumption in the residential sector. Emissions of N_2O exhibited a more constant decreasing trend from 1990 to 1999, dropping by about 15 percent over the period. Decreased emissions CH_4 and N_2O emissions from stationary sources may be the result of stringent Building and Appliance Standards implemented in California.

Table 16: CH_4 Emissions from Stationary Source Combustion: 1990-1999 ($MMTCO_2$ Eq.)

Sector/Fuel Type	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999
Electric Utilities	**0.01**	**0.01**	**0.01**	**0.01**	**0.01**	**0.01**	**0.01**	**0.01**	**0.01**	**0.00**
Coal	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Petroleum	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Natural Gas	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.00
Wood	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Industrial	**0.18**	**0.18**	**0.18**	**0.18**	**0.18**	**0.17**	**0.17**	**0.18**	**0.19**	**0.23**
Coal	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
Petroleum	0.03	0.03	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02
Natural Gas	0.06	0.07	0.07	0.08	0.07	0.08	0.08	0.08	0.09	0.12
Wood	0.08	0.07	0.07	0.07	0.07	0.06	0.06	0.07	0.06	0.07
Commercial/Institutional	**0.06**	**0.06**	**0.06**	**0.06**	**0.06**	**0.06**	**0.06**	**0.05**	**0.06**	**0.06**
Coal	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Petroleum	0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Natural Gas	0.03	0.03	0.03	0.03	0.03	0.03	0.02	0.03	0.03	0.02
Wood	0.02	0.03	0.03	0.03	0.03	0.03	0.03	0.02	0.02	0.03
Residential	**0.44**	**0.46**	**0.47**	**0.42**	**0.42**	**0.45**	**0.45**	**0.28**	**0.27**	**0.28**
Coal	0.00	0.00	0.00	0.01	0.01	0.01	0.01	0.01	0.01	0.00
Petroleum	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00
Natural Gas	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.06	0.06
Wood	0.38	0.40	0.42	0.36	0.35	0.39	0.39	0.23	0.20	0.21
Total	**0.69**	**0.71**	**0.73**	**0.67**	**0.67**	**0.69**	**0.69**	**0.52**	**0.52**	**0.56**

Note: Totals may not sum due to independent rounding.

Table 17: N_2O Emissions from Stationary Source Combustion: 1990-1999 ($MMTCO_2$ Eq.)

Sector/Fuel Type	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999
Electric Utilities	**0.02**	**0.01**	**0.02**	**0.02**	**0.02**	**0.01**	**0.01**	**0.01**	**0.01**	**0.00**
Coal	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Petroleum	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Natural Gas	0.01	0.01	0.02	0.01	0.02	0.01	0.01	0.01	0.01	0.00
Wood	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Industrial	**0.32**	**0.30**	**0.30**	**0.28**	**0.29**	**0.27**	**0.27**	**0.27**	**0.26**	**0.31**
Coal	0.03	0.03	0.03	0.02	0.02	0.03	0.02	0.02	0.03	0.03
Petroleum	0.12	0.11	0.11	0.10	0.10	0.10	0.10	0.10	0.10	0.10
Natural Gas	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.03	0.04
Wood	0.15	0.14	0.14	0.14	0.14	0.13	0.12	0.13	0.11	0.14
Commercial/Institutional	**0.02**	**0.02**	**0.02**	**0.02**	**0.02**	**0.02**	**0.02**	**0.02**	**0.02**	**0.02**
Coal	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Petroleum	0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Natural Gas	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
Wood	0.00	0.01	0.01	0.01	0.01	0.01	0.01	0.00	0.00	0.01
Residential	**0.09**	**0.10**	**0.10**	**0.09**	**0.09**	**0.09**	**0.09**	**0.06**	**0.06**	**0.06**
Coal	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Petroleum	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Natural Gas	0.02	0.02	0.01	0.02	0.02	0.01	0.01	0.01	0.02	0.02
Wood	0.07	0.08	0.08	0.07	0.07	0.08	0.08	0.04	0.04	0.04
Total	**0.46**	**0.43**	**0.44**	**0.41**	**0.42**	**0.40**	**0.39**	**0.36**	**0.35**	**0.39**

Note: Totals may not sum due to independent rounding.

2.3.1. Methodology

Methane and N_2O emissions from stationary combustion in California were estimated following the Tier 1 method in the IPCC guidelines (IPCC / UNEP / OECD / IEA 1997), the same approach used in the U.S. Inventory (EPA 2001).

Emissions of CH_4 and N_2O were estimated from four primary fuel types—coal, oil, natural gas, and wood. The consumption data for each fuel type were grouped into four sectors (e.g. industrial, residential, commercial / institutional, and electric utilities) and then multiplied by IPCC emission factors specific to each fuel type and sector (IPCC / UNEP / OECD / IEA 1997).

Annual energy consumption data for each primary fuel type were obtained for each sector (Table 18). These data were then converted from gross calorific values (GCV) (i.e., higher heating values) to net calorific values (NCV) (i.e., lower heating values), as the IPCC emission factors are based on NCV. To make this adjustment, a 10 percent reduction for natural gas and wood, and a five percent reduction for coal and oil were assumed; thus natural gas and wood values were multiplied by 0.90 while coal and oil values were multiplied by 0.95.

The consumption data were then converted into gigajoules (GJ) and multiplied by the appropriate emission factor (in g / GJ) to estimate emissions of each gas. These values were then multiplied by the global warming potential (GWP) for each gas, 21 for CH_4 and 310 for N_2O, to express emissions in CO_2 equivalents.

2.3.2. Data Sources

Energy consumption data by sector and primary fuel type were obtained primarily from the *State Energy Data Report (SEDR), 1999* (EIA 1999) (Table 18). Industrial still gas data was taken from the *Petroleum Industry Information Reporting Act*, which receives this information directly from California refineries, and is thus a more accurate accounting than the EIA *SEDR* (PIIRA 2001). The assumption used to convert from GCV to NCV was a basic version of the International Energy Agency’s convention and is consistent with the U.S. Inventory (EPA 2001). All emission factors were taken from the IPCC guidelines (IPCC / UNEP / OECD / IEA 1997) (Table 19).

Table 18: Energy Consumption Data by Sector and Fuel Type (TBtu)

Sector/Fuel Type	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999
Electric Utilities	**518**	**468**	**587**	**501**	**637**	**411**	**333**	**387**	**278**	**146**
Coal	0	0	0	0	0	0	0	0	0	0
Petroleum	46	6	4	21	19	5	7	2	2	1
Natural Gas	471	462	583	480	619	405	326	385	276	146
Wood	0	0	0	0	0	0	0	0	0	0
Industrial	**1,470**	**1,511**	**1,483**	**1,488**	**1,471**	**1,450**	**1,485**	**1,521**	**1,636**	**1,923**
Coal	65	63	65	54	54	58	50	47	62	63
Petroleum	670	607	589	543	553	521	544	539	533	543
Natural Gas	607	726	706	775	741	764	787	826	947	1,196
Wood	129	115	123	116	123	106	104	110	94	120
Commercial/Institutional	**345**	**345**	**320**	**281**	**288**	**307**	**265**	**279**	**323**	**269**
Coal	0	1	0	2	3	2	3	2	2	0
Petroleum	47	44	23	14	13	18	14	15	20	15
Natural Gas	294	295	293	260	267	282	243	258	297	249
Wood	4	4	5	5	5	5	5	4	4	5
Residential	**617**	**616**	**582**	**600**	**611**	**569**	**571**	**541**	**637**	**637**
Coal	0	0	0	1	1	1	1	1	1	0
Petroleum	23	27	19	19	19	19	16	15	24	22
Natural Gas	531	522	493	520	532	484	489	487	578	579
Wood	63	67	70	60	58	65	65	38	33	36
Total	**2,950**	**2,939**	**2,971**	**2,870**	**3,007**	**2,736**	**2,654**	**2,728**	**2,873**	**2,975**

Source: EIA 1999

Note: Totals may not sum due to independent rounding. Wood is included in estimates of CH_4 and N_2O emissions from fossil fuel combustion. However, because wood is a biogenic source, it is not included in Table 13.

Table 19: CH_4 and N_2O Emission Factors by Fuel Type and Sector (g/GJ)

Sector/Fuel Type	CH_4	N_2O
Electric Utilities		
Coal	1	1.4
Petroleum	3	0.6
Natural Gas	1	0.1
Wood	30	4.0
Industrial		
Coal	10	1.4
Petroleum	2	0.6
Natural Gas	5	0.1
Wood	30	4.0
Commercial/Institutional		
Coal	10	1.4
Petroleum	10	0.6
Natural Gas	5	0.1
Wood	300	4.0
Residential		
Coal	300	1.4
Petroleum	10	0.6
Natural Gas	5	0.1
Wood	300	4.0

Source: IPCC/UNEP/OECD/IEA 1997

2.4. Methane and Nitrous Oxide from Mobile Source Combustion

The combustion of fuel in mobile sources results in emissions of CO_2, CH_4, and N_2O. The methodology for estimating emissions of CO_2 is discussed earlier in this chapter, and involves a simple calculation based on the quantity and characteristics of the fuel combusted. The emission pathways of CH_4 and N_2O are more complex, as they depend on air-fuel mixes, combustion temperatures, fuel characteristics, and the use of pollution control equipment. For example, N_2O emissions are largely dependent on the catalytic processes used to control NO_x, CO, and hydrocarbon emissions. Methane emissions are determined not only by the methane content of the fuel, but also by the amount of uncombusted hydrocarbons passing through the engine, and the presence of pollution control technologies such as catalytic converters (EPA 2001).

Methane and N_2O emissions were estimated for both highway vehicles and aviation. As highway vehicles have been extensively studied due to their significant effect on local air pollution, activity data for this source were readily available. Since emissions from non-highway sources are much less significant--and therefore less studied--the underlying activity data for modes other than aviation were not available at the state level.

Table 20 and Table 21 provide CH_4 and N_2O emission estimates from mobile combustion by vehicle and fuel type in California. In 1999, total CH_4 emissions were 0.41 MMTCO$_2$ Eq., representing 9.1 percent of the U.S. total, while N_2O emissions were 6.24 MMTCO$_2$ Eq., representing 9.8 percent of the U.S. total. From 1990 to 1999, emissions of CH_4 and N_2O decreased by 24 and 9 percent, respectively, for mobile sources. Decreased emissions were attributable to reductions in emissions from gasoline passenger cars and gasoline light-duty trucks, which constitute the majority of emissions in California. Although vehicle miles traveled (VMT) for these vehicles increased by 17 percent over this period, emissions of both N_2O and CH_4 decreased due to the implementation of stricter air pollution control regulations in California during the study period. These regulations are more stringent than similar regulations in other states, and explain why emissions of CH_4 and N_2O from mobile sources in California have decreased more rapidly than in the United States as a whole.

Table 20: CH_4 Emissions from Mobile Source Combustion (MMTCO$_2$ Eq.)

Fuel Type/ Vehicle Type	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999
Gasoline Highway	**0.49**	**0.47**	**0.46**	**0.45**	**0.43**	**0.41**	**0.39**	**0.38**	**0.37**	**0.37**
Passenger Cars	0.25	0.25	0.24	0.23	0.22	0.21	0.21	0.20	0.20	0.19
Light-Duty Trucks	0.18	0.18	0.18	0.17	0.17	0.16	0.15	0.15	0.15	0.14
Heavy-Duty Vehicles	0.05	0.04	0.03	0.03	0.03	0.03	0.03	0.02	0.02	0.02
Motorcycles	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.00	0.00
Diesel Highway	**0.02**	**0.02**	**0.02**	**0.02**	**0.02**	**0.02**	**0.02**	**0.02**	**0.02**	**0.02**
Passenger Cars	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Light-Duty Trucks	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Heavy-Duty Vehicles	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02
Non-Highway	**0.03**	**0.03**	**0.03**	**0.03**	**0.03**	**0.03**	**0.03**	**0.03**	**0.03**	**0.03**
Aviation	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03
Total	**0.54**	**0.52**	**0.51**	**0.49**	**0.48**	**0.46**	**0.44**	**0.43**	**0.42**	**0.41**

Note: Totals may not sum due to independent rounding.

Table 21: N_2O Emissions from Mobile Source Combustion ($MMTCO_2$ Eq.)

Fuel Type/ Vehicle Type	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999
Gasoline Highway	**6.24**	**6.51**	**6.61**	**6.59**	**6.43**	**6.23**	**6.01**	**5.78**	**5.70**	**5.64**
Passenger Cars	3.48	3.60	3.64	3.60	3.52	3.42	3.31	3.19	3.12	3.05
Light-Duty Trucks	2.60	2.74	2.79	2.80	2.71	2.61	2.50	2.40	2.38	2.38
Heavy-Duty Vehicles	0.16	0.17	0.17	0.19	0.19	0.20	0.20	0.19	0.21	0.21
Motorcycles	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Diesel Highway	**0.21**	**0.20**	**0.20**	**0.20**	**0.20**	**0.20**	**0.21**	**0.20**	**0.20**	**0.21**
Passenger Cars	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
Light-Duty Trucks	0.01	0.01	0.01	0.01	0.01	0.02	0.02	0.02	0.02	0.02
Heavy-Duty Vehicles	0.19	0.18	0.18	0.18	0.18	0.18	0.19	0.18	0.18	0.18
Non-Highway	**0.37**	**0.35**	**0.34**	**0.35**	**0.39**	**0.37**	**0.41**	**0.40**	**0.41**	**0.39**
Aviation	0.37	0.35	0.34	0.35	0.39	0.37	0.41	0.40	0.41	0.39
Total	**6.82**	**7.06**	**7.15**	**7.14**	**7.02**	**6.81**	**6.63**	**6.39**	**6.32**	**6.24**

Note: Totals may not sum due to independent rounding.

2.4.1. Methodology

Estimates of CH_4 and N_2O emissions were obtained by applying emission factors to activity data for each category. For highway vehicles, these data include annual VMT, age distribution, vehicle mileage accumulation, and pollution control technology type for each vehicle type. For aviation, data on energy consumption of jet fuel and aviation gasoline was used. Estimates of these gases were developed using a methodology similar to that outlined in the U.S. Inventory (EPA 2001), which is consistent with the IPCC guidelines (IPCC / UNEP / OECD / IEA 1997).

2.4.1.1. Highway Vehicles

Methane and N_2O emissions from highway vehicles were estimated by determining the total VMT that can be attributed to each control technology and fuel type and applying emission factors specific to each technology and fuel. As both new and older cars are on the road at any given time and pollution control technologies on highway vehicles have advanced dramatically since the early 1970s, it was necessary to allocate the VMT in each calendar year across 25 model years for each vehicle category. These VMT data were then allocated to control technologies based on the distribution of these technologies in each model year.

Step 1: Determine VMT by Vehicle Type, Fuel Type, and Model Year.

California VMT data (Table 22) for gasoline and diesel highway vehicles were obtained for each vehicle type and fuel type from the California Air Resources Board's EMFAC2000 model (ARB 2000).

Table 22: Vehicle Miles Traveled for Highway Vehicles (10^6 Miles)

Year	Gasoline				Diesel		
	Passenger Cars	Light-Duty Trucks	Heavy-Duty Vehicles	Motorcycles	Passenger Cars	Light-Duty Trucks	Heavy-Duty Vehicles
1990	152,695	68,855	7,524	1,310	2,224	1,139	12,603
1991	154,404	70,912	6,738	1,315	2,064	1,184	11,970
1992	155,385	72,460	6,475	1,178	1,933	1,236	11,897
1993	156,300	75,232	6,432	1,113	1,794	1,349	11,989
1994	157,749	76,980	6,373	1,044	1,674	1,425	11,928
1995	159,344	78,691	6,183	1,024	1,554	1,542	12,106
1996	160,321	80,228	6,122	1,025	1,445	1,660	12,467
1997	161,510	81,923	5,610	786	1,328	1,765	11,774
1998	164,499	86,311	5,836	754	1,226	1,893	12,009
1999	167,513	91,016	5,907	722	1,135	1,957	12,218

Source: ARB 2000

These vehicle categories are divided into gasoline passenger cars or light duty gasoline vehicles (LDGV), light-duty gasoline trucks (LDGT), heavy-duty gasoline vehicles (HDGV), diesel passenger cars or light duty diesel vehicles (LDDV), light-duty diesel trucks (LDDT), heavy-duty diesel vehicles (HDDV), and motorcycles (MC). Total VMT for each vehicle category was distributed across 25 model years according to the methodology described in the U.S. Inventory:

> "Total VMT were distributed based on the VMT distribution by vehicle age. This distribution was derived by weighting the temporally fixed age distribution of the U.S. vehicle fleet according to vehicle registrations by the average annual age-specific vehicle mileage accumulation rates of U.S. vehicles which were both obtained from EPA's Mobile6 model." (EPA 2001)

Age distribution, vehicle mileage accumulation, and the percent VMT allocated to each model year are shown in Table 23, Table 24, and Table 25, respectively.

Table 23: Age Distribution by Vehicle/Fuel Type for Highway Vehicles (percent)

Vehicle Age (year)	LDGV[a]	LDGT[b]	HDGV[c]	LDDV[d]	LDDT[e]	HDDV[f]	MC[g]
1	5.3%	5.8%	4.9%	5.3%	5.9%	4.2%	14.4%
2	7.1%	7.6%	8.9%	7.1%	7.4%	7.8%	16.8%
3	7.1%	7.5%	8.1%	7.1%	6.9%	7.2%	13.5%
4	7.1%	7.3%	7.4%	7.1%	6.4%	6.7%	10.9%
5	7.0%	7.1%	6.8%	7.0%	6.0%	6.2%	8.8%
6	7.0%	6.8%	6.2%	7.0%	5.6%	5.8%	7.0%
7	6.9%	6.5%	5.6%	6.9%	5.2%	5.3%	5.6%
8	6.8%	6.1%	5.1%	6.8%	4.8%	5.0%	4.5%
9	6.6%	5.7%	4.7%	6.6%	4.5%	4.6%	3.6%
10	6.3%	5.2%	4.3%	6.3%	4.2%	4.3%	2.9%
11	5.9%	4.7%	3.9%	5.9%	3.9%	4.0%	2.3%
12	5.4%	4.2%	3.6%	5.4%	3.6%	3.7%	9.7%
13	4.6%	3.6%	3.3%	4.6%	3.4%	3.4%	0.0%
14	3.6%	3.1%	3.0%	3.6%	3.2%	3.2%	0.0%
15	2.9%	2.6%	2.7%	2.9%	2.9%	2.9%	0.0%
16	2.3%	2.2%	2.5%	2.3%	2.7%	2.7%	0.0%
17	1.8%	1.8%	2.3%	1.8%	2.5%	2.5%	0.0%
18	1.4%	1.4%	2.1%	1.4%	2.4%	2.4%	0.0%
19	1.1%	1.2%	1.9%	1.1%	2.2%	2.2%	0.0%
20	0.9%	1.1%	1.7%	0.9%	2.1%	2.0%	0.0%
21	0.7%	1.1%	1.6%	0.7%	1.9%	1.9%	0.0%
22	0.6%	1.0%	1.5%	0.6%	1.8%	1.8%	0.0%
23	0.4%	1.0%	1.3%	0.4%	1.7%	1.6%	0.0%
24	0.4%	0.9%	1.2%	0.4%	1.6%	1.5%	0.0%
25	1.0%	4.6%	5.4%	1.0%	7.3%	7.2%	0.0%

[a] LDGV (gasoline passenger cars, also referred to as light-duty gas vehicles)

[b] LDGT (light-duty gas trucks)

[c] HDGV (heavy-duty gas vehicles)

[d] LDDV (diesel passenger cars, also referred to as light-duty diesel vehicles)

[e] LDDT (light-duty diesel trucks)

[f] HDDV (heavy-duty diesel vehicles)

[g] MC (motorcycles)

Note: Based on U.S. vehicle registrations.

Table 24: Annual Age-specific Vehicle Mileage Accumulation of U.S. Vehicles (miles)

Vehicle Age (year)	LDGV	LDGT	HDGV	LDDV	LDDT	HDDV	MC
1	14,910	19,906	20,218	14,910	26,371	28,787	4,786
2	14,174	18,707	18,935	14,174	24,137	26,304	4,475
3	13,475	17,559	17,100	13,475	22,095	24,038	4,164
4	12,810	16,462	16,611	12,810	20,228	21,968	3,853
5	12,178	15,413	15,560	12,178	18,521	20,078	3,543
6	11,577	14,411	14,576	11,577	16,960	18,351	3,232
7	11,006	13,454	13,655	11,006	15,533	16,775	2,921
8	10,463	12,541	12,793	10,463	14,227	15,334	2,611
9	9,947	11,671	11,987	9,947	13,032	14,019	2,300
10	9,456	10,843	11,231	9,456	11,939	12,817	1,989
11	8,989	10,055	10,524	8,989	10,939	11,719	1,678
12	8,546	9,306	9,863	8,546	10,024	10,716	1,368
13	8,124	8,597	9,243	8,124	9,186	9,799	1,368
14	7,723	7,925	8,662	7,723	8,420	8,962	1,368
15	7,342	7,290	8,028	7,342	7,718	8,196	1,368
16	6,980	6,690	7,610	6,980	7,075	7,497	1,368
17	6,636	6,127	7,133	6,636	6,487	6,857	1,368
18	6,308	5,598	6,687	6,308	5,948	6,273	1,368
19	5,997	5,103	6,269	5,997	5,454	5,739	1,368
20	5,701	4,642	5,877	5,701	5,002	5,250	1,368
21	5,420	4,214	5,510	5,420	4,588	4,804	1,368
22	5,152	3,818	5,166	5,152	4,209	4,396	1,368
23	4,898	3,455	4,844	4,898	3,861	4,023	1,368
24	4,656	3,123	4,542	4,656	3,542	3,681	1,368
25	4,427	2,822	4,259	4,427	3,250	3,369	1,368

Table 25: VMT Distribution by Vehicle Age and Vehicle/Fuel Type (percent)

Vehicle Age (year)	LDGV	LDGT	HDGV	LDDV	LDDT	HDDV	MC
1	7.51%	9.41%	7.89%	7.51%	11.50%	8.27%	19.39%
2	9.52%	11.56%	13.48%	9.52%	13.07%	14.00%	21.15%
3	9.05%	10.62%	11.11%	9.05%	11.15%	11.86%	15.82%
4	8.59%	9.70%	9.85%	8.59%	9.51%	10.05%	11.82%
5	8.14%	8.80%	8.43%	8.14%	8.11%	8.52%	8.77%
6	7.68%	7.92%	7.21%	7.68%	6.92%	7.22%	6.37%
7	7.22%	7.04%	6.16%	7.22%	5.90%	6.13%	4.60%
8	6.72%	6.19%	5.27%	6.72%	5.04%	5.20%	3.31%
9	6.20%	5.36%	4.51%	6.20%	4.30%	4.41%	2.33%
10	5.64%	4.57%	3.86%	5.64%	3.67%	3.74%	1.62%
11	5.03%	3.82%	3.31%	5.03%	3.13%	3.18%	1.09%
12	4.38%	3.14%	2.83%	4.38%	2.67%	2.70%	3.73%
13	3.54%	2.52%	2.42%	3.54%	2.28%	2.29%	0.00%
14	2.67%	1.99%	2.07%	2.67%	1.95%	1.94%	0.00%
15	2.01%	1.54%	1.76%	2.01%	1.66%	1.65%	0.00%
16	1.52%	1.16%	1.52%	1.52%	1.42%	1.40%	0.00%
17	1.14%	0.87%	1.30%	1.14%	1.21%	1.19%	0.00%
18	0.86%	0.64%	1.12%	0.86%	1.04%	1.01%	0.00%
19	0.65%	0.50%	0.96%	0.65%	0.89%	0.86%	0.00%
20	0.49%	0.43%	0.82%	0.49%	0.76%	0.73%	0.00%
21	0.37%	0.37%	0.70%	0.37%	0.65%	0.62%	0.00%
22	0.28%	0.32%	0.60%	0.28%	0.55%	0.53%	0.00%
23	0.21%	0.27%	0.52%	0.21%	0.47%	0.45%	0.00%
24	0.16%	0.23%	0.44%	0.16%	0.40%	0.38%	0.00%
25	0.43%	1.04%	1.85%	0.43%	1.75%	1.65%	0.00%

Note: Estimated by weighting data in Table 23 by data in Table 24.

Step 2: Allocate VMT Data to Control Technology Type.

California VMT by vehicle category for each model year was allocated to control technology type based on the technology distribution in each model year. Table 26 shows this distribution for gasoline passenger cars and light-duty trucks, Table 27 for gasoline heavy-duty vehicles, and Table 28 for diesel vehicles. These technology categories are described in the U.S. Inventory as follows,

> "The categories 'Tier 0' and 'Tier 1' were substituted for the early three-way catalyst and advanced three-way catalyst categories, respectively, as defined in the Revised 1996 IPCC Guidelines. Tier 0, Tier 1, and LEV are actually U.S. emission regulations, rather than control technologies; however, each does correspond to particular combinations of control technologies and engine design. Tier 1 and its predecessor Tier 0 both apply to vehicles equipped with three-way catalysts. The introduction of 'early three-way catalysts,' and 'advance three-way catalysts' as described in the Revised 1996 IPCC Guidelines, roughly correspond to the introduction of Tier 0 and Tier 1 regulations (EPA 1998)."

Table 26: Control Technology Assignments for California Gasoline Passenger Cars and Light-Duty Trucks (percent of VMT)

Model Years	Non-catalyst	Oxidation	Tier 0	Tier 1	LEV
1973-1974	100%	-	-	-	-
1975-1979	-	100%	-	-	-
1980-1981	-	15%	85%	-	-
1982	-	14%	86%	-	-
1983	-	12%	88%	-	-
1984-1991	-	-	100%	-	-
1992	-	-	60%	40%	-
1993	-	-	20%	80%	-
1994	-	-	-	90%	10%
1995	-	-	-	85%	15%
1996-1999	-	-	-	80%	20%

Note: Dash (-) indicates not applicable.

Table 27: Control Technology Assignments for Gasoline Heavy-Duty Vehicles (percent of VMT)

Model Years	Uncontrolled	Non-catalyst	Oxidation	Tier 0
A1981	100%	-	-	-
1982-1984	95%	-	5%	-
1985-1986	-	95%	5%	-
1987	-	70%	15%	15%
1988-1989	-	60%	25%	15%
1990-1999	-	45%	30%	25%

Note: Dash (-) indicates not applicable.

Table 28: Control Technology Assignments for Diesel Highway VMT

Vehicle Type/Control Technology	Model Years
Diesel Passenger Cars and Light-Duty Trucks	
Uncontrolled	1966-1982
Moderate control	1983-1995
Advanced control	1996-1999
Heavy-Duty Diesel Vehicles	
Uncontrolled	1966-1972
Moderate control	1983-1995
Advanced control	1996-1999
Motorcycles	
Uncontrolled	1966-1995
Non-catalyst controls	1996-1999

Step 3: Determine the Amount of CH_4 and N_2O Emitted by Vehicle, Fuel, and Control Technology Type.

Emissions of CH_4 and N_2O were calculated by multiplying emission factors specific to fuel and control technology by the total VMT allocated to each technology type. All emission factors are consistent with those used in the U.S. Inventory (EPA 2001) (Table 29).

Table 29: Emission Factors and Fuel Economy for Highway Mobile Combustion

Vehicle Type/Control Technology	N_2O (g/km)	CH_4 (g/km)	"Fuel Economy" (g CO_2/km)
Gasoline Passenger Cars			
Low Emission Vehicles	0.0176	0.025	280
Tier 1	0.0288	0.030	285
Tier 0	0.0507	0.040	298
Oxidation Catalyst	0.0322	0.070	383
Non-Catalyst	0.0103	0.120	531
Uncontrolled	0.0103	0.135	506
Gasoline Light-Duty Trucks			
Low Emission Vehicles	0.0249	0.030	396
Tier 1	0.0400	0.035	396
Tier 0	0.0846	0.070	498
Oxidation Catalyst	0.0418	0.090	498
Non-Catalyst	0.0117	0.140	601
Uncontrolled	0.0118	0.135	579
Gasoline Heavy-Duty Vehicles			
Tier 0	0.1729	0.075	1,017
Oxidation Catalyst	0.0870	0.090	1,036
Non-Catalyst Control	0.0256	0.125	1,320
Uncontrolled	0.0269	0.270	1,320
Diesel Passenger Cars			
Advanced	0.0100	0.01	237
Moderate	0.0100	0.01	248
Uncontrolled	0.0100	0.01	319
Diesel Light Trucks			
Advanced	0.0200	0.01	330
Moderate	0.0200	0.01	331
Uncontrolled	0.0200	0.01	415
Diesel Heavy-Duty Vehicles			
Advanced	0.0300	0.04	987
Moderate	0.0300	0.05	1,011
Uncontrolled	0.0300	0.06	1,097
Motorcycles			
Non-Catalyst Control	0.0042	0.13	219
Uncontrolled	0.0054	0.26	266

Source: IPCC/UNEP/OECD/IEA 1997, EPA 1998

2.4.1.2. Aviation

Activity data for aviation were based on California energy consumption statistics for jet fuel and aviation gasoline (Table 30). Emissions of CH_4 and N_2O were calculated by dividing energy consumption by the heat content of the fuel to obtain an estimate of fuel consumption (in kg), and then multiplying this value by the appropriate emission factor in IPCC / UNEP / OECD / IEA (1997). Table 31 displays heat contents and emission factors.

Table 30: Aviation Energy Consumption by Fuel Type (BBtu)

Year	Kerosene-Based Jet Fuel	Naphtha-Based Jet Fuel	Aviation Gasoline
1990	475,899	58,767	5,581
1991	464,662	43,447	5,506
1992	456,033	33,515	5,345
1993	482,909	21,819	4,134
1994	559,814	325	4,003
1995	539,923	428	4,073
1996	588,261	122	3,881
1997	584,776	48	4,222
1998	597,535	0	2,899
1999	559,477	0	4,167

Source: EIA 1999

Table 31: Heat Contents and Emission Factors for Aviation Fuels

Fuel Type	Heat Contents (Btu/kg)	N_2O (g/kg fuel)	CH_4 (g/kg fuel)
Jet Fuel	44.96	0.1	0.087
Aviation Gasoline	44.93	0.04	2.64

Source: Heat contents are based on data found in EIA (2000); emission factors are from IPCC/UNEP/OECD/IEA (1997).

2.4.2. Data Sources

2.4.2.1. Highway Vehicles

The California Air Resources Board provided VMT by vehicle type for 1990-1999 (ARB 2000). Age distribution and vehicle mileage accumulation for each vehicle type was obtained from EPA's Office of Transportation and Air Quality Mobile6 model (EPA 2000). Control technology data for highway vehicles were obtained from the EPA report, *Emissions of Nitrous Oxide from Highway Mobile Sources: Comments on the Draft Inventory of U.S. Greenhouse Gas Emissions and Sinks, 1990-1996* (EPA 1998). This report provides California-specific control technology data for gasoline passenger cars and gasoline light-duty trucks which represent 92 percent of VMT.

The emission factors used were identical to those in the U.S. Inventory. Methane emission factors for both diesel and gasoline-fueled vehicles were obtained from IPCC / UNEP / OECD / IEA (1997), and were developed using EPA's MOBILE5a model. N_2O emission factors for gasoline-fueled passenger cars and diesel vehicles were also obtained from

IPCC / UNEP / OECD / IEA (1997), while N_2O emission factors for other types of gasoline-fueled vehicles – light-duty trucks, heavy-duty vehicles, and motorcycles – were obtained from the EPA report *Emissions of Nitrous Oxide from Highway Mobile Sources: Comments on the Draft Inventory of U.S. Greenhouse Gas Emissions and Sinks, 1990-1996* (EPA 1998).

2.4.2.2. Aviation

Estimates of energy consumption of jet fuel and aviation gasoline were obtained from EIA (1999). U.S. default emission factors for CH_4 and N_2O were obtained from the IPCC guidelines (IPCC / UNEP / OECD / IEA 1997).

2.5. Coal Mining

During the process of coalification, geological and biological forces convert vegetation into coal and CH_4 over millions of years. All coal mining results in methane emissions. The quantity of CH_4 emissions depends upon the amount of CH_4 remaining in the coal and surrounding strata when mining occurs. Deeper coal usually generates and stores more CH_4 than coal deposits closer to the surface. Therefore, underground mines generate the largest amount of emissions while surface mines release lower quantities of CH_4. Not all of the methane contained in coal is released during mining. Some CH_4 remains in the coal and is released during processing, storage, and transportation; these emissions are classified as post-mining emissions.

Only surface mines were operated in California during the period from 1990 through 1999 (Table 32). In 1990, total CH_4 emissions from mining in California were 0.18 $MMTCO_2$ Eq. Table 33). The bulk of these emissions originated from surface mining. Surface coal mining was discontinued in 1992, thus there were no emissions for mining and post-mining activities from 1993 on.

Table 32: California Coal Production (Surface Mines)

Year	Coal Production (metric tons)
1990	55,376
1991	56,604
1992	103,386
1993	0
1994	0
1995	0
1996	0
1997	0
1998	0
1999	0
2000	0

Source: DOE 2000

Table 33: Emissions from Coal Mining in California (MMTCO2 Eq.)

	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999
Surface Mining	0.16	0.16	0.29	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Post-Mining Operations	0.03	0.03	0.05	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Total	**0.18**	**0.19**	**0.34**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**

Note: Totals may not sum due to independent rounding.

2.5.1. Methodology

Methane emissions from surface mining operations in California were estimated using methods consistent with EIIP guidance (EIIP 1999). Emissions are the sum of (1) emissions that occur during mining and (2) post-mining emissions.

Methane emissions from surface mines were estimated by multiplying the total amount of surface coal production by a basin-specific methane emission factor (6.4 ft^3 CH_4/short ton coal), which accounts for methane liberated from the coal itself and from surrounding strata. This equation is shown below:

Emissions from surface mines (ft^3 CH_4) = surface coal production (short tons) x 6.4 (ft^3 CH_4/short ton)

Methane emissions from post-mining operations in California were estimated by multiplying the total amount of surface coal production by a basin-specific post-mining methane emission factor (1.04 ft^3 CH_4/short ton), as shown below.

Emissions from post-mining operations (ft^3 CH_4) = surface coal production (short tons) x 1.04 (ft^3 CH_4/short ton)

2.5.2. Data Sources

Data on coal production was obtained from the *Coal Industry Annual*, Department of Energy (1990-1999). This data was confirmed with the California Division of Mines and Tunneling (2001) and the California Department of Mines and Geology (2001). Emission factors for surface mining operations were taken from the EIIP guidance and the U.S. Inventory (EIIP 1999, EPA 2001).

2.6. Natural Gas Systems

The natural gas system is characterized by four major stages: field production, processing, transmission and storage, and distribution. Methane emissions from natural gas systems are generally associated with normal operations, system upsets, and routine maintenance associated with each of the four stages of the natural gas system—field production, processing, transmission and storage, and distribution (EPA 2001). Overall, natural gas systems emitted 2.9 MMTCO$_2$ Eq. in 2000, slightly below 1990 emissions (Table 34). Improvements in technology and management practices, as well as retirement and replacement of old equipment, have helped reduce emissions.

Table 34: CH_4 Emissions from Natural Gas Systems ($MMTCO_2$ Eq.)

Source	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999
Field Production	0.10	0.10	0.10	0.09	0.09	0.09	0.08	0.08	0.08	0.08
Processing	0.56	0.56	0.56	0.56	0.56	0.56	0.56	0.60	0.60	0.58
Transmission and Storage	0.79	0.79	0.81	0.81	0.81	0.81	0.80	0.80	0.82	0.85
Distribution	1.89	1.79	1.73	1.59	1.48	1.54	1.47	1.43	1.38	1.39
Total	**3.34**	**3.24**	**3.19**	**3.05**	**2.94**	**3.00**	**2.91**	**2.91**	**2.87**	**2.90**

Emissions from this source represented nearly 0.7 percent of gross emissions in California and 0.8 percent of energy sector emissions.

Field production emissions occur at the gas wellhead, along the gathering pipelines, and at the field treatment facilities, in particular at dehydrators and separators. Emissions from field production accounted for approximately two percent of CH_4 emissions from natural gas systems between 1990 and 1999. During this period, emissions decreased approximately 20 percent, in line with the overall decrease in natural gas production.

During processing operations, impurities within the raw gas are removed, leaving a “pipeline quality” gas, which is injected into the transmission system. Processing plants accounted for approximately 20 percent of CH_4 emissions from natural gas systems in 1999. Emissions increased between 1990 and 1999 by approximately four percent. This increase stems from an increase in the number of processing facilities operating in the state during this period.

Natural gas transmission involves the high-pressure transport of gas across large distances from field production and processing to distribution interfaces. Fugitive emissions from reciprocating and turbine compressor stations account for the majority of emissions during this stage. Methane emissions from transmission and storage accounted for approximately 27 percent of CH_4 emissions from natural gas systems between 1990 and 1999. The emission increase in this stage was in line with transmission pipeline increase during the period.

Distribution pipelines take the high-pressure gas from the transmission system and reduce the pressure for distribution through mains and service lines to the end user. In 1999 there were approximately 93,000 miles of distribution mains, an increase of over 9,700 miles since 1990. Distribution system emissions stem mainly from fugitive losses at gate stations and non-plastic piping (cast iron and steel). The distribution system accounted for approximately 48 percent of methane emissions from natural gas systems in 1999. Between 1990 and 1999, CH_4 emissions decreased by nearly 26 percent. These reductions are due to an increase in the use of plastic piping, which has lower emissions than other types of piping.

2.6.1. Methodology

Methane emissions from the natural gas system were estimated using methodology described in the EIIP guidance (EIIP 1999). California’s natural gas system was described by defining key activity parameters for each of the four major stages (field production, processing, transmission and storage, and distribution). Emissions for each stage were estimated by multiplying the activity parameters by their associated emission factors and summing all the sources for each stage. Table 35 presents the activity data parameters and corresponding emission factors for each stage. Total methane emissions were estimated by adding the emission estimates for each stage. This methodology can be summarized by the following equation:

$$CH_4\ Emissions = \sum_{i=1}^{n}\left[Activity\ Data \times EF\right]_{Field\ Production} + \sum_{i=1}^{n}\left[Activity\ Data \times EF\right]_{Processing} + \sum_{i=1}^{n}\left[Activity\ Data \times EF\right]_{Transmission\ /\ Storage} + \sum_{i=1}^{n}\left[Activity\ Data \times EF\right]_{Distribution}$$

Where:

φ indicates the sum across all stage activity data in Table 35
EF = Emission Factor (metric tons CH_4 / unit)

Table 35: Natural Gas System Activity Data and Emission Factors

System Stage/ Activity Data	Emission Factors (metric tons CH_4/unit)
Field Production	
Non-Associated Wells (only produce gas)	2.54
Associated Wells (produce gas and oil)	0.02
Number of Offshore Platforms	8.26
Miles of Gathering Pipeline	0.37
Processing	
Number of Gas Processing Plants	948
Transmission/Storage	
Miles of Transmission Pipeline	0.68
Number of Gas Transmission Stations	891
Number of Gas Storage Stations	914
Number of LNG Storage Stations	914
Distribution	
Miles of Cast Iron Distribution Pipeline	4.63
Miles of Unprotected Steel Main Pipeline	2.16
Miles of Protected Steel Main Pipeline	0.11
Miles of Plastic Main Pipeline	0.42
Number of Unprotected Steel Services	0.033
Number of Protected Steel Services	0.0035

Source: EIIP 1999

2.6.2. Data Sources

The activity data compiled for each of the four major stages includes: number of associated/non-associated wells (CDC 2001a); number of offshore platforms (CDC 2001a); miles of gathering, transmission, distribution and services pipeline (DOT 2001); number of processing facilities (O&J 1997-2001); number of transmission facilities (EIA 2001); and number of storage fields (CDC 2001b).

2.7. Petroleum Systems

The petroleum system is characterized by three major stages: field production, transportation, and refining. Methane emissions from petroleum systems generally stem from fugitive emissions, vented emissions, fuel combustion emissions, and operational upsets (EPA 2001). Total methane emissions from petroleum systems in 2000 were estimated to be 0.35 MMTCO$_2$ Eq. Since 1990, emissions have gradually decreased due to a reduction in state-level oil production (Table 36).

Table 36: CH$_4$ Emissions from Petroleum Systems (MMTCO$_2$ Eq.)

Source	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999
Field Production	0.31	0.31	0.31	0.31	0.31	0.31	0.31	0.30	0.29	0.28
Transportation	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02
Refining	0.07	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06
Total	**0.40**	**0.40**	**0.39**	**0.39**	**0.39**	**0.39**	**0.39**	**0.38**	**0.38**	**0.36**

Emissions from petroleum systems in California accounted for 0.08 percent of gross state emissions and 0.10 percent of energy sector emissions.

Field production operations accounted for the majority (78 percent) of total methane emissions from petroleum systems. Vented methane from oil wells, and related processing equipment, account for the majority of emissions associated with oil production. Between 1990 and 1999, methane emissions decreased by approximately 10 percent. This is attributable to a decline in the quantity of crude oil produced within the state during this period.

Crude oil transportation activities, which include venting from tanks and loading operations from marine vessels, accounted for approximately six percent of total methane emissions from petroleum systems.

Crude oil refining operations accounted for approximately 17 percent of total methane emissions from petroleum systems. Vented emissions from refinery blowdowns are the primary contributor to emissions, while fugitive losses stemming from system leaks in the fuel gas line account for the remainder. Refining emissions decreased by approximately 14 percent between 1990 and 1999. This reduction is attributable to the decline in crude oil production within the state.

2.7.1. Methodology

Methane emissions from petroleum systems were estimated using the methodology described in the EIIP guidance (EIIP 1999).

California's petroleum system was described by defining key activity parameters for each of the three major stages (field production, transportation and refining). Emissions for each stage were estimated by multiplying the activity parameters by their associated emission factors, and summing all the sources for each stage. Table 37 shows the activity data parameters and corresponding emission factors for each stage. Total methane emissions were estimated by adding the emission estimates for each stage. This methodology can be summarized by the following equation:

$$CH_4\ Emissions = \sum_{i=1}^{n}\left[Activity\ Data \times EF\right]_{Field\ Production} + \sum_{i=1}^{n}\left[Activity\ Data \times EF\right]_{Transportation} + \sum_{i=1}^{n}\left[Activity\ Data \times EF\right]_{Refining}$$

Where:

φ indicates the sum across stage activity data in Table 37

EF = Emission Factor (lbs CH_4 / MMBtu)

Table 37: Petroleum System Activity Data and Emission Factors

System Stage/Activity Data	Emission Factor (lbs. CH_4/MMBtu)
Field Production	
Oil Production	0.0062
Vented/Flared Emissions	0.0099
Transportation	
Oil Tankered	0.0017
Refining	
Oil Refined	0.0017

Source: EIIP 1999

2.7.2. Data Sources

Activity data for field production includes total oil production (CDC 2001) and total vented and flared emissions (EIA 2001). Transportation activity data, in particular, the total quantity of oil tankered, were obtained from California Energy Commission, *1995 Fuels Report* (Commission 1995). State-level tankered information was only available for 1993. Thus, the quantity transported to / from refineries was assumed to remain constant from 1990 through 1999. The total oil refined in California was obtained from the Commission, *Monthly California Refining Industry Operating Report* (Commission 1997-2000, Commission 2001).

2.8. International Bunker Fuels

According to the guidance for national- and state-level inventories (IPCC / UNEP / OECD / IEA 1997 and EIIP 1999, respectively), emissions from international transportation activities, or bunker fuels, are to be estimated but not attributed to the national- or state-level totals, to the extent feasible. Although California has both aviation and marine fuels that fall under this category, only marine fuels were estimated due to data limitations. This section explains the approach used to quantify CO_2, CH_4, and N_2O emissions from fuels consumed by marine vessels leaving the ports of San Diego, Los Angeles, and San Francisco for other countries. In the national inventory, fuel consumed by this source category is deducted from the total fossil fuels consumed in the state. Due to the quality and availability of data on bunker fuels, emissions from this source are estimated, but are not subtracted out of the emissions from fossil fuel combustion. Greenhouse gas emissions from international bunker fuels attributed to California totaled 10.68 $MMTCO_2$ Eq. in 1999 (Table 38). These emissions consisted primarily of CO_2 (10.58 $MMTCO_2$ Eq.), but also included CH_4 (0.02 $MMTCO_2$ Eq.) and N_2O (0.08 $MMTCO_2$ Eq.). Emissions from marine bunker fuels in California in 1999 represented about 17 percent of U.S. emissions from this source.

Emissions of CO_2, CH_4, and N_2O decreased by approximately 52 percent between 1991 and 1993, and remained at approximately this level through 1999, resulting in an overall trend of declining emissions. As a result, this decrease is more drastic than the slight decline on the national level during this time period.

Table 38: Emissions from International Bunker Fuels, 1990-1999 ($MMTCO_2$ Eq.)

Gas/Fuel Type	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999
CO_2	**21.76**	**22.75**	**12.58**	**10.50**	**9.05**	**10.77**	**10.42**	**10.71**	**9.83**	**10.58**
Distillate Fuel Oil	1.32	1.10	0.78	0.84	0.51	0.65	0.43	0.52	0.67	0.37
Residual Fuel Oil	20.44	21.66	11.80	9.66	8.54	10.12	9.99	10.19	9.16	10.21
CH_4	**0.04**	**0.05**	**0.03**	**0.02**	**0.02**	**0.02**	**0.02**	**0.02**	**0.02**	**0.02**
Distillate Fuel Oil	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Residual Fuel Oil	0.04	0.04	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02
N_2O	**0.17**	**0.17**	**0.10**	**0.08**	**0.07**	**0.08**	**0.08**	**0.08**	**0.07**	**0.08**
Distillate Fuel Oil	0.01	0.01	0.01	0.01	0.00	0.01	0.00	0.00	0.01	0.00
Residual Fuel Oil	0.16	0.16	0.09	0.07	0.06	0.08	0.08	0.08	0.07	0.08
Total	**21.97**	**22.97**	**12.70**	**10.60**	**9.13**	**10.88**	**10.52**	**10.81**	**9.93**	**10.68**

Note: Totals may not sum due to independent rounding.

2.8.1. Methodology

Emissions of CO_2 from international bunker fuels were estimated using the same basic methodology as was used to estimate emissions from consumption of all fossil fuels in the section, "CO_2 from Fossil Fuel Combustion." Marine bunker fuel consumption of distillate diesel and residual fuel were obtained (in barrels) and multiplied by the heat content coefficient of each fuel to determine the energy consumed. Next, the appropriate carbon content coefficients and fraction oxidized factors were applied to estimate carbon emissions. Emissions of CH_4 and N_2O were estimated by multiplying IPCC emission factors by fuel consumption data. Emissions from aviation bunker fuels were not estimated because activity data were not available at the state level.

2.8.2. Data Sources

Distillate diesel and residual fuel oil consumption data from passenger and freight marine vessels departing from California ports (Table 39) were obtained from the Foreign Trade Division of the U.S. Department of Commerce's Bureau of the Census (DOC 1991 through 2000). When compared to state fossil fuel consumption data obtained from EIA, the Department of Commerce data appeared to include fuel in vessels prior to arriving in California in addition to fuel purchased in California (which is reported by EIA). Carbon content coefficients were taken from Chapter 1 of the EIIP guidance (EIIP 1999). Emission factors for CH_4 and N_2O and the fraction of carbon oxidized during combustion were obtained from the IPCC guidelines (IPCC / UNEP / OECD / IEA 1997). Heat content coefficients were obtained from Annex A of the *Annual Energy Review 2000* (EIA 2000). Table 40 shows the relevant coefficients and factors.

Table 39: International Bunker Fuel Consumption, 1990-1999 (Million Bbl)

Fuel Type	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999
Distillate Fuel Oil	3.14	2.60	1.84	1.99	1.20	1.54	1.01	1.22	1.59	0.87
Residual Fuel Oil	41.65	44.14	24.05	19.68	17.41	20.63	20.36	20.77	18.67	20.82
Total	**44.79**	**46.74**	**25.90**	**21.67**	**18.61**	**22.18**	**21.37**	**22.00**	**20.27**	**21.69**

Source: DOC 1991 through 2000

Table 40: Relevant Coefficients and Factors

Fuel Type	Heat Content (MMBtu/barrel)	Carbon Content (lbs C/MMBtu)	Fraction Oxidized	CH_4 Emission Factor (g/kg)	N_2O Emission Factor (g/kg)
Distillate Fuel Oil	5.825	44.0	0.99	0.03	0.08
Residual Fuel Oil	6.287	47.4	0.99	0.03	0.08

Sources: EIIP 1999, EPA 2001, EIA 2000, IPCC/UNEP/OECD/IEA 1997

CHAPTER 3 – INDUSTRIAL PROCESSES

3.0 Industrial Processes

A large number of processes in the industrial sector contribute greenhouse gas emissions to the atmosphere. These emissions result from non-energy-related industrial activities, such as process-related chemical reactions, or through the direct use of man-made gaseous compounds. Carbon dioxide (CO_2) is emitted from numerous industrial processes including cement production, lime production, limestone and dolomite consumption, soda ash production and consumption, and CO_2 production. Nitric acid production releases nitrous oxide (N_2O), while the substitution of ozone depleting substances, semiconductor manufacturing, and electric utilities emit man-made fluorinated greenhouse gases such as sulfur hexafluoride (SF_6) and hydrofluorocarbons (HFCs).

In 1999, emissions from industrial processes in California constiuted 16.2 million metric tons of carbon dioxide equivalent (MMTCO$_2$ Eq.) (Table 41). These emissions represented seven percent of the U.S. greenhouse gas emissions from industrial processes, and four percent of California's gross greenhouse gas emissions. Carbon dioxide emissions from industrial processes in 1999 were 6.2 MMTCO$_2$ Eq. The majority of these emissions, nearly 89 percent, were generated from the cement production sector. Nitrous oxide emissions from nitric acid production in 1999 were estimated at 0.3 MMTCO$_2$ Eq. Combined emissions of HFCs and SF_6 in 1999 accounted for 9.7 MMTCO$_2$ Eq., approximately 60 percent of sectoral emissions. Overall, emissions from industrial process increased by 105 percent from 1990 to 1999. This increase was driven by emissions from substitutes for ozone-depleting substances, which grew from one percent of total 1990 industrial process emissions to 43 percent in 1999.

Table 41: Emissions from Industrial Processes (MMTCO$_2$ Eq.)

Fuel/End-Use Sector	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999
CO_2	**5.30**	**4.90**	**4.69**	**4.74**	**5.32**	**5.46**	**5.64**	**5.79**	**5.86**	**6.24**
Cement Production	4.62	4.26	4.07	4.18	4.75	4.81	4.97	5.12	5.19	5.55
Lime Production	0.25	0.22	0.20	0.15	0.16	0.18	0.16	0.16	0.15	0.14
Limestone and Dolomite Consumption	0.14	0.13	0.12	0.11	0.12	0.16	0.18	0.18	0.19	0.20
Soda Ash Consumption	0.22	0.21	0.21	0.21	0.21	0.22	0.21	0.22	0.22	0.21
CO_2 Consumption	0.07	0.08	0.08	0.08	0.08	0.09	0.11	0.12	0.12	0.13
N_2O	**0.53**	**0.52**	**0.56**	**0.38**	**0.38**	**0.49**	**0.30**	**0.30**	**0.28**	**0.28**
Nitric Acid Production	0.53	0.52	0.56	0.38	0.38	0.49	0.30	0.30	0.28	0.28
HFCs and SF_6	**2.07**	**2.09**	**2.29**	**2.84**	**3.54**	**5.43**	**6.81**	**7.87**	**8.73**	**9.70**
Substitution of Ozone Depleting Substances	0.12	0.10	0.19	0.65	1.23	2.94	4.15	5.15	6.10	7.00
Semiconductor Manufacture	0.36	0.36	0.36	0.46	0.52	0.67	0.86	0.86	0.84	0.84
Electric Utilities	1.60	1.63	1.74	1.74	1.80	1.81	1.81	1.87	1.80	1.87
Total	**7.90**	**7.50**	**7.53**	**7.96**	**9.25**	**11.37**	**12.75**	**13.97**	**14.87**	**16.22**

Note: Totals may not sum due to independent rounding.

3.1. Cement Production

Cement manufacture results in CO_2 emissions through its intensive use of raw materials and its extensive energy consumption. Although CO_2 is emitted in both of these ways, only the manufacturing portion is considered below, and emissions related to energy consumption are examined in the Energy chapter.

Carbon dioxide is the result of a chemical conversion process used in the production of clinker, a component of cement. During this process, limestone ($CaCO_3$) is heated to high temperatures in a kiln to form lime (calcium oxide or CaO). The simplified stoichiometric relationships are as follows:

$CaCO_3 + \text{heat}\ \gamma\ \ CaO + CO_2$

After heating, the clinker is allowed to cool, and then mixed with small amounts of gypsum to produce Portland cement.

Table 42 presents historical CO_2 emissions from cement manufacturing from 1990 to 1999. In 1999, total CO_2 emissions from cement manufacturing in California were 5.6 $MMTCO_2$ Eq. While emissions decreased in 1991 and 1992 due to a decrease in production, they have thereafter shown a consistent upward trend throughout the period as clinker production in California increased. In 1999, California accounted for approximately 14 percent of national greenhouse gas emissions from cement production. Emissions from this sector represented approximately one percent of California's gross emissions.

Table 42: Emissions from Cement Production ($MMTCO_2$ Eq.)

Source	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999
Cement Production	4.62	4.26	4.07	4.18	4.75	4.81	4.97	5.12	5.19	5.55

3.1.1. Methodology

Estimates of state-level CO_2 emissions from cement production were based on the following equation presented in *EIIP Volume VIII: Estimating Greenhouse Gas Emissions* (EIIP 1999):

$$\textit{California } CO_2 \textit{ Emissions} = (\textit{State Clinker Production} \times \textit{CaO Content}_{(\%)} \times 0.785) \times \textit{CKD Correction Factor}$$

The quantity of clinker produced in California was multiplied by the percent lime (CaO) content of the clinker. The default CaO content is 65 percent (IPCC 2000). The total metric tons of CO_2 emitted was calculated by multiplying the quantity of CaO by its corresponding CO_2 / CaO stoichiometric ratio (i.e., the molecular weight of CO_2 (44g) / molecular weight of CaO (56g) = 0.785).

Carbon dioxide emissions are also emitted from cement kiln dust (CKD) that is not recycled during the production process. The CKD is largely a mix of calcinated and uncalcinated raw materials and clinker, and accounts for the portion of materials that does not become part of the clinker, and is lost to the system. To account for CO_2 emissions emitted from CKD, IPCC recommends that these additional CKD CO_2 emissions should be estimated as two percent of the CO_2 emissions from clinker production (IPCC 2000). Hence, the total metric tons of CO_2 emitted during clinker production was multiplied by the CKD correction factor of 1.02.

3.1.2. Data Sources

The activity data for clinker production were obtained from U.S. Geological Survey (USGS), *Minerals Yearbook: Cement* (USGS 1990-2000) (Table 43). The lime content of clinker and the CKD correction factor were obtained from the IPCC *Good Practice Guidance* (IPCC 2000).

Table 43: Annual Clinker Production (10^3 Metric Tons)

Source	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999
Clinker Production	8,874	8,178	7,819	8,024	9,123	9,227	9,543	9,824	9,964	10,645

Source: USGS 1990-2000

3.2. Lime Production

Lime is used in a wide variety of applications, including steelmaking, construction, pulp and paper manufacturing, and sewage treatment. Lime production involves three main stages: stone preparation, calcination, and hydration. Carbon dioxide is emitted during the calcination stage when limestone is heated in a kiln to produce CaO and CO_2. Carbon dioxide is a by-product and is usually released into the atmosphere. However, some CO_2 may be recovered for use in other processes such as sugar refining or precipitated calcium carbonate production.

Table 44 presents emissions from lime production in California from 1990 through 1999. In 1999, total CO_2 emissions from lime production were 0.1 $MMTCO_2$ Eq. Since 1990, emissions have gradually declined due to a reduction in state production. In 1999, CO_2 emissions from state lime production accounted for approximately one percent of national CO_2 emissions from this source.

Table 44: Emissions from Lime Production ($MMTCO_2$ Eq.)

Source	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999
Lime Production	0.25	0.22	0.20	0.15	0.16	0.18	0.16	0.16	0.15	0.14

3.2.1. Methodology

Estimates of state CO_2 emissions from lime manufacturing were based on the following equation presented in the EIIP guidance (EIIP 1999):

$$\boxed{CO_2\ Emissions = State\ Lime\ Production \times 0.785}$$

The quantity of lime (CaO) produced was multiplied by its respective CO_2 / CaO stoichiometric ratio to estimate the total metric tons of CO_2 emitted. The CO_2 / CaO stoichiometric ratio is equal to the molecular weight of CO_2 (44g) / molecular weight of CaO (56g), or 0.785.

3.2.2. Data Sources

Lime production data for 1990 through 1999 (Table 45) were obtained from the California Department of Conservation, Division of Mines and Geology (CDC 2001).

Table 45: Lime Production (metric tons)

	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999
Lime Production	313,191	278,695	254,184	193,000	203,166	228,221	207,886	199,716	185,191	181,560

Source: CDC 2001

3.3. Limestone and Dolomite Consumption

Limestone ($CaCO_3$) and dolomite ($CaCO_3MgCO_3$) are basic raw materials used by a variety of industries, including the metallurgy, chemical, and construction industries. Carbon dioxide emissions from limestone and dolomite consumption occur when the compounds are used as a flux or purifier in metallurgical furnaces, as a raw material in glass making, or as a sorbant in flue gas desulfurization (FGD) systems (EPA 2001). Limestone and dolomite are collectively referred to as limestone by the industry, and intermediate compounds are seldom distinguished (EPA 2001).

As shown in Table 46, emissions from this sector decreased from 1990 through 1993 (from 0.14 to 0.11 $MMTCO_2$ Eq.), reflecting a decline in crushed stone consumption throughout the United States. Since 1993, emissions have steadily increased. In 1999, CO_2 emissions from limestone and dolomite production were 0.2 $MMTCO_2$ Eq., representing an 80 percent increase over 1993 emissions. This increase reflects an upward trend in crushed stone consumption at the national level. In 1999, state-level emissions from this source accounted for two percent of the national limestone and dolomite consumption emissions, and just 0.05 percent of gross state emissions.

Table 46: Emissions from Limestone and Dolomite Production ($MMTCO_2$ Eq.)

Source	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999
Limestone and Dolomite Production	0.14	0.13	0.12	0.11	0.12	0.16	0.18	0.18	0.19	0.20

3.3.1. Methodology

State-level data for limestone and dolomite consumption within metallurgical furnaces, glass making, and FGD systems were not available, as state consumption data for limestone and dolomite include other activities, such as construction, that do not produce CO_2 emissions.

In order to obtain CO_2 emissions from limestone and dolomite consumption in California, national emissions from limestone and dolomite consumption were multiplied by the ratio of California's limestone and dolomite consumption for all industrial activities to the national consumption for all industrial activities. It was assumed that the ratio would be consistent with the use of limestone and dolomite for CO_2-producing activities at the state level.

3.3.2. Data Sources

National CO_2 emissions from limestone and dolomite consumption were obtained from the *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-1999* (EPA 2001). National and California state limestone and dolomite consumption data were obtained from the U.S. Geological Survey (USGS), *Minerals Yearbook: Annual Crushed Stone Reports* (USGS 1994-2000).

3.4. Soda Ash Production and Consumption

Soda ash (Na_2CO_3) is an alkaline substance also known as sodium carbonate. It is produced on a commercial scale, and it acts as a raw material in various industrial processes and consumer products including glass, soap, detergents, paper, and food.

Only two forms of soda ash are produced worldwide--natural soda ash and synthetic soda ash. The United States, the world's largest soda ash-producing country, only produces natural soda ash, and all production occurs in California and Wyoming.

The soda ash production process in California employs sodium carbonate-bearing brines. These brines are treated with CO_2 in carbonation towers. As the sodium carbonate is converted into a precipitate of sodium bicarbonate, it is then calcined back into sodium carbonate. Although CO_2 is generated as a byproduct of the reaction, it is captured and recycled, and therefore no CO_2 is emitted as a result of the process (EIIP 1999). Carbon dioxide is emitted, however, when soda ash is consumed.

Table 47 presents CO_2 emissions from soda ash consumption in California from 1990 through 1999. Emissions from soda ash consumption in California stayed relatively flat during the period, alternating between 0.22 and 0.21 MMTCO$_2$ Eq. In 1999, emissions from soda ash consumption were 0.05 percent of gross emissions in California, and five percent of national emissions from this source.

Table 47: Emissions from Soda Ash Consumption (MMTCO$_2$ Eq.)

Source	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999
Soda Ash Consumption	0.22	0.21	0.21	0.21	0.21	0.22	0.21	0.22	0.22	0.21

3.4.1. Methodology

Estimates of state-level CO_2 emissions from soda ash consumption were based on the following equation presented in the EIIP guidance (EIIP 1999):

$$\boxed{CO_2\ Emissions = State\ Soda\ Ash\ Consumption \times EF}$$

Per U.S. Geological Surveys *Mineral Yearbooks: Soda Ash Annual Report*, the primary national consumers of soda ash are glass manufacture (50 percent), chemicals (27 percent) and soap manufacture (11 percent) (USGS 2001). Since limited consumption data exists for the state of California, Standard Industrial Classifications (SIC) annual payroll data for California and total U.S. were compared for the glass and soap manufacturing industries. Chemical industry payroll data were assumed to mirror both glass and soap industry data. The ratios of state to national annual payrolls for the associated industries were used to apportion soda ash consumption from the national to state level.

In order to obtain CO_2 emissions from soda ash consumption in California, the soda ash consumption was multiplied by an emission factor of 0.415 tons CO_2/ton soda ash.

3.4.2. Data Sources

National soda ash consumption data were obtained from U.S. Geological Surveys, *Mineral Yearbooks: Soda Ash Annual Report*, (USGS 1994-2000). National and California payroll data for the glass and soap manufacturing industries were obtained from U.S. Census Bureau, *Annual Survey of Manufacturers* (U.S. CB 1996). SIC codes for glass manufacturing are 321 and 322, and the SIC code for soap manufacturing is 284.

The soda ash consumption emission factor was taken from the EIIP guidelines (EIIP 1999).

3.5. Carbon Dioxide Consumption

Carbon dioxide is produced from natural wells, as a by-product from chemical production, or by means of separation from crude oil and natural gas. This gas is also used for a variety of applications including enhanced oil recovery, chemical production, food processing, and carbonated beverages. Carbon dioxide produced from fossil fuel consumption, that is, CO_2 generated from chemical production processes that use hydrocarbon as a raw material (e.g. ammonia production), are accounted for in the Energy chapter. In addition, CO_2 used in enhanced oil recovery is considered to be sequestered, as it is re-injected into the ground and leak rates are uncertain.

Table 48 presents emissions from CO_2 consumption in California from 1990 to 1999. In 1999, CO_2 emissions from CO_2 consumption were 0.1 MMTCO_2 Eq. Emissions from this sector have shown a consistent upward trend, reflective of increasing CO_2 production capacity at both national and state levels. In 1999, eight percent of national emissions from CO_2 consumption were attributable to California. These emissions represent 0.03 percent of California’s gross greenhouse gas emissions in 1999.

Table 48: Emissions from CO_2 Consumption (MMTCO$_2$ Eq.)

Source	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999
CO_2 Consumption	0.07	0.08	0.08	0.08	0.08	0.09	0.11	0.12	0.12	0.13

3.5.1. Methodology

Carbon dioxide emission estimates were based on the assumption that, except for enhanced oil recovery that is considered sequestered, all end-use applications release 100 percent of the CO_2 manufactured. Because industries associated with CO_2 consumption are widespread throughout the United States, state emissions were estimated by pro-rating national emissions based on state CO_2 production capacity. Estimates of state-level emissions from CO_2 consumption were based on the following equation:

$$\textit{State } CO_2 \textit{ Emissions} = \textit{National } CO_2 \textit{ Emissions} \times \textit{State Production Capacity} \div \textit{National Production Capacity}$$

In order to estimate CO_2 emissions from carbon dioxide consumption in California, national emissions from CO_2 consumption were multiplied by the ratio of California's CO_2 production capacity to the national production capacity. Production capacity data were only available for the years 1990, 1992, 1993, 1995, 1996 and 1998. For years 1991, 1994, and 1997, production capacity was estimated through interpolation. For 1999, national and state production capacity was assumed to remain constant at 1998 levels.

3.5.2. Data Sources

National CO_2 emissions data were obtained from the U.S. Inventory (EPA 2001), as shown in Table 49. National- and state-level CO_2 production capacity data were obtained from the *Directory of Chemical Producers* (SRI 1990, 1992, 1993, 1995, 1996, 1998).

Table 49: National CO_2 Emissions from CO_2 Consumption (MMTCO$_2$ Eq.)

Gas	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999
CO_2	0.80	0.84	0.88	0.91	0.90	0.97	1.14	1.29	1.41	1.57

Source: EPA 2001

3.6. Nitric Acid Production

Nitrous oxide is generated as a by-product of nitric acid (HNO_3) production. Nitric acid is mainly used to produce synthetic commercial fertilizer and is also a component of adipic acid and explosives. Small quantities of nitric acid are also used in stainless steel pickling, metal etching, rocket propellants, and nuclear fuel processing.

Nitric acid production usually occurs through the catalytic oxidation of ammonia, where N_2O is released into the atmosphere as a by-product of the process (EPA 2001). Although the nitric acid industry regulates emissions of NO and NO_2, only non-selective catalytic reduction (NSCR) technologies are capable of further reducing N_2O emissions. Modern plants typically do not install NSCR technologies due to their high-energy costs and gas temperatures.

Table 50 presents the emissions from this sector in California from 1990 to 1999. In 1999, emissions from nitric acid production were 0.3 MMTCO$_2$ Eq. Between 1990 and 1999, emissions have fluctuated in line with California's nitric acid production levels. By 1999, emissions were approximately 48 percent lower than 1990 levels. In 1999, state-level emissions accounted for approximately one percent of national emissions from this source.

Table 50: Emissions from Nitric Acid Production (MMTCO$_2$ Eq.)

Source	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999
Nitric Acid Production	0.53	0.52	0.56	0.38	0.38	0.49	0.30	0.30	0.28	0.28

3.6.1. Methodology

Nitrous oxide emissions from nitric acid production were estimated using the following equation taken from the EIIP guidance (EIIP 1999):

$$N_2O\ Emissions = State\ Nitric\ Acid\ Production \times EF$$

In order to obtain state-level nitric acid production in California, national nitric acid production levels were multiplied by the ratio of California's nitric acid production capacity to the national production capacity. Production capacity data were only available for the years 1990, 1992, 1993, 1995, 1996 and 1998. For years 1991, 1994, and 1997, nitric acid production capacity was estimated through interpolation. For 1999, national and state production capacity was assumed to remain constant at 1998 levels. Estimated state nitric acid production was then multiplied by a default emission factor of 0.008 tons N_2O per ton nitric acid produced to determine state-level N_2O emissions.

3.6.2. Data Sources

National nitric acid production data was obtained from the U.S. Inventory (EPA 2001). National and state-level nitric production capacity data were obtained from the *Directory of Chemical*

Producers (SRI 1990, 1992, 1993, 1995, 1996, 1998). The N_2O emission factor was based on the IPCC guideline default (IPCC 2000).

3.7. Substitution of Ozone-Depleting Substances

Ozone-depleting substances (ODS) are being phased out under the terms of the Montreal Protocol and the Clean Air Act Amendments of 1990, and 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 industrial applications such as refrigeration and air conditioning equipment, solvent cleaning, foam production, sterilization, fire extinguishing, and aerosols. Hydrofluorocarbons and PFCs are now being used in most of these applications.

The trends of ODS substitute emissions in California echo the trends that appear on a national level. In the early 1990s, ODS substitute emissions primarily consisted of HFC-134a from refrigeration and motor vehicle air conditioning end-uses. By the mid-1990s, other end-uses, such as foam blowing, aerosol propellants, solvents and sterilization, began using a larger variety of high GWP substitutes. By 1995, ODS substitutes for halons entered widespread use in the United States as halon production was phased-out.

The use and subsequent emissions of HFCs and PFCs as ODS substitutes has been increasing from small amounts in 1990 to 7.0 $MMTCO_2$ Eq. in 1999 (Table 51). Although the absolute magnitude of emissions from ODS substitutes is relatively small (two percent of gross California emissions in 1999), its growth has been faster than any other sector. The increase has been driven by efforts to phase-out ODS in the United States. This trend is expected to continue, although improvements in the technologies associated with the use of ODS substitutes may help to offset further increases in these emissions.

Table 51: ODS Substitute Emission Estimates ($MMTCO_2$ Eq.)

Gas	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999
HFC-23	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.01	0.02	0.04
HFC-32	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
HFC-125	0.00	0.00	0.08	0.17	0.10	0.16	0.23	0.30	0.38	0.45
HFC-134a	0.09	0.09	0.10	0.46	1.01	2.29	3.01	3.73	4.29	4.87
HFC-143a	0.00	0.00	0.00	0.01	0.02	0.05	0.10	0.16	0.23	0.32
HFC-236fa	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.09	0.17
CF_4	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Others*	0.03	0.01	0.01	0.01	0.10	0.44	0.80	0.93	1.08	1.17
Total	**0.12**	**0.10**	**0.19**	**0.65**	**1.23**	**2.94**	**4.15**	**5.15**	**6.10**	**7.00**

Source: EPA 2001

*Others include HFC-152a, HFC-227ea, HFC-4310mee, and PFC/PFPEs, the latter being a proxy for a diverse collection of PFCs and perfluoropolyethers (PFPEs) employed for solvent applications. For estimating purposes, the global warming potential (GWP) value used for PFC/PFPEs was based upon C_6F_{14}.

Note: Totals may not sum due to independent rounding.

3.7.1. Methodology

The EIIP guidelines for estimating emissions from this source instruct states to disaggregate national estimates of ODS substitute emissions by applying a ratio of state to national population to the national emission estimates (EIIP 1999). Thus, California ODS substitute emissions for the years 1990 through 1999 were estimated based on the following equation:

California ODS substitute emissions = U.S. ODS substitute emissions ×

(California population / national population)

The EPA estimates ODS substitute emissions using a detailed vintaging model of ODS-containing equipment and products. The U.S. Inventory describes the vintaging model as follows:

> "The name of the model refers to the fact that the model tracks the use and emissions of various compounds for the annual "vintages" of new equipment that enter service in each end-use. This vintaging model predicts ODS and ODS substitute use in the United States based on modeled estimates of the quantity of equipment or products sold each year containing these chemicals and the amount of the chemical required to manufacture and / or maintain equipment and products over time. Emissions for each end-use are estimated by applying annual leak rates and release profiles, which account for the lag in emissions from equipment as they leak over time. By aggregating the data for more than 40 different end-uses, the model produces estimates of annual use and emissions of each compound." (EPA 2001)

3.7.2. Data Sources

Two primary data sources were used to develop estimates of ODS substitute emissions. National emission estimates of ODS substitutes (Table 52) were obtained from the U.S. Inventory (EPA 2001). National and state population estimates (Table 53) were obtained from the U.S. Census Bureau (2000) and the California State Department of Finance (2001), respectively.

Table 52: National Emissions of ODS Substitutes (MMTCO$_2$ Eq.)

Gas	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999
HFC-23	0.00	0.00	0.00	0.00	0.00	0.02	0.06	0.12	0.20	0.29
HFC-32	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.01
HFC-125	0.00	0.00	0.66	1.35	0.84	1.34	1.89	2.49	3.13	3.61
HFC-134a	0.73	0.73	0.81	3.75	8.17	18.65	24.65	30.52	34.91	39.44
HFC-143a	0.00	0.00	0.00	0.05	0.19	0.42	0.79	1.27	1.85	2.57
HFC-236fa	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.09	0.75	1.34
CF$_4$	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Others*	0.21	0.11	0.04	0.10	0.77	3.57	6.58	7.64	8.80	9.44
Total	**0.94**	**0.84**	**1.52**	**5.24**	**9.97**	**24.00**	**33.98**	**42.14**	**49.65**	**56.71**

Source: EPA 2001

*Others include HFC-152a, HFC-227ea, HFC-4310mee, and PFC/PFPEs, the latter being a proxy for a diverse collection of PFCs and perfluoropolyethers (PFPEs) employed for solvent applications. For estimating purposes, the GWP value used for PFC/PFPEs was based upon C_6F_{14}.

Note: Totals may not sum due to independent rounding.

Table 53: Ratio of California to U.S. Population

Year	CA Population	U.S. Population	Ratio
1990	30,595,770	249,464,396	0.12
1991	30,945,000	252,153,092	0.12
1992	31,478,000	255,029,699	0.12
1993	31,858,000	257,782,608	0.12
1994	32,075,000	260,327,021	0.12
1995	32,223,000	262,803,276	0.12
1996	32,396,000	265,228,572	0.12
1997	32,743,000	267,783,607	0.12
1998	33,186,000	270,248,003	0.12
1999	33,660,000	272,690,813	0.12
2000	34,207,000	281,421,906	0.12

3.8. Semiconductor Manufacturing

Two processes within the course of semiconductor manufacturing use and emit fluorinated greenhouse gases, such as trifluoromethane (HFC-23), perfluoromethane (CF_4), perfluoroethane (C_2F_6), and sulfur hexafluoride (SF_6). The exact combination of compounds is specific to the process employed. Plasma etching uses fluorinated compounds that selectively remove substrate material from the silicon to create pathways. Chemical vapor deposition chambers, which are used for used for depositing materials that will act as insulators and wires, are periodically cleaned using PFCs and other gases. A portion of the PFCs flowing into the chemical vapor deposition chamber flows through without reacting with the chamber and is emitted to the atmosphere, unless emission abatement technologies are used. Both processes also emit reacted fluorinated compounds. Because the exact combination of compounds used and the resulting reacted or unreacted compounds emitted are difficult to estimate on an individual basis, emissions are not estimated by gas, but are provided as weighted average total emissions in Table 54.

Table 54: Emissions of Fluorinated Compounds from Semiconductor Manufacturing (MMTCO$_2$ Eq.)

Source	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999
Semiconductor Manufacturing	0.36	0.36	0.36	0.46	0.52	0.67	0.86	0.86	0.84	0.84

Emissions from semiconductor manufacturing grew from 0.4 MMTCO$_2$ Eq. in 1990 to 0.8 MMTCO$_2$ Eq. in 1999, representing an increase of approximately 136 percent. This rapid growth is the result of not only the rapid growth in the semiconductor industry, but also the increasing complexity of the semiconductor products, which leads to greater use of PFCs per semiconductor chip. However, the growth in emissions is slowing down, and emissions from this sector have declined slightly since 1997. As reported in the U.S. Inventory (EPA 2001), this is due to the implementation of PFC emission reduction methods, which are expected to lead to even greater improvements over the next decade. Emissions from this sector were responsible for 0.2 percent of gross California emissions in 1999.

3.8.1. Methodology

The EIIP guidelines do not provide a method for estimating state-level emissions from this source. However, in an effort to make the California greenhouse gas inventory as comprehensive as possible, semiconductor manufacturing emissions have been estimated by apportioning national emissions from semiconductor manufacturing on the basis of population. Thus, California semiconductor manufacturing emissions for the years 1990 through 1999 were estimated based on the following equation:

California semiconductor manufacturing emissions =
U.S. semiconductor manufacturing emissions × (California population / national population)

The EPA estimates semiconductor manufacturing emissions using a combination of modeling methods and data provided by semiconductor manufacturers. The U.S. Inventory describes the methodology as follows:

> "Emissions have been estimated using two sets of data. For 1990 through 1994, emissions were estimated based on the historical consumption of silicon (square centimeters), the estimated average number of interconnecting layers in the chips produced, and an estimated per-layer emission factor. (The number of layers per chip, and hence the PFC emissions per square centimeter of silicon, increases as the line-width of the chip decreases.) The average number of layers per chip was based on industry estimates of silicon consumption by line-width and of the number of layers per line-width. The per-layer emission factor was based on the total annual emissions reported by the participants in the PFC Emission Reduction Partnership for the Semiconductor Industry. For the three years for which gas sales data are available (1992 to 1994), the estimates derived using this method are within 10 percent of the estimates derived using gas sales data and average values for emission factors and (GWPs)."
>
> "For 1995 through 1999, emissions were estimated based on the total annual emissions reported by the participants in the PFC Emission Reduction Partnership for the Semiconductor Industry. Partners estimate their emissions using a range of methods. The partners with relatively high emissions typically multiply estimates of their PFC consumption by process-specific emission factors that they have either measured or obtained from tool suppliers. To estimate total U.S. emissions from semiconductor manufacturing, based on reported partner emissions, a per-plant emission factor was estimated for the partners. This per-plant emission factor was then applied to PFC-using plants operated by semiconductor manufacturers who were not partners, considering the varying characteristics of the plants operated by partners and non-partners (e.g., typical plant size and employed linewidth technology). The resulting estimate of non-partner emissions was added to the emissions reported by the partners to obtain total U.S. emissions." (EPA 2001)

3.8.2. Data Sources

Three primary data sources were used to develop estimates of fluorinated greenhouse gas emissions from semiconductor manufacturing. National emission estimates (Table 55) were obtained from the U.S. Inventory (EPA 2001). National and state population estimates (Table 53) were obtained from the U.S Census Bureau (2000) and the California State Department of Finance (2001), respectively.

Table 55: National Fluorinated Greenhouse Gas Emissions from Semiconductor Manufacturing ($MMTCO_2$ Eq.)

	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999
Semiconductor Manufacturing	2.90	2.90	2.90	3.70	4.22	5.50	7.00	7.00	6.80	6.80

Source: EPA 2001

3.9. Electric Utilities

Sulfur hexafluoride (SF_6) gas is mostly used as an electrical insulator in circuit breakers, gas-insulated substations, and switchgear. This equipment is used in the transmission and distribution of electricity (EPA 2001). The advantages of SF_6 include reduced flammability as well as allowing for more compact substations in dense urban areas (EPA 2001).

Sulfur hexafluoride emissions occur due to leaks and faulty seals, particularly in older equipment. Other emissions occur during installation and servicing. Venting does not occur much these days, due to increased awareness and increased costs of SF_6.

As shown in Table 56, emissions of SF_6 have increased by 17 percent between 1990 and 1999, from 1.6 to 1.9 $MMTCO_2$ Eq. This trend is also reflected in total electricity consumption in California, which was at its highest in 1999. These emissions were 0.4 percent of gross emissions in California and 7 percent of national emissions from this source.

Table 56: SF_6 Emissions from Electric Utilities ($MMTCO_2$ Eq.)

Gas	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999
SF_6	1.60	1.63	1.74	1.74	1.80	1.81	1.81	1.87	1.80	1.87

3.9.1. Methodology

Since state-level SF_6 data are not available, state guidance provided in the EIIP guidance recommends that SF_6 emissions be estimated using the following equation (EIIP 1999):

$$\boxed{\begin{array}{c}\textit{State } SF_6 \textit{ Emissions} = \textit{National } SF_6 \textit{ Emissions} \times \textit{State Electricity Consumption} \\ \div \textit{ National Electricity Consumption}\end{array}}$$

This method treats electricity consumption data as a proxy for estimating fugitive SF_6 emissions occurring at equipment used in electricity transmission and distribution. The ratio of state electricity to national electricity consumption was used to pro-rate national emissions. State SF_6 emissions were calculated as the product of its relative share of national electricity consumption and national emissions.

3.9.2. Data Sources

National SF_6 emissions estimates (Table 57) were obtained from the U.S. Inventory (EPA 2001). National and state electricity consumption data were obtained from the Energy Information Administration's *Annual Energy Review 2000* (EIA 2001).

Table 57: National SF_6 Emission Estimates from Electric Utilities (MMTCO$_2$ Eq.)

Gas	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999
SF_6	20.50	21.54	22.58	23.62	24.66	25.70	25.70	25.70	25.70	25.70

Source: EPA 2001

CHAPTER 4 – AGRICULTURE

4.0 Agriculture

Methane (CH_4) and nitrous oxide (N_2O) are emitted from a variety of agricultural sources, including enteric fermentation, manure management, rice cultivation, agricultural soil management, and agricultural residue burning.

California agriculture generated 12.9 million metric tons of carbon dioxide equivalent emissions ($MMTCO_2$ Eq.) of CH_4 and 15.6 $MMTCO_2$ Eq. of N_2O, for a total of approximately 28.4 $MMTCO_2$ Eq. of greenhouse gas emissions in 1999 (Table 58). Emissions from agriculture represented nearly seven percent of 1999 gross emissions in California. In 1999, California's agricultural emissions represented approximately six percent of national emissions from agricultural sources.

Agricultural soil management is the primary source of agricultural N_2O emissions, yielding 95 percent of emissions in 1999. Methane emissions from agriculture are driven by enteric fermentation and manure management, representing 55 and 41 percent of 1999 emissions, respectively.

Table 58: Emissions from Agriculture ($MMTCO_2$ Eq.)

Gas/Source	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999
CH_4	**11.26**	**11.51**	**11.74**	**11.11**	**11.98**	**12.33**	**11.87**	**12.34**	**12.17**	**12.85**
Enteric Fermentation	7.53	7.25	7.37	6.59	7.14	7.25	6.77	6.88	6.84	7.08
Manure Management	3.29	3.87	3.93	4.03	4.30	4.55	4.55	4.88	4.80	5.21
Rice Cultivation	0.41	0.36	0.41	0.45	0.50	0.48	0.52	0.54	0.50	0.52
Agricultural Residue Burning	0.03	0.03	0.03	0.04	0.04	0.04	0.04	0.04	0.04	0.04
N_2O	**15.82**	**14.19**	**14.50**	**15.51**	**14.86**	**16.76**	**16.32**	**14.92**	**15.26**	**15.57**
Agricultural Soils	14.93	13.35	13.68	14.69	14.04	15.93	15.51	14.10	14.45	14.74
Manure Management	0.81	0.76	0.74	0.72	0.70	0.72	0.70	0.70	0.70	0.71
Agricultural Residue Burning	0.09	0.08	0.09	0.10	0.11	0.11	0.11	0.11	0.11	0.12
Total	**27.09**	**25.70**	**26.24**	**26.62**	**26.84**	**29.09**	**28.20**	**27.25**	**27.43**	**28.42**

Note: Totals may not sum due to independent rounding.

4.1. Enteric Fermentation

Methane is produced in the digestive systems of animals, as microbes ferment food consumed by the animal. This process, known as enteric fermentation, results in the production and eventual release of CH_4 through exhalation or eructation. The quantity of CH_4 produced is dependent on the type of digestive system and the diet characteristics of the animal.

Animals can have either a ruminant or non-ruminant digestive system. Ruminants, such as cattle, sheep, goats, camels, and buffalo, emit the majority of CH_4 because fermentation occurs in their rumen, or fore stomach. The fore stomach allows coarse plant material to be digested through microbial fermentation, so that the animal can use the products. Non-ruminant animals, such as pigs, horses, mules, rabbits, and guinea pigs, produce CH_4 through microbial fermentation in the large intestine. Fermentation in the large intestine produces less CH_4 than fermentation in the fore stomach; thus, these animals produce less CH_4 (on a per-animal basis) than ruminant animals.

Table 59 shows methane emission estimates from enteric fermentation. Total emissions from livestock in California in 1999 were 7.1 $MMTCO_2$ Eq.

Table 59: CH_4 Emissions from Enteric Fermentation in California (10^3 $MTCO_2$ Eq.)

Livestock Type	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999
Dairy Cattle	3,669	3,742	3,861	3,548	3,824	3,878	3,556	3,752	3,776	4,052
Beef Cattle	3,444	3,089	3,089	2,637	2,885	2,951	2,800	2,724	2,673	2,630
Horses	240	241	242	243	242	243	244	244	245	248
Sheep	168	171	167	150	181	171	155	148	134	136
Swine	6	7	8	8	8	8	7	7	7	6
Goats	4	4	4	4	4	4	4	4	4	4
Total	**7,531**	**7,253**	**7,371**	**6,590**	**7,144**	**7,255**	**6,765**	**6,879**	**6,839**	**7,076**

Note: Totals may not sum due to independent rounding.

On average, CH_4 produced through the process of enteric fermentation accounted for two percent of gross California emissions, with emissions of 7.5 $MMTCO_2$ Eq. in 1990 and 7.1 $MMTCO_2$ Eq. in 1999. Overall, emissions from this source decreased by six percent between 1990 and 1999, with maximum emissions occurring in 1990, and a great deal of fluctuation in the following years. The main driver for this decrease is the declining beef cattle population in California during the ten-year period. Emissions from enteric fermentation in California represent roughly six percent of U.S. emissions from this source. In the United States, CH_4 emissions from enteric fermentation account for approximately two percent of gross emissions and have decreased two percent since 1990. The national decrease in emissions is driven by a decrease in both dairy cattle populations and emission factors.

Because emissions by animal type are estimated based on animal populations and animal-specific emission factors, animals with the greatest populations and highest emission factors are likely to account for the majority of emissions. Thus, the majority of emissions from enteric fermentation—both in California and in the United States—are attributable to beef and dairy cattle.

4.1.1. Methodology

Due to their large population, large size, and particular digestive characteristics, cattle account for the majority of CH_4 emissions from livestock in California. Additionally, cattle production systems are better characterized in comparison with other livestock management systems. As a result, a more detailed methodology, i.e., Intergovernmental Panel on Climate Change (IPCC) Tier 2, was used for estimating emissions from cattle. Emission estimates for sheep, goats, swine, and horses were handled using the simpler IPCC Tier 1 approach.

The methodology for estimating emissions from enteric fermentation is based on the methodology utilized in the *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-1999* (EPA 2001), where it is described using the four steps below.

Step 1: Characterize the Cattle Population

Each stage in the cattle life cycle was modeled to simulate the cattle population from birth to slaughter. This level of detail accounts for the variability in methane emissions associated with each life stage. Given cattle often remain in one stage for less than one year (e.g., beef calves are weaned at seven months), the stages are modeled on a per month basis. The type of cattle use also impacts methane emissions (e.g., beef versus dairy). Consequently, cattle life stages were modeled for several categories of dairy and beef cattle.” (EPA 2001)

The categories used to estimate population include:

- calves;
- dairy cows;
- dairy heifer replacements;
- beef cows;
- beef heifer replacements;
- heifer and steer stockers;
- feedlot animals; and
- bulls.

The statistics gathered for each category include birth estimates, end of year population data, feedlot placement information, and slaughter weight data. These statistics were used in the model to initiate and track cohorts of individual animal types having distinct emission profiles. Other performance factors, such as pregnancy, lactation, average weights, and weight gain, are also tracked for each of the cattle population categories.

Table 60 shows the average annual population for each cattle category. Note that these populations differ from those reported by the California Agricultural Statistics Service (CASS) to the U.S. Department of Agriculture (USDA) because the model calculates monthly population variations. As a result, the cattle population modeled for estimates of emissions from enteric fermentation will not correspond to the cattle population used to estimate emissions from manure management, which is taken from the USDA estimates. Calf populations are not given, because cattle do not emit CH_4 until they are weaned. Populations of cattle from age 0-6 months are used only to track populations as they get older and begin to emit CH_4.

Table 60: Average Annual Cattle Populations by Sub-Category (1,000 Head)

Livestock Type	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999
Dairy Cows	1,115	1,150	1,160	1,200	1,233	1,271	1,320	1,379	1,399	1,440
Dairy Replacements (7-12 Months)	153	150	166	165	182	186	191	192	201	210
Dairy Replacements (12-23 Months)	367	355	390	392	430	444	457	462	470	504
Beef Cows	955	900	880	840	861	849	838	816	815	810
Beef Replacements (7-12 Months)	37	37	36	34	37	36	35	34	33	33
Beef Replacements (12-23 Months)	87	87	82	78	88	88	85	84	81	78
Steer Stockers	423	329	374	391	391	385	377	368	344	284
Heifer Stockers	0	36	63	31	32	20	46	27	13	13
Feedlot Animals	446	346	332	159	311	366	307	328	339	378
Bulls*	71	70	69	69	75	75	70	69	64	69

*Only the end-of-year census statistics were used for bulls.

Step 2: Characterize Cattle Nutrition

> "To support development of digestible energy (DE, the percent of gross energy intake digestible to the animal) and methane conversion rate (Y_m, the fraction of gross energy converted to methane) values for each of the cattle population categories, data were collected on diets considered representative of different regions. For both grazing animals and animals being fed mixed rations, representative regional diets were estimated using information collected from state livestock specialists and from USDA (1996a). The data for each of the diets (e.g., proportions of different feed constituents, such as hay or grains) were used to determine chemical composition for use in estimating DE and Y_m for each animal type."
>
> "DE and Y_m values were estimated for each cattle population category based on physiological modeling and expert opinion. DE and Y_m values for dairy cows and most grazing animals were estimated using a model (Donovan and Baldwin

> 1999) that represents physiological processes in the ruminant animals. The three major categories of input required by the model are animal description (e.g., cattle type, mature weight), animal performance (e.g., initial and final weight, age at start of period), and feed characteristics (e.g., chemical composition, habitat, grain or forage). Data used to simulate ruminant digestion is provided for a particular animal that is then used to represent a group of animals with similar characteristics. The model accounts for differing diets (i.e., grain-based, forage-based, range-based), so that Y_m values for the variable feeding characteristics within the U.S. cattle population can be estimated."
>
> "For feedlot animals, DE and Y_m values were taken from Johnson (1999). In response to peer reviewer comments (Johnson 2000), values for dairy replacement heifers are based on EPA (1993)." (EPA 2001)

These diet characteristics are used to implement the equations described for Tier 2 in the *Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Inventories* (IPCC 2000).

Table 61 shows the average annual emission factors implied by the models calculations.

Table 61: Implied Emission Factors for Cattle, by Sub-Category (kg CH_4/head/yr)

Livestock Type	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999
Dairy Cows	130	130	131	115	120	117	101	103	101	106
Dairy Replacements (7-12 Months)	40	40	40	40	40	40	40	40	40	40
Dairy Replacements (12-23 Months)	63	63	63	63	63	63	63	63	63	63
Beef Cows	83	83	83	83	83	83	83	83	83	83
Beef Replacements (7-12 Months)	47	47	47	47	47	47	47	47	47	47
Beef Replacements (12-23 Months)	74	74	74	74	74	74	74	74	74	74
Steer Stockers	64	64	64	64	64	64	64	64	64	64
Heifer Stockers	NA	56	57	57	57	57	57	57	57	57
Feedlot Animals	47	49	47	46	37	38	35	33	33	33
Bulls*	100	100	100	100	100	100	100	100	100	100

*The national emission factor was used for bulls.

Step 3: Determine Cattle Emissions

> "In order to estimate methane emissions from cattle, the population was divided into region, age, sub-type (e.g., calves, heifer replacements, cows, etc.), and production (i.e., pregnant, lactating, etc.) groupings to more fully capture any differences in methane emissions from these animal types. Cattle diet

> characteristics developed under Step 2 were used to develop regional emission factors for each sub-category. Tier 2 equations from IPCC (2000) were used to produce methane emission factors for the following cattle types: dairy cows, beef cows, dairy replacements, beef replacements, steer stockers, heifer stockers, steer feedlot animals, heifer feedlot animals, and steer and heifer feedlot step-up diet animals. To estimate emissions from cattle, population data were multiplied by the emission factor for each cattle type." (EPA 2001)

Table 62 shows emissions for each cattle sub-category.

Table 62: CH_4 Emissions from Enteric Fermentation from Cattle, by Sub-Category (Gg)

Livestock Type	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999
Dairy Cows	145	150	153	137	148	149	133	142	142	153
Dairy Replacements (7-12 Months)	6	6	7	7	7	8	8	8	8	8
Dairy Replacements (12-23 Months)	23	22	25	25	27	28	29	29	30	32
Beef Cows	80	75	73	70	72	71	70	68	68	68
Beef Replacements (7-12 Months)	2	2	2	2	2	2	2	2	2	2
Beef Replacements (12-23 Months)	6	6	6	6	6	6	6	6	6	6
Steer Stockers	27	21	24	25	25	25	24	24	22	18
Heifer Stockers	0	2	4	2	2	1	3	2	1	1
Feedlot Animals	21	17	16	7	12	14	11	11	11	12
Bulls	7	7	7	7	7	8	7	7	6	7

Step 4: Determine Other Livestock Emissions

Emission estimates for other animal types, including sheep, goats, swine, and horses, were based upon average emission factors representative of entire populations of each animal type. Methane emissions from these animals accounted for a minor portion of total CH_4 emissions from livestock in California from 1990 through 1999. Populations and emission factors used in calculating emissions from other livestock are shown in Table 63 and Table 64, respectively.

Table 63: Populations for Other Domesticated Livestock (1,000 Head)

Livestock Type	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999
Horses	635	638	641	642	640	642	644	644	647	655
Sheep	1,000	1,015	995	895	1,080	1,020	920	880	800	810
Swine	195	215	265	260	255	240	210	210	210	190
Goats	34	34	34	35	36	38	39	40	40	40

Source: AHC 1996; FAO 2001; USDA 1994a-b; 1998b; 1999d,g,e; 2000b,d

Table 64: Emission Factors for Other Domesticated Livestock (kg CH_4/head/year)

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

Source: IPCC 2000

4.1.2. Data Sources

Data for non-equine animal populations was state-level data compiled from data collected by the California Agricultural Statistics Service (CASS) (Coe 2001) and published in reports issued by the National Agricultural Statistics Service (NASS) of the U.S. Department of Agriculture (USDA 1994a-b, 1995a-b, 1996, 1997, 1998a-b, 1999a-g, 2000a-e). Since equine data was not available at the state-level, the equine population was estimated using California data for 1995 from the American Horse Council (AHC 1996) in conjunction with national population statistics available from the Food and Agriculture Organization (FAO 2001). Horses were assumed to constitute the entire equine population, since their numbers overwhelm any of the other equine animal types. Diet characterizations and the associated emission factors for cattle were taken from the model used in the U.S. Inventory (EPA 2001). Most of these emission factors were available at the regional level; however, there exists an emission factor specific to California because it comprises an entire region. Emission factors for bulls and other livestock were obtained from the *Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Inventories* (IPCC 2000), and are consistent with the U.S. Inventory.

4.2. Manure Management

Methane and N_2O are both produced during the management of livestock manure. Methane is produced when manure decomposes anaerobically. Nitrous oxide is produced from the nitrogen in manure and urine as it goes through the nitrogen cycle and the processes of nitrification and denitrification.

If manure is managed in a liquid storage system (e.g., lagoons, ponds, tanks, or pits) anaerobic conditions occur and CH_4 is produced as a result. If manure is managed as a solid or deposited on pastures or rangelands, the aerobic conditions produce little or no CH_4 during decomposition. Other factors that contribute to the amount of CH_4 produced are temperature, moisture levels, and manure composition. Generally as temperature and moisture increase, so does the amount of CH_4 produced. Manure composition is dependent on diet type, with diets consisting of higher energy content and digestibility producing greater quantities of CH_4.

Nitrous oxide emissions from livestock manure and urine occur when the waste first goes through a period of aerobic decomposition, followed by a period of anaerobic decomposition. This process allows nitrification (conversion of ammonia nitrogen to nitrites) to occur during the aerobic phase and denitrification (conversion of nitrites to N_2O) to occur during the anaerobic stage. Emissions of N_2O are likely to occur in management systems that will provide these conditions. For example, conditions in a drylot system are generally aerobic, allowing nitrification to occur. However, anaerobic pockets may develop after periods of rain, enabling the waste to undergo denitrification and thus produce N_2O emissions.

Some of these N_2O emissions from livestock manure and urine are accounted for under agricultural soil management. These include manure and urine on pastures, ranges, or paddocks, as well as manure that is spread directly on fields or as daily spread after removal from a management system (e.g., lagoon, pit, etc.). All other N_2O emissions associated with manure management are estimated in this section.

Table 65 shows methane emission estimates from manure management. Methane emissions from livestock in California in 1999 were 5.2 $MMTCO_2$ Eq. Total manure N_2O emissions in California in 1999 were 0.7 $MMTCO_2$ Eq. (Table 66). Total emissions from manure management in California were 5.9 $MMTCO_2$ Eq. (Table 67).

Table 65: CH_4 Emissions from Manure Management (10^3 $MTCO_2$ Eq.)

Livestock Type	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999
Beef Cattle	99	92	88	90	88	90	85	86	86	89
Dairy Cattle	2,920	3,492	3,543	3,652	3,919	4,170	4,183	4,508	4,431	4,834
Swine	64	72	90	88	86	87	75	76	68	65
Poultry	136	137	133	126	130	133	133	139	138	146
Other	72	74	75	76	76	75	74	74	73	74
Sheep	12	15	15	16	16	15	14	13	12	12
Goats	2	2	2	2	2	2	2	2	2	2
Horses	57	58	58	58	58	58	58	58	59	59
Total	**3,291**	**3,869**	**3,930**	**4,032**	**4,299**	**4,555**	**4,550**	**4,882**	**4,796**	**5,208**

Note: Totals may not sum due to independent rounding.

Table 66: N2O Emissions from Manure Management (103 MTCO2 Eq.)

Livestock Type	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999
Beef Cattle	166	142	128	148	121	136	110	123	130	134
Dairy Cattle	261	257	276	277	297	304	309	314	321	342
Swine	0	0	0	0	0	0	0	0	0	0
Poultry	369	349	320	279	270	270	265	253	237	225
Other	10	12	12	13	13	12	12	11	11	11
Sheep	7	9	9	10	10	9	8	8	7	7
Goats	3	3	3	3	3	3	3	3	3	3
Horses	-	-	-	-	-	-	-	-	-	-
Total	**806**	**759**	**736**	**716**	**702**	**724**	**696**	**702**	**699**	**712**

Note: Totals may not sum due to independent rounding.

Table 67: Total Emissions from Manure Management (10^3 MTCO$_2$ Eq.)

Livestock Type	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999
Beef Cattle	264	234	216	238	210	227	196	209	216	223
Dairy Cattle	3,181	3,749	3,819	3,929	4,216	4,474	4,492	4,822	4,752	5,176
Swine	64	73	90	88	86	87	75	76	68	65
Poultry	505	486	454	405	400	403	398	392	375	371
Other	82	86	87	88	89	88	86	85	83	84
Sheep	20	24	24	25	26	24	22	21	19	19
Goats	5	5	5	5	5	5	5	5	5	5
Horses	57	58	58	58	58	58	58	58	59	59
Total	**4,096**	**4,628**	**4,666**	**4,748**	**5,001**	**5,279**	**5,246**	**5,584**	**5,494**	**5,919**

Note: Totals may not sum due to independent rounding.

In California, manure management resulted in one percent of gross state emissions in 1999. Methane accounted for the majority of emissions with 88 percent, while N_2O emissions represent 12 percent of total emissions from this source in 1999. Over the period from 1990 through 1999, emissions from manure management increased by more than 44 percent, due almost entirely to the increase in CH_4 emissions from dairy cows. Dairy cow CH_4 emissions increased 65 percent as a result of increases in population, volatile solids (VS) production, and the weighted MCF.

U.S. emissions from manure management followed a similar trend during this period. Total emissions from manure management in the United States rose from 42.4 $MMTCO_2$ Eq. in 1990 to 51.6 $MMTCO_2$ Eq. in 1999, a 22 percent increase (EPA 2001). This trend in U.S. emissions was driven by increased emissions from both swine and dairy cows.

Dairy cattle accounted for the majority of CH_4 emissions from manure management, followed by poultry, beef cattle, swine, horses, sheep and goats. In the United States, swine are responsible for the greatest CH_4 emissions from manure management, followed by dairy cattle, beef cattle, and poultry. Methane emissions from manure management in California represented 15 percent of 1999 U.S. emissions from this source.

As shown in Table 66, the majority of N_2O emissions from manure management in California were from poultry and dairy cattle, followed beef cattle, with minor emissions from sheep and goats. Similarly in the United States, poultry are the greatest source of N_2O emissions, followed by beef and dairy cattle. Nitrous oxide emissions from manure management in California represented four percent of 1999 U.S. emissions from this source.

4.2.1. Methodology

Methane and N_2O emissions from manure management systems are estimated using the methods outlined in *EIIP Volume VIII: Estimating Greenhouse Gas Emissions* (EIIP 1999) and the *Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Inventories* (IPCC 2000). Both types of emissions are functions of livestock populations, animal-specific emissions factors, manure management practices, and emission factors for manure management. Table 68 through Table 73 present the livestock populations, animal-specific data, methane conversion factors (MCFs), N_2O emission factors, and manure management system data used in this analysis. The steps for calculating the CH_4 and N_2O emissions are outlined below.

4.2.1.1. Methane Emissions

The main driver of CH_4 emissions from this source is the quantity of volatile solids produced by livestock. Volatile solids are defined as the solid organic fraction of manure that will oxidize and be driven off as a gas at a temperature of 1,112 degrees Fahrenheit. To estimate the amount of volatile solids, livestock population is multiplied by a typical animal mass (TAM) factor and the ratio of volatile solids to TAM. The potential CH_4 emissions are then calculated by multiplying the volatile solids by an animal-specific CH_4 generating capacity factor. Finally, potential CH_4 emissions are multiplied by a weighted MCF that accounts for the percent of the population in each management system and the effect that each particular management system has on CH_4 emissions. The MCF is always between zero and one, with zero representing a zero emissions management practice and one representing a practice that maximizes CH_4 emissions.

4.2.1.2. Nitrous Oxide Emissions

The main driver of N_2O emissions is the amount of unvolatilized nitrogen in manure, either organically bound or in the form of ammonia. This quantity of nitrogen is termed the total Kjeldahl nitrogen. Kjeldahl nitrogen is estimated as the product of animal population, TAM, and the ratio of TAM to Kjeldahl nitrogen. Eighty percent of the total Kjeldahl nitrogen was considered to remain unvolatilized. To calculate emissions, the unvolatilized nitrogen is multiplied by an emission factor and weighted by the management systems used, expressing the amount of nitrogen emitted as N_2O. It is important to note that this method only calculates emissions for managed systems; N_2O emissions from manure applied to agricultural soils via daily spread operations or deposition onto pasture, range, or paddock are accounted for in the section of this chapter on agricultural soil management.

Table 68: Annual Livestock Populations by Sub-Category (1,000 Head)

Livestock Type	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999
Beef										
Feedlot Steers	371	305	275	321	272	305	242	275	289	293
Feedlot Heifers	90	90	82	90	67	75	65	68	72	81
NOF Bulls	71	70	69	69	75	75	70	69	64	69
NOF Calves	1,227	1,337	1,210	1,243	1,348	1,331	1,335	1,339	1,365	1,465
NOF Heifers	235	236	241	222	238	229	240	226	212	225
NOF Steers	344	288	324	308	361	334	367	345	307	323
NOF Cows	962	912	892	859	872	861	845	824	826	815
Dairy										
Dairy Cows	1,114	1,140	1,158	1,203	1,230	1,271	1,319	1,379	1,400	1,441
Dairy Heifers	521	505	553	548	601	613	619	623	638	687
Swine										
Breeding Swine	28	29	37	33	32	31	27	27	27	25
Market Swine	167	186	228	227	223	209	183	183	183	165
Market<60lb.	60	64	82	74	70	65	57	60	70	55
Market 60-119 lb.	49	51	58	60	65	58	51	45	50	50
Market 120-179 lb.	31	40	45	49	45	44	40	45	40	35
Market >180 lb.	27	31	43	44	43	42	35	33	23	25
Poultry										
Layers	35,900	35,200	33,300	31,300	31,500	29,700	29,800	30,500	29,993	31,248
Hens > 1 yr	18,000	17,200	17,700	16,500	17,200	16,860	16,520	15,270	14,350	13,568
Pullets	17,690	17,900	15,500	14,700	14,218	12,750	13,230	15,090	15,558	17,600
Chickens	210	100	100	100	82	90	50	140	85	80
Broilers	42,018	43,673	42,364	39,273	41,127	42,873	42,582	43,145	43,145	43,145
Turkeys	13,125	11,757	10,500	8,654	7,875	8,049	8,036	7,326	6,477	5,833
Other										
Sheep	1,000	1,015	995	895	1,080	1,020	920	880	800	810
Feedlot	225	280	285	305	305	288	259	248	226	228
Not on Feed	775	735	710	590	775	732	661	632	574	582
Goats	34	34	34	35	36	38	39	40	40	40
Horses	635	638	641	642	640	642	644	644	647	655

Source: AHC 1996, FAO 2001, USDA 1994a-6, 1995a-b, 1998a-b, 1999a-d, 2000a-g

Table 69: Constants for Calculating Emissions

Livestock Type	Average TAM (kg)	Total Kjeldahl Nitrogen (kg/day/ 1000 kg mass)	Volatile Solids (VS) (kg/day/1000 kg mass)	Maximum CH_4 Generation Potential (m^3 CH_4/kg VS)
Feedlot Steers	420	0.3	5.44	0.33
Feedlot Heifers	420	0.3	5.44	0.33
NOF Bulls	750	0.31	6.04	0.17
NOF Calves	159	0.3	6.41	0.17
NOF Heifers	590	0.33	6.20	0.17
NOF Steers	318	0.31	6.04	0.17
NOF Cows	420	0.31	6.04	0.17
Dairy Cows	604	0.44	See Table 70	0.24
Dairy Heifers	476	0.31	7.77	0.17
Breeding Swine	198	0.24	2.6	0.48
Market Swine <60 lb.	15.9	0.60	8.8	0.48
Market Swine 60-119 lb.	40.6	0.42	5.40	0.48
Market Swine 120-179 lb.	67.8	0.42	5.40	0.48
Market Swine >180 lb.	90.8	0.42	5.40	0.48
Hens > 1 yr	1.8	0.83	10.8	0.39
Pullets	1.8	0.62	9.7	0.39
Chickens	1.8	0.83	10.8	0.39
Broilers	0.9	1.10	15.00	0.36
Turkeys	6.8	0.74	9.70	0.36
Sheep on Feed	27	0.42	9.21	0.36
Sheep not on Feed	27	0.42	9.21	0.19
Goats	64	0.45	9.53	0.17
Horses	450	0.30	10.00	0.33

Source: EIIP 1999, EPA 2001

Table 70: Volatile Solids Produced Per Cow Based on Milk Production (kg/day/1000 kg mass)

Livestock Type	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999
Dairy Cows	8.50	8.52	8.57	8.61	8.96	8.80	8.69	8.87	8.77	9.11

Source: EPA 2001

Table 71: Weighted MCFs by Animal Type (percent)

Livestock Type	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999
Beef										
Feedlot Steers	1.9%	1.9%	1.9%	1.9%	1.9%	1.9%	1.9%	1.9%	1.9%	1.9%
Feedlot Heifers	1.9%	1.9%	1.9%	1.9%	1.9%	1.9%	1.9%	1.9%	1.8%	1.9%
NOF Bulls	1.2%	1.2%	1.2%	1.2%	1.2%	1.2%	1.2%	1.2%	1.2%	1.2%
NOF Calves	1.2%	1.2%	1.2%	1.2%	1.2%	1.2%	1.2%	1.2%	1.2%	1.2%
NOF Heifers	1.2%	1.2%	1.2%	1.2%	1.2%	1.2%	1.2%	1.2%	1.2%	1.2%
NOF Steers	1.2%	1.2%	1.2%	1.2%	1.2%	1.2%	1.2%	1.2%	1.2%	1.2%
NOF Cows	1.2%	1.2%	1.2%	1.2%	1.2%	1.2%	1.2%	1.2%	1.2%	1.2%
Dairy										
Dairy Cows	41.5%	48.4%	48.1%	47.5%	47.9%	50.2%	49.2%	49.7%	48.6%	49.7%
Dairy Heifers	1.8%	1.8%	1.8%	1.8%	1.8%	1.8%	1.8%	1.8%	1.8%	1.8%
Swine										
Breeding Swine	45.2%	45.9%	45.9%	45.1%	45.4%	47.7%	47.2%	47.7%	46.1%	47.2%
Market Swine										
Market<60lb.	45.0%	45.8%	45.7%	45.0%	45.3%	47.8%	47.3%	47.9%	46.3%	47.4%
Market 60-119 lb.	45.0%	45.8%	45.7%	45.0%	45.3%	47.8%	47.3%	47.9%	46.3%	47.4%
Market 120-179 lb.	45.0%	45.8%	45.7%	45.0%	45.3%	47.8%	47.3%	47.9%	46.3%	47.4%
Market >180 lb.	45.0%	45.8%	45.7%	45.0%	45.3%	47.8%	47.3%	47.9%	46.3%	47.4%
Poultry										
Layers										
Hens > 1 yr	7.4%	7.8%	8.1%	8.3%	8.7%	9.4%	9.4%	9.8%	10.1%	10.6%
Pullets	7.4%	7.8%	8.1%	8.3%	8.7%	9.4%	9.4%	9.8%	10.1%	10.6%
Chickens	7.4%	7.8%	8.1%	8.3%	8.7%	9.4%	9.4%	9.8%	10.1%	10.6%
Broilers	1.5%	1.5%	1.5%	1.5%	1.5%	1.5%	1.5%	1.5%	1.5%	1.5%
Turkeys	1.5%	1.5%	1.5%	1.5%	1.5%	1.5%	1.5%	1.5%	1.5%	1.5%
Other										
Sheep										
Feedlot	10.0%	10.0%	10.0%	10.0%	10.0%	10.0%	10.0%	10.0%	10.0%	10.0%
Not on Feed	1.2%	1.2%	1.2%	1.2%	1.2%	1.2%	1.2%	1.2%	1.2%	1.2%
Goats	10.0%	10.0%	10.0%	10.0%	10.0%	10.0%	10.0%	10.0%	10.0%	10.0%
Horses	1.2%	1.2%	1.2%	1.2%	1.2%	1.2%	1.2%	1.2%	1.2%	1.2%

Source: EIIP 1999, EPA 2000

Table 72: Weighted N_2O Emission Factors for Managed Systems (kg N_2O/kg N excreted)

Livestock Type	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999
Beef										
Feedlot	0.0200	0.0200	0.0200	0.0200	0.0200	0.0200	0.0200	0.0200	0.0200	0.0200
Not on Feed	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Dairy										
Dairy Cows	0.0020	0.0020	0.0020	0.0020	0.0019	0.0019	0.0019	0.0019	0.0019	0.0019
Dairy Heifers	0.0200	0.0200	0.0200	0.0200	0.0200	0.0200	0.0200	0.0200	0.0200	0.0200
Swine	0.0017	0.0017	0.0017	0.0017	0.0017	0.0017	0.0017	0.0017	0.0017	0.0017
Poultry										
Layers	0.0114	0.0106	0.0098	0.0091	0.0083	0.0076	0.0068	0.0060	0.0053	0.0045
Broilers & Turkeys	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02
Sheep										
Feedlot	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02
Not on Feed	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Goats	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02
Horses	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA

Source: EIIP 1999, EPA 2000

Table 73: Percent of Manure Managed by Animal Type (percent)

Livestock Type	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999
Beef										
Feedlot	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
Not on Feed	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Dairy										
Dairy Cows	86%	86%	86%	87%	87%	87%	88%	88%	88%	88%
Dairy Heifers	86%	86%	86%	87%	87%	87%	88%	88%	88%	88%
Swine	10%	10%	10%	10%	10%	10%	10%	10%	10%	10%
Poultry										
Layers & Broilers	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
Turkeys	93%	93%	93%	93%	93%	93%	93%	93%	93%	93%
Sheep										
Feedlot	100%	100%	99%	99%	100%	100%	100%	100%	100%	100%
Not on Feed	0%	0%	1%	1%	0%	0%	0%	0%	0%	0%
Goats	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
Horses	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%

Source: EIIP 1999, EPA 2000

4.2.2. Data Sources

Non-equine animal populations were compiled from data collected by the California Agricultural Statistics Service (CASS) (Coe 2001) and published in reports issued by the National Agricultural Statistics Service (NASS) of the U.S. Department of Agriculture (USDA 1994a-b, 1995a-b, 1998a-b, 1999a-d, 2000a-g). Since equine data was not available at the state level, the equine population was estimated using California data for 1995 from the American Horse Council (AHC 1996) in conjunction with national population statistics available from the Food and Agriculture Organization (FAO 2001). Horses were assumed to constitute the entire equine population, since their numbers overwhelm any of the other equine animal types.

Where possible, state-level data was taken from the analysis used for the U.S. Inventory (EPA 2001). Data gleaned from this source includes:

- typical animal mass (TAM) for each livestock type;
- Kjeldahl nitrogen for each livestock type;
- volatile solid production for each livestock type, except sheep, goats, and horses;
- methane generating capacity for each livestock type, except sheep, goats, and horses;
- weighted MCFs for each livestock type, except NOF beef, sheep, goats, and horses;
- weighted N_2O emissions factors for all livestock types, except sheep and goats; and
- percent of manure in managed systems for all livestock, except poultry, goats, and horses.

When data was not available from the U.S. Inventory, California data from the EIIP guidance was used (EPA 2001, EIIP 1999). Data from EIIP, Chapter 7, includes:

- volatile solid production for sheep, goats, and horses;
- methane generating capacity for sheep, goats, and horses;
- weighted MCFs for NOF beef, sheep, goats, and horses;
- weighted N_2O emissions factors for sheep and goats; and
- percent of manure in managed systems for poultry, goats, and horses.

4.3. Rice Cultivation

All rice in California is grown on flooded fields. This cropping practice results in anaerobic conditions in the soil and subsequent production of CH_4 by soil-decomposing methanogenic bacteria. Most of this CH_4 produced by bacteria is either oxidized by methanotrophic soil bacteria or dissolved in ground water and leached away. However, some of the CH_4 is transferred from the soil to the atmosphere via diffusive transport through the rice plants.

Rice cultivation is a small source of CH_4 emissions in California. In 1999, CH_4 emissions from this source totaled approximately 0.5 $MMTCO_2$ Eq., less than one percent of gross emissions in the state (Table 74). From 1990-1999 emissions from rice cultivation fluctuated, but showed an increasing trend in response to the increase in rice area harvested. Emissions from rice cultivation in California grew by 28 percent over this ten-year period, while national emissions increased by roughly 23 percent. Rice cultivation in California accounted for approximately five percent of national emissions from this source in 1999.

Table 74: CH_4 Emissions from Rice Cultivation ($MMTCO_2$ Eq.)

Gas	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999
CH_4	0.41	0.36	0.41	0.45	0.50	0.48	0.52	0.54	0.50	0.52

4.3.1. Methodology

Methane emissions from rice cultivation are estimated using the method outlined in the IPCC guidelines (IPCC / UNEP / OECD / IEA 1997). Though the *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-1999* (EPA 2001) did not follow this method, the *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2000,* scheduled to be published in 2002, is expected to employ this methodology.

California emissions were estimated by multiplying the area of rice harvested annually in California by a California-specific emission factor:

CH_4 Emissions from Rice Cultivation = Harvested rice area (hectares) x CA specific emission factor (kg CH_4 / ha-season)

The California-specific emission factor is 122 kg CH_4 / ha-season. This emission factor was derived from the scientific literature. Note that California does not grow a ratoon crop of rice.

To enable quantitative comparisons among greenhouse gases, CH_4 emissions were converted into a standard unit, $MMTCO_2$ Eq. The units of CH_4 emitted were multiplied by the global warming potential (GWP) for CH_4 and then divided by 10^9 to convert from kilograms to million metric tons.

4.3.2. Data Sources

Data for the area of rice harvested, shown in Table 75, were obtained from the California Rice Commission (2000). This source drew on information presented in *California Field Crops Statistics 1983-92* (California Department of Food and Agriculture 1993), *Rice Situation & Outlook Report* (United States Department of Agriculture 1994), and *California Field Crop Review* (California Department of Food and Agriculture 2001).

Table 75: Rice Areas Harvested (1,000 Hectares)

	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999
Area	160	142	160	177	196	188	203	209	194	205

Source: California Rice Commission 2000

The California-specific emission factor was derived from published results of field measurements of CH_4 emissions from California rice fields (Cicerone et al. 1992, Bossio et al. 1999, Fitzgerald et al. 2000, and Redeker et al. 2000). Measured seasonal CH_4 emissions from all plots on which rice was grown were averaged to derive the emission factor of 122 kg CH_4 / ha-season.[i] To represent the wide range of rice cultivation conditions that exist in California (and that vary from farm-to-farm as well as from year-to-year), experiments on fields with and without added nitrogen fertilizer, experiments on fields with and without winter flooding, and experiments with all variations of rice straw management (incorporated, rolled, or burned) were included.

4.4. Agricultural Soil Management

The microbial processes of nitrification and denitrification[ii] naturally produce N_2O in soils. As a result of agricultural cropping practices designed to augment the amount of nitrogen in soils, the nitrogen available to microorganisms for nitrification and denitrification increases, subsequently increasing the amount of N_2O emitted from the soil. Nitrogen can be applied to or deposited on soils both directly and indirectly.

Soil management activities that add nitrogen to soils directly include fertilizer use; application of livestock manure during daily spread operations (i.e., manure and urine spread directly onto fields without going through a manure management system); application of sewage sludge and crop residues; and production of nitrogen-fixing crops. The cultivation of high-organic content soils (histosols) heightens the mineralization of existing nitrogen-rich organic matter that is naturally present in histosols, thereby increasing N_2O emissions from these soils (EPA 2001). Nitrous oxide emissions from soils are also enhanced by manure deposited directly on soils by animals in pastures, ranges, and paddocks.

Indirect emissions of N_2O induced by agricultural applications of nitrogen and livestock excretion occur through two pathways: (1) nitrogen volatilization to NH_3 and NO_x, causing eventual atmospheric deposition and ultimately leading to emissions of N_2O from soils; and (2) leaching and runoff of fertilizer and animal waste nitrogen into groundwater and surface water systems. Indirect emissions of N_2O through atmospheric deposition can also occur from non-agricultural sources such as NO_x emissions from transportation and power generation; however, indirect emissions from these sources are largely uncertain and are not estimated in this analysis.

Nitrous oxide emissions from agricultural soils accounted for 14.9 $MMTCO_2$ Eq. in 1990 and 14.7 $MMTCO_2$ Eq. in 1999, representing roughly 3 percent of gross emissions in California. Direct emissions from agricultural soils decreased by 3 percent, while indirect emissions remained relatively constant through the ten-year period. Nitrous oxide emissions from the sector as a whole decreased by just over one percent from 1990 through 1999, mainly as a result of a slight decline in fertilizer consumption. Among all emission sources in this sector, the only ones that increased from 1990 to 1999 were direct emissions from crop residues and indirect emissions from livestock manure.

As shown in Table 76, indirect emissions accounted for approximately 61 percent of total emissions, with direct emissions accounting for the remaining 39 percent. The greatest sources of indirect N_2O emissions from agricultural soils were livestock and leaching/runoff, which comprised 25 percent and 19 percent of total emissions from agricultural soils, respectively. Commercial fertilizer application was the dominant source of direct N_2O emissions, accounting for 18 percent of total emissions.

Table 76: N_2O Emissions from Agricultural Soils ($MMTCO_2$ Eq.)

	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999
Direct	**5.99**	**5.31**	**5.39**	**5.76**	**5.57**	**6.23**	**6.07**	**5.53**	**5.64**	**5.78**
Fertilizers	2.82	2.27	2.46	2.92	2.54	3.33	3.16	2.54	2.70	2.72
Crop Residues	0.37	0.32	0.35	0.37	0.40	0.38	0.41	0.45	0.43	0.43
N-Fixing Crops	1.32	1.28	1.15	1.07	1.18	1.09	1.08	1.15	1.14	1.23
Histosols	0.18	0.16	0.16	0.15	0.15	0.15	0.15	0.14	0.14	0.14
Livestock	1.31	1.29	1.27	1.24	1.30	1.28	1.27	1.25	1.24	1.26
Indirect	**8.94**	**8.03**	**8.28**	**8.93**	**8.48**	**9.69**	**9.45**	**8.57**	**8.80**	**8.96**
Fertilizers	2.50	2.02	2.19	2.60	2.26	2.96	2.81	2.25	2.40	2.42
Livestock	3.61	3.54	3.52	3.49	3.57	3.61	3.62	3.66	3.65	3.74
Leaching/Runoff	2.82	2.47	2.58	2.84	2.64	3.12	3.02	2.66	2.75	2.80
Total	**14.93**	**13.35**	**13.68**	**14.69**	**14.04**	**15.93**	**15.51**	**14.10**	**14.45**	**14.74**

Note: Totals may not sum due to independent rounding.

4.4.1. Methodology

Nitrous oxide emissions from agricultural soil management were estimated using methods found in the EIIP guidance (EIIP 1999) and the IPCC guidelines (IPCC / UNEP / OECD / IEA 1997), as amended by the IPCC *Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Inventories* (IPCC 2000). These are also the methods employed in the U.S. Inventory (EPA 2001). There are three types of N_2O emissions from soils: (1) direct emissions from managed soils, where the N_2O is emitted from nitrogen-related cropping practices; (2) direct emissions from livestock manure deposited on pasture, range, and paddock; and (3) indirect emissions, where nitrogen-containing compounds are released to the atmosphere or groundwater, and--following denitrification / nitrification--are emitted as N_2O. Sources of direct emissions from managed soils include fertilizer and manure use in cropping, application of crop residues to soils, production of nitrogen-fixing crops, and cultivation of histosols. Indirect emissions arise from fertilizer use, livestock manure, and nitrogen-containing leachate and runoff. This section describes emission calculation methodologies for each of these subsectors.

4.4.1.1. Direct N_2O Emissions from Managed Soils

Estimates of direct N_2O emissions from managed soils were based on the amount of nitrogen deposited annually on managed soils in the following forms: (1) commercial fertilizer application (including sewage sludge); (2) manure application from daily spread operations; (3) production of nitrogen-fixing crops; (4) nitrogen returned to soils through the application of crop residues; and (5) cultivation of high-organic content soils (histosols). Estimates from each of these sources of nitrogen were summed to develop a total estimate for direct emissions from managed agricultural soils.

Data for the total nitrogen load of both synthetic and organic commercial fertilizers used annually were available at the state level. To avoid double-counting the emissions from manure, organic fertilizer consumption data were adjusted to represent only non-manure organic fertilizers. Non-manure organic fertilizer consumption was then multiplied by its average nitrogen content (EIIP 1999).

Following methodologies used in the U.S. Inventory (EPA 2001), the nitrogen in manure was calculated for each animal type. Percentages of California livestock manure deposited in daily spread operations were taken from the U.S. Inventory (EPA 2001). Manure nitrogen is equal to the product of the animal population, the TAM, and the Kjeldahl nitrogen emission factor,[iii] according to the following equation:

Amount of Nitrogen in Manure = Animal Population (head) x TAM (kg / head) x Kjeldahl nitrogen emission factor (kg N / 1000 kg animal mass / day) x 365 days / year

The amount of nitrogen added to soils by nitrogen-fixing crops was calculated as the product of legume production, the fraction of dry matter, and the nitrogen content of the aboveground biomass. The production mass was adjusted to include the residue. These calculations are reflected in the following equation, and key assumptions are presented in Table 77 (EPA 2001):

Amount of Nitrogen Returned to Soils from N-Fixing Crops (kg N) =
Crop Production (kg) x (1 + Ratio of Residue Mass to Crop Mass (kg residue / kg crop)) x Dry Matter Fraction of Residue (kg dm / kg residue) x Fraction of Residue Applied x Nitrogen Content (kg N / kg dm)

When much of the crop mass for a specific crop is not harvested (e.g., the stalks and cobs of corn), and is instead left on the field, the nitrogen in these “crop residues” is returned to the soil. Nitrogen from residues of corn, wheat, barley, sorghum, oats, rye, rice, soybeans, peanuts, beans, and peas were calculated as the product of the crop production, the mass ratio of residue to crop, the dry matter fraction of the crop residue, the amount of residue that is not burned, and the nitrogen content of the residue.

Table 77: Key Assumptions for Nitrogen-Fixing Crop Production and Crop Residue Application

Crop	Residue: Crop Mass Ratio	Residue Dry Matter Fraction	Fraction Residue Applied	N Content of Residue (kg N/kg dm)
Alfalfa	0.0	0.85	0.9	0.0300
Corn	1.0	0.91	0.9	0.0058
Wheat	1.3	0.93	0.9	0.0062
Barley	1.2	0.93	0.9	0.0077
Sorghum	1.4	0.91	0.9	0.0108
Oats	1.3	0.92	0.9	0.0070
Rye	1.6	0.90	0.9	0.0048
Rice	1.4	0.91	1.0	0.0072
Soybeans	2.1	0.86	0.9	0.0230
Peanuts	1.0	0.90	0.9	0.0106
Dry Edible Beans	2.1	0.86	0.9	0.0062
Dry Edible Peas	1.5	0.87	0.9	0.0062

Source: EPA 2001

Note: For the derivation of activity data for nitrogen-fixing crop production, the IPCC default nitrogen content of aboveground biomass (3 percent) was used.

Estimates of annual emissions of N_2O resulting from histosol cultivation were based on the total acreage of histosols in California that are cultivated each year. These areas were multiplied by an emission factor for histosols (kg N_2O-N / ha-yr) in order to estimate emissions from this source (IPCC 2000, EIIP 1999).

Following each of these sets of calculations, the nitrogen derived from each source was classified as either volatilized or unvolatilized. Direct emissions result from nitrogen that resides in soil being transformed into atmospheric N_2O. Indirect N_2O emissions, on the other hand, involve the transport of nitrogen from the soil to another matrix (either the atmosphere or groundwater), and usually as a species other than N_2O. Emission then takes place from this intermediate matrix. Generally, unvolatilized nitrogen is the source of direct emissions; volatilized nitrogen is the source of indirect emissions.[iv] One hundred percent of the nitrogen associated with crop residues, nitrogen-fixing crops, and histosols was considered unvolatilized. Ninety percent of the synthetic fertilizer nitrogen was assumed to remain unvolatilized, and eighty percent of the non-manure organic fertilizer was assumed to remain unvolatilized (IPCC 2000, EIIP 1999, EPA 2001).

To estimate the N_2O emissions from the unvolatilized nitrogen sources, the nitrogen content of each source was multiplied by an emission factor. The factor expresses the ratio of nitrogen emitted as N_2O to the total unvolatilized nitrogen added to the nitrogen cycle. For fertilizers, crop residues, and legumes, N_2O emissions are equal to 1.25 percent of the total unvolatilized nitrogen (IPCC 2000, EIIP 1999, EPA 2001). The emission factor for histosols yields a value for emissions of N_2O; therefore, it was not necessary to convert from unvolatilized nitrogen to N_2O.

4.4.1.2. Direct N_2O Emissions from Pasture, Range, and Paddock Livestock Manure

Direct N_2O emissions from pasture, range, and paddock livestock manure are based on the amount of nitrogen in manure for each animal type. This value is equal to the product of the animal population, the typical animal mass (TAM), and the Kjeldahl nitrogen emission factor. This calculation is represented by the following equation:

Amount of Nitrogen in Manure (kg N / year) = Animal Population (head) x TAM (kg / head) x Kjeldahl nitrogen emission factor (kg N / 1000 kg animal mass / day) x 365 (days / year)

TAM data for dairy cattle, beef cattle, swine, and poultry were taken from the U.S. Inventory (EPA 2001). TAM data for sheep, goats, and horses, and Kjeldahl nitrogen emission factors for all livestock are from the EIIP guidelines (1999). Table 78 provides these data. Eighty percent of the manure that is deposited directly onto pasture, range, or paddock was estimated to be unvolatilized, and emissions from this source are equal to two percent of the total unvolatilized nitrogen (EPA 2001, EIIP 1999, IPCC 2000). Percentages of California livestock manure deposited on pasture, range and paddock for dairy and beef cattle, swine, and sheep were taken from the U.S. Inventory (EPA 2001); percentages for goats, horses, and poultry were extracted from the EIIP guidelines (1999).

Table 78: Typical Animal Mass and Kjeldahl Nitrogen Emission Factors by Animal

Animal Type	Typical Animal Mass (TAM) (kg)[a]	Kjeldahl Nitrogen (kg/day of K-N/ 1000 kg)[b]
Dairy Cows	604	0.44
Dairy Heifers	476	0.31
Feedlot Steers and Heifers	420	0.30
NOF Bulls	750	0.31
NOF Calves	159	0.30
NOF Cows	590	0.33
NOF Steers	318	0.31
NOF Heifers	420	0.31
Market Swine[c]	15 – 91	0.42 – 0.60
Breeding Swine	198	0.24
Layers[d]	1.8	0.62 – 0.83
Broilers	0.9	1.10
Turkeys	6.8	0.74
Sheep	27	0.42
Goats	64	0.45
Horses	450	0.30

[a] TAM data for dairy cattle, beef cattle, swine, and poultry are from EPA (2001). TAM data for sheep, goats, and horses are from EIIP (1999).

[b] Kjeldahl nitrogen emission factors are from EIIP (1999).

[c] TAMs and Kjeldahl nitrogen emission factors for market swine vary based on weight.

[d] Kjeldahl nitrogen emission factors for layers vary based on age group.

4.4.1.3. Indirect N_2O Emissions from Soils

Estimates of indirect N_2O emissions from soils include (1) volatilization of NH_3 and NO_x from nitrogen deposition in fertilizer application and livestock manure; and (2) leaching and runoff of nitrogen from agricultural fields.[v] Fertilizer and manure emissions were calculated by multiplying the volatilized portion of each source's total nitrogen content by emission factors of 0.1 and 1 percent for manure and fertilizers, respectively. Like the factor used for determining the direct emissions, this factor reflects the ratio of nitrogen emitted as N_2O to total volatile nitrogen (i.e., nitrogen in the form of NO_x, NH_3, and N_2O). Emissions from leaching and runoff are a function of the portion of unvolatilized nitrogen from manure and fertilizers that enter groundwater. Following guidance developed by EIIP (1999) and IPCC (2000), as well as methods used in the U.S. Inventory (EPA 2001), estimates of indirect emissions are based on the following assumptions: 30 percent of the unvolatilized nitrogen in fertilizer and manure enter leachate and runoff, and 2.5 percent of groundwater nitrogen is emitted as N_2O.

4.4.2. Data Sources

Fertilizer consumption data was obtained from *Fertilizing Materials Tonnage Reports*, published by the California Department of Food and Agriculture (CDFA 1992 - 2000). Crop production data were taken from *Crop Reports*, released by the California County Agricultural Commissioners (CCAC 2001). The animal population data sets used for the manure management emissions estimates were used to estimate N_2O emissions from agricultural soils as well (EPA 2001, AHC 1996, FAO 2001, USDA 200a-g, USDA 1999a-d, USDA 1998a-b, UDSA 1995a-b, USDA 1994a-b). See the section on Manure Management for further information on these data sources. Histosol cultivation acreage was estimated based on the expert judgment of two California State soil scientists (Vinson 2001, Simpson 2001). All emission factors and conversion factors can be found in the EIIP guidance (1999), IPCC guidance (2000), or the U.S. Inventory (EPA 2001).

4.5. Agricultural Residue Burning

Agricultural cropping practices result in large quantities of crop residues each year. These residues can be disposed of through a number of means: plowing crop waste back into the soil, composting waste and reapplying to the soil, landfilling, or burning. Open field burning, which is a common practice in California, is a net source of CH_4, N_2O, carbon monoxide (CO), and nitrogen oxides (NO_x). Because the carbon released in field burning is assumed to be reabsorbed the next growing season, this practice is not considered a net source of CO_2. Emissions from CO_2 are reported below (Table 79), but are not included in total emissions from agricultural residue burning.

Emissions due to agricultural residue burning totaled 0.2 $MMTCO_2$ Eq. in 1999, a 25 percent increase from 1990 emissions (Table 80). This increase is largely due to the increase in agricultural crop production. The production of almonds, corn, rice, and walnuts increased while the production of barley and wheat declined over the ten-year period.

Table 79: Emissions from Agricultural Residue Burning by Gas and by Crop (10^3 $MTCO_2$ Eq.)

	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999
CH_4 Emissions										
Almonds	6	6	6	6	7	6	7	7	7	8
Barley	1	1	1	1	1	1	1	1	0	0
Corn	1	1	2	2	2	2	2	2	2	2
Rice	18	15	18	20	22	22	22	23	22	23
Walnuts	3	3	3	3	3	3	3	3	4	4
Wheat	4	3	4	4	4	3	4	4	4	3
Total	**33**	**29**	**33**	**35**	**38**	**37**	**40**	**40**	**39**	**40**
N_2O Emissions										
Almonds	15	15	15	15	16	16	16	16	17	19
Barley	1	1	1	1	1	1	1	1	1	0
Corn	1	1	1	1	1	1	2	2	2	2
Rice	65	57	65	73	82	80	83	84	82	86
Walnuts	6	6	6	6	6	6	6	6	7	7
Wheat	3	2	3	3	3	3	4	3	3	3
Total	**91**	**81**	**91**	**100**	**110**	**106**	**112**	**113**	**111**	**116**
CO_2 Emissions										
Almonds	451	429	434	453	474	458	486	484	510	553
Barley	20	17	18	18	19	18	16	13	11	8
Corn	51	48	53	57	59	60	71	78	81	72
Rice	1,221	1,068	1,224	1,379	1,558	1,503	1,564	1,593	1,546	1,621
Walnuts	155	159	159	163	165	168	167	167	173	175
Wheat	123	86	111	112	112	102	138	124	117	97
Total	**2,020**	**1,808**	**1,999**	**2,181**	**2,388**	**2,308**	**2,441**	**2,459**	**2,439**	**2,527**

Note: Totals may not sum due to independent rounding.

Rice straw was the largest source of CH_4, N_2O, and CO_2 emissions in California (Table 79). Less significant CH_4 emissions resulted from burning almonds, wheat, and walnuts. After rice, almonds and walnuts were the next largest source of N_2O emissions. Recognizing that rice burning is a significant source of greenhouse gas emissions, the state has adopted measures to limit burning of rice residues. Agricultural burning of other crops is also undergoing systematic curtailment (Jenkins and Turn 1994).

Table 80: Emissions from Agricultural Residue Burning (10^3 $MTCO_2$ Eq.)

	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999
CH_4	33.10	29.35	32.60	35.30	38.35	37.00	39.63	39.66	39.25	39.95
N_2O	91.13	81.31	90.50	99.62	110.06	106.36	111.60	112.72	111.12	115.75
Total	**124.23**	**110.66**	**123.11**	**134.91**	**148.41**	**143.36**	**151.23**	**152.39**	**150.37**	**155.69**

Note: Totals may not sum due to independent rounding.

4.5.1. Methodology

The method used to estimate CH_4, N_2O, and CO_2 emissions from open burning of agricultural crop wastes in California was created by B.M. Jenkins and his colleagues at the University of California at Davis (Jenkins and Turn 1994, Jenkins et al. 1992). Together, Jenkins and his colleagues developed California-specific parameters for estimating criteria pollutant emissions from this source.

Jenkins et al. developed parameters for six crops--almonds, walnuts, wheat, barley, corn, and rice--which account for 97 percent of the agricultural biomass burned in California (excluding wildfires and prescribed forest burns). Crop-specific parameters include (1) residue yield, to determine the amount of residue produced; (2) burn fraction, to quantify the amount of crop residue that actually burns on the field; and (3) crop- and greenhouse gas-specific emission factors.

Estimates of emissions from agricultural residue burning in California were developed by multiplying production area for each crop type by the crop-specific parameters as shown in the equation below:

Emissions = [Production Area] x [Residue Yield] x [Burn Fraction] x [Emission Factor]

4.5.2. Data Sources

Crop production acreage data were obtained from *Crop Reports* published by the California County Agricultural Commissioners (1990-2000). The parameters (burn fractions, residue yields, and CH_4 and CO_2 emission factors) used to estimate agricultural residue burning emissions were taken from Jenkins et al. (1992) and Jenkins and Turn (1994) (Table 81). Nitrous oxide emission factors were derived from the emission factors for NO_x using the ratios of NO_x-N / N and N_2O-N / N provided in the IPCC guidelines (Jenkins and Turn 1994, IPCC / UNEP / OECD / IEA 1997).

Table 81: Parameters Used in Estimating Emissions from the Agricultural Waste Burned

	Almonds	Walnuts	Wheat	Barley	Corn	Rice
Burn Fraction (percent)	84%	95%	11%	7%	3%	99%
Residue Yield (ton/ha dry basis)	1.89	1.46	3.66	2.51	9.06	6.75
CH_4 Emission Factor (percent dry crop mass)	0.12%	0.16%	0.18%	0.25%	0.18%	0.08%
CO_2 Emission Factor (percent dry crop mass)	183%	164%	120%	117%	131%	117%
N_2O Emission Factor (percent dry crop mass)	0.02%	0.02%	0.01%	0.02%	0.01%	0.02%

Source: Jenkins et al. 1992, Jenkins and Turn 1994

CHAPTER 5 –LAND-USE CHANGE AND FORESTRY

5.0 Land-Use Change and Forestry

This section includes estimates of the net carbon dioxide (CO_2) flux caused by (1) changes in forest carbon stocks; (2) changes in agricultural soil carbon stocks; and (3) changes in yard trimming carbon stocks in landfills. Estimated total annual net CO_2 flux from land-use change and forestry in 1999 was 18.8 million metric tons of carbon dioxide equivalent ($MMTCO_2$ Eq.) (Table 82). Sequestration offset six percent and four percent of total state emissions in 1990 and 1999, respectively. Over the ten-year period from 1990 to 1999, net sequestration has declined by 27 percent. This decline is primarily due to changes in two carbon stocks: forests and landfilled yard trimmings. The decrease in forest carbon flux was driven by changes in the amount of carbon sequestered in wood products and landfills.

Table 82: Net Carbon Flux from Land-Use Change and Forestry ($MMTCO_2$ Eq.)

Source	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999
Forests	-21.16	-21.16	-17.27	-17.27	-17.27	-17.27	-17.27	-17.27	-17.27	-17.27
Agricultural Soils	0.06	0.09	0.11	0.07	0.16	0.27	0.27	0.35	0.25	0.33
Landfilled Yard Trimmings	-4.49	-4.14	-3.81	-3.49	-3.18	-2.89	-2.61	-2.34	-2.11	-1.85
Total	**-25.58**	**-25.21**	**-20.97**	**-20.68**	**-20.29**	**-19.88**	**-19.61**	**-19.26**	**-19.13**	**-18.79**

Note: Totals may not sum due to independent rounding.

5.1. Changes in Forest Carbon Stocks

The 38.5 million acres of forested land in California cover 39 percent of the land base. In recent decades, area of forested land has declined slightly (Birdsey 2001). Overall, California's forests were a net sink of CO_2–indicating that forest growth outpaced forest clearing, harvests, and decomposition. In 1999, net sequestration due to forest carbon stocks was 17.3 $MMTCO_2$ Eq., 18 percent lower than net sequestration in 1990. Table 83 presents the estimates of forest carbon sequestration by forest component.

Table 83: Net Carbon Flux from Forest Carbon Stocks ($MMTCO_2$ Eq.)

Source	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999
Biomass	-18.5	-18.5	-18.7	-18.7	-18.7	-18.7	-18.7	-18.7	-18.7	-18.7
Forest Floor & Course Woody Debris	5.2	5.2	5.8	5.8	5.8	5.8	5.8	5.8	5.8	5.8
Soils	3.1	3.1	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0
Wood Products and Landfills	-11.0	-11.0	-7.4	-7.4	-7.4	-7.4	-7.4	-7.4	-7.4	-7.4
Total	**-21.2**	**-21.2**	**-17.3**	**-17.3**	**-17.3**	**-17.3**	**-17.3**	**-17.3**	**-17.3**	**-17.3**

Source: Birdsey and Lewis 2001

Notes: Negative values indicate net sequestration. 1997 carbon flux estimates are used as a proxy for 1998 and 1999. Lightly shaded areas indicate values based on a combination of historical data and projections. Totals may not sum due to independent rounding.

In the state, forest carbon flux offset 17.3 $MMTCO_2$ Eq., four percent, of gross 1999 emissions. Forest carbon flux accounted for 83 percent and 92 percent of state sinks in 1990 and 1999, respectively. Forest carbon flux accounted for an increased proportion of state sinks as carbon storage from landfilled yard trimmings decreased from 1990 through 1999.

Storage in live biomass accounted for the majority of sequestration during the period from 1990 through 1999. Wood products and landfills--including the wood removed from the forest for product manufacture or use as fuel wood and discarded wood products in landfills--also resulted in net sequestration of carbon. Soils were a net source of emissions--the high rate of loss associated with land use conversion outweighed the slower pace of carbon accumulation in the land that remained forested. The forest floor also acted as a net source of emissions in California, though the reported decrease in carbon could be due to the reclassification of forest types and lack of consistent age class information.

Between 1987 and 1997, total carbon stocks increased, mostly due to increases in ponderosa pine and other softwood forest types. Carbon stocks for fir-spruce, chaparral, and pinyon-juniper decreased during the period (Table 84).

Table 84: Area of Forested Land by Forest Type (1,000 acres)

Forest Type	1987	1992	1997	Average Annual Change		
				1987-1992	1992-1997	1987-1997
Douglas-fir	1,718	2,060	2,402	68	68	68
Ponderosa pine	5,717	6,830	7,944	223	223	223
Western white pine	5	186	366	36	36	36
Fir-spruce	7,810	6,007	4,205	-361	-361	-361
Hemlock-Sitka spruce	59	41	24	-3	-3	-3
Larch	0	0	0	0	0	0
Lodgepole pine	952	702	452	-50	-50	-50
Redwood	1,270	1,090	910	-36	-36	-36
Other Hardwoods	9,781	9,327	8,873	-91	-91	-91
Other forest types	1,229	3,905	6,581	535	535	535
Pinyon-juniper	2,699	2,161	1,622	-108	-108	-108
Chaparral	8,021	6,424	4,827	-319	-319	-319
Non-stocked	120	231	341	22	22	22
Total	**39,381**	**38,964**	**38,547**	**-83**	**-83**	**-83**

Source: Birdsey and Lewis 2001

Note: Totals may not sum due to independent rounding.

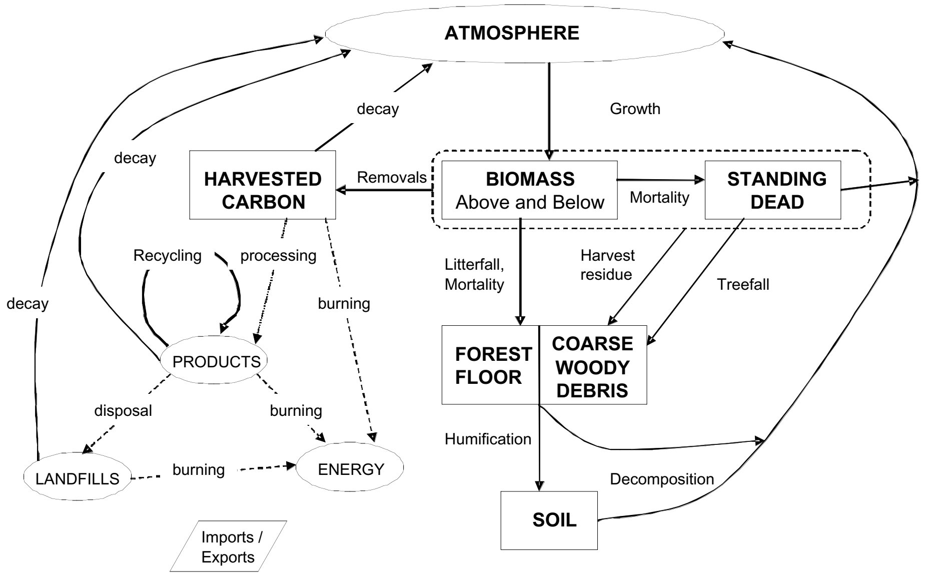
5.1.1. Methodology

Carbon sequestration and emissions associated with Land-Use Change and Forestry are characterized through the application of a U.S. Department of Agriculture, Forest Service (USDA-FS) model that tracks forest carbon flows related to tree growth, forest removals, and decomposition. The model partitions ecosystem carbon (C) into three separate components (Birdsey and Lewis 2001):

- biomass, which includes all aboveground and belowground portions of all live and dead trees and understory vegetation;
- forest floor, which includes all dead organic matter above the mineral soil horizons except standing dead trees; and

- soil, which includes all organic C in the mineral horizons to a depth of 1 m.

The carbon estimates for the forest components are based on forest age, type, productivity class, and land-use history. These parameters characterize the forest and ecosystem carbon dynamics, as well as the understory, soil, and forest floor models that best describe carbon flows. Additionally, the model tracks carbon in forest products (e.g., lumber, plywood, paper), accounting for the C sequestered during products' lifetimes, as well as carbon stored (net of degradation) in landfills. Figure 23 illustrates forest sector carbon flows.



Source: Birdsey and Lewis 2001

Figure 23: Forest Sector Carbon Flows

Estimates of carbon stocks are not made for each year; rather, they are simulated for five-year intervals (1987, 1992, and 1997). Data for 1992 were not updated for California. Thus, 1992 carbon stocks were estimated through interpolation using 1987 and 1997 data. For any year bracketed by these dates, the change in carbon stored over the interval, divided by five years, represents the annual flux. Birdsey and Lewis' estimates do not include 1998 and 1999; therefore, for the purpose of this inventory, carbon flux was assumed to remain constant from 1997 through 1999.

5.1.2. Data Sources

The forest carbon model used to develop these estimates is maintained by the USDA-FS and is detailed in the working paper entitled "Carbon Stock Changes in California's Forests, 1987-1997" (Birdsey and Lewis 2001). Data sources and methods used to develop California-specific estimates are described in this working paper. Inventory data was obtained from the Resource Planning Act (RPA) Assessments for 1987 and 1997. Areas of forested land by class and by forest type appear above in Table 84 and below in Table 85. Birdsey (1996) explains the methods used to estimate forest carbon storage for the components of ecosystem carbon; Row and Phelps (1991) work is the basis for estimates of carbon stored in forest products and landfills; and Plantinga and Birdsey (1993) and Birdsey (1992) explain the methods used to estimate soil carbon.

Table 85: Area of Forested Land by Land Class (1,000 acres)

				Average Annual Change		
Land Class	**1987**	**1992**	**1997**	**1987-1992**	**1992-1997**	**1987-1997**
Timberland	16,712	17,332	17,952	124	124	124
Other forest land	17,766	16,196	14,626	-314	-314	-314
Reserved timberland	4,903	5,435	5,968	107	107	107
Total	**39,381**	**38,964**	**38,547**	**-83**	**-83**	**-83**

Source: Birdsey and Lewis 2001

Note: Totals may not sum due to independent rounding.

5.2. Changes in Agricultural Soil Carbon Stocks

Changes in agricultural soil carbon stocks include emissions due to the application of crushed limestone and dolomite to agricultural soils as well as changes in mineral and organic soil carbon stocks. Lime, in the form of crushed limestone ($CaCO_3$) and dolomite ($CaMg(CO_3)_2$), is commonly added to agricultural soils to inhibit acidification. These compounds degrade once they come in contact with acid soils, generating CO_2 emissions. The rate of degradation is dependent on soil conditions and the type of mineral being applied.

Data on mineral and organic soils were not available for California; therefore, carbon fluxes from these soils could not be included in the inventory. The California Energy Commission is considering options for estimating carbon fluxes from these soils in future inventories.

Emissions due to liming of agricultural soils totaled 0.1 $MMTCO_2$ Eq. in 1990 and 0.3 $MMTCO_2$ Eq. in 1999 (Table 86). The increase in annual emissions from liming is due to increasing amounts of lime applied to agricultural soils.

Table 86: Net CO_2 Flux from Agricultural Soils ($MMTCO_2$ Eq.)

Source	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999
Mineral Soils	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Organic Soils	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Liming of Soils	0.1	0.1	0.1	0.1	0.2	0.3	0.3	0.4	0.2	0.3
Total	**0.1**	**0.1**	**0.1**	**0.1**	**0.2**	**0.3**	**0.3**	**0.4**	**0.2**	**0.3**

Note: Lightly shaded areas indicate values based on a combination of historical data and projections. All other values are based on historical data only.

5.3. Liming of Soils

5.3.1. Methodology

Carbon dioxide emissions associated with the degradation of limestone and dolomite on agricultural soils were calculated by multiplying the annual amounts of limestone and dolomite applied by their respective CO_2 emission factors (0.120 metric ton C / metric ton limestone, 0.130 metric ton C / metric ton dolomite). As noted in the *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-1999*, "the default emission factor for dolomite provided in the Workbook volume of the *Revised 1996 Intergovernmental Panel on Climate Change Guidelines* (IPCC / UNEP / OECD / IEA 1997) is incorrect. The value provided is 0.122 metric ton carbon / metric ton of dolomite; the correct value is 0.130 metric ton carbon / metric ton of dolomite" (EPA 2001). These emission factors assume that all of the carbon in these materials evolves as CO_2 in the same year in which the minerals are applied (EPA 2001).

The annual application rates of limestone and dolomite were derived from estimates provided by the California Department of Food and Agriculture (CDFA 2001). CDFA reports total lime used on agricultural soils. No data were available for 1990 and 1991. Total lime use in those years was derived using regression analysis.

Total lime use is further broken out into limestone and dolomite used for agriculture. This breakout was calculated by applying the proportions of total limestone and dolomite sold or used in California to total agricultural lime use. Industry statistics in the *Minerals Yearbook* and *Mineral Industry Surveys* provided values for the total limestone and dolomite sold or used in California (Tepordei 1993, 1994, 1995, 1996, 1997, 1998, 1999, 2000, 2001; USGS 2001). USGS (U.S. Bureau of Mines prior to 1997) obtained this data by surveying crushed stone manufacturers. Data on the total limestone and dolomite sold or used in California were not available in 1990, 1992, and 2000. Data from 1991 to 1999 was used to extrapolate total consumption for 1990 and to interpolate total consumption for 1992.

5.3.2. Data Sources

Amounts of total lime used in agriculture were obtained from the California Department of Food and Agriculture (CDFA 2001). Values for the total limestone and dolomite sold or used in California were found in the *Minerals Yearbook*, published by the Bureau of Mines through 1996 and by the U.S. Geological Survey from 1997 to the present.

5.4. Changes in Yard Trimming Carbon Stocks in Landfills

Landfilled yard trimmings, like landfilled forest products, can store carbon indefinitely. In California, yard trimmings (i.e., grass clippings, leaves, branches) comprised approximately 15 percent of the total waste disposed in 1990 and 10 percent in 1999 (CIWMB 2001). The decreased disposal rate for yard trimmings on a national level is typically attributed to programs banning or discouraging disposal, coupled with a significant increase in the number of composting facilities. The decrease in the yard trimmings landfill disposal rate has resulted in a significant decrease in the rate of landfill carbon storage from 4.5 MMTCO$_2$ Eq. in 1990 to 1.9 MMTCO$_2$ Eq. in 1999 (Table 87).

Carbon flux associated with landfilled yard trimmings represented roughly 10 percent of state sinks, and was responsible for offsetting 0.4 percent of gross state emissions in 1999.

Table 87: Net Carbon Flux from Landfilled Yard Trimmings (MMTCO$_2$ Eq.)

Source	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999
Landfilled Yard Trimmings	-4.5	-4.1	-3.8	-3.5	-3.2	-2.9	-2.6	-2.3	-2.1	-1.9

5.4.1. Methodology

Carbon storage in landfilled yard trimmings is calculated using the same methods as are used to develop national estimates for the U.S. Inventory:

> "The methodology for estimating carbon storage is based on a life cycle analysis of greenhouse gas emissions and sinks associated with solid waste management (EPA 1998). According to this methodology, carbon storage is the product of the mass of yard trimmings disposed, on a wet weight basis, and a storage factor. The storage factor, which is the fraction of total carbon that is assumed to be stored permanently, is based on a series of experiments designed to evaluate methane generation and residual organic material in landfills (Barlaz 1998). These experiments analyzed grass, leaves, branches, and other materials, and were designed to promote biodegradation by providing ample moisture and nutrients."
>
> "This analysis assumes that the composition of yard trimmings consists of 50 percent grass clippings, 25 percent leaves, and 25 percent branches on a wet

weight basis. Each component uses a different storage factor. The weighted average carbon storage factor is 0.23 (metric ton of carbon stored indefinitely per metric ton [wet weight] of yard trimmings landfilled.” (EPA 2001) (Table 88)

Table 88: Composition of Yard Trimmings in MSW and Carbon Storage Factor (metric ton of carbon/ metric ton yard trimmings)

Component	Percent	Storage Factor
Grass	50%	0.13
Leaves	25%	0.43
Branches	25%	0.23
Total/Weighted Average	**100%**	**0.23**

5.4.2. Data Sources

The yard trimmings discard rate was obtained from the California Integrated Waste Management Board (CIWMB 2001). The report provides estimates for the years 1990 and 1999. Estimates in these years were used to interpolate disposal rates for the years from 1991 through 1998.

The CIWMB report does not specify tons of discarded materials landfilled and combusted. The percentages of waste combusted and landfilled in California were taken from BioCycle’s annual report “The State of Garbage in America” (BioCycle 1998, 1999, 2000). These percentages were applied to yard trimmings disposed to determine the proportion of discards managed in landfills.

Carbon storage factors were obtained from an EPA report on life-cycle greenhouse gas emissions from waste management (EPA 1998).

CHAPTER 6 – WASTE

6.0 Waste

Waste management in California results in methane (CH_4) emissions from landfills, carbon dioxide (CO_2) and nitrous oxide (N_2O) emissions from waste combustion, and CH_4 and N_2O emissions from wastewater treatment. Because methodologies are not currently available to develop a complete estimate of N_2O emissions from wastewater, this inventory reflects only the portion of wastewater N_2O emissions attributable to human sewage.

In total, waste management and treatment activities in California emitted 16.0 million metric tons of carbon dioxide equivalent (MMTCO$_2$ Eq.) of greenhouse gas emissions in 1999, an 18 percent decline since 1990 (Table 89). Landfills accounted for the majority (83 percent) of waste emissions and were responsible for the overall trend in sectoral emissions. Waste sector emissions in California represented four percent of the state's gross greenhouse gas emissions in 1999 and six percent of national waste sector emissions in 1999.

Table 89: Emissions from Waste (MMTCO$_2$ Eq.)

Gas/Source	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999
CH_4	**18.21**	**18.30**	**18.57**	**18.64**	**18.39**	**17.92**	**16.43**	**15.60**	**13.64**	**14.56**
Landfills	16.95	17.02	17.26	17.32	17.06	16.58	15.09	14.24	12.27	13.17
Wastewater Treatment	1.27	1.28	1.30	1.32	1.33	1.33	1.34	1.36	1.37	1.39
N_2O	**0.96**	**0.89**	**0.88**	**0.96**	**0.89**	**0.96**	**0.93**	**1.03**	**1.06**	**1.08**
Human Sewage	0.93	0.87	0.85	0.94	0.86	0.93	0.91	1.00	1.04	1.05
Waste Combustion	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02
CO_2	**0.30**	**0.30**	**0.31**	**0.31**	**0.32**	**0.32**	**0.32**	**0.31**	**0.30**	**0.31**
Waste Combustion	0.30	0.30	0.31	0.31	0.32	0.32	0.32	0.31	0.30	0.31
Total	**19.47**	**19.49**	**19.75**	**19.91**	**19.59**	**19.19**	**17.68**	**16.93**	**15.01**	**15.95**

Note: Totals may not sum due to independent rounding.

6.1. Landfills

Landfills are the largest source of anthropogenic CH_4 emissions in California. In 1999, emissions were 13.2 MMTCO$_2$ Eq., approximately six percent of national emissions from landfills. Municipal solid waste (MSW) landfills accounted for 93 percent of total CH_4 generated, with industrial landfills accounting for the remainder.

Methane emissions are the result of the decomposition of organic materials (e.g., paper, food scraps, and yard trimmings) in landfills. The *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-1999* (EPA 2001) describes the CH_4 production process as follows:

> "This decomposition process is a natural mechanism through which microorganisms derive energy. After being placed in a landfill, organic waste is initially digested by aerobic bacteria. After the oxygen supply has been depleted,

> the remaining waste is consumed by anaerobic bacteria, which break down organic matter into substances such as cellulose, amino acids, and sugars. These substances are further broken down through fermentation into gases and short-chain organic compounds that form the substrates for the growth of methanogenic bacteria. Methane-producing anaerobic bacteria convert these fermentation products into stabilized organic materials and biogas consisting of approximately 50 percent CO_2 and 50 percent CH_4, by volume. Methane production typically begins one or two years after waste disposal in a landfill and may last from 10 to 60 years."

While there is variability in the duration of CH_4 generation, the U.S. Inventory and the EPA's Landfill Methane Outreach Program assume that CH_4 is emitted over a 30-year time horizon.

Factors influencing landfill CH_4 emissions include the quantity of solid waste in landfills (waste-in-place) that is less than thirty years old, the composition of this waste, the quantity of CH_4 recovered for energy projects or flared, and the amount of CH_4 oxidized. The total amount of waste-in-place in California landfills increased from 760 million tons in 1990 to 932 million tons in 1999, a gain of 23 percent. This increase resulted in an increase in CH_4 generation from 27.1 MMTCO$_2$ Eq. in 1990 to 31.8 MMTCO$_2$ Eq. in 1999 (Table 90). The amount of CH_4 recovered, meanwhile, increased from 7.6 MMTCO$_2$ Eq. to 15.7 MMTCO$_2$ Eq. during this period.

Table 90: Emissions of CH_4 from Landfills (MMTCO$_2$ Eq.)

Activity	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999
Potential Emissions	**27.1**	**27.8**	**28.4**	**29.0**	**29.5**	**30.0**	**30.4**	**30.9**	**31.4**	**31.8**
MSW Generation	25.3	25.9	26.5	27.1	27.6	28.0	28.5	28.9	29.3	29.7
Small Landfills	4.2	4.3	4.5	4.6	4.7	4.8	4.9	5.0	5.1	5.2
Large Landfills	21.1	21.6	22.1	22.5	22.9	23.2	23.6	23.9	24.2	24.6
Industrial Generation	1.8	1.8	1.9	1.9	1.9	2.0	2.0	2.0	2.1	2.1
Emissions Recovered	**-7.6**	**-8.1**	**-8.5**	**-8.9**	**-9.7**	**-10.6**	**-12.5**	**-13.8**	**-16.2**	**-15.7**
Landfill Gas-to-Energy	-6.3	-6.3	-6.3	-6.8	-7.8	-7.8	-7.9	-8.3	-8.7	-9.4
Flare	-1.3	-1.8	-2.1	-2.1	-1.9	-2.8	-4.6	-5.5	-7.5	-6.3
Oxidation	**-2.5**	**-2.6**	**-2.7**	**-2.7**	**-2.8**	**-2.8**	**-2.8**	**-2.9**	**-2.9**	**-3.0**
Net Emissions	**16.9**	**17.0**	**17.3**	**17.3**	**17.1**	**16.6**	**15.1**	**14.2**	**12.3**	**13.2**

Note: Totals may not sum due to independent rounding.

The net effect of these two trends--the relatively modest increase in CH_4 generation coupled with the large increase in recovery--was a 22 percent decrease in net landfill emissions over the ten-year period. This is a significantly larger decrease, in percentage terms, than the one percent decrease that occurred for the United States as a whole during this period. This difference can be attributed to the rapid adoption of CH_4 recovery technologies in California, which increased at a significantly higher rate than nationwide recovery (EPA 2001). Trends in waste-in-place and CH_4 generation from California landfills were similar to national trends.

6.1.1. Methodology

Per the *EIIP Volume VIII: Estimating Greenhouse Gas Emissions* (EIIP 1999), CH_4 emissions from landfills were estimated as the total amount of CH_4 produced from municipal landfills, plus the CH_4 produced by industrial landfills, minus the CH_4 recovered and combusted, minus the CH_4 oxidized before being released into the atmosphere. In accordance with the EIIP Guidelines, the following steps were taken to estimate landfill CH_4 emissions in California:

Step 1: Estimate Total Waste-In-Place (WIP) at Municipal Landfills

Total waste-in-place was calculated as the sum of waste disposal over a thirty-year period. Waste disposal data for 1990 through 1999 (Table 91) were previously available from California records (CIWMB 2001). Waste disposal from 1960 to 1989 was estimated by multiplying per capita disposal by California population estimates (CA DOF 2001). Since data on per capita disposal were unavailable prior to 1990, the 1990 estimate of California per capita disposal was adjusted to the years 1961 to 1989 using national growth rates in per capita disposal over this period (EPA 1999a, U.S. Census Bureau 2000).

Step 2: Estimate Total Methane Generation

The estimate of total CH_4 generation was calculated as the sum of CH_4 generation from small and large municipal landfills, plus industrial landfills. In order to estimate generation from municipal landfills, the following information was needed: (1) the amount of WIP in small versus large landfills; and (2) rainfall in California. In California, 86 percent of the waste landfilled was assumed to be disposed at large landfills, which are defined as having more than 1.1 million tons of WIP. The remaining 14 percent was assumed to be disposed at small landfills (EIIP 1999). California was classified as an arid state because it receives less than 25 inches of rain per year (EIIP 1999).

Small Landfills

Using EIIP's suggested equations for estimating CH_4 generation from small landfills in arid climates, a factor of 0.27 was multiplied by WIP at small landfills to estimate generation in cubic feet / day. To obtain this estimate in tons per year, a conversion factor of 0.0077 was used (EIIP 1999). These steps are summarized in the following equation:

$$CH_{4\,\text{Small}}\,(\text{tons } CH_4/\text{yr}) = WIP_{\text{Small}}\,(\text{tons}) \times \frac{0.27\ \text{ft}^3/\text{day}}{\text{ton}} \times \frac{0.0077\ \text{tons } CH_4/\text{yr}}{\text{ft}^3/\text{day}}$$

Where: $WIP_{\text{Small}} = WIP_{\text{Total}} \times 14$ percent

Large Landfills

To estimate CH_4 generation at large landfills, it was first necessary to determine the average WIP per large landfill, calculated as the total WIP from large landfills divided by the number of large landfills. This estimate was then entered into the following equation (EIIP 1999):

$$CH_{4\,\text{Large}}\ (\text{tons } CH_4/\text{yr}) = N \times [417{,}957 + [0.16 \times (\text{Ave WIP}_{\text{Large}}\ (\text{tons})] \times \frac{0.0077 \text{ tons } CH_4/\text{yr}}{\text{ft}^3/\text{day}}$$

Where: N = Number of large landfills in California
Ave. $\text{WIP}_{\text{Large}} = \text{WIP}_{\text{Large}} / N$
$\text{WIP}_{\text{Large}} = \text{WIP}_{\text{Total}} \times 86$ percent

Industrial Landfills

Methane generation from industrial landfills was estimated as seven percent of total CH_4 generation from municipal landfills, in accordance with the EIIP guidelines (1999).

Step 3: Estimate and Adjust for Methane Recovery and Oxidation

The final step in estimating net CH_4 emissions from California landfills was to adjust for the amount of CH_4 that was either: (1) recovered, in either a flaring or landfill gas-to-energy (LFGTE) project; or (2) oxidized before being released into the atmosphere.

Methane Recovery

The amount of CH_4 recovered through flaring or LFGTE projects was estimated using data and methods presented in the U.S. Inventory (EPA 2001a). Flare estimates were based on confidential sales data collected from flare equipment vendors on an annual basis. Because these data are collected as confidential business information (CBI), emission reductions for California were extracted for the state as a whole, and not for individual landfills. Recovery through LFGTE projects was estimated using a state-specific database compiled by the EPA's Landfill Methane Outreach Program (LMOP) (EPA 1999). The methodology used to estimate CH_4 recovery for flaring and LFGTE is described in more detail in the U.S. Inventory (EPA 2001).

Oxidation

The amount of CH_4 oxidized was assumed to be 10 percent of CH_4 generated (EIIP 1999).

6.1.2. Data Sources

California landfill disposal data for 1990 through 1999 (Table 91) were taken directly from the California Integrated Waste Management Board's *Landfill Tonnage Reports* (CIWMB 2001). These data, originally reported by county, were aggregated to reflect state disposal. Waste disposal estimates for 1960 through 1989 were calculated using California population data from the State of California Department of Finance (CA DOF 2001), U.S population data from the U.S. Census Bureau (U.S. Census Bureau 2000), and national per capita landfilled information from the *Characterization of Municipal Solid Waste in the United States: 1998 Update* (EPA 1999a). The number of large landfills was estimated using LMOP data, and the fractions of large and small landfills in California were taken from the EIIP guidance (EPA 1999b, EIIP 1999). Estimates of CH_4 recovered through flaring were taken directly from the U.S. Inventory flare estimates (EPA 2001). Data on CH_4 recovered through LFGTE were obtained from the LMOP database.

Table 91: California Waste Disposal Data 1990-1999 (million tons)

	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999
Waste Disposed	40.1	36.5	36.0	34.6	34.4	33.6	32.9	33.7	35.6	35.5

Source: CIWMB 2001

6.2. Waste Combustion

During combustion of MSW, organic materials are converted to CO_2. According to the Intergovernmental Panel on Climate Change (IPCC) *Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories*, inventories should only account for the CO_2 resulting from combustion of those organic materials that are of fossil origin (i.e., plastic, synthetic rubber and synthetic fibers) (IPCC/UNEP/OECD/IEA1997). Carbon dioxide emitted from combustion of organic wastes that are of biogenic origin (i.e., paper, food scraps, yard trimmings) are considered part of the natural carbon cycle. Therefore, this section excludes these emissions. In addition, this section provides estimates of N_2O emissions resulting from combustion.

In California, there was little variation in CO_2 and N_2O emissions from MSW combustion between 1990 and 1999 (Table 92). Nitrous oxide emissions stayed virtually constant at 0.02 MMTCO$_2$ Eq. per year, while CO_2 emissions increased slightly, rising from 0.30 MMTCO$_2$ Eq in 1990 to 0.31 MMTCO$_2$ Eq in 1999. In 1999, California emissions of CO_2 and N_2O from waste combustion accounted for approximately 1 and 10 percent, respectively, of corresponding national emissions.

Table 92: Emissions of N_2O and CO_2 from Waste Combustion (MMTCO$_2$ Eq.)

Gas	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999
N_2O	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02
CO_2	0.30	0.30	0.31	0.31	0.32	0.32	0.32	0.31	0.30	0.31

6.2.1. Methodology

The methodology used to estimate greenhouse gas emissions from waste combustion was based on the EIIP guidelines (EIIP 1999). Separate calculations were used to estimate CO_2 and N_2O emissions.

6.2.1.1. Non-biogenic CO_2 Emissions from Waste Combustion

To estimate non-biogenic CO_2 emissions, the amount of waste combusted was multiplied by a factor of 0.40 short tons of CO_2 per short ton of MSW combusted to obtain emissions in short tons. This estimate was then converted to metric tons using the ratio of 0.9072 metric tons per short ton. These steps are summarized in the following equation (EIIP 1999):

$$\text{MTCO}_2\text{ Eq.} = \text{MSW (short tons)} \times \frac{0.40\text{ short tons CO}_2}{\text{MSW (short tons)}} \times \frac{0.9072\text{ MT}}{\text{short ton}}$$

Where: MSW = tons of MSW combusted

6.2.1.2. Nitrous Oxide Emissions from Waste Combustion

To estimate N_2O emissions from combustion of municipal solid waste, the amount of waste combusted was multiplied by a factor of 0.0001 short tons of N_2O per short ton of municipal waste combusted. This quantity was then converted to metric tons of CO_2 equivalent using the ratio of 0.9072 metric tons per short ton and the global warming potential (GWP) for N_2O, which is 310. These steps are summarized in the following equation (EIIP 1999):

$$\text{MTCO}_2\text{ Eq.} = \text{MSW (short tons)} \times \frac{0.0001\text{ tons N}_2\text{O}}{\text{MSW (short tons)}} \times \frac{0.9072\text{ MT}}{\text{short ton}} \times 310$$

Where: MSW = tons of MSW combusted

6.2.2. Data Sources

Combustion data for 1995 through 2000 were obtained from the California Integrated Waste Management Board's Disposal Reporting System (CIWMB 2001). Data for 1990 through 1994 were acquired through phone conversations with officials at the three permitted incineration sites operating in California during those years (Foley 2001, Simsko 2001, and Healey 2001). Table 93 shows the total combustion estimates for 1990 to 1999.

Table 93: Waste Combusted (metric tons)

	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999
MSW Combusted	746,038	742,273	778,530	779,405	795,610	793,680	794,968	765,508	762,194	774,895

Source: CIWMB 2001, Foley 2001, Simsko 2001, Healey 2001

6.3. Municipal Wastewater

Methane is produced through the anaerobic degradation of organic material in wastewater. The organic content of wastewater is expressed as the biochemical oxygen demand (BOD).

Generally, wastewater with higher BOD concentrations will produce more CH_4 than wastewater with lower BOD concentrations (EPA 2001).

In 1999, CH_4 emissions from domestic wastewater treatment in California were 1.4 $MMTCO_2$ Eq. Emissions have increased by approximately 10 percent since 1990, in response to the increase in state population over this period. Table 94 provides emission estimates for the period 1990 through 1999 from domestic wastewater treatment in California.

Table 94: CH_4 Emissions from Wastewater Treatment in California ($MMTCO_2$ Eq.)

Source	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999
Wastewater Treatment	1.27	1.28	1.30	1.32	1.33	1.33	1.34	1.36	1.37	1.39

6.3.1. Methodology

Methane emissions from wastewater were estimated using the following equation taken from *EIIP Volume VIII, Estimating Greenhouse Gas Emissions* (1999):

$$\boxed{CH_4\ Emissions = State\ Population \times D \times FTA \times EF}$$

Where: D = Organic Load in BOD per person (Default = 6×10^{-8} Gg BOD / person / day)
FTA = Fraction of BOD that degrades anaerobically (Default = 15 percent)
EF = Emission Factor (Default = 0.6 Gg CH_4 / Gg BOD)

To estimate emissions from wastewater, the total state population was multiplied by the wastewater BOD generation rate to obtain the daily BOD generated. The daily BOD generated was then multiplied by the fraction of BOD metabolized anaerobically and by the CH_4 emission factor, to obtain total CH_4 emissions. The result was then multiplied by 365 days to obtain annual estimates of CH_4 from wastewater treatment. It was assumed that no CH_4 emissions from this source were recovered in California.

6.3.2. Data Sources

Population data for 1990 through 2000 were obtained from the California Department of Finance (CA DOF 2001). Organic load and CH_4 emission factors were based on the IPCC guideline defaults (2000), while the fraction of BOD treated anaerobically was taken from the EIIP guidance (1999).

6.4. Human Sewage

Nitrous oxide is a product of nitrification and denitrification processes that occur naturally in domestic and industrial wastewater containing nitrogen-rich organic matter. Nitrification converts ammonium (NH_4^+) into nitrate (NO_3^-) through an aerobic process, while denitrification occurs anaerobically and converts NO_3^- to N_2O.

Table 95 provides emission estimates for the period 1990 through 1999 from human sewage in California. In 1999, N_2O emissions from human sewage were 1.1 $MMTCO_2$ Eq. Emissions have increased by approximately 13 percent since 1990, due to both the increases in state population and the per capita protein intake.

These data assume that not all sewage nitrogen is discharged into aquatic environments. A certain amount is also applied to soils via sewage sludge applications. The N_2O estimates presented here account for the amount of nitrogen in sewage sludge applied to soils. Other sewage sludge-related emissions estimates are covered in the Agricultural Soil Management section.

Table 95: N_2O Emissions from Human Sewage in California ($MMTCO_2$ Eq.)

Source	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999
Human Sewage	0.93	0.87	0.85	0.94	0.86	0.93	0.91	1.00	1.04	1.05

6.4.1. Methodology

Nitrous oxide emissions from sewage in wastewater were estimated using the following equation taken from the EIIP guidance (EIIP 1999):

$$N_2O\ Emissions = Protein \times Frac_{NPR} \times State\ Population \times EF$$

Where: Protein = Annual per capita protein consumption

$Frac_{NPR}$ = Fraction of nitrogen in protein (percent)

EF = Emission factor (kg N_2O-N / kg sewage-N produced)

Nitrous Oxide-Nitrogen emissions from human sewage were estimated by multiplying the annual per capita consumption of protein by (1) the fraction of nitrogen in protein; (2) state population estimates; and (3) an N_2O emission factor.

6.4.2. Data Sources

Population data for 1990 through 2000 were obtained from the California Department of Finance (CA DOF 2001). Annual per capita protein intake data were taken from the U.S. Inventory (EPA 2001). California state average protein consumption was assumed to be consistent with national levels. The fraction of nitrogen in protein, as well as, the N_2O emission factor was obtained from IPCC (2000).

CHAPTER 7 – CALIFORNIA EMISSIONS IN CONTEXT

7.0 California Emissions in Context

This chapter analyzes California's greenhouse gas emissions in the context of emissions from natural sources and emissions from other states and countries. Additionally, the trends in emissions are examined, with emphasis on the impacts of energy and environmental policies on the level of emissions and the rate of change in emissions from 1990 to 1999. Sub-section 25730(a) of Division 15 of the Public Resources Code, requires the California Energy Commission to

> *"update the inventory of greenhouse gas emissions from all sources located in the state, as identified in the commission's 1998 report entitled, "Appendix A: Historical and Forecasted Greenhouse Gas Emissions Inventories for California." Information on natural sources of greenhouse gas emissions shall be included to the extent that information is available. The inventory shall include information that compares emissions from similar inventories prepared for the United States and other states or countries, and shall include information on relevant current and previous energy and air quality policies, activities, and greenhouse gas emissions reductions and trends since 1990, to the extent that information is available."*

Despite the limited data and resources available, the Commission developed preliminary estimates of the impacts of air quality and energy programs on state greenhouse gas emissions trends. This chapter also presents a preliminary assessment on the role of out-of-state power plants serving California on the observed in-state emission trends.

This chapter is organized as follows:
- Natural emissions in California;
- Comparison of California's emissions with emissions from other states and countries;
- Emission trends and factors underlying trends (including impacts of state policies);
- Expected future emission levels; and
- Uncertainty and the limitations of the emission estimates.

7.1. Natural Emissions in California

Of the greenhouse gases reported in this inventory, three are produced by natural sources: carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O). These gases are continuously emitted to and removed from the atmosphere by natural processes. In the absence of human intervention, the atmospheric concentrations of these gases would remain fairly stable for very long periods of time. By changing the amounts of these gases that are emitted or removed from the atmosphere, human activities can influence the abundance of the gases in the atmosphere. The purpose of this section is to compare the anthropogenic emissions in the inventory to the natural sources of these gases. Each is discussed in turn.

7.1.1. Carbon Dioxide

Without human intervention, the natural carbon cycle would maintain a relatively stable atmospheric concentration of CO_2 over human time scales. Large amounts of carbon move into and out of the atmosphere annually. The oceans and land vegetation release and absorb on the order of 200 billion metric tons of carbon annually, representing about 735 billion metric tons of CO_2. Human activities are increasing the emissions of CO_2 into the atmosphere through the burning of fossil fuels. Additionally, changes in land use and forestry affect the exchange of carbon between the atmosphere and the land and its vegetation.

Compared to the amounts of carbon moved annually in the natural carbon cycle, global anthropogenic emissions are small, on the order of 25 billion metric tons of CO_2. Although these emissions are only about 3-4 percent of the naturally cycling carbon, they are sufficient to change the atmospheric abundance of CO_2. Measurements indicate that the atmospheric CO_2 concentration remained constant in the past millennium, and only increased with the start of the industrial revolution. The release of carbon to the atmosphere from the combustion of fossil fuels and changes in land-use patterns, e.g., the conversion of forests into urban areas, are the reasons for this increase (IPCC 2001b).

The CO_2 emissions from fossil fuel combustion in California contribute to the increased atmospheric abundance of CO_2. Although small compared to the amount of carbon flowing annually in the natural carbon cycle, the carbon in these fuels would remain in the ground and separated from the atmosphere if the fuels were not extracted and burned. Similarly, the impacts of human activity in California on the exchange of carbon from land and vegetation are small compared to the natural cycle. Nevertheless, these impacts, assessed in Chapter 5, contribute to the changing abundance of CO_2 in the atmosphere.

7.1.2. Nitrous Oxide

Nitrous oxide (N_2O) is a potent greenhouse gas, with a 100-year global warming potential of 310. It is a stable compound that decays slowly in the atmosphere, with an atmospheric lifetime of over 121 years. During the past two centuries, atmospheric concentrations of N_2O have risen by approximately 13 percent (IPCC 2001a).

Figure 24 demonstrates that concentrations have increased since the industrial revolution. This increase is generally thought to result from anthropogenic sources. As evidence of this relationship, the average atmospheric concentrations of N_2O are about 0.8 ppb greater in the Northern Hemisphere than in the Southern Hemisphere, consistent with the fact that about 60 percent of emissions occur in the Northern Hemisphere (IPCC 2001a).

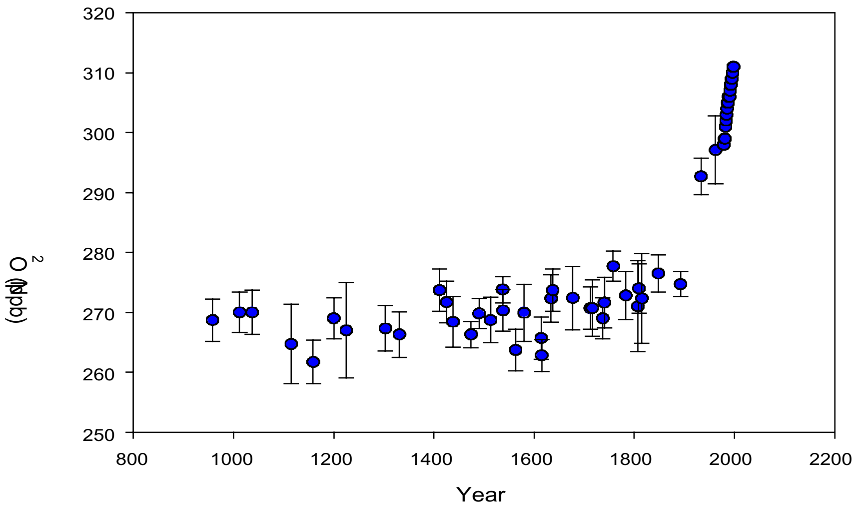


Figure 24: Atmospheric N$_2$O Concentrations (ppb)

Source: Flückiger 1999

Table 96 lists the contribution of natural and anthropogenic N_2O sources at a global scale. Anthropogenic emissions are lower than emissions from natural sources but result in an imbalance in the earth's nitrogen cycle, resulting in the observed increase in atmospheric N_2O concentrations.

Table 96: Estimated Emissions (in Tg – N per year) for N$_2$O Sources

Source Origin	Source Description	Estimated Emissions	Uncertainties
Natural Sources	Natural Soils	6	3.3--9.7
	Ocean	3	1--5
Anthropogenic Sources	Cultivated Soils	3.5	1.8--5.3
	Biomass Burning	0.5	0.2--1
	Industrial Sources	1.3	0.7--1.8
Other Minor Sources		0.4	0.2--0.5
Total		**14.7**	**10--17**

Source: IPCC 2001a, IPCC 1996

N_2O emissions from soil occur through the nitrification and denitrification of nitrogen in soils. Nitrification is a process of biological oxidation of ammonium (NH_4^+) to nitrite (NO_2-) and nitrate (NO_3^-). This process plays a significant role in the nitrogen cycle because it provides nutrients for denitrifying bacteria and affects the overall reduction rate of nitrate in the denitrification process. Denitrification is the reduction process of nitrate to form nitrous oxide and molecular nitrogen. Production of N_2O and N_2 by microbial denitrification occurs when bacteria capable of denitrification colonize a location where oxygen is essentially absent and water, nitrate and decomposed organic compounds are present (Liu 1996).

The following are some of the main factors that influence the emission of nitrous oxide from soil (IPCC 1996).

- Soil water content, which regulates the oxygen supply.
- Temperature, which influences microbial activity.
- Soil nitrate or ammonium concentration.
- Available organic carbon (denitrifying bacteria require a usable organic carbon source, and microbial respiration of organic carbon may also regulate soil oxygen supply).
- Soil acidity, which controls both nitrification and denitrification and the nitrous oxide / nitrogen ratio in denitrification processes.

Table 97 presents the first statewide estimates for annual N_2O emissions from native soil sources in California. These estimates were generated using the Cal-CASA model (Potter 1998, Potter 2000). This model was adapted from an early version of the Ames-CASA model to estimate ammonia (NH_3) emissions in California as part of a project funded by the California Air Resources Board though a contract with the National Aeronautics and Space Administration and Fresno State University.

Emissions from fertilizer use are considered anthropogenic emissions and are reported in Chapter 4, Section 4.4. Therefore, the N_2O emissions reported in this table for cropland do not include emissions from fertilizer usage of any kind. The total natural N_2O emissions from soils in California are estimated as 5.94 Gg-N (2.9 MMTCO_2 Eq.). This level of natural emissions is about one-eighth the total statewide anthropogenic N_2O emissions of 23.5 MMTCO_2 Eq., reported in Chapter 1. Consequently, natural N_2O emissions in California appear to be much smaller than anthropogenic emissions.

Table 97: California's Estimated Emissions from Soils (Gg – N per year) of N_2O from Native Soils

Type	Emission	Total Area (ha)
Evergreen Needleleaf Forest	2.28	12,435,200
Mixed Forest	0.03	262,400
Woodlands/Wooded Grasslands	1.09	6,656,000
Grassland	0.27	1,952,000
Bare Soil	0	710,400
Cropland	2.14	8,505,600
Deciduous Broadleaf Forest	0.01	96,000
Open Shrubland	0.12	9,491,200
Total	**5.94**	**40,108,800**

Source: Potter 2001

7.1.3. Methane

Methane's globally averaged atmospheric concentration has more than doubled since the beginning of the industrial revolution, reaching 1,745 parts per billion (ppb) in 1998. This rapid increase in concentrations is believed to be associated with substantial increases in methane emissions from human activities.

Table 98 lists the most important natural and anthropogenic global sources of methane (CH_4). Although the major sources of CH_4 have probably been identified, many of the source strengths are still uncertain due to the difficulty in assessing the global emission rates of the biospheric sources, whose strengths are highly variable in space and time (IPCC 2001a). The emissions from the various sources add up to a global total of about 500 Tg per year, of which about 60 percent are related to human activities, such as agriculture, fossil fuel use, and waste disposal (IPCC 2001a).

As seen in Table 98, wetlands are the primary source of natural CH_4 emissions globally, accounting for about 70 percent of natural emissions. However, estimates of global methane fluxes from wetlands suggest that methane emissions from temperate-zone wetlands are a small proportion of the total--typically between 5 and 10 million metric tons of methane per year worldwide (including U.S. wetlands)--when compared with estimated global wetlands emissions of 110 million metric tons (Mathews 1987*)*. This being the case, California's wetlands, on average, should emit less methane than the global average.

One survey of experiments conducted in the United States found emissions estimates for wetlands ranging from a negative flux (methane absorption) to a flux of 213 grams of methane per square meter per year, largely dependent on habitat type (Mathews 1987*)*. California has about 454,000 acres of nonagricultural wetlands (Bertoldi, 1996). Using the highest reported emission factor of 213 g/m^2 year, California's wetlands would produce about 0.39 Tg per year of methane (8.19 $MMTCO_2$ Eq.). These worst-case natural methane emissions are about one-fourth as large as the 31.6 $MMTCO_2$ Eq. of anthropogenic methane emissions estimated for the 1990 to 1999 period and reported in Chapter 1.

Table 98: Estimated Global Emissions of Methane
(Tg per year)

Source Origin	Source Description	Estimated Emissions	Uncertainties
Natural	Wetlands	115	55--150
	Termites	20	10--50
	Oceans	10	5--50
	Other Natural Sources	15	10--40
Anthropogenic	Fossil Fuel Related	100	70—120
	Enteric Fermentation	85	65--100
	Rice Paddies	60	20--100
	Biomass Burning	40	20--80
	Landfills	40	20--80
	Animal Waste	25	20--30
	Domestic Sewage	25	20--30
Total		**535**	**410 - 660**

Source: IPCC 2001a

7.2. Comparison of California Emissions with Other States and Countries

This section compares California emissions with emissions from other states and nations. The comparison focuses on CO_2 emissions from the combustion of fossil fuels because this source accounts for the overwhelming majority of anthropogenic greenhouse gas emissions (84 percent of gross emissions when preliminary estimates of emissions from bunker fuels are excluded).

7.2.1. California's Emissions as Compared to Other States

Figure 25 shows that California's anthropogenic emissions from the combustion of fossil fuels are larger on an absolute basis than all other states with the exception of Texas. However, CO_2 emissions on an absolute basis are not appropriate for comparisons across states, given the variability in state populations and state economies. For this reason, emissions are often compared on a per capita or per Gross State Product (GSP) basis.

Figure 26 presents CO_2 emissions from the combustion of fossil fuels on a per capita basis for each of the states in 1999, and Figure 27 presents emissions per thousand dollars of GSP for the same year. When these results are plotted on a single figure among a sample of high and low-emitting states, California emissions appear to be among the lowest in the nation, both on a per capita basis and per GSP basis (Figure 28). Note that Figure 25 through Figure 28 present emissions from fossil fuel combustion including emissions from bunker fuels because the data necessary to estimate and exclude these emissions for all states are not available.

When considering California's emissions in comparison to other states' emissions, it is important to realize that fossil fuel combustion emissions are dependent on many other factors, including climate, the composition of the state's industrial base, and energy and air quality programs and their effects on greenhouse gas emissions. Using a decomposition analysis, researchers at Lawrence Berkeley National Laboratory concluded that the differences in climate and types of industry explain two-thirds of the lower energy consumption per capita in

California as compared to the U.S. as a whole. The balance, or one-third of the total, is due to lower energy intensities that are the result, in part, of higher energy efficiency appliance and building standards, and demand side management (DSM) programs implemented in California (Schipper 1995). Therefore, it appears that California's lower emissions per capita and per GSP are due, in part, to a more energy-efficient economy.

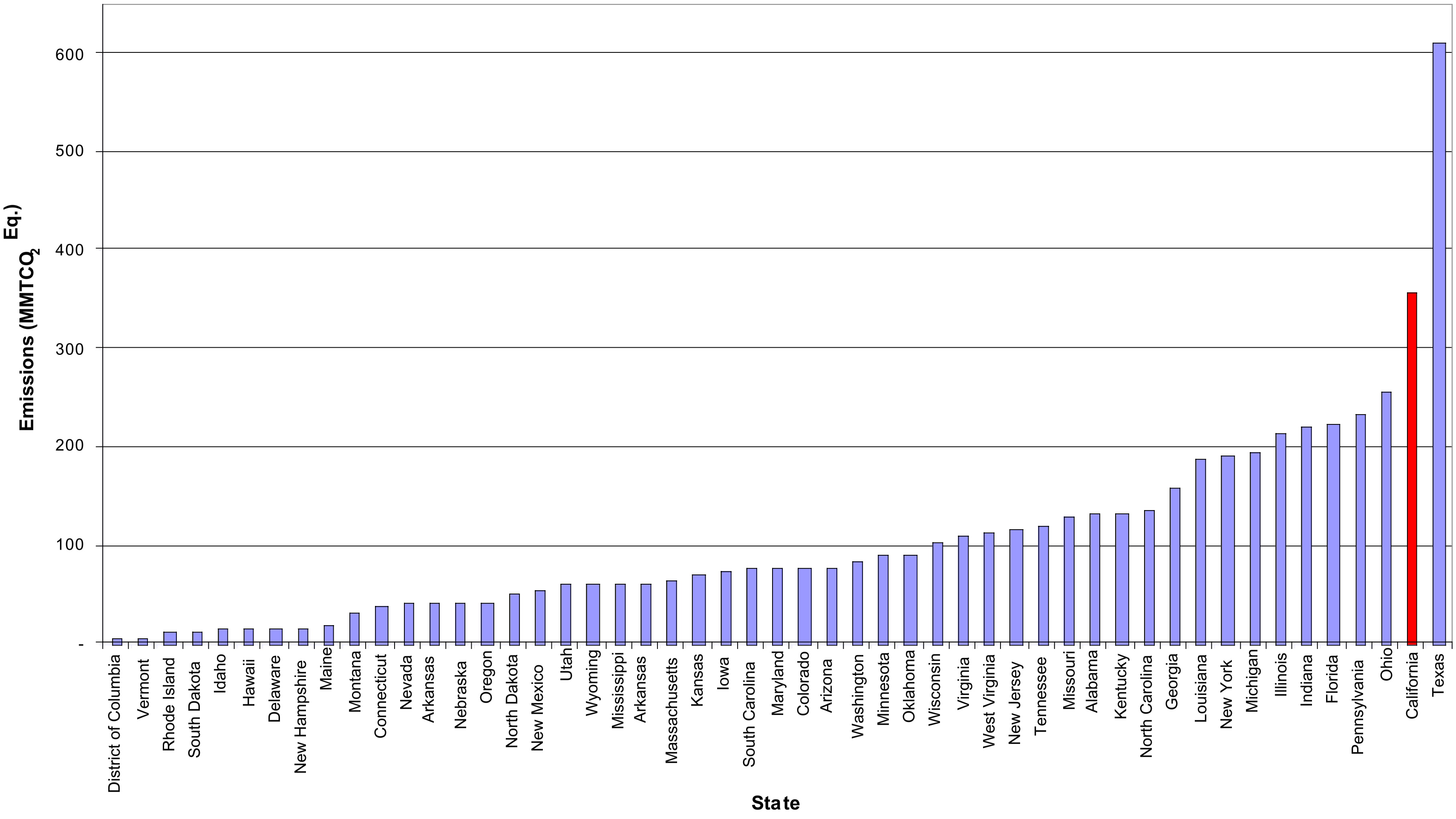
Energy-intensive manufacturing represents approximately 10 percent of the total economic output in California, compared to about 22 percent for the U.S. as a whole. Therefore, California's lower emissions reflect a lower level of energy-intensive industrial activity. However, when comparing within individual industry categories, manufacturing energy intensity (measured as the ratio of energy consumed to value added) is lower in California than in the U.S. as a whole (Schipper 1995). Consequently, energy efficiency appears to reduce California's industrial energy emissions as well.

In the transportation sector, the data show that per capita fuel use for cars and light trucks is slightly lower in California than for the nation as a whole. This result goes against the common belief that Californians consume more fuel for personal transport than most other states. Substantial amounts of fuel purchased in California may be associated with the transport of goods and services to and from foreign destinations for other states using California only as a convenient route. This will tend to increase the relative importance of transportation as a source of emissions in the state (Schipper 1995).

In addition to being more efficient, the California economy's energy consumption is also less carbon-intense. California uses less fossil energy to generate electricity than other states, or the U.S. as a whole (see Figure 29). In fact, as Figure 30 shows, California's electricity production relies heavily on natural gas, hydroelectric power, nuclear power, cogeneration, and renewable energy sources (e.g. wind, biomass). These choices have helped reduce carbon dioxide emissions from what they otherwise would have been.

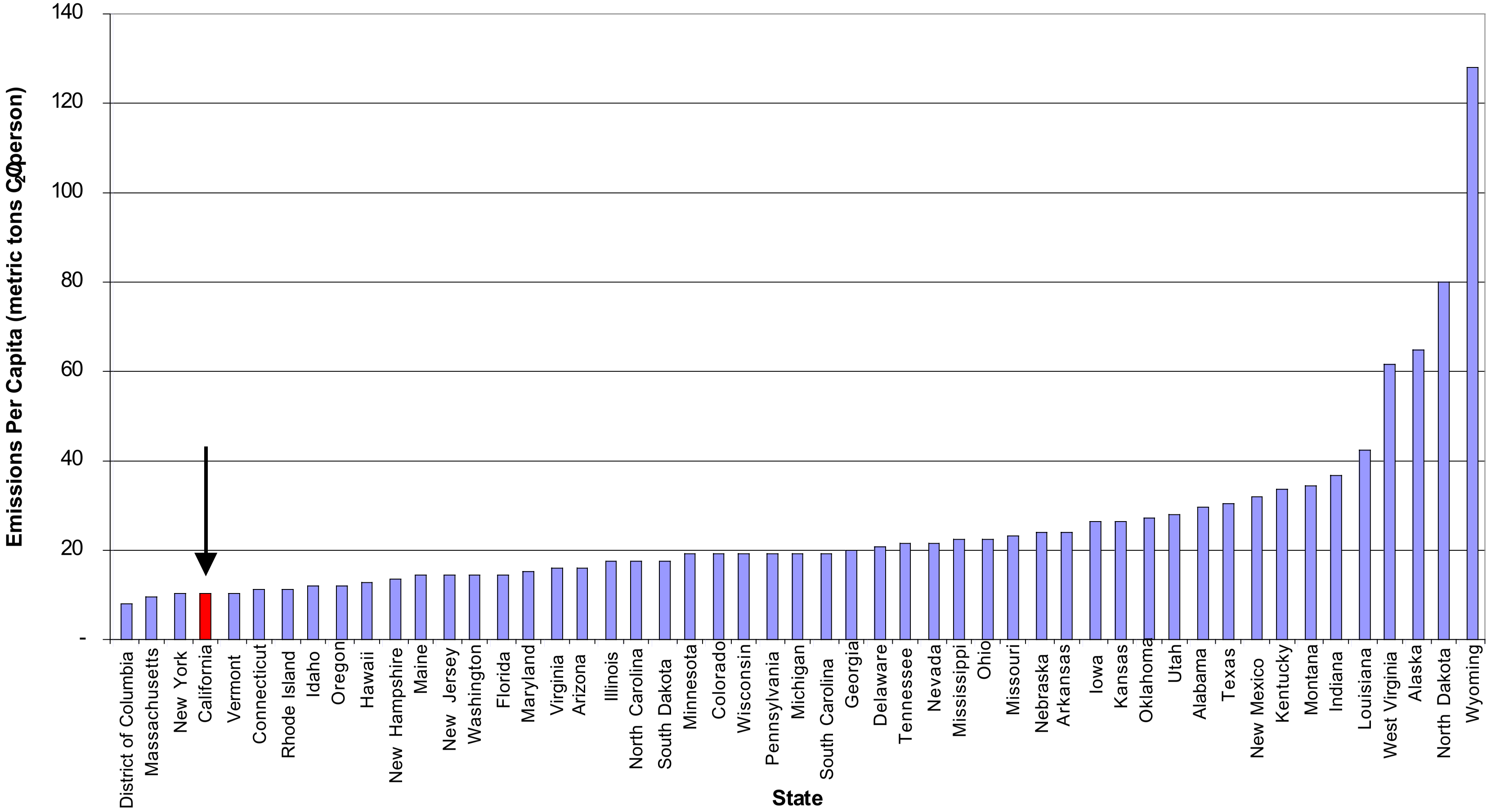
As shown in Figure 31, California's electricity use per capita has remained flat compared to national per capita use, which increased by approximately 1.5 percent per year. On the demand side, reduced electricity consumption results from California programs such as energy efficiency in building and appliance standards. These programs have resulted in increased electricity conservation, which was particularly pronounced during the sharp electricity supply shortages experienced in California from 2000 to 2001. Preliminary data suggest that per capita electricity use dropped by seven percent from 2000 levels in 2001.

Changes in California's economy have contributed to the reduction in emissions per unit of GSP. Emissions per dollar of GSP have fallen, as shown in Figure 32. Section 7.3.2 explains some of the economic factors underlying this trend in emissions per GSP.



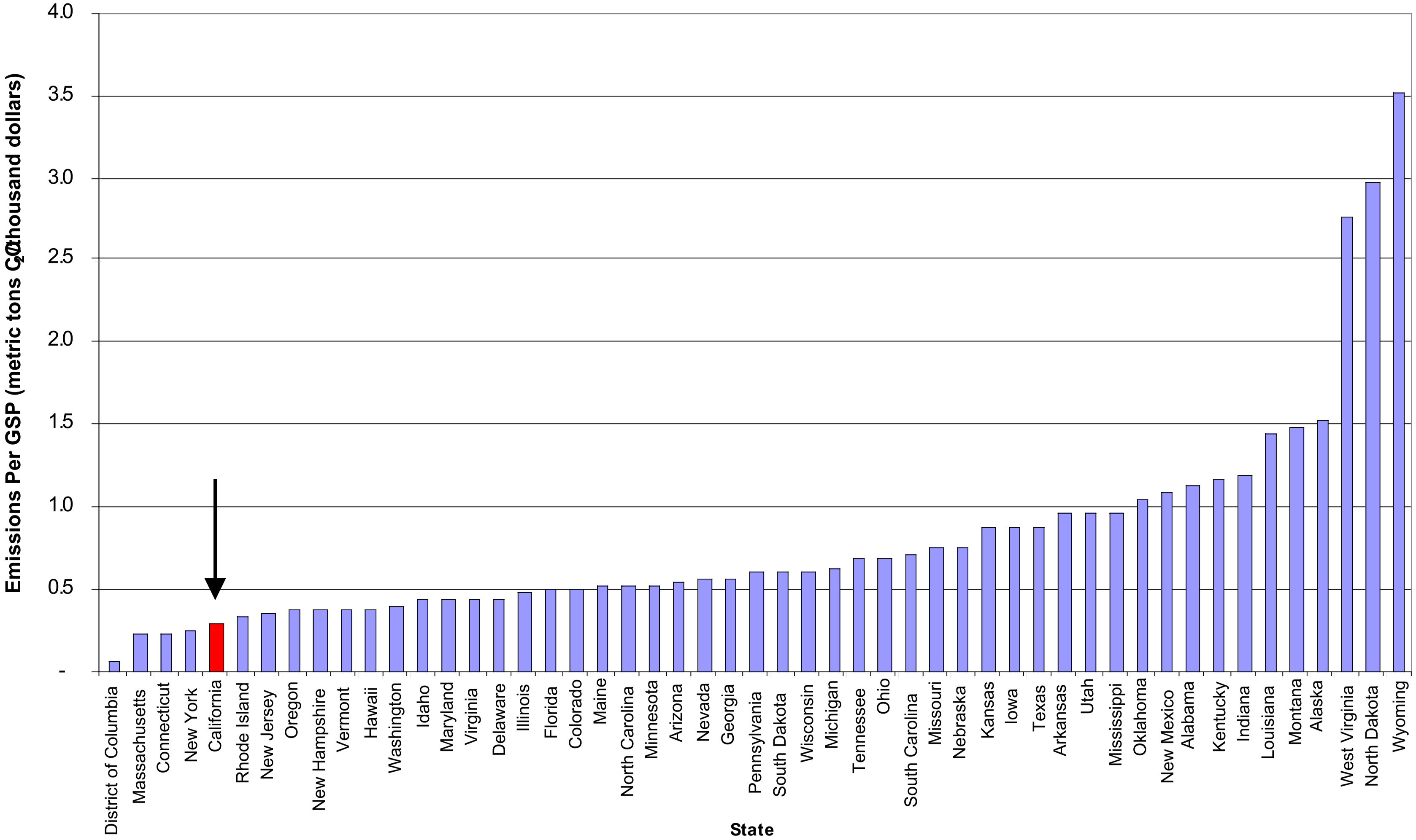
Source: California emissions from Chapter 2, Section 2.1. All other state emission estimates taken from EIA 1999.

Figure 25: CO_2 Emissions from Fossil Fuel Combustion by State: 1999



Sources: California emissions from Chapter 2, Section 2.1; population from CA DOF 2001. All other state emission estimates taken from EIA 1999; state populations from U.S. Census Bureau 1999.

Figure 26: CO_2 Emissions per Capita by State: 1999



Sources: California emissions from Chapter 2, Section 2.1; all other state emission estimates taken from EIA 1999. GSP for all states taken from DOC 2001.

Figure 27: CO_2 Emissions per Gross State Product by State: 1999

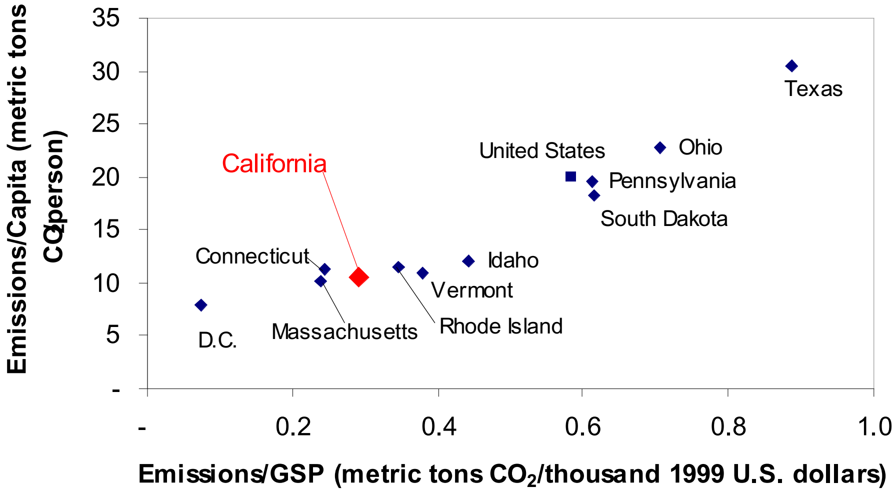


Figure 28: 1999 Carbon Intensity from the Combustion of Fossil Fuels for California, the United States, and Selected States

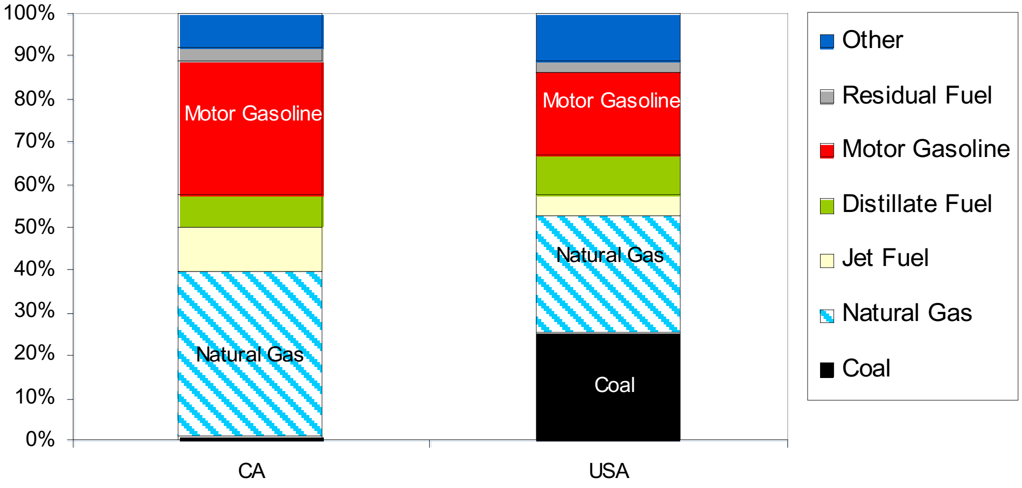


Figure 29: 1999 Fossil Fuel Consumption in California and United States

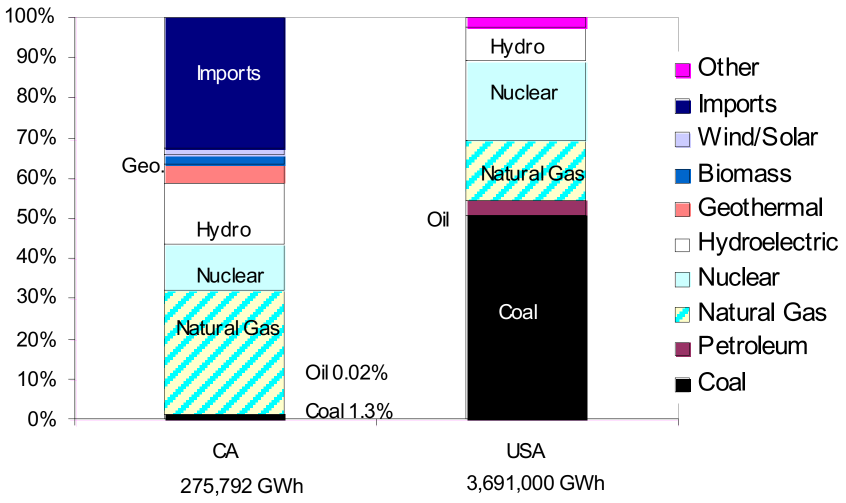


Figure 30: 1999 Distribution of Electricity Sources in California and United States

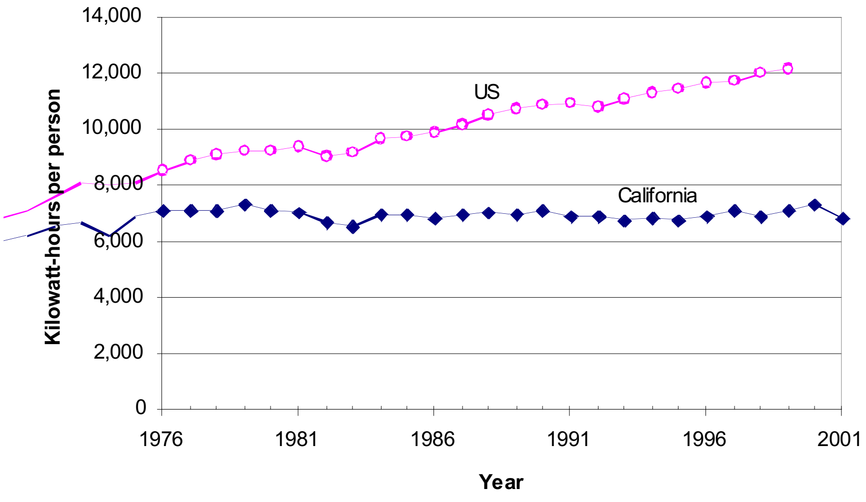


Figure 31: California and United States Electricity per Capita Trends Since 1976

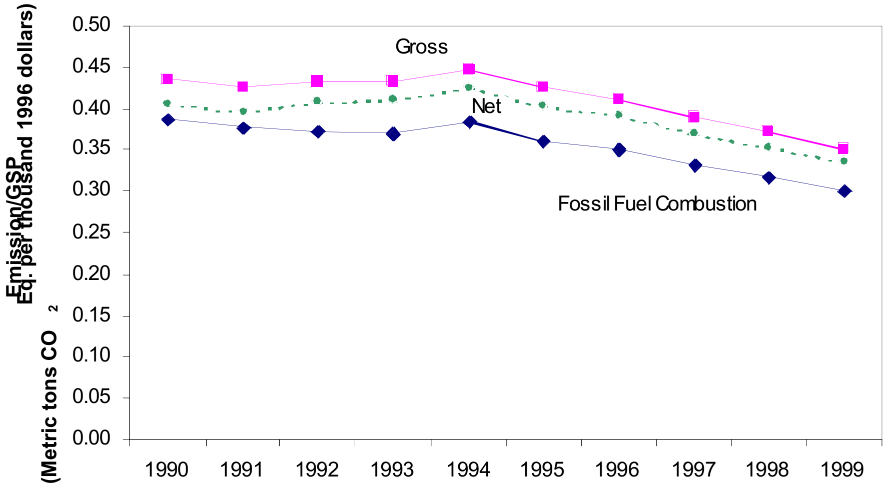


Figure 32: California Emissions per Dollar of Gross State Product (excluding marine bunker fuels)

7.2.2. California's Emissions as Compared to Selected Countries

Figure 33 presents CO_2 emissions from the combustion of fossil fuels per capita and per GSP or gross domestic product (GDP) for California and representative countries. California's emissions per GSP are lower than emissions per GDP for some of the major industrialized countries but still higher than the emissions from various countries including France, Sweden, and the Netherlands. On a per capita basis, California emissions are higher than nearly all of the countries listed, and are lower than emissions in the U.S. and Canada.

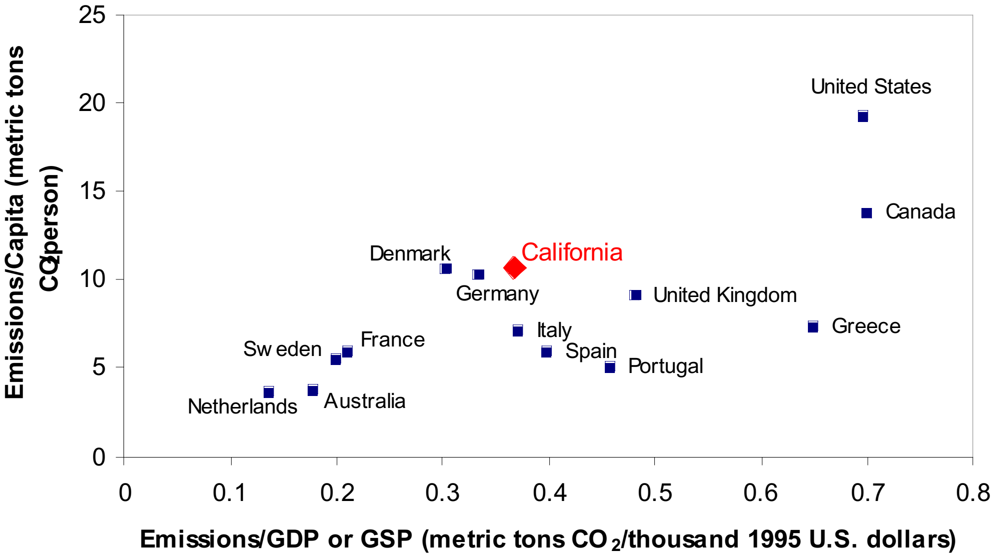


Figure 33: 1995 Carbon Intensities for California and Selected Countries Fossil Fuel Combustion

7.3. Emissions Trends and the Impacts of Past Policies

This section presents the trends in California's greenhouse gas emissions and examines the role of energy and air quality programs on these trends. Because CO_2 emissions from fossil fuel combustion dominate the emissions inventory, these emissions provide the focus for this section. To provide an historical context to recent emissions trends, the period 1970 to 1999 is examined. Within this period, the trends and factors affecting emissions from 1990 to 1999 are emphasized because 1990 is commonly viewed as the baseline year for emissions inventories. Trends in emissions from 1970 to 1999 presented in this section represent emissions *including* bunker fuels because bunker data prior to 1990 are not available; however, text and figures discussing trends from 1990 to 1999 *exclude* bunker fuels.

Bunker Fuel Emissions

According to the UNFCC and EPA inventory guidelines, marine and aviation bunker fuel emissions should, if possible, be estimated and subtracted from total CO_2 emissions. Under the accounting guidelines, however, if the data cannot be disaggregated sufficiently to estimate these emissions, total emissions (i.e., including bunker fuel) should be reported in the inventory as part of in-state emissions. As described in Chapter 2, Section 2.7 (International Bunker Fuels), bunker fuel data for the aviation sector were not available, and bunker fuel data obtained for marine vessels appeared to be inconsistent with state-wide fuel consumption data. Thus, it was difficult to reliably estimate the effect of bunker fuels. Although much of the report presents emission estimates including bunker fuels, both the Executive Summary and this chapter attempt to use preliminary estimates of bunker fuel emissions to clarify trends in state emissions. For this reason, estimates of California emissions cited in this chapter reflect total emissions minus estimated marine bunker fuel emissions.

This section begins with a discussion of CO_2 emissions trends. Next, the factors contributing to the trends are discussed, including: economic and population growth; energy efficiency policies; energy and environmental policies; transportation issues (primarily vehicle fuel economy standards); and electricity imports. This section ends with an estimate of the impacts of these various factors on the change in emissions from 1990 to 1999.

7.3.1. Trend in CO_2 Emissions from Fossil Fuel Combustion

This section presents the trends in CO_2 emissions from fossil fuel combustion in California. Figure 34 shows that these emissions have remained relatively flat for the period 1970 to 1999. The emissions peaked in 1979 at approximately 400 $MMTCO_2$ Eq., and have remained below this level through 1999.

The relative importance of the sectors underlying trends in total emissions has changed over time. Figure 35 shows the percentage that each sector contributed to total emissions in each year. As shown in the figure, from 1970 to 1999 the contribution of the transportation sector increased from 42 percent in 1970 to 59 percent in 1999. The contribution of the transportation sector peaked in 1996 at about 61 percent. Also shown in Figure 35, the electric utility sector's share of emissions has declined. As discussed below, this decline is driven, at least in part, by energy and environmental policies. Of note, the apparent decline in the share of electric utilities in the late 1990s is driven by the sale of fossil-fuel electric power plants from utilities to industrial entities. Following the sales of these plants, the emissions are counted under the industrial sector, and not under the electric utility sector (Chapter 2 describes this issue in more detail).

Underlying the shifts in the contribution of each sector to total emissions are shifts in the contributions of each fuel. Figure 36 shows the trends in the CO_2 emissions from each fuel. Emissions from transportation fuels (e.g., motor gasoline and jet fuel) increased from 1970 to 1999. The emissions patterns for natural gas and residual fuel oil are more complex. In the early 1970s, natural gas emissions were declining while residual fuel oil emissions were increasing rapidly. At that time, these fuels were substitutes for each other in many industrial applications, including electricity production. Following the second oil price shock in the 1970s, the use of residual fuel oil declined significantly. To some extent, natural gas was the replacement fuel. This fuel switch resulted in lower CO_2 emissions because natural gas has a lower carbon content than residual fuel oil.

Figure 37 examines the emissions trend for 1990 to 1999. During this period, total CO_2 emissions from fossil fuel combustion first declined slightly, and then increased. The CO_2 emissions from fuel combustion in 1999, excluding bunker fuels, are estimated to be about 3.0 percent higher than the emissions in 1990. The trends in each of the sectors are also shown. The rapid decline (73 percent decrease from 1990 to 1999) in emissions from electric utilities was due to the change of ownership to non-utilities. Transportation emissions, the largest sector, mirror the trend in overall CO_2 emissions.

Fuel demand for diesel (distillate), jet fuel (for commercial and military transport), and motor gasoline in the transportation sector increased in the 1990 to 1999 period (Figure 38). However, emissions from residual fuel oil in this sector declined significantly over the same period (47 percent decrease). Overall emissions from the transportation sector increased by approximately seven percent between 1990 and 1999.

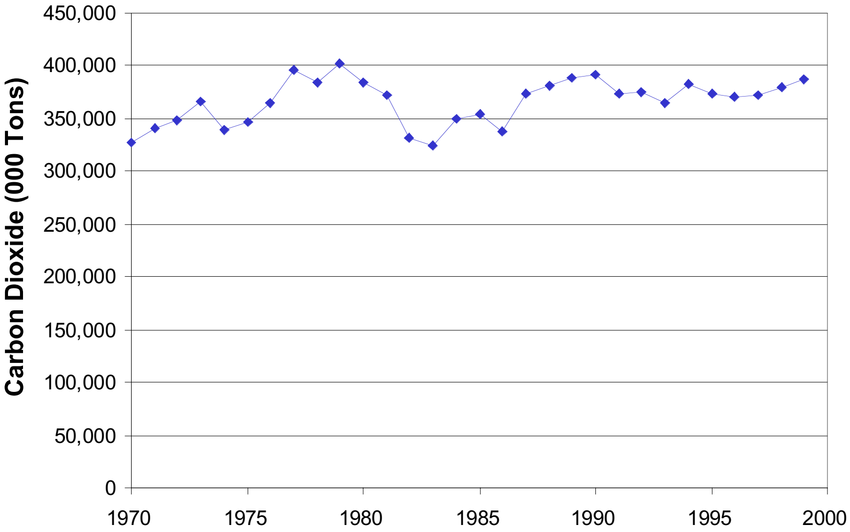


Figure 34: CO$_2$ Emissions in California from Fossil Fuel Combustion: 1970-1999

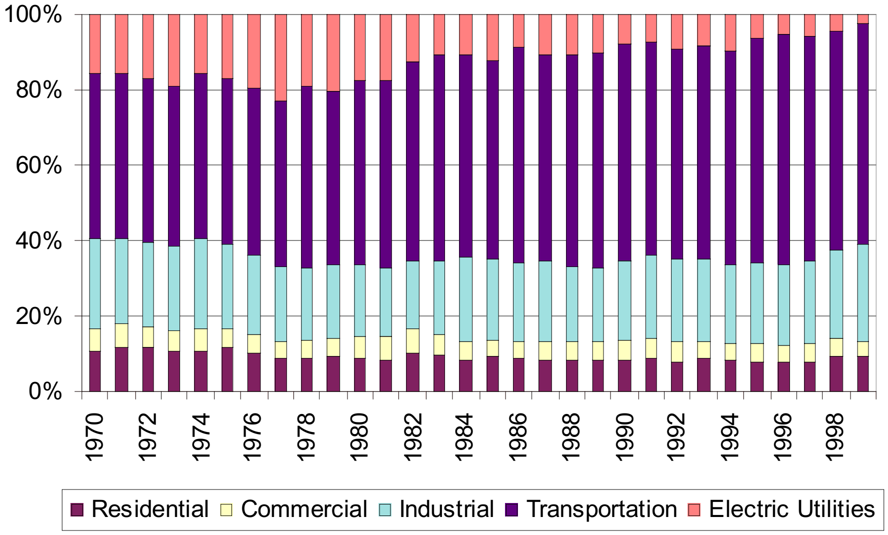


Figure 35: Changing Mix of Emissions by Sector: CO$_2$ Emissions in California from Fossil Fuel Combustion

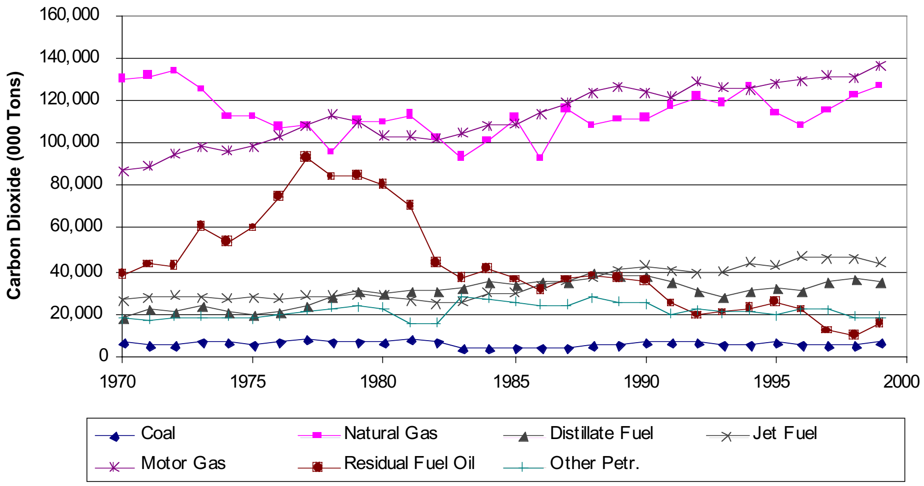


Figure 36: CO$_2$ Emissions in California from Fossil Fuel Combustion by Fuel Type

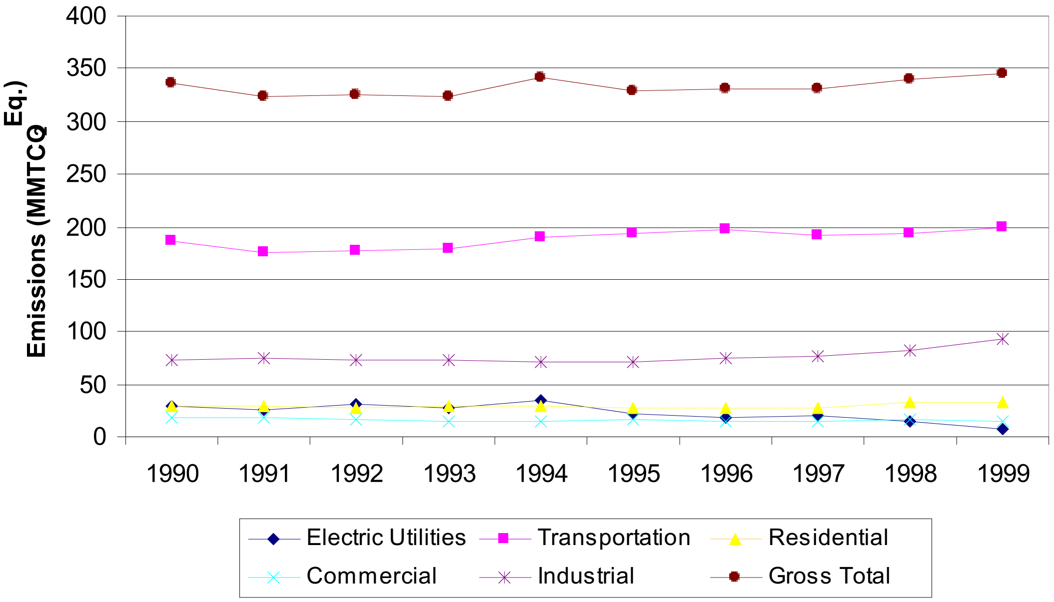


Figure 37: California CO$_2$ Emissions from Fossil Fuel Combustion by Sector (excluding marine bunker fuels): 1990-1999 (MMTCO$_2$Eq.)

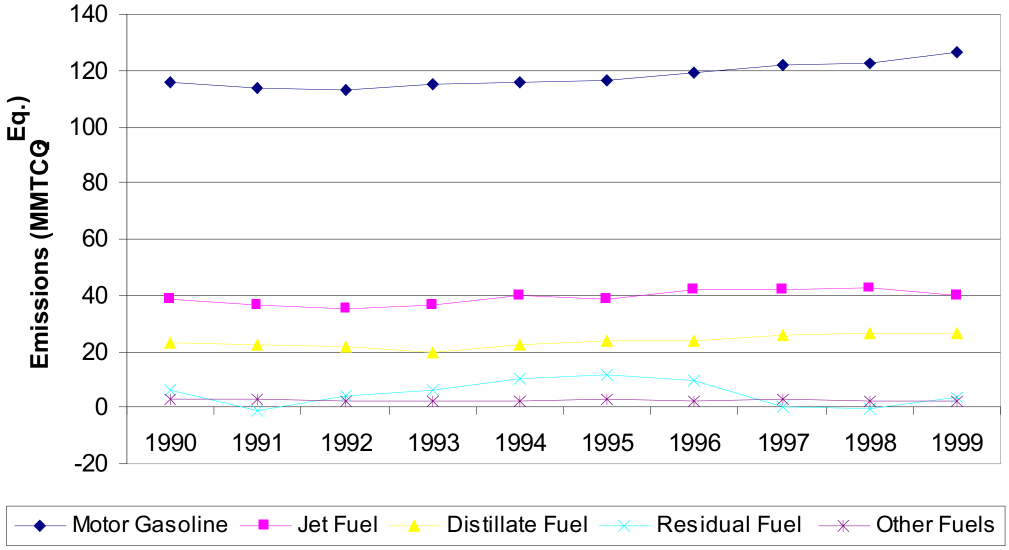


Figure 38: California CO_2 Emissions from Fossil Fuel Combustion in the Transportation Sector by Fuel Type (excluding marine bunker fuels): 1990-1999 ($MMTCO_2$ Eq.)

The following sections describe the factors that influenced these emissions trends.

7.3.2. Economic and Population Growth

Historically, trends in energy consumption have been linked to economic and population growth. Following the oil price shocks in the 1970s and subsequent analyses of various energy policies, the relationship between energy use and economic growth has received considerable scrutiny. Within this context, CO_2 emissions from fossil fuel combustion are expected to track relatively closely with trends in energy use, adjusting for changes in fuel mix and the relative carbon intensity of the various fuels. Consequently, it is appropriate to examine how CO_2 emissions trends compare to economic and population growth trends.

As shown in Figure 39, CO_2 emissions from fossil fuel combustion tracked economic and population growth in the early 1970s (the data are shown relative to 1970, which is set to 100). Following the oil price shocks in the 1970s, and the resulting dislocations in the energy sector, the linkage between these energy-related emissions and economic growth appears to have de-coupled in the 1980s in California. This de-coupling is evidenced by the decline in emissions from 1979 through 1983 while the economy (measured as Gross State Product, GSP) and population grew. Emissions remained flat through 1986, and then started to grow slightly through the end of the decade. Economic and population growth both outpaced the growth in emissions during this period.

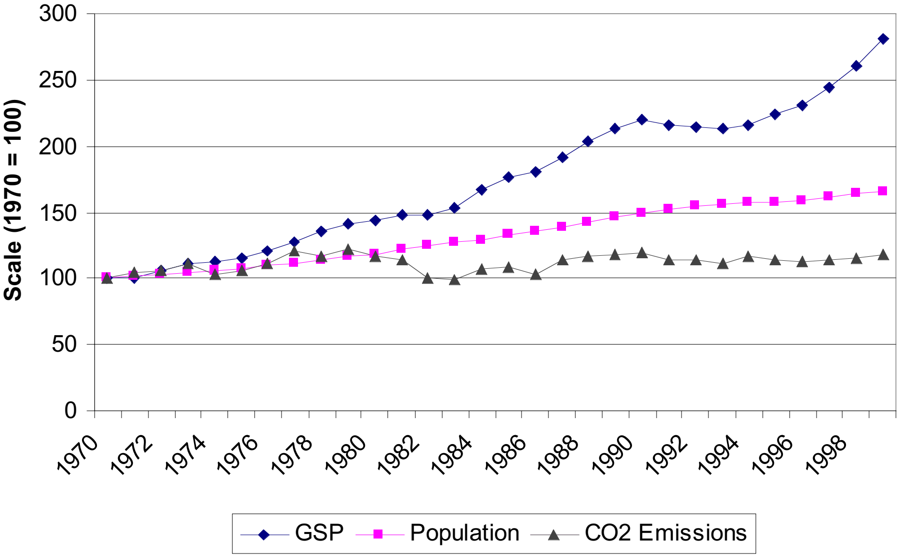


Figure 39: Relative Growth in GSP, Population, and CO_2 Emissions from Fossil Fuel Combustion in California: 1970-1999

In the early 1990s, the state economy contracted, and emissions declined. However, in the late 1990s, the economic boom in California was not accompanied by a commensurate increase in CO_2 emissions from fossil fuel combustion.

The changes in the real prices for energy had an important impact on the relationship between energy consumption and economic growth in the 1980s. However, California-specific policies have also had important impacts, and remain influential through the 1990s. As a result, CO_2 emissions from fossil fuel combustion per unit of GSP have declined significantly over this period, particularly in the late 1990s. This trend is shown in Figure 40.

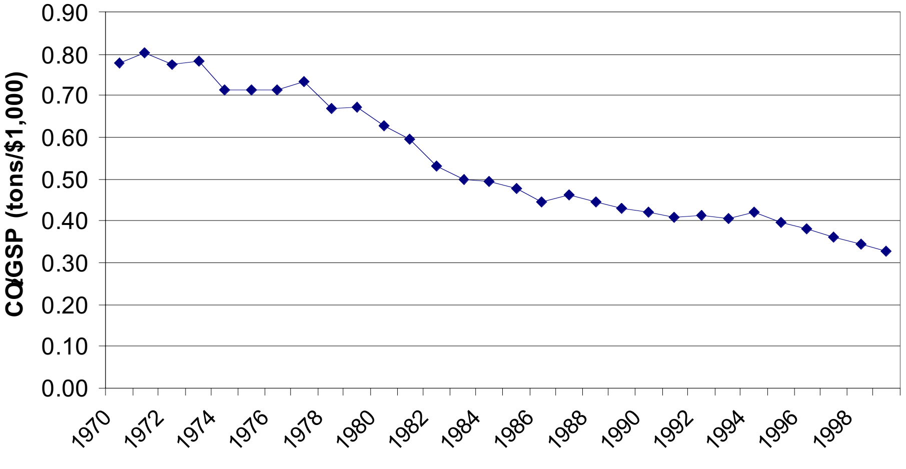


Figure 40: California CO_2 Emissions from Fossil Fuel Combustion Per Unit of GSP: Tons per Thousand Dollars (1996 dollars)

The rate of growth in several sectors of California's economy may have contributed to the reduction in emissions per unit of GSP. For the period 1990 to 1999, five sectors and sub-sectors of the state economy accounted for 74 percent of the State's economic growth. These sectors and subsectors of the California economy have lower than average energy intensities and include manufacturing of electronic equipment and computers and related equipment, wholesale trade, finance, insurance, and real-estate, and services (Table 99). Consequently, the pattern of economic growth during the 1990s probably contributed to the decline in CO_2 emissions per unit of GSP. However, the extent of this impact has not been quantified.

Table 99: Growth Rates for the Fastest Growing Sectors in California: 1990-1999

Sector or Sub-sector of the State Economy	Growth from 1990-1999	Portion of Sate GSP Growth from 1990-1999
Manufacturing – Industrial Machinery*	233%	11.5%
Manufacturing – Electronic Equipment	366%	16.5%
Wholesale Trade	66.1%	14.0%
Finance, Insurance, and Real Estate	15.3%	13.0%
Services	23.3%	18.8%
Total	**34.2%**	**73.9%**

Source: DOC 2001

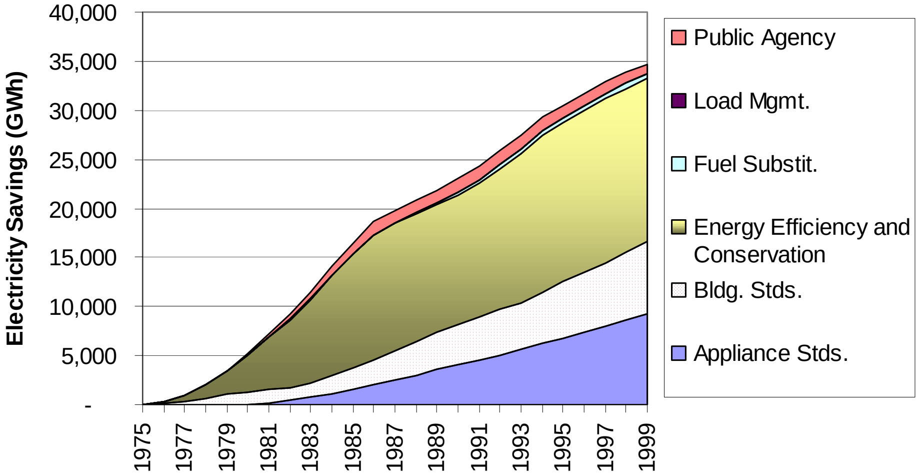
* This sub-sector includes the manufacture of computers (SIC 35: industrial and commercial machinery and computer equipment).

7.3.3. Energy Efficiency Policies

California has been aggressive in promoting energy efficiency. California implemented appliance energy performance standards beginning in 1977, and has continued to promote energy efficiency since. Similar federal standards were not in effect until 1990 with the implementation of the National Appliance Energy Conservation Act of 1987. These standards have had a long-term effect on emissions because of the relatively long useful life of some of the appliances included in the standards, such as gas furnaces and refrigerators. California also enacted building standards affecting new buildings after 1978 and has continued to update its standards with the most recent update promulgated in 2001.

Under the auspices of the California Public Utilities Commission (CPUC), California's electric and gas utilities have undertaken significant efforts to improve the efficiency of electricity and natural gas use among residential and non-residential customers. A report evaluating the effectiveness and benefits of energy efficiency programs (RAND 2000) estimates that if there had been no improvements in energy intensity from 1977 to 1995, the state economy would have been three percent smaller than it was in 1995. This represents a benefit to California's economy in 1995 of about $875 to $1300 per capita (1998 dollars). From 1977 to 1995, the state's electric utilities spent a cumulative total of about $125 per capita (1998 dollars) on energy efficiency programs for the industrial and commercial sectors. The RAND report indicates that not only have the programs been effective in reducing energy consumption, they have also resulted in net cost savings to Californians.

The California Energy Commission recently conducted a retrospective analysis of the impact of past efficiency measures on in-state energy consumption as required by Sections 44 and 45 of Assembly Bill 1105 (Chapter 67, Statues of 1999) (CEC 1999, CEC 2001a). This report, “A Proposal for a New Millennium,” provides a comprehensive analysis of the energy savings of past energy efficiency programs started in the mid-1970s. Figure 41 presents the electric energy savings associated with these programs. As the graph shows, these electric energy savings have enabled electricity consumption to be lower than would otherwise have been the case.



Source: CEC 1999, CEC 2001a

Figure 41: Annual Electricity Savings from Energy Efficiency Programs and Standards Implemented Before 1999

These electricity savings are significant relative to total electricity generation and consumption in the state. By 1990, Figure 41 indicates that these efforts were saving over 20,000 MWh per year, and by 1999 the total was approaching 35,000 MWh per year. These savings are on the order of 10 to 15 percent of the annual electricity consumption in the state. In the absence of these savings, additional electricity would have either been produced in-state or imported from other states. By reducing the demand for electricity during the 1990s, these savings helped to dampen the increasing trend in California’s CO_2 emissions between 1990 and 1999. Savings from energy conservation programs, including electricity savings, in 1999 relative to 1990 are estimated at about 7.1 MMTCO_2 Eq.

7.3.4 Energy Supply and Environmental Policies

Energy supply and environmental policies have had significant impacts on CO_2 emissions from fossil fuel combustion in California. Among these policies are NO_x emissions restrictions and policies promoting cogeneration and renewable resources. Additionally, the availability of hydroelectric (hydro) power has affected emissions.

Air Quality Regulations Limiting NO_x Emissions

Air quality regulations that limit NO_x emissions favor the use of natural gas as a fuel over residual fuel oil and other petroleum products. These regulations have influenced emissions from the industrial, commercial, and electric utility sectors, primarily due to the lower carbon content of natural gas as compared to petroleum fuels.

Power plants switched from residual fuel oil to natural gas mostly in the 1976 to 1982 period. This switch may have been driven largely by economic conditions favoring natural gas over residual fuel oil. From 1992 to 1996, however, residual fuel oil (heavy oil) available for power plants was less expensive than natural gas in California (EIA 2001). In theory, assuming that enough residual fuel oil was available, utility and commercial boilers could have switched back to residual fuel oil. This switch back to residual fuel oil did not occur, in part due to the existing air quality regulations, which have imposed stringent nitrogen oxide (NO_x) emission standards on existing power plants. It is unlikely that utility and commercial boilers would be able to comply with these standards while burning residual fuel oil. In fact using this fuel may damage the equipment installed to control NO_x emissions. Some air quality regulations allow burning of fuels other than natural gas only if there is a natural gas curtailment situation.

Another NO_x-related effect results from a program adopted by the San Joaquin Valley Air Quality Management District. In 1988, the district regulated NO_x emissions from enhanced oil recovery (EOR) units in Kern County. Most of the EOR units were dual fired (residual or crude oil and natural gas). With the entrance in operation of the Kern River Transmission Company and the Mojave Pipeline, oil producers could execute long-term, non-interruptible contracts, for natural gas. These contracts made natural gas more economically attractive. Moreover, the SJVAQMD’s rule favors the use of natural gas over liquid fuels because it is apparently less expensive to comply with emission standards for natural gas (0.14 Lb / MMBtu) than with the limits for liquid fuels (0.20 lb / MMBtu) (Goff 2002). The combination of the increased availability of natural gas and the NO_x rule resulted in a substantial switch from heavy oils to natural gas with concomitant reductions in CO_2 emissions.

The NO_x retrofit rules for existing boilers, process heaters, and steam generators adopted by the local air districts in California and implemented after the mid-1990s have resulted in a shift from distillate fuel oil to natural gas. These rules are very stringent, requiring levels of control of 30 parts per million by volume (ppmv) corrected for three percent oxygen when burning natural gas and 40 ppmv at three percent oxygen when burning liquid fuels (BAAQMD 2002; SCAQMD 2002). It appears to be more economical to comply with the emission limitation rules when burning natural gas than burning distillate.

Cogeneration and Renewable Resources

The Public Utility Regulatory Policies Act of 1978 (PURPA) encouraged non-utilities to produce electricity by exempting them from previous legislative or regulatory restrictions. Most of the non-utilities that started producing electricity consisted of “qualifying facilities” that used cogeneration power plants or renewable energy as a fuel source. PURPA required utilities to purchase all electricity offered for sale by these non-utility generators.

Cogeneration is the simultaneous production and use of electricity and useful heat. For example, in an industrial complex a cogeneration power plant may use a gas turbine to generate electricity and use the flue gases from the gas turbine as source of heat in a heat recovery steam generator (boiler). Without a boiler this “waste heat” is released to the atmosphere with the flue gases from the gas turbine. The steam produced by the boiler can then be used in a manufacturing process. Cogeneration is much more efficient than having two separate systems: one to generate electricity and the other to produce useful heat.

Renewable energy resources include solar, wind, biomass and geothermal energy. These energy sources generally do not emit CO_2 emissions to the atmosphere (the only exception is small amounts of CO_2 emitted by certain geothermal power plants). Biomass energy, if produced in a sustainable manner, is not a net emitter of CO_2 because the carbon released during combustion to generate electricity is re-absorbed by plants in the next growing season.

California has been the national leader in the development of non-utility electric power generation. In 1991, non-utility generators in California and Texas produced about 53,000 and 49,000 GWh of electricity respectively, and together represented about 41 percent of the nation’s non-utility electricity production. By establishing standard contracts, the California Public Utilities Commission was instrumental in the development of non-utility generation in California. Cogeneration has been the largest proportion of the non-utility generation. The state’s cogeneration power plants produced about 23.4 percent of the electricity generated from all in-state sources in 1997. This compares well with the 9.5 percent contributed by cogeneration in the U.S. as a whole for the same year. In addition, much of the non-utility generation is from renewable resources—California non-utility production of solar, wind, and geothermal resources has been the largest in the nation.

Figure 42 shows how cogeneration and other small power producers (including production from renewable resources) increased in importance from 1986 to 1997 (1997 is prior to the sales of the in-state fossil fuel power plants by the electric utilities). The substantial growth in these sources of electricity, primarily through the early 1990s, was an important factor limiting the growth in CO_2 emissions from fossil fuel combustion.

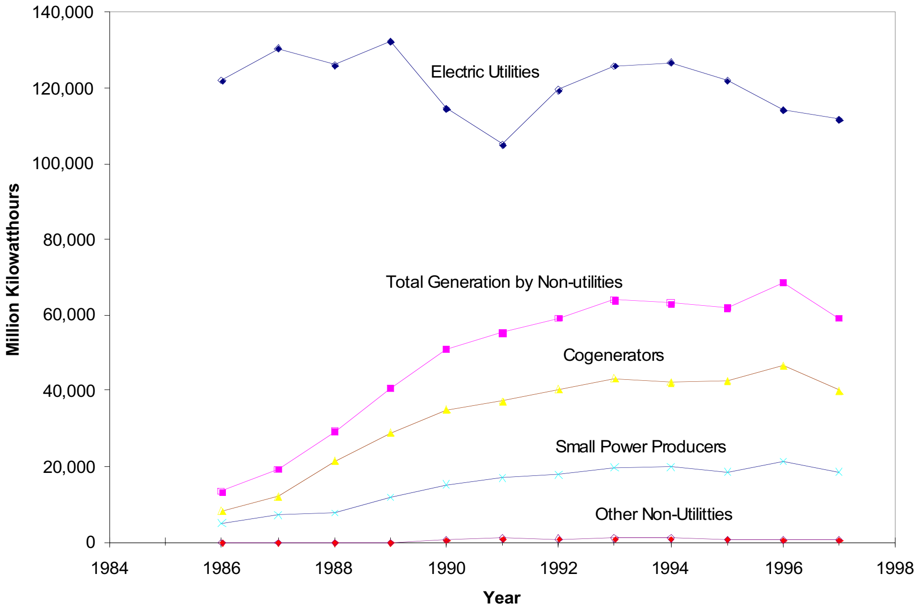


Figure 42: California In-state Electricity Generation

Other Factors: Nuclear Energy and Hydro Power

The increased reliance on nuclear energy in California also constrained CO_2 emissions from the combustion of fossil fuels. Nuclear power generated less than 10,000 GWh per year from 1975 to 1983 and increased to almost constant levels of about 30,000 GWh per year after 1988. Since nuclear power does not emit CO_2 to the atmosphere, this increase helped to reduce the growth in emissions. Because nuclear power generation did not increase significantly in the 1990s, nuclear power had no appreciable impact on the emissions trend during the period from 1990 through 1999.

Depending on the availability of water, the amount of electricity produced by hydroelectric (hydro) power plants can change dramatically from year to year resulting in significant changes in carbon dioxide emissions from in-state power plants. This variability is evident in Figure 43, where the effects of a five-year drought from 1987 to 1991 led to decreased hydroelectric power generation. The drought reduced precipitation from 40 to 70 percent from normal levels during this period. The effects of the drought on California's emissions are evident in the estimates of California's greenhouse gas emissions in 1990, as the portion of electricity typically provided by in-state hydro resources was met by generation from natural gas burning power plants. The below-average hydropower production in 1990 is estimated to have increased CO_2 emissions in that year by 8.2 $MMTCO_2$ Eq. Hydro production increased after 1992, which moderated emission increases that otherwise would have been associated with higher levels of electricity generation.

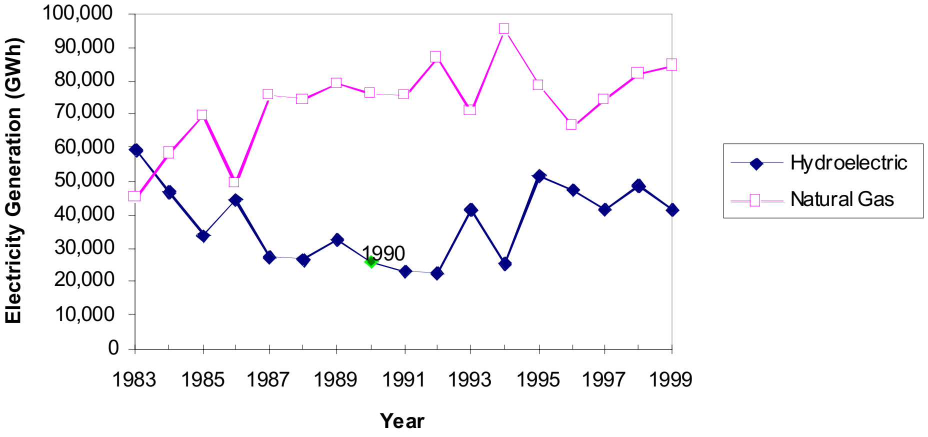


Figure 43: Generation from In-State Hydro and Natural Gas Power Plants: 1983-1999

7.3.5. Transportation Issues

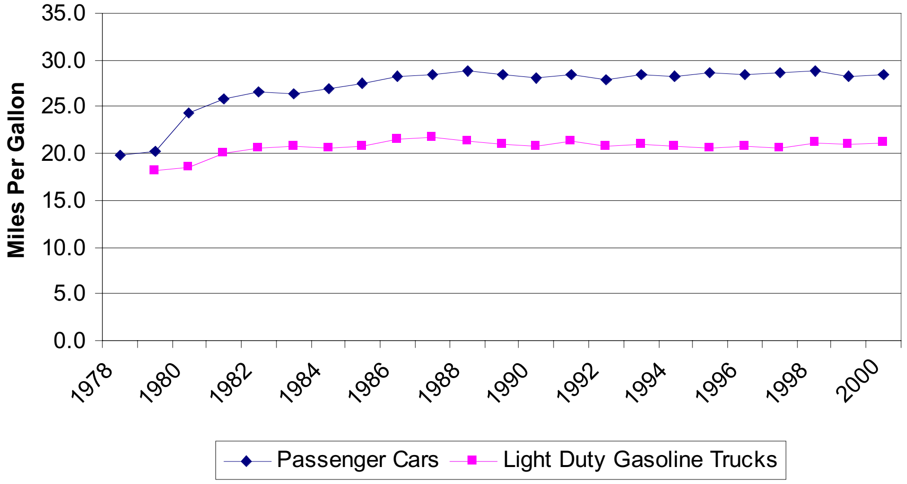
The trend in CO_2 emissions from fossil fuel combustion in the transportation sector was influenced by several inter-related factors. This section provides additional information on motor vehicle fuel economy, residual fuel oil, and bunker fuel (beyond those incorporated in preliminary estimates in this report) and describes how these factors may be affecting emission trends in California.

Fuel Economy

The fuel type responsible for the majority of transportation sector emissions is motor gasoline (Figure 38), which is used primarily in passenger cars and light-duty trucks (which include sport utility vehicles). Increases in vehicle miles traveled (VMT) for passenger cars and light duty trucks have driven increases in the use of motor gasoline. Counterbalancing the increases in VMT have been improvements in fuel economy.

Figure 44 shows that the fuel economy of new passenger cars sold in the U.S. increased substantially from 1978 through 1983, and then steadily through 1988, after which time it leveled off. Improvements were also realized in new light duty trucks, although these improvements were smaller. The improvements in fuel economy were the result of the corporate average fuel economy (CAFE) standards promulgated at the federal level.

Although the fuel economy of new passenger cars and light duty trucks leveled off by 1988, the efficiency of the overall fleet of cars on the road continued to improve throughout the 1990s as older cars (with poorer fuel economy) were retired. Consequently, motor gasoline CO_2 emissions increased by only 9.4 percent from 1990 to 1999 even though VMT increased by 9.7 percent for passenger cars and by 32 percent for light duty trucks (the VMT data are presented in Chapter 2, Section 2.3). It is notable that the fuel economy of the overall fleet is not expected to continue to improve because fewer of the older, less fuel-efficient cars, remain to be retired. Additionally, the shift in the composition of the fleet toward sport utility vehicles is pushing overall fleet fuel economy down. The result of these trends is that in the absence of new fuel economy initiatives, CO_2 emissions from motor gasoline in the transportation sector may be expected to change in the future at a rate that is similar to the rate of change in VMT for passenger cars and light duty trucks. The slower rate of growth of emissions observed in the 1990s will not likely persist under these conditions.



Source: DOT 1999

Figure 44: Total U.S. Fuel Economy of New Vehicles by Year Sold

Residual Fuel Oil

Emissions from residual fuel oil declined in 1991 and 1992, and then again in 1997 (see Figure 38). By 1999, CO_2 emissions from residual fuel oil in the transportation sector had declined 50 percent relative to 1990 levels, or about 13 MMTCO$_2$ Eq. The amount of crude oil processed by California refineries decreased by about 9 percent between 1990 and 1999. Residual fuel oil production dropped from 83,171 to 36,988 million barrels (an approximate 56 percent decline) (CEC 2002). Given that nearly all of the residual fuel oil consumed in California during the 1990s was used for marine vessels, the initial drop in consumption of residual fuel oil in 1991 and 1992 may have been due to the adoption in 1991 of a new state tax on residual fuel oil sold as a fuel to marine vessels (Franco 1997). This tax was repealed in July 1992, with the repeal taking effect in January 1993. It is unclear why residual fuel oil sales did not recover after 1993. A possible explanation is that residual fuel oil production declined as the result of refinery modernizations that were required for the state reformulated gasoline program. The modernizations increased refineries' capacity to break down heavy petroleum compounds into lighter hydrocarbons, reducing the need to produce fuels with perhaps lower commercial value, such as residual fuel oil. This explanation is supported by an observed decrease in residual fuel oil production at the national level. According to the EIA, the federal Clean Air Act of 1990

> "mandated reduction in various pollutants in fuels and in emissions from stationary sources. To produce these fuels required costly upgrades to refineries, which increased the costs of all petroleum products. These upgrades have also substantially reduced the amount of residual fuel oil that is produced," (EIA 1996).

Whatever the causes of the declines in the consumption of residual fuel oil in marine vessels in California in the 1990s, decreased consumption dampened the trend in transportation-related emissions. Without the reduction in residual fuel oil emissions, the CO_2 emissions from the transportation sector (excluding marine bunker fuels) would have increased by nearly nine percent from 1990 to 1999, as compared to the seven percent increase reported in the inventory. The impact of residual fuel oil emissions on trends in transportation emissions is further complicated by the uncertainty surrounding preliminary estimates of marine bunker fuel emissions.

Bunker Fuel

Although this report includes preliminary estimates of emissions from marine bunker fuels, these emissions are very uncertain. In addition, the Commission was not able to include an estimates of emissions from aviation bunkers to due lack of data. This section provides some additional details on these emissions and their impact on state emissions and emission trends.

The U.S. Bureau of Transportation Statistics reports that in 1997, 23,877 thousand metric tons were shipped from California ports to domestic destinations. This figure includes transfers to Alaska, intra-state commerce, Hawaii, the Pacific Northwest, the South Central region, and the Pacific Islands by tankers and barges. The foreign trade from California for the same year was 42,977 thousand metric tons (DOT 1999). About 85 percent of the foreign trade (by tonnage) is to the Far East (DOT 1999). Since on average, more fuel may be needed for travel to foreign ports than to domestic ports, the share of fuel used for international transport should be higher than what can be estimated from just looking at the relative tonnage shipped to domestic and foreign ports. Informal contacts with firms selling residual fuel oil suggest that most of the fuel is used for international transport (Metz 2002). This view is confirmed by the limited data available for estimating these bunker fuel quantities. Marine bunker fuel emissions were estimated at about 22.0 and 10.7 $MMTCO_2$ Eq. for 1990 and 1999, respectively. As mentioned earlier, these emissions have already been subtracted from the totals used to describe trends in this chapter.

As with residual fuel oil in marine vessels, jet fuel used in international transport is considered a bunker fuel. It was not possible to estimate of the proportion of jet fuel used for international air transport, and thus California’s emissions throughout the 1990s are overstated in this report (i.e., the totals include emissions for international transport, which should be excluded). The impact of excluding aviation bunkers from state totals in 1990 and 1999 would likely be to reduce the overall growth in emissions somewhat. This assumes that the amount of jet fuel used for international transport has increased over the past decade.

7.3.6. Electricity Imports

The trend in CO_2 emissions from the combustion of fossil fuels shown in Figure 34 is also influenced by California’s increased dependence on imported electricity since the early 1970s. By convention, emissions associated with electricity produced in other states are excluded from state greenhouse gas inventories (EIIP 1999).

Figure 45 presents the amount of electricity consumed in California as reported in a draft Energy Commission Staff Report (CEC 2001d). This figure also presents the amount of in-state electricity generation as reported by the Energy Information Administration, which includes generators with an installed capacity of at least 1 MW. The total generation figure includes non-utility generation starting in 1983, which, as discussed earlier, is an important source of electricity in California. Data on non-utility generation prior to 1983 are not available. However, it is believed that non-utility generation, which includes self-generation, was minimal before the 1980s (prior to the effects of PURPA).

The apparent amount of electricity net imports into California was calculated by subtracting the in-state generation from total estimated electricity consumption. To take into account transmission losses, the consumption was first multiplied by 1.10, producing the "adjusted consumption" shown in the figure. From this analysis it is clear that there has been a net increase in imported power since 1970. From the mid-1970s to the mid-1990s, there is an increase in annual net imports of about 20,000 GWh.

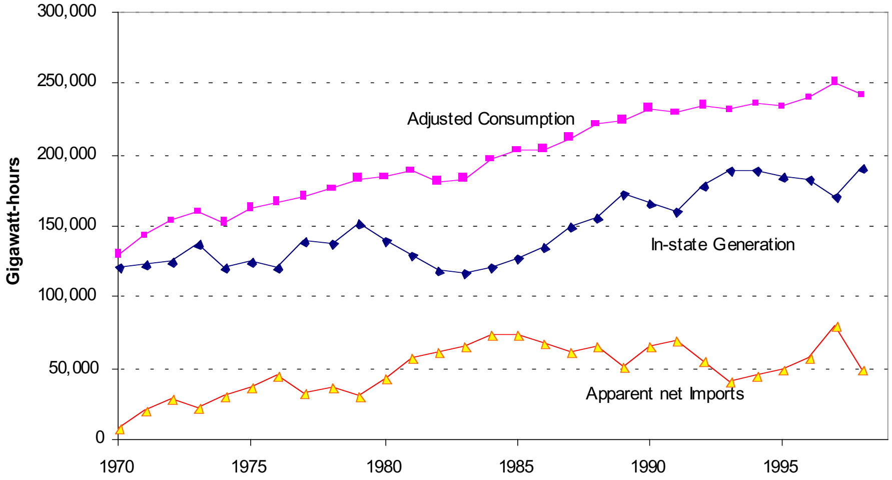


Figure 45: In-state Electricity Generation, Electricity Consumption and Apparent Net Import of Electricity to California

It is difficult to estimate the emissions associated with these electricity imports, particularly for the beginning of the period (the mid-1970s) due to a lack of data on energy transactions. If it is assumed that emissions from out-of-state power plants in the mid-1970s had the same emissions rate as those of the mid-1990s (about 800 metric tons of CO_2 per GWh) (CEC 1998), then annual out-of-state emissions to supply California electricity would have increased by about 16 $MMTCO_2$ Eq. over that period. This represents about 5 percent of California's CO_2 emissions observed in the 1990s. Of note is that if these out-of-state power plants had been built in California in compliance with California rules and regulations, they most likely would have been natural gas burning units with lower CO_2 emissions rates.

Table 100 presents more detailed data on the amount of imported electricity during the 1990 to 1999 period. The California Department of Finance publishes this information in their annual California Statistical Abstract based on data provided by the Commission. Table 100 breaks out the electricity imports that are generated by out-of-state power plants owned by California utilities. For historical reasons, the amount reported in the Statistical abstract and in other Commission publications includes out-of-state power generated by power plants owned by California utilities in the in-state generation category. Figure 46 shows the significance of including out-of-state emissions in the estimation of total gross emissions. When emissions from imported electricity are added to gross state emissions, annual emissions increase by an average of 16 percent during the 1990 to 1999 period.

To estimate the CO_2 emissions associated with the coal-fired electricity imports shown in the table, the standard procedures described in Chapter 2 were used. For the imported electricity from the Pacific Northwest (PNW) and Pacific Southwest (PSW), an emission factor of 800 metric tons of CO_2 per GWh was used, based on a report prepared in 1998 by Commission Staff reporting out-of-state emission levels for 1994 and 1995 (CEC 1998). The imports from the Pacific Northwest (PNW) are believed to be mostly from hydroelectric power plants, which do not emit carbon dioxide. Since the amount of electricity imported from PNW in 1994 and 1995 was relatively low during those years, the emission factor of 800 metric tons of CO_2 per GWh may overstate emissions.

Table 100: Generation and CO_2 Emissions from Out-of-state Power Plants

	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999
California-owned Out-of-State Generation (GWh)										
Coal	17,710	20,392	28,806	20,358	22,440	16,788	22,590	24,838	31,836	32,726
Nuclear	5,646	6,879	7,019	6,044	6,351	7,396	7,905	8,035	8,306	8,337
Remaining Imports										
PNW	31,665	28,819	19,600	15,466	15,315	19,890	29,529	25,204	19,428	26,051
PSW	30,294	27,054	18,104	27,426	28,040	27,624	20,167	27,517	28,135	23,436
All Imports	**85,315**	**83,144**	**73,529**	**69,294**	**72,146**	**71,699**	**80,190**	**85,593**	**87,704**	**90,549**
Emissions from Imported Electricity ($MMTCO_2$ Eq.)										
Coal	18.1	20.9	29.5	20.9	23.0	17.2	23.1	25.5	32.6	33.5
Nuclear	0	0	0	0	0	0	0	0	0	0
PNW	25.2	23.0	15.6	12.3	12.2	15.8	23.5	20.1	15.5	20.8
PSW	24.1	21.6	14.4	21.9	22.3	22.0	16.1	21.9	22.4	18.7
Total	**67.5**	**65.4**	**59.6**	**55.0**	**57.5**	**55.1**	**62.7**	**67.5**	**70.5**	**73.0**

Figure 46: Impact of Out-of-State Imported Electricity Emissions on Gross California Emissions (excluding marine bunker fuels)

Using these assumptions, it is estimated that the CO_2 emissions associated with the imported electricity is on the order of 67.5 $MMTCO_2$ Eq. in 1990 and 73.0 $MMTCO_2$ Eq. in 1999. While emissions from imported electricity in any given year are significant, they do not significantly influence the trend in emissions during the 1990s because they increase by only 5.5 $MMTCO_2$ Eq., or less than 2 percent of annual emissions from fossil fuel combustion.

7.3.7. Other Factors Affecting Emissions Trends

Although CO_2 emissions from fossil fuel combustion dominate the state greenhouse gas emissions inventory, trends in the emissions of other gases and sources are significant during the 1990 to 1999 period. In particular, the emissions of compounds replacing stratospheric ozone depleting substances increased by 7 $MMTCO_2$ Eq. from 1990 to 1999. This is one of the largest increases of any individual source in the inventory over this period. Carbon dioxide emissions from fossil fuel combustion in the industrial sector actually increased by a greater amount from 1990 to 1999 (20 $MMTCO_2$ Eq.); however, most of this increase is associated with the movement of fossil fuel electric power plants from the electric utility sector to the industrial sector. The decline in carbon sequestration (sinks) also contributes to increased net emissions over the 1990 to 1999 period. As discussed in Chapter 5, the annual rate of carbon sequestration declined by about 7 $MMTCO_2$ Eq. during this period.

As a result of requirements to control emissions of volatile organic compounds (VOCs), CH_4 emissions from landfills were reduced. These emissions were reduced by collecting and combusting the landfill gas that would otherwise have been emitted. In some cases energy is produced from the gas. Emissions from landfills were reduced from 17 $MMTCO_2$ Eq. in 1990 to about 13 $MMTCO_2$ Eq. in 1999. Policies requiring the diversion of organic wastes from landfills have also helped to reduce landfill CH_4 emissions. These policies encourage composting, thereby reducing the amount of waste in landfills that is available to degrade into CH_4. Properly managed composting facilities aerate the compost, eliminating emissions of CH_4 associated with anaerobic environments and resulting in carbon-rich soil amendments that may be used to restore degraded soils. The impacts of these waste diversion policies on CH_4 emission has not been quantified.

Nitrous oxide (N_2O) emissions from gasoline passenger vehicles and light duty trucks have also been influence by environmental control policies. As discussed above in Chapter 2, the early catalyst technologies for controlling VOC emissions increased N_2O emissions. Subsequent improved catalysts (Tier 1 and LEV) have reduced N_2O emissions. As a result of the penetration of the new control technologies into the vehicle fleet, the N_2O emissions from gasoline vehicles declined by about 0.6 $MMTCO_2$ Eq. between 1990 and 1999.

7.3.8. Summary Impacts of Policies on Emissions Trends

The overall impact of the various policies and related factors on emissions and the trend in emissions is summarized in Table 101. As shown in the table, fuel switching to natural gas; relatively low hydropower production in 1990 that was compensated for by burning fossil fuels in power plants; the continuing effect of energy efficiency policies and standards; and, an increase of electricity imports, reduced emissions in both 1990 and 1999. The electricity imports have the largest impact on annual emissions; however, imported electricity emissions have a relatively minor impact on the trend in total emissions during the 1990s (less than 2 percent).

The energy-related factors summarized in Table 101 reduced the emission trend between 1990 and 1999 by approximately 34 $MMTCO_2$ Eq. or 8 percent of 1999 gross emissions (excluding marine bunker fuels). In other words, were it not for these factors, gross emissions in California would have increased by about 34 $MMTCO_2$ Eq., or about 12 percent from 1990 to 1999, as opposed to the 3.5 percent and 5.5 percent rise in gross and net emissions, respectively, excluding bunker fuels. Emission controls at landfills were estimated to have reduced California's 1999 emissions by an additional 4 $MMTCO_2$ Eq.

Table 101: Summary Impact of Policies and Other Factors on Emissions: 1990-1999

Policies and Other Factors Affecting Emissions	Impacts on Emissions Inventory ($MMTCO_2$ Eq.)		Impacts on the Emissions Growth (1990-1999)
	1990	1999	
Energy Efficiency Policies and Standards	-15.5	-22.6	-7.1
NO_x and VOC Emissions Controls and Conversion to Natural Gas	Not Quantified on a yearly basis.		-13
Cogeneration and Renewable Resources	Not quantified. Reduced emissions.		Reduced the rate of emissions growth.
Below Average Hydro Power in 1990	+8.2	Not Applicable	-8.2
Electricity Imports	-67.5	-73.0	-5.5
Federal Vehicle Fuel Economy Standards	Not quantified. Reduced emissions.		Reduced the rate of emissions growth.
VOC Emissions Controls from Landfills	0.0	-4.0	-4.0

Note: Negative values indicate that the policy or factor reduced emissions or reduced the growth in emissions from 1990 to 1999. All values are in $MMTCO_2$ Eq.

7.4. Expected Future Emission Levels

The Commission staff forecasts significant increases in natural gas, motor gasoline, diesel fuel, and jet fuel consumption. For example, fuel use in California's transportation sector, representing nearly 60 percent of carbon dioxide emissions from fuel combustion, is forecast to increase from 1990 levels by 60 percent through 2020.

The data needed to estimate emissions in 2020 for sectors other than transportation are currently unavailable. It is possible, however, to forecast gross emissions for all sectors through the year 2010. Using existing forecasts and assuming consumption of all other fuels remains constant, carbon dioxide emissions from the combustion of fossil fuels in California will increase by about 20 percent from 1990 levels by 2010. Since consumption of other fuels is also likely to increase, this level represents the minimum expected increase in greenhouse gas emissions by the year 2010.

7.5. Uncertainty and Limitations of the Emission Estimates

The emission estimates presented in this inventory represent the best estimates available. They are subject to change in the future for several reasons, such as: the use of new improved methodologies, revised fuel consumption and other activity data, and inclusion of new sources not covered by this inventory. A report being prepared by the Public Interest Energy Research (PIER) Program in the California Energy Commission will look into the sources of uncertainty and limitations with the existing estimation methods and will propose a research agenda designed to improve the methods used to estimate emissions in California.

There are limits in the state of the science for estimating greenhouse gas emissions inventories, and as a result this report carries significant uncertainty. For some sectors, the methods are accurate only to an order of magnitude; for this reason the emission trends reported in this inventory should be interpreted with caution. This inventory uses the best sources of information and methods available given the limitations of time and resources.

CHAPTER 8 – GLOSSARY, ABBREVIATIONS, AND CHEMICAL NAMES

8.0 Glossary, Abbreviations, and Chemical Names

Btu	British thermal unit. The quantity of heat required to raise the temperature of one pound of water 1º F at or near 39.2º F.
BOD	Biochemical oxygen demand
BTS	Bureau of Transportation Statistics, DOT
Bunker fuels	Fuel supplied to ships and aircraft, both domestic and foreign for international transport, consisting primarily of residual and distillate fuel oil for ships and kerosene-based jet fuel for aircraft. Note: For the purposes of greenhouse gas emissions inventories, data on emissions from combustion of international bunker fuels are subtracted from national emissions totals.
C	Carbon
C_2F_6	Perfluoroethane, hexafluoroethane
$CaCO_3$	Calcium carbonate, limestone
CAFE	Corporate Average Fuel Economy. Program begun in 1974 which establishes more stringent fuel economy standards.
$CaMg(CO_3)_2$	Dolomite
CaO	Calcium oxide, lime
CASS	California Agricultural Statistics Service
CF_4	Perfluoromethane
CFC	Chlorofluorocarbon
CH_4	Methane
CKD	Cement kiln dust
CO	Carbon monoxide
CO_2	Carbon dioxide
Commission, CEC	California Energy Commission
DOC	U. S. Department of Commerce
DOE	U. S. Department of Energy
DOT	U. S. Department of Transportation
DSM	Demand Side Management
EIA	Energy Information Administration, U.S. Department of Energy
EIIP	Emission Inventory Improvement Program
EOR	Enhanced oil recovery
EPA	United States Environmental Protection Agency
FAO	Food and Agriculture Organization
FGD	Flue gas desulphurization
GCV	Gross calorific values

GDP	Gross Domestic Product
GHG	Greenhouse gas. Gases, such as water vapor, carbon dioxide, nitrous oxide, methane, hydrofluorocarbons (HFCs), perfluorocarbons (PFCs), sulfur hexafluoride, that are transparent to solar (short-wave) radiation but opaque to long-wave radiation, thus preventing long-wave radiant energy from leaving the atmosphere. The net effect is a trapping of absorbed infrared radiation and a tendency to warm the planet's surface.
GJ	Gigajoules
GSP	Gross state product
GWh	Gigawatthour
GWP	Global warming potential. An index used to compare the relative radiative forcing of different gases without directly calculating the changes in atmospheric concentrations. GWPs are calculated as the ratio of the radiative forcing that would result from the emission of one kilogram of a greenhouse gas to that from the emission of one kilogram of carbon dioxide over a fixed period of time, such as 100 years.
HCFC	Halogenated chlorofluorocarbon
HDDV	Heavy-duty diesel vehicle
HDGV	Heavy-duty gasoline vehicle
HFC	Hydrofluorocarbon
HFC-23	Trifluoromethane
HNO_3	Nitric acid
IEA	International Energy Association
IPCC	Intergovernmental Panel on Climate Change
LBNL	Lawrence Berkeley National Laboratory
LDDT	Light-duty diesel truck
LDDV	Light duty diesel vehicle (diesel passenger car)
LDGT	Light-duty gasoline truck
LDGV	Light duty gasoline vehicle (gasoline passenger car)
LEV	Low emission vehicle
LFGTE	Landfill gas-to-energy
LMOP	EPA's Landfill Methane Outreach Program
LPG	Liquefied petroleum gas(es)
MC	Motorcycle
MCF	Methane conversion factor
$MMTCO_2$ Eq.	Million metric tons of carbon dioxide equivalent
MSW	Municipal solid waste
N_2O	Nitrous oxide

N, N_2	Atomic nitrogen, molecular nitrogen
Na_2CO_3	Sodium carbonate, soda ash
NASS	USDA's National Agricultural Statistics Service
NCV	Net calorific values
NH_3	Ammonia
NH_4^+	Ammonium
NMVOC	Nonmethane volatile organic compounds
NO_3^-	Nitrate radical
NO_x	Oxides of nitrogen; nitrogen oxide
NSCR	Non-selective catalytic reduction
O_3	Ozone
ODS	Ozone depleting substance
OECD	Organization of Economic Co-operation and Development
PFC	Perfluorocarbon
PFPE	Perfluoropolyether
PIER	Public Interest Energy Research
PIIRA	Petroleum Industry Information Reporting Act
PNW	Pacific Northwest
ppm	Parts per million
ppmv	Parts per million by volume
PSW	Pacific Southwest
PURPA	Public Utility Regulatory Policies Act of 1978
SBSTA	Subsidiary Body for Scientific and technical Advice
SEDR	EIA's State Energy Data Report
SF_6	Sulfur hexafluoride
TAM	Typical animal mass
TBtu	Trillion Btu
U.S.	United States
UNEP	United Nations Environmental Programme
UNFCCC	United Nations Framework Convention on Climate Change
USDA	U. S. Department of Agriculture
USGS	U.S. Geological Survey
VMT	Vehicle miles traveled
VS	Volatile solids

CHAPTER 9 – REFERENCES

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[i] Some rice fields in these experiments were left unvegetated as control plots.

[ii] Nitrification is the anaerobic process by which bacteria oxidize ammonium salts to nitrites, and then further oxidize the nitrites to nitrates. Denitrification occurs when bacteria reduce nitrate to gaseous nitrogen compounds, resulting in the release of nitrogen to the atmosphere. Nitrous oxide is produced as a byproduct of both of these processes (Brock 1994).

[iii] Kjeldahl nitrogen refers to amount of nitrogen that is either organically bound or in the form of ammonia.

[iv] Leachate and runoff, a source of indirect emissions, is a slightly different case. Emissions from leachate and runoff are a function of the unvolatilized nitrogen that enters groundwater.

[v] Note that existing methods do not account for potential N_2O emissions due to atmospheric nitrogen deposition from non-agricultural sources.