

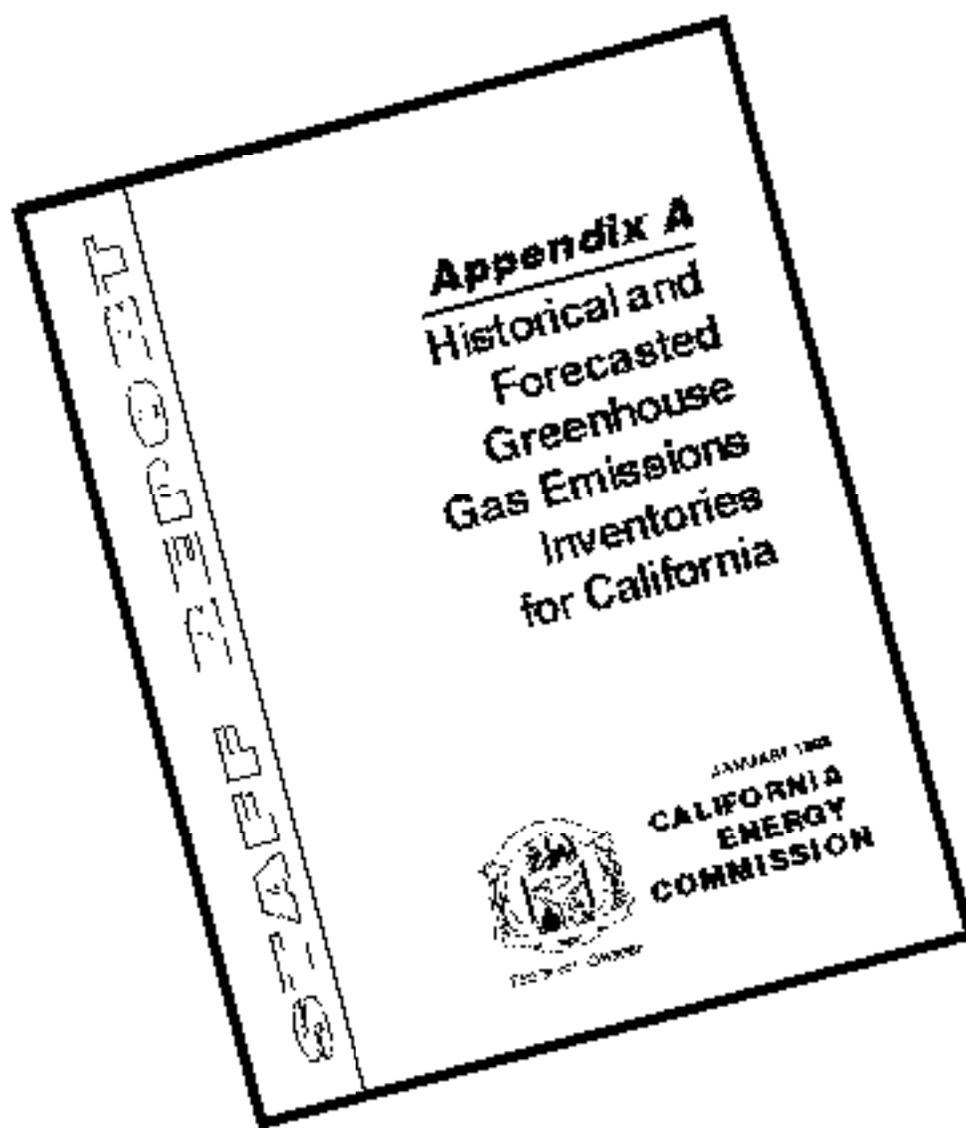
Appendix A
**Historical and
Forecasted
Greenhouse
Gas Emissions
Inventories
for California**



Pete Wilson, *Governor*

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CALIFORNIA ENERGY COMMISSION

Guido Franco, *Technical Project Manager & Principal Author*
Chuck Mizutari, *Manager*

TECHNOLOGY EVALUATION OFFICE

Nancy J. Deller, *Deputy Director*

ENERGY TECHNOLOGY DEVELOPMENT DIVISION

David Maul, *Acting Office Manager*
Bob Therkelson, *Deputy Director*

**ENERGY FACILITIES SITING &
ENVIRONMENTAL PROTECTION DIVISION**

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United States - Environmental Protection Agency

California State Agencies

California Electric Utility Industry

California Energy Commission

Ezra Amir
Rick Buell
Jim Fore
Matt Layton
Tom MacDonald
David Maul
Greg Newhouse
Jim Page
Shawn Pittard
Leigh Stamets
Chris Tooker

Report Production

J. Maralyn Blackman
Nancy Baker
Madeleine Meade

Consultation and Review Staff - Other California State Agencies

California Air Resources Board

James Lerner
Marla Mueller

Department of Forestry and Fire Protection

Gerald Ahlstrom

Integrated Waste Management Board

Timothy Crist
Tracy Harper

Department of Water Resources

Maurice Roos

Department of Transportation

Steve Borroum

Energy Technology Development Division

Nancy J. Deller, Deputy Director

Michael De Angelis, Deputy Division Chief

Technology Evaluation Office

Chuck Mizutani, Office Manager

Energy Facilities Siting and Environmental Protection Division

Bob Therkelsen, Deputy Director

Environmental Protection Office

David Maul, Acting Office Manager

Shawn Pittard, Program Supervisor

Chris Tooker, Program Supervisor

Project Manager

Nancy J. Powers

Technical Report Manager

Guido Franco

Principal Authors

Guido Franco

Joseph Loyer

Amanda Stennick

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Overview

Historical and Forecasted GHG Emissions Inventories for California

Introduction

Under the United Nations' Framework Convention on Climate Change (FCCC), countries are required to prepare inventories of greenhouse gas (GHG) emissions for 1990, and are encouraged to periodically update their historical and forecasted emissions inventories. Future commitments to reduce GHG emissions, if adopted, will be compared against the 1990 baseline emissions inventories. Similarly, in the United States, the U.S. Environmental Protection Agency (U.S. EPA) is encouraging states to prepare inventories for their own states. This report has been developed as part of that effort.

This report presents the historical and forecasted GHG emissions inventories for California, using a common methodology. The historical period covered includes 1990 through 1994, and the forecast covers the years 2000, 2005 and 2010. The year 1994 has been selected in this overview chapter to illustrate the contribution of different subsectors or fuels to California's total annual emissions.

The emission estimates presented in the report are based on methodologies presented in the "State Workbook: Methodologies for Estimating Greenhouse Gas Emissions,"¹ which are, in turn, based on methodologies developed by the Intergovernmental Panel on Climate Change (IPCC).² The IPCC was formed in 1988 to carry out studies on climate change under the auspices of the United Nations Environmental Program and the World Meteorological Organization. In the preparation of this report, the U.S. EPA's guidelines have been followed, except where more detailed data or methodologies were available for evaluating California sources of emissions. In such cases, the underlying assumptions have been fully documented, and explanations for the selected data and methodologies have been provided.

Scientific and Technical Aspects of Global Climate Change

The temperature of the Earth's atmosphere is the result of the balance of different factors, such as the amount of solar radiation reaching our planet, the capability of different surfaces on the earth and clouds to reflect incoming solar radiation (albedo effect), the amount of thermal energy radiated to outer space by the Earth, the presence of aerosols in the atmosphere, and the atmospheric concentration of greenhouse gases. Greenhouse gases, such as water vapor and carbon dioxide, are transparent to the radiation coming from the sun (shortwave radiation), allowing it to pass through the atmosphere, heating the Earth's surface. Thermal energy is then radiated in the longwave spectrum back into the atmosphere. The greenhouse gases, which are not transparent to the outgoing longwave radiation, partially block it, resulting in a heating of the atmosphere. The energy balance established between incoming and outgoing radiation determines the ambient atmospheric temperatures.

Different greenhouse gases, some of which are shown in Table 1 below, have different effects on the Earth's radiative energy balance. The IPCC developed the concept of Global Warming Potential (GWP) to compare the radiative forcing effect of different greenhouse gases. The GWP is the ratio of the global warming capability, or radiative forcing of a gas, relative to carbon dioxide. The GWP most frequently used is the 100-year GWP, which is calculated by integrating all the greenhouse effects of a gas over a 100-year period. This particular GWP is used in this report to compare the emissions of different greenhouse gases in California. Table 1 contains a list of the GWPs used in this inventory. Note that gases can contribute to the greenhouse effect either directly or indirectly. Indirect effects occur when a gas, through chemical transformation in the atmosphere, produces a greenhouse gas, or when it influences the atmospheric lifetime of greenhouse gases.

Table 1 Global Warming Potential for Greenhouse Gases	
Gas	GWP (100 Years)
Carbon dioxide	1
Methane	21*
Nitrous oxide	310
HFC-143a	1,300
HFC-23	11,700
HFC-152a	140
<i>*The GWP for methane includes indirect effects of tropospheric ozone production and stratospheric water vapor production. Source: IPCC³</i>	

Many greenhouse gases occur naturally as a result of the Earth's geological, hydrological, and biological cycles. They include water vapor, carbon dioxide (CO₂), methane (CH₄), nitrous oxide (N₂O), and ozone (O₃). Some human-made compounds, including chlorofluorocarbons (CFCs), partially halogenated chlorofluorocarbons (HCFCs), hydrofluorocarbons (HFCs), and perfluorinated carbons (PFCs), also function as greenhouse gases. In addition, other photochemically important gases, such as carbon monoxide (CO), oxides of nitrogen (NO_x), and non-methane volatile organic compounds (NMVOCs), while they do not function as greenhouse gases per se, contribute indirectly to the greenhouse effect. NO_x and NMVOC react in the atmosphere in the presence of sunlight to produce tropospheric ozone, which is a greenhouse gas. Carbon monoxide reacts in the atmosphere with certain compounds, such as the hydroxyl radical, that otherwise would react with and destroy methane and ozone. In addition, carbon monoxide is oxidized in the atmosphere to CO₂.

Summary of Historical GHG Emissions for California

Table 2 presents a summary of the historical inventory of anthropogenic (originated from human activities) greenhouse gas emissions for California.

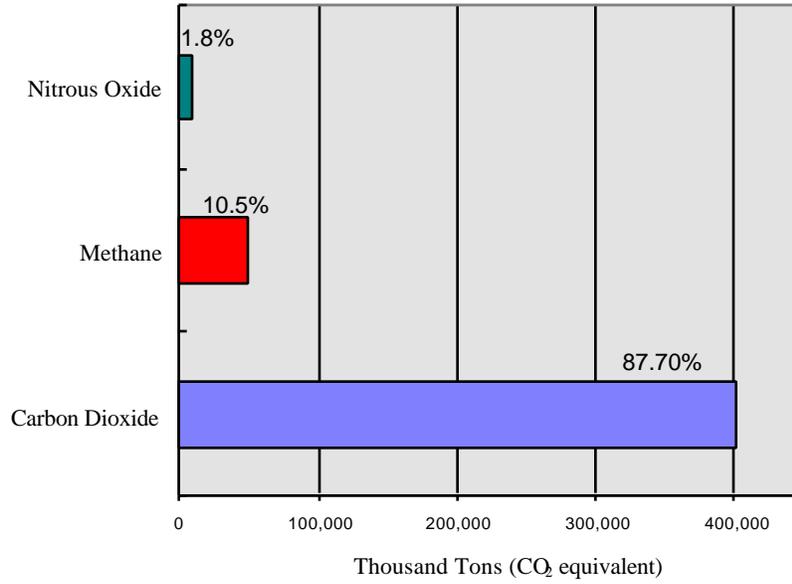
Table 2					
California Greenhouse Gas Emissions: 1990 to 1994					
CO₂ Equivalent (Thousand Tons)					
	1990	1991	1992	1993	1994
Carbon Dioxide (CO₂)					
Fossil Fuel Combustion	389,270	373,104	374,499	365,558	383,143
Other	14,577	14,132	14,225	13,847	17,085
Subtotal	403,848	387,236	388,724	379,405	400,227
Methane (CH₄)					
Landfills	24,864	26,053	27,443	28,570	29,767
Agriculture	15,628	15,363	15,391	15,477	15,590
Oil and Gas Systems	2,647	2,676	2,651	2,639	2,621
Other	1,345	1,348	1,335	1,344	1,350
Subtotal	44,484	45,440	46,820	48,030	49,327
Nitrous Oxide (N₂O)					
Agriculture	3,187	3,065	3,129	3,121	3,454
Fuel Combustion	4,399	4,523	4,501	4,677	4,773
Industrial Processes	411	411	411	411	411
Subtotal	7,998	7,998	8,041	8,209	8,637
HFCs and PFCs*					
Total California Emissions	456,329	440,674	443,586	435,644	458,191
* There are two sources of HFCs and PFCs: primary aluminum smelting and HCFC-22 production. There is no primary aluminum smelting in California and the production of HCFC-22 could not be determined.					

All of the emissions in Table 2 are shown as carbon dioxide equivalents and are presented in short tons (one short ton is equal to 2,000 pounds). They were calculated using the GWPs shown in Table 1. Subsequent paragraphs in this overview present methane and nitrous oxide emissions in their full molecular weight.⁴ To compare these emissions to the emissions included in Table 1, they should be multiplied by their respective GWP.

As can be seen from Figure 1, CO₂ emissions accounted for 87.7 percent of the total greenhouse gas emissions in California, on average, when all the emissions are expressed as carbon dioxide equivalent. Methane accounted for about 10.5 percent of the emissions, with landfills and agricultural operations being the main sources of methane. N₂O contributed only marginally (1.8 percent) to the total of California emissions. As shown in Table 2, total emissions of greenhouse gases have increased slightly from 1990 levels. They were at their lowest levels in 1993 due to a drop in the combustion of fossil fuels.

Figure 1 is a graphical representation of the relative contribution of the different greenhouse gases in California in 1994.

Figure 1
Total California Greenhouse Gas Emissions
Measured as CO₂ Equivalent: 1994



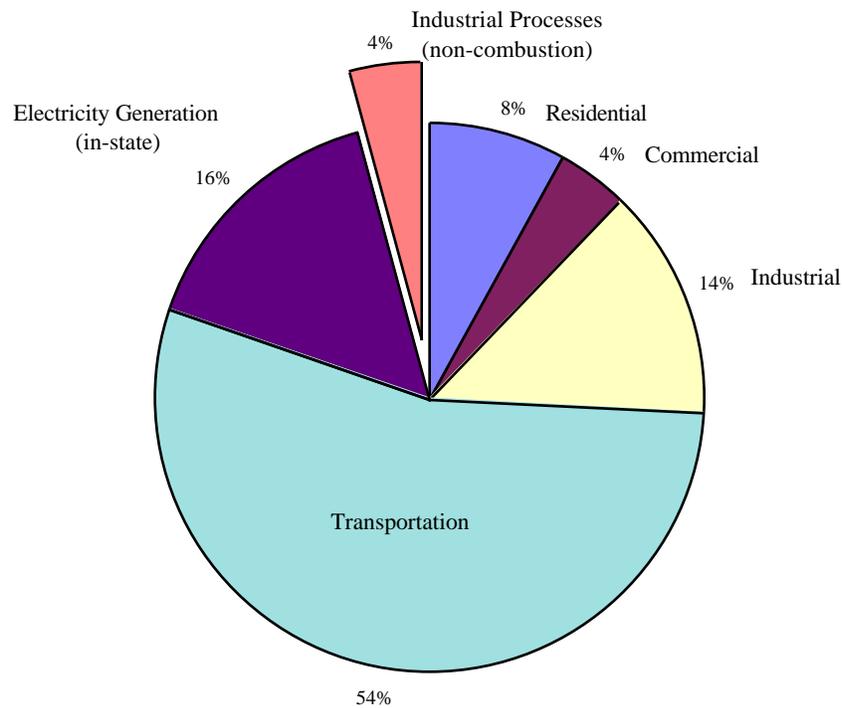
The following sections describe, in more detail, the sources of each of the greenhouse gases presented in Table 2.

Carbon Dioxide Emissions

Carbon dioxide is the main greenhouse gas produced by anthropogenic activities. Since the beginning of the Industrial Revolution, atmospheric concentrations of CO₂ have risen more than 25 percent, mainly from the combustion of fossil fuels.⁵ Most of the CO₂ emitted from 1990 through 1994 in California was from fossil fuel combustion, with minor contributions from other activities, such as limestone consumption and cement production. Table 3 summarizes the 1990 and 1994 CO₂ emissions by source type. Figure 2 presents the relative contribution to the total 1994 carbon dioxide emissions by sector. Emissions in the industrial processes category only include carbon dioxide emissions released from the transformation of the raw materials used in those industrial activities. Emissions from the combustion of fossil fuels in those industries are included in the industrial sector in the fossil fuel combustion category.

Table 3					
Sources of CO₂ Emissions in California: 1990 to 1994					
(Thousand Tons)					
Source	1990	1991	1992	1993	1994
Fossil Fuel Combustion					
Residential	32,483	32,280	29,973	31,720	32,413
Commercial	20,815	20,720	18,817	16,418	16,835
Industrial*	60,879	59,613	58,017	53,414	55,170
Transportation	223,760	211,281	210,128	206,751	216,488
Electricity Generation	51,333	49,211	57,564	57,255	62,237
Subtotal	389,270	373,104	374,499	365,558	383,143
Industrial Processes					
Cement Production	4,989	4,573	4,806	4,482	5,095
Lime Production	271	241	220	166	175
Limestone Consumption	8,890	8,890	8,771	8,771	11,386
Soda Ash Prod./ Consump.	0	0	0	0	0
Carbon Dioxide Manufacture	428	428	428	428	428
Subtotal	14,577	14,132	14,225	13,847	17,085
Total	403,848	387,236	388,724	379,405	400,227
* The industrial sector does not include emissions from non-utility electricity generation. These emissions are included in the Electricity Generation sector.					

Figure 2
Contribution of Carbon Dioxide Emissions: 1994

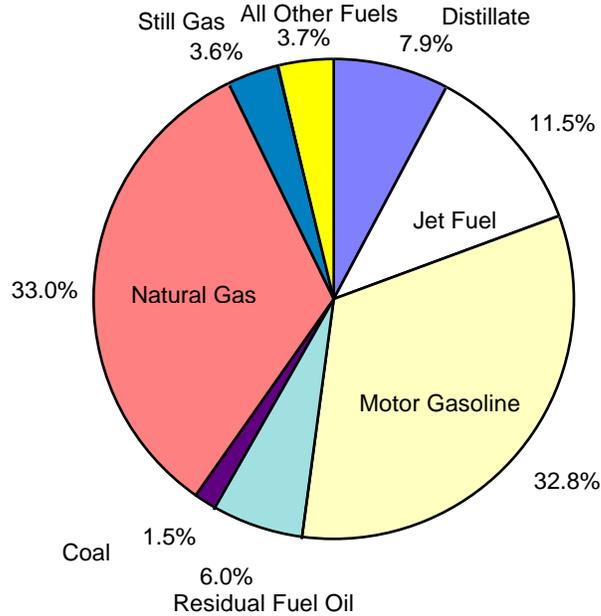


Carbon Dioxide Emissions from the Consumption of Fossil Fuels

Carbon dioxide is emitted when the carbon contained in fossil fuels is oxidized during combustion. Depending on the carbon content of the fuel, its combustion generates different amounts of carbon dioxide. Coal contains the highest amount of carbon per unit of energy, approximately 56 pounds per million Btu, while petroleum-based products contain 43 lbs., 23 percent less carbon per unit of energy, and natural gas has 31 lbs., about 45 percent less carbon than coal.

In 1994, California emitted approximately 383 million tons of carbon dioxide from the combustion of fossil fuels. Most of the emissions were generated from the combustion of natural gas and motor gasoline. For the same year, natural gas was responsible for approximately 126 million tons, or 33 percent of the total CO₂. The combustion of gasoline in the transportation sector accounted for around 126 million tons (also 33 percent). The share of natural gas emissions as a share of total emissions from the combustion of fossil fuels has increased from about 29 percent in 1990 to the 33 percent estimated for 1994. Coal use in California is minimal, and its combustion generates less than 2 percent of the total emissions from fuel combustion, as seen in Figure 3. This is in sharp contrast to the 36 percent contribution of coal combustion to the consumption of fossil fuels⁶ for overall U.S. emissions.

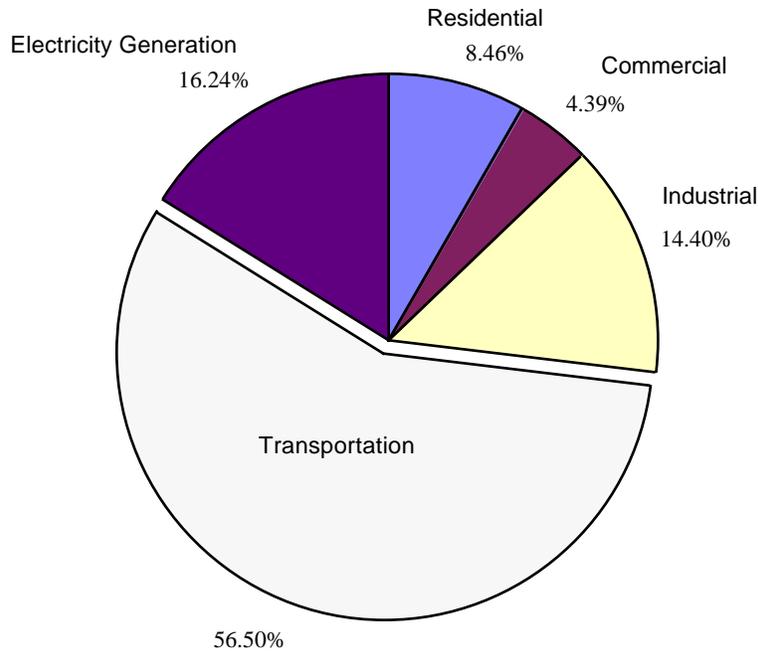
Figure 3
Contribution of CO₂ Emissions from the Consumption
of Fossil Fuels by Fuel Type: 1994



The 1994 CO₂ emissions contribution by sector, as illustrated in Figure 4, shows that the transportation sector was responsible for the largest share (56.5 percent) of total CO₂ emissions from fossil fuel consumption. The industrial⁷ and in-state electricity generation (utility and non-utility power plants) sectors emitted about 14.4 and 16.2 percent, respectively. Non-utility generation by itself contributed about 6.4 percent of the total emissions, which means that approximately 39.5 percent of the emissions from the electricity generation sector are produced by this subsector. The percent contribution by in-state electricity generation to the state total is much lower than the 36 percent contribution in 1994 by electric utilities to the national inventory.⁸ The significantly higher contribution by the electricity generation sector to overall U.S. emissions is due to the extensive reliance on coal-fired power plants outside California.

A significant portion of the electricity consumed in California is generated outside the state. Following U.S. EPA's directions, emissions associated with out-of-state generation of power serving California are not counted towards the state inventory, but are part of the inventories of states where the power plants are located. However, to gain an understanding of the magnitude of the emissions associated with out-of-state generation serving California, Figure 5 presents the CO₂ emissions from in-state and out-of-state power plants for 1990. As can be seen in Figure 5, out-of-state emissions exceed in-state emissions significantly, even though the majority of the electricity consumed in California is produced locally. This is because natural gas is the main source of energy in fossil fuel burning power plants in the state, while a significant portion of the out-of-state electricity from fossil fuel burning power plants is generated by burning coal.

Figure 4
Carbon Dioxide Emissions from Fossil Fuel Consumption
by Sector: 1994



Carbon Dioxide Emissions from Industrial Processes

Carbon dioxide can be generated as a by-product in the production or consumption of several products. The industrial processes included in this inventory are: cement production, lime production, limestone consumption, soda ash production and consumption, and carbon dioxide manufacturing. CO₂ emissions from the combustion of fossil fuels in these processes are not considered in this section, since they are already included in the previous section on fossil fuel combustion.

Figure 5
CO₂ Emissions and Electricity Generation from
In-State and Out-of-State Power Plants Serving California: 1990

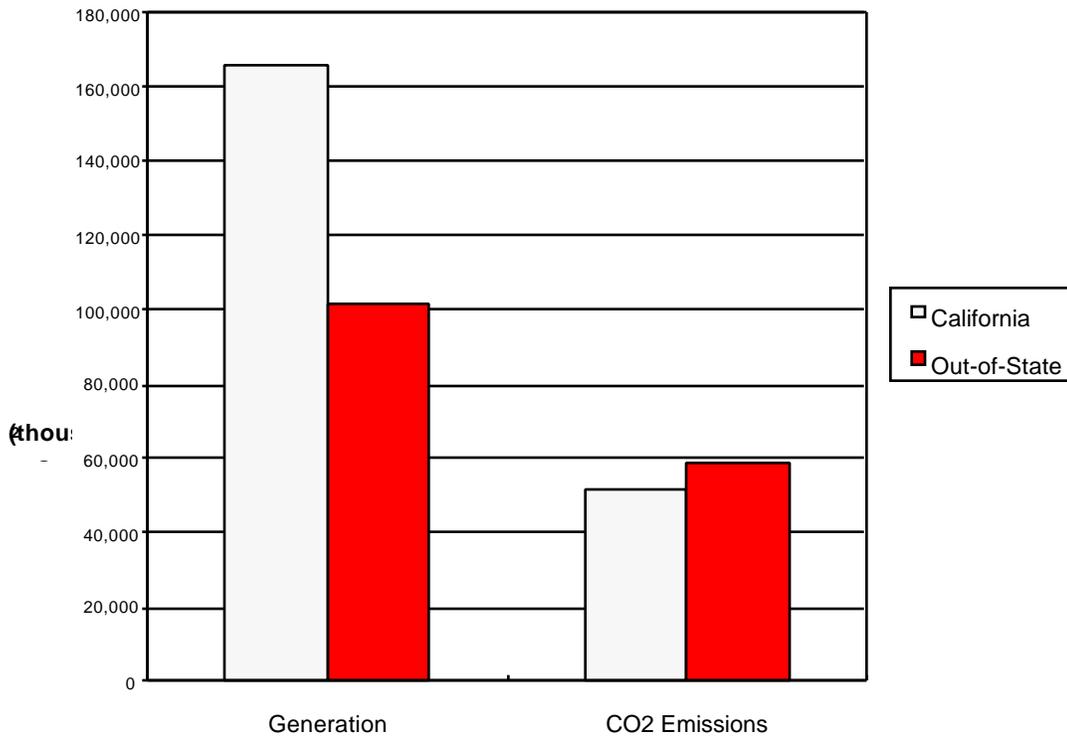


Table 4 presents the estimated historical carbon dioxide emissions from industrial processes in California. Total emissions have increase slightly, as expected, following the general increase in cement and lime production and limestone consumption.

	1990	1991	1992	1993	1994
Cement Production	4,989	4,573	4,806	4,482	5,095
Lime Production	271	241	220	166	175
Limestone Consumption	8,890	8,890	8,771	8,771	11,386
Soda Ash Prod. and Consump.	0	0	0	0	0
Carbon Dioxide Manufacture	428	428	428	428	428
Total	14,577	14,132	14,225	13,847	17,085

Limestone is a common raw material used in the construction, agricultural, chemical, and the metallurgical industries. Carbon dioxide is released when limestone, mainly calcium carbonate (CaCO₃), is heated in a kiln in the production of lime or cement. Lime and

cement production have increased from 1990 through 1994, with corresponding increases in carbon dioxide emissions. The assumption used to calculate historical CO₂ emissions from limestone consumption is that all the carbon present in the limestone is released as CO₂.

Soda ash (sodium carbonate) is produced in California exclusively from sodium carbonate-bearing brines. In this process, there is no net release of CO₂ to the atmosphere. Although the consumption of soda ash does release a very small amount of CO₂, information on the amount of soda ash consumed in the state was unobtainable. For these two reasons, carbon dioxide emissions from this subsector are assumed to be zero.

Carbon dioxide is used in several manufacturing processes including food processing, beverage carbonation, water treatment and chemical processing. In 1990, California produced 0.43 million tons of carbon dioxide. It is assumed that all CO₂ emissions are eventually released to the atmosphere from these manufacturing processes and, therefore, included in the 1990 inventory. Since this is a relatively minor source of emissions and due to lack of information, the 1990 emissions were assumed to remain constant through 1994.

Carbon Dioxide from Forest and Land Use Changes

Because of California's Forest Practices Act, which requires reforestation of logged areas, logging is no longer a major source of carbon release. However, permanent release of carbon does occur when forest and grasslands are converted to pasture, croplands, or to other uses, such as shopping malls, parking lots, and suburban communities. The opposite effect occurs when more areas are set aside for forestry, or when existing forests are allowed to increase their biomass to its maximum sustainable potential. Additionally, the abandonment of lands that were managed previously (e.g., croplands, pasture) and allowed to regrow naturally can re-accumulate significant amounts of carbon in their biomass and soils.

Quantification of the amount of carbon (or carbon dioxide) that has been released or captured by changes in biomass in forests, or due to changes in land uses, was infeasible at this time. The existing methodologies for such quantification are far from being fully developed, and, at best, can only produce an order-of-magnitude estimate of the amount of carbon released or sequestered. In addition, the data needed were not available, or if available, were conflicting.

Methane Emissions

After carbon dioxide, CH₄ is the most important greenhouse gas generated from anthropogenic activities. Methane concentrations in the atmosphere have more than doubled in the last two centuries, mainly due to human activities. Methane has a GWPs of 21, which indicates that in a 100-year period, a unit mass of methane has the same global warming effect as 21 mass units of carbon dioxide.

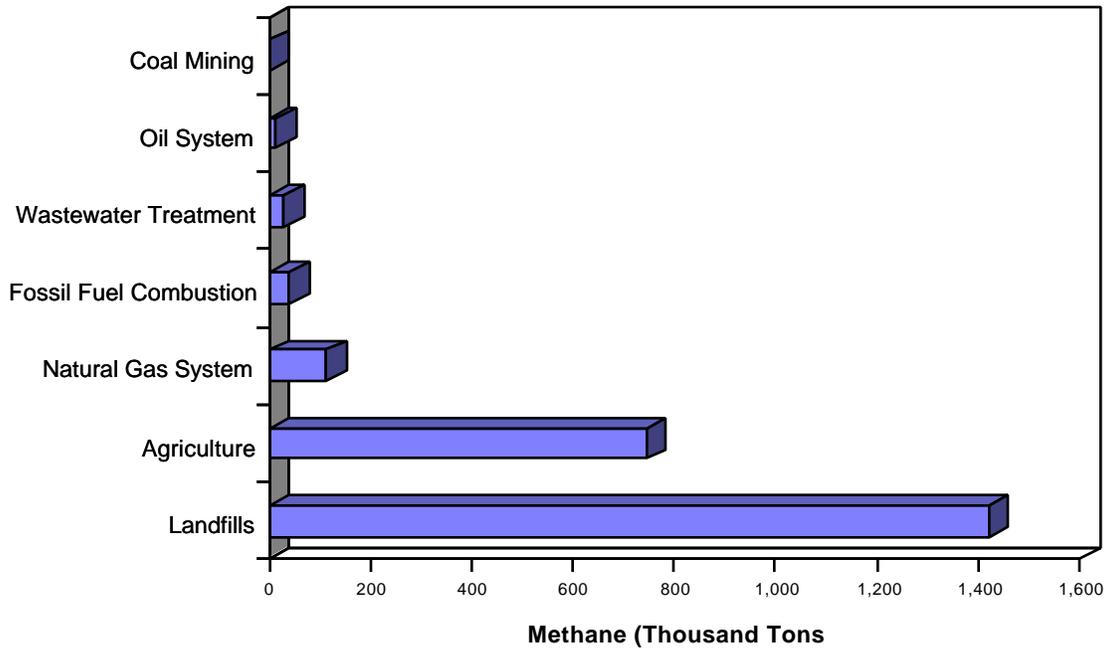
Table 5 and Figure 6 present summaries of the historical methane emissions in California, which indicate that landfills and agriculture are the largest sources of atmospheric methane in the state. Landfills generate methane from the anaerobic (without or under low oxygen conditions) bacterial decomposition of organic matter. Several factors affect the production of methane in a landfill, including waste composition, moisture content, and landfill size.

The agricultural sector is the second largest source of methane emissions in the state. Most of the emissions from this sector come from enteric fermentation in domestic livestock. Manure management and rice cultivation are also significant contributors to methane emissions from this sector. Agricultural waste burning produces only a marginal fraction of the total methane emissions from agricultural operations (see Figure 7).

	1990	1991	1992	1993	1994
Natural Gas System	113,815	115,321	114,395	113,839	112,918
Landfills	1,183,979	1,240,637	1,306,832	1,360,489	1,417,478
Oil System	12,236	12,091	11,860	11,804	11,870
Fossil Fuel Combustion	39,527	39,161	37,943	37,867	37,652
Agriculture	744,209	731,572	732,885	737,011	742,360
Coal Mining	10	10	10	10	10
Wastewater Treatment	24,500	25,000	25,600	26,100	26,600
Total Emissions	2,118,276	2,163,792	2,229,525	2,287,120	2,348,888

Methane is also found trapped in coal seams and surrounding rock strata and is released during coal mining and post-mining activities. Coal mining in the state is almost non-existent and, when present, is only surface mining. The total amount of methane released from coal mining in California in 1990 was 10 tons, which was assumed to remain at the same level during the historical period covering 1990 through 1994.

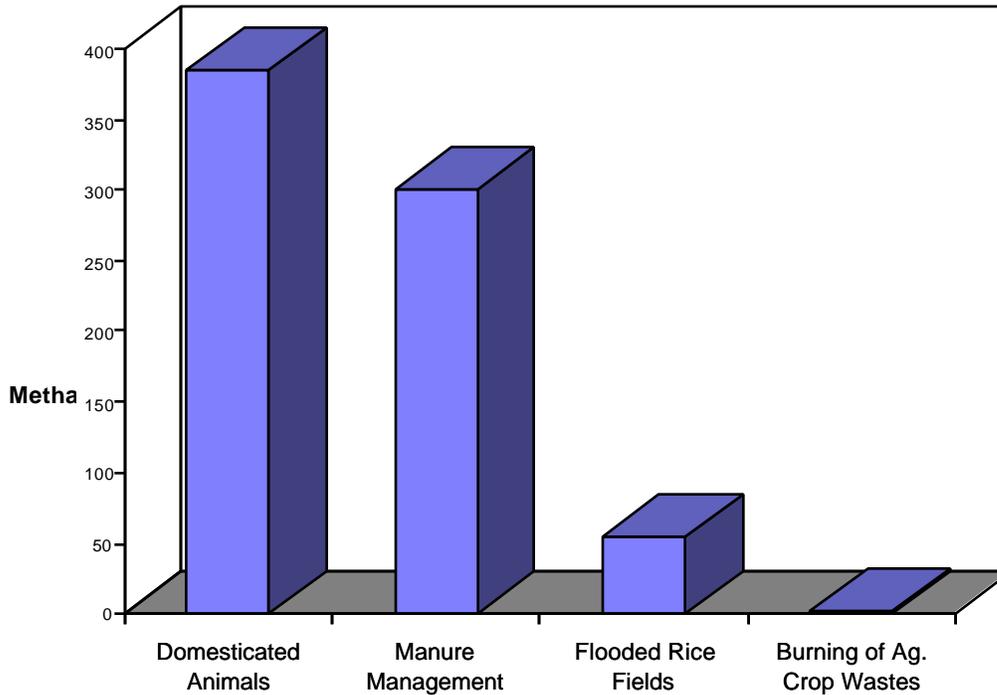
Figure 6
California Sources of Methane: 1994



Methane is released from crude oil extraction, processing, storage, and transportation. It is present in crude oil, and is released from system leaks, flaring activities, system disruptions, and routine maintenance operations. The 1994 methane emissions from the oil system are about 11,870 tons per year, which represents only 0.56 percent of the total anthropogenic emissions in the state.

Methane is the main constituent of natural gas. Any atmospheric release of natural gas from the natural gas system results in net emissions of methane to the atmosphere. In 1990, the emissions from the natural gas system accounted for 113,815 tons of methane. About half of the emissions are fugitive emissions from field production and from distribution and transmission pipelines.

Figure 7
Methane Emissions from Agriculture by Source: 1994



Methane emissions from the natural gas system have increased slightly with the increased consumption of natural gas in the state. On average, the natural gas system in California emits about 0.053 tons per million standard cubic feet (tons/mcf) consumed. This is significantly lower than the 0.328 tons/mcf emitted by the U.S. natural gas system as a whole. The reason for this difference is mainly due to substantially lower fugitive emission rates per mile in distribution and transmission pipelines in the state and the fact that the state inventory does not consider methane emissions from transmission pipelines serving California located outside the state.⁹ Fossil fuel combustion and water treatment plants are relatively minor contributors of methane emissions. They contributed about 1.8 and 1.2 percent, respectively, to the total 1994 methane emissions.

Nitrous Oxide Emissions

Nitrous oxide emissions constitute a relatively small portion of the total greenhouse gas emissions in California, even though nitrous oxide is 310 times more powerful as a greenhouse gas than CO₂ over a 100-year time period.

Table 6 presents historical California N₂O emissions. As can be seen in Table 6 and Figure 8, most of the N₂O emissions originate from the use of fossil fuel. The second main source of N₂O is the use of fertilizer in agriculture. Fertilizers add nitrogen to the soil, some of which is released as nitrous oxide as a result of natural microbial processes.

The combustion of fossil fuels in the transportation sector releases trace amounts of N₂O. This gas is not a criteria pollutant, and therefore there is no standard limiting its release. Recently, it has been found that the use of catalytic converters in cars significantly increases

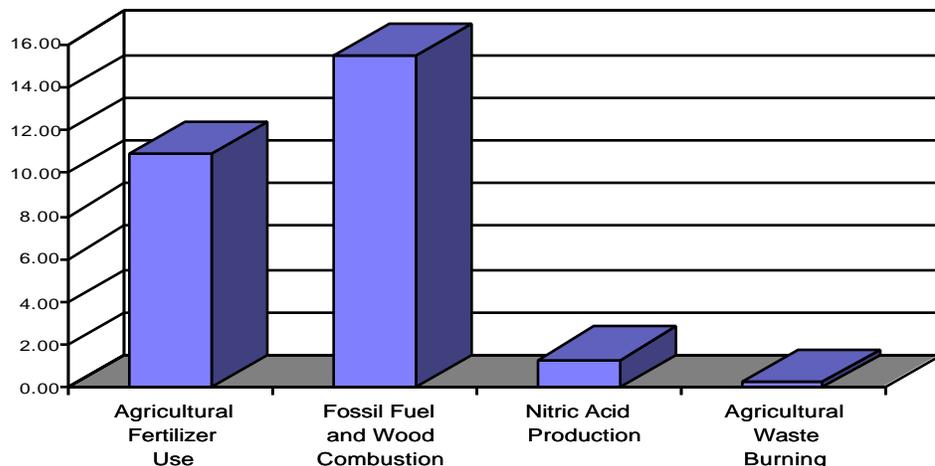
the amount of nitrous oxide they emit. This is perhaps the reason that on-road vehicles produce almost 50 percent of the total N₂O emissions in the state.

Table 6 Sources of N₂O Emissions (Tons)					
Sources	1990	1991	1992	1993	1994
Agricultural Fertilizer Use	10,006	9,634	9,841	9,827	10,904
Fossils Fuels and Wood Combustion	14,191	14,589	14,521	15,088	15,396
Nitric Acid Production	1,325	1,325	1,325	1,325	1,325
Agricultural Waste Burning	276	252	253	242	237
Total	25,798	25,800	25,940	26,482	27,862

Nitric acid is a raw material used in the production of synthetic commercial fertilizer, adipic acid, and explosives. Its production releases N₂O to the atmosphere. Nitric acid production in 1990 in California emitted 1,325 tons of N₂O. Due to a lack of better sources of information, this amount was assumed to remain constant for subsequent years.

Some of the nitrogen contained in agricultural waste is released during combustion as N₂O. The open burning of agricultural wastes in California emitted about 237 tons of N₂O in 1994. This is a relatively minor source of N₂O in the state.

**Figure 8
Sources of Nitrous Oxide Emissions: 1994**



Emissions of HFCs and PFCs

HFCs and PFCs are alternatives to some of the ozone-depleting compounds whose use is being phased out by the Montreal Protocol on Substances that Deplete the Ozone Layer. Their 1990 emissions are relatively minor. For example, it is estimated that in the U.S. they represented approximately 1.3 percent of the total greenhouse gas emissions when all the greenhouse gases are represented in CO₂ equivalent terms. However, their GWP values are extremely high. For example, the GWP for HFC-134a is 1,200. Since the production of these gases is expected to increase in the future, it is necessary to keep track of their present and future production.

Most of the U.S. emissions of HFCs and PFCs in 1990 were by-products of various production processes. PFCs (CF₄ and C₂F₆) are released during the production of aluminum in primary smelting operations. Since the aluminum produced in California originates from recycling, no PFCs were released in California from aluminum smelting. In 1990, HFC (specifically HFC-23) emissions in the U.S. were mainly a by-product of the production of HCFC-22. No information on HCFC-22 production in California is available, and therefore HFC emissions are not reported here. The omission of HFCs from the state inventory is expected to have a minimum impact on the total inventory.

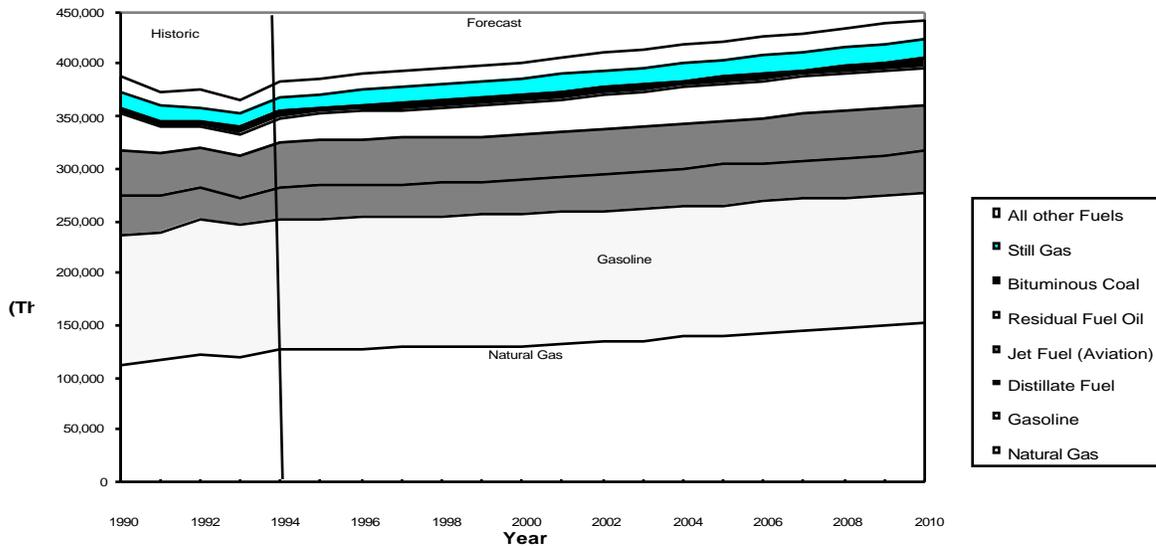
Forecast of California Greenhouse Gas Emissions: 2000, 2005 and 2010

Table 7 presents a summary of the estimated emissions of greenhouse gases, measured as carbon dioxide equivalent, for the years 2000, 2005, and 2010. Emissions are expected to increase by about 15 percent by the year 2010, with respect to the 1990 baseline year. In the historical inventory and forecast, approximately 85 percent of the emissions, again measured as carbon dioxide equivalent, originate from the combustion of fossil fuels. Methane would remain as the second most important greenhouse gas in California after carbon dioxide, and would continue to contribute slightly more than 8 percent of the total emissions. Nitrous oxide emissions would increase by about 42 percent by 2010, with respect to their 1990 level, but still remain as a minor fraction of total greenhouse gas emissions.

	1990*	2000	2005	2010
Carbon Dioxide				
Fossil Fuel Comb.	389,270	399,979	418,581	437,709
Ind. Processes	14,577	18,058	25,502	27,040
Methane	44,484	51,971	53,323	55,385
Nitrous Oxide	7,998	9,840	10,591	11,388
Total	456,329	479,849	507,996	531,523
* Historical baseline year				

Carbon dioxide emissions from the combustion of fossil fuels are expected to increase by 12.4 percent over 1990 emissions levels by the year 2010. This is a modest growth rate, due in part to an almost constant level of consumption of motor gasoline in the state, and to the increased penetration of natural gas, with its relatively lower carbon content, as the fuel of choice in the state. Motor gasoline demand is forecasted to stay at about the same level as improvements in fuel economy, and substitution of alternative fuels is expected to offset growth in vehicle miles traveled. The forecast includes fleet average fuel economy growth at about one percent annually, due to technology enhancement and materials substitution. Along with increased use of compressed natural gas vehicles, the forecast assumes implementation of the California Zero Emission Vehicle requirements.¹⁰ As shown in Figure 9, natural gas and motor gasoline are expected to continue as the main sources of carbon dioxide emissions in the state, followed by jet fuel, distillate fuel oil, and residual fuel oil.

Figure 9
Historical and Forecasted Carbon Dioxide Emissions
from the Combustion of Fossil Fuels



Organization of the Chapters

This document includes 14 technical chapters which follow the organization of the U.S. EPA State Workbook. The information for this overview chapter has been extracted from the 14 technical chapters. As indicated before, all the calculations in the technical chapters were made according to the U.S. EPA's proposed standard methodologies, except when available information deemed it advisable to use alternative approaches. In such instances, the alternative methodologies have been fully explained and documented.

Since this report was conceived initially as a continuation of the *1990 California Greenhouse Emissions Inventory*, some technical information on methodologies included in the 1990 inventory was not repeated in this document. The reader is advised to consult that report to gain a more complete understanding of the basic methodologies used.

In general, emissions estimates presented in this report for 1990 may be slightly different than the emissions included in the *1990 California Greenhouse Emissions Inventory*. This is the result of revising the methods and calculations and, in some cases, using new sources with more complete historical information for 1990 to 1994. For example, one important change with respect to the *1990 California Greenhouse Emissions Inventory* is the use of fuel consumption data from the Energy Information Administration (EIA), instead of from the Commission's *1991 Fuels Report*.¹¹ Subsequent Fuels Reports did not disaggregate energy consumption data at the same level as in 1991; therefore, EIA data was used for the detailed comparison required in this report. The use of the EIA data has somewhat changed the estimated emissions for 1990, considered the baseline year for this inventory.

Conclusions and Recommendations

The Climate Change Action Plan released by President Clinton in October 1993 committed the U.S. to a reduction of greenhouse gas emissions to their 1990 levels by the year 2000. The historical inventory indicates that total GHG emissions in California by 1994 increased by only 0.58 percent from 1990 levels (see Table 2). For the U.S., for the same period, the increase was close to 4 percent.¹² However, this slow increase in emissions may not continue, and an increase of about 4.8 percent with respect to the baseline year is expected by the year 2000. The minor decrease in carbon dioxide emissions from the combustion of fossil fuels through 1994 is the main factor in the observed slow increase in total GHG emissions. There is good reason to believe that most of the observed decrease in carbon dioxide emissions from the combustion of fossil fuels was due to both the state of the economy¹³ and to a significant reduction in residual fuel oil use in marine vessels.¹⁴ These conditions were temporary and, for this reason a significant increase in total emissions is expected by the year 2000 and beyond.

Electrical energy conservation programs in California have been successful in slowing the increasing demand for power production. This has resulted in lower criteria pollutant emissions from power plants, which are expected to continue in the future. At the same time, emissions from in-state power plants are tightly controlled, only contributing about 4 percent to the total annual state NO_x inventory. For these reasons, electricity conservation programs, even though important, are only a small contributor to the efforts to achieve compliance with ambient air quality standards for criteria pollutants. Electricity conservation programs are extremely important, however, in any serious effort to reduce the emission of greenhouse gases in the state, or the nation, and have also been found to be one of the most cost-effective measures to reduce CO₂ emissions.¹⁵ The importance of energy conservation programs in reducing carbon dioxide emissions is clear when it is considered that, in 1994, about 16 percent of carbon dioxide emissions from the combustion of fossil fuels in California originated from burning fossil fuels in power plants. Out-of-state power plants serving California emit even more carbon dioxide than in-state plants. Since where carbon dioxide emissions occur is irrelevant, from a global climate change perspective, electricity conservation programs in California play an extremely important role in reducing carbon dioxide emissions from both in-state and out-of-state power plants.

In July, 1997 the U.S. EPA established new more stringent national ambient air quality standards for tropospheric ozone and particulate matter. The agency is also developing general guidelines on how to develop comprehensive air quality management plans that take into consideration the relationships between both types of pollutants. A similar approach was taken by the South Coast Air Quality Management District in the development of their 1997 PM10 Air Quality Management Plan. Studies at the regional and national levels seem to indicate that reduction in CO₂ emissions may also result in significant sustainable reductions in the emission of several criteria pollutants. For these reasons, it seems advisable to start an exploratory quantitative analysis in California on cost effective options to reduce greenhouse gases and criteria pollutants in an integrated fashion.

ENDNOTES

1. U.S. EPA, Office of Policy, Planning and Evaluation, State and Local Reach Program *State Workbook, Methodologies for Estimating Greenhouse Gas Emissions*, January 1995.
2. Intergovernmental Panel on Climate Change, Organization for Economic Co-Operation and Development, *IPCC Guidelines for National Greenhouse Gas Inventories, 3 volumes: Vol. 1, Reporting Instructions; Vol. 2, Workbook; Vol. 3, Draft Reference Manual*, 1994. Paris, France.
3. Contribution of WGI to the Second Assessment Report of the Intergovernmental Panel on Climate Change, *Climate Change 1995, The Science of Climate Change*, Table 4.
4. Carbon dioxide emissions can be represented as carbon (C) or carbon dioxide (full molecular weight). Carbon dioxide measured as carbon should be multiplied by the ratio of the molecular weight of carbon dioxide (44) and divided by the molecular weight of carbon (12) to obtain emissions in its full molecular weight.
5. Intergovernmental Panel on Climate Change - Working Group 1, *Climate Change 1992: The Supplementary Report to the IPCC Scientific Assessment*, 1992.
6. U.S. EPA, Office of Policy, Planning and Evaluation, *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-1993*, September 1994. 230-R-94-014.
7. In most inventories the disaggregation of emissions are attributed to four sectors: commercial, industrial, transportation, and electric utilities. Since in this overview chapter the "electricity generating" sector replaces the electric utilities sector, the "industrial" sector in this overview chapter does not include emissions from non-utility generation that would otherwise be attributed to the industrial sector. If emissions from non-utility generation are attributed to the industrial sector, this sector becomes the second largest contributor to carbon dioxide emissions, after the transportation sector.
8. If we also consider that non-utility generation represented 11.3 percent of the total U.S. generation in 1994, the emissions from utility and non-utility generation, at the national level, would be closer to 40 percent. *1994 Capacity and Generation of Non-Utility Sources of Energy*. Edison Electric Institute.

November 1995, page 2. *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-1994*. Office of Policy, Planning, and Evaluation. U.S. Environmental Protection Agency. November 1995, page 14.

9. A recent study jointly founded by the Gas Research Institute and the U.S. EPA found that the leakage rates from pipelines outside California are higher by a factor of two or three. Distribution and transmission pipelines in California seldom use cast iron pipes. However, they are very common outside of California and were found to be responsible for most of the fugitive emissions.
10. California Energy Commission, 1995 Fuels Report, December 1995.
11. California Energy Commission, *1991 Fuels Report*, 1991.
12. Energy Information Administration, *Emissions of Greenhouse Gases in the United States, 1995*, October 1996. Table ES2. In keeping with the EIA's approach, this document for California includes emissions from the consumption of "international bunker fuels" in the U.S. national inventory.
13. The unemployment rates from 1990 through 1995 shows that the state's economy was at its lowest point in 1993, with a partial recovery seen in 1994 and continued in 1995.
14. The significant drop in the sales of residual fuel oil to marine vessels was the result of the adoption of a tax in 1991 which was repealed in January, 1993.
15. Krause, Florentine, Oliver, D. and Koomey, J., *Negawatt Power: The Cost and Potential of Electrical Efficiency in Western Europe: Energy Policy in the Greenhouse. Volume II, Part 3B*, 1995. International Project for Sustainable Energy Paths.

Chapter 1 ---

CARBON DIOXIDE EMISSION FROM THE COMBUSTION OF FOSSIL FUELS

INTRODUCTION

This chapter presents the estimated historical and forecasted future carbon dioxide (CO₂) emissions from the combustion of fossil fuels in California. The historical record covers the period from 1990 through 1994, and the forecast covers the years 2000, 2005, and 2010. The forecast is based mostly on energy consumption forecasts contained in the California Energy Commission's *1995 Fuels Report*.¹

HISTORICAL EMISSIONS: 1990-1994

The historical fuel consumption data used were obtained in electronic form from the Energy Information Administration (EIA).² The EIA develops energy consumption statistics at the state and national level and publishes the results in an annual publication, *State Energy Data Report*. The EIA historical fuel consumption data are extremely well-documented. However, this report replaces some EIA data with the Commission's own data, when believed to be more accurate.

It should be noted that the *1990 California Greenhouse Emissions Inventory* was based on fuel consumption data from the 1991 Fuels Report.³ As previously mentioned in the *Overview*, in adopting the EIA report date for this update, some estimates of emissions for 1990 (considered the baseline year) have been found to differ, causing different results, in some cases, in this update to the *1990 Inventory*. Commission staff will continue to revise 1990 baseline year estimates as data collection and analysis technologies and methodologies improve.

Residential Sector

Direct fuel consumption⁴ in the residential sector is dominated by natural gas, representing approximately 96 percent, as shown in Table 1-1. Since consumption of electricity in this sector is not a primary fuel, it is not included in Table 1-1. Electricity generation will be treated as a separate sector of the California energy system. The EIA estimates coal

consumption (both lignite and bituminous) for the residential sector based on the combined coal delivered to the residential and commercial sectors, as reported in its "Coal Distribution Report." The EIA splits total coal consumption, allocating 35 percent to the residential sector and the remainder to the commercial sector. Coal consumption in the residential sector is probably overestimated for California, but the EIA numbers were considered the best source of information available. Even so, reported coal consumption represents less than 0.25 percent of total fossil fuel consumed in this sector.

As with natural gas, consumption of liquified petroleum gas (LPG) is estimated based on the combined amount sold to the residential and commercial sectors. Based on a 1974 study by the Federal Energy Administration's "Project Independence Blueprint Task Force," the EIA assumes that 85 percent of the LPG is sold to the residential sector and the balance to the commercial sector

Table 1-1 shows a minor downward trend in total energy consumption from 1990 through 1992, followed by an increase in 1993 and 1994. Energy consumption and related CO₂ emissions almost returned to 1990 levels in 1994. A cursory review of the population-weighted cooling and heating degree days in California⁵ for this period does not seem to explain these changes.⁶ Other factors, such as the state of the economy and efficiency improvements, may be the cause of this trend.

Commercial Sector

Table 1-2 presents the historical energy consumption and related CO₂ emissions for the commercial sector, showing that consumption of natural gas in 1990 represented approximately 86 percent of total energy consumed (excluding electricity) in this sector. This percentage continuously increases, reaching 94 percent in 1994. Natural gas consumption as reported by the EIA for the commercial sector also includes consumption in agriculture, forestry, and fisheries operations. Although California normally includes agriculture, forestry, and fisheries in the industrial sector, this report retains these areas in the commercial sector, in keeping with EIA's approach.

Natural gas and total energy consumption for this sector shows a declining trend from 1990 to 1993 with, again, slightly increased consumption levels observed in 1994.

Table 1-1
Energy Consumption and CO₂ Emissions from the Combustion of Fossil Fuels
Residential Sector: 1990-1994

	1990	1991	1992	1993	1994
			1.2	0.9	0.9
			0.2	0.4	0.4
LPG	20.8	25.1	17.4	18.2	18.0
Bituminous Coal	0.2	0.4	0.0	1.2	1.3
Natural Gas	530.8	522.3	492.7	519.9	531.7
Total	553.7	549.4	511.5	540.5	552.3
Fuel	CO ₂ Emissions (Thousand Tons)				
	1990	1991	1992	1993	1994
Distillate Fuel Oil	105	93	93	72	69
Kerosene	40	36	15	30	30
LPG	1,430	1,724	1,194	1,246	1,237
Bituminous Coal	21	36	0	117	137
Natural Gas	30,888	30,392	28,671	30,255	30,940
Total	32,483	32,280	29,973	31,720	32,413

Table1-2
Energy Consumption and CO₂ Emissions from the Combustion of Fossil Fuels
Commercial Sector: 1990-1994

Fuel	Energy Consumption (Trillion Btu)				
	1990	1991	1992	1993	1994
Distillate Fuel Oil	26.7	25.9	11.6	9.3	8.8
Kerosene	0.1	0.1	0.1	0.1	0.1
LPG	3.7	4.4	3.1	3.2	3.2
Motor Gasoline	10.1	8.6	7.8	1.4	1.2
Residual Fuel Oil	5.6	4.8	0.3	0.1	0.0
Bituminous Coal	0.4	0.7	0.0	2.1	2.5
Natural Gas	294.1	295.3	292.8	259.8	267.4
Total	340.7	339.9	315.7	276.0	283.2
Fuel	CO ₂ Emissions (Thousand Tons)				
	1990	1991	1992	1993	1994
Distillate Fuel Oil	2,134	2,069	928	740	700
Kerosene	8	10	9	8	6
LPG	252	304	211	220	218
Motor Gasoline	782	672	606	107	92
Residual Fuel Oil	484	413	23	10	4
Bituminous Coal	38	68	0	218	255
Natural Gas	17,115	17,183	17,040	15,115	15,560
Total	20,815	20,720	18,817	16,418	16,835

Industrial Sector

Natural gas also dominates the industrial sector, but represents less than 50 percent of total fuel consumption (see Table 1-3). Refinery gas, or *still* gas (any form or mixture of gases produced in refineries by distillation, cracking, reforming and other processes), is an important fuel in this sector. Principal constituents are methane, ethane, normal butane, butylene, propane, and propylene. The EIA state data is based on national estimated still gas consumption, which is apportioned to each state based on the state's refinery capacities. Data reported to the Commission by California refineries more accurately reflect the actual consumption of still gas in California, and therefore is used instead of the EIA data.⁷

The "Other Petroleum Fuels" category in Table 1-3 includes 15 fuels which, together with still gas, are referred to as "Other Petroleum Products" in the EIA data base. As previously mentioned, still gas is treated in this report as a separate fuel, because of both its significance and the availability of California-specific data.

Although natural gas use increases from 1990 through 1994, total fuel consumption data for the industrial sector remains almost unchanged. Asphalt, road oil, and lubricants can be considered as fuels; however, they are not used as such and, therefore, contribute only minimally to CO₂ emissions from this sector. The assumptions used in this report, from the EPA Workbook,⁸ are that all the carbon in asphalt and road oil is sequestered and that only 50 percent of the amount of oil used as lubricants is eventually oxidized or combusted, releasing CO₂.

Transportation Sector

Fuel consumption in the transportation sector is dominated by motor gasoline, which represents approximately 60 percent, with jet fuel the second most important fuel. Jet fuel consumption reported in Table 1-4 includes both kerosene-type and naphtha-type fuels. Until a few years ago, the consumption of kerosene-type and naphtha-type jet fuels occurred almost exclusively in commercial and military aircraft, respectively. However, in recent years, military cut-backs and a decision to switch to kerosene-type fuel has caused a significant decline in the consumption of naphtha-type fuel. The next two most important fuels are distillate fuel oil and residual fuel oil. Approximately 86 percent of distillate fuel oil in transportation is used to fuel trucks, buses, and automobiles; 9.7 percent is used in railroads; and the remainder in marine vessel bunkering.⁹ Residual fuel oil is mainly heavy oil used in marine vessels and military applications. Most residual fuel oil consumed in the state (around 95 percent) is sold as a fuel to marine vessels.¹⁰

**Table 1-3
Energy Consumption and CO₂ Emissions from the Combustion of Fossil Fuels
Industrial Sector: 1990-1994**

Fuel	Consumption (Trillion Btu)				
	1990	1991	1992	1993	1994
Asphalt & Road Oil	98.6	94.6	90.0	82.5	81.2
Distillate Fuel Oil	111.5	83.5	64.7	51.1	52.6
Kerosene	0.2	0.2	0.1	0.3	0.2
LPG	44.6	34.9	53.6	36.3	40.9
Lubricants	13.1	11.7	11.9	12.1	12.7
Motor Gasoline	16.5	17.2	17.3	14.0	14.5
Residual Fuel Oil	11.7	11.1	11.9	9.7	8.5
Bituminous Coal	64.7	63.0	64.8	53.6	54.2
Natural Gas	606.5	725.7	705.7	775.3	741.4
Still Gas	245.1	243.9	232.7	243.1	236.8
Other Pet. Fuels	307.4	257.1	282.1	242.5	257.9
Total	1,520.0	1,542.8	1,534.8	1,520.6	1,500.8
Fuel	CO ₂ Emissions (Thousand Tons)				
	1990	1991	1992	1993	1994
Asphalt & Road Oil	0	0	0	0	0
Distillate Fuel Oil	8,903	6,666	5,164	4,084	4,199
Kerosene	17	16	10	20	18
LPG	3,058	2,395	3,676	2,493	2,808
Lubricants	529	473	482	491	513
Motor Gasoline	1,283	1,334	1,346	1,087	1,126
Residual Fuel Oil	1,008	953	1,022	832	732
Bituminous Coal	6,580	6,403	6,586	5,450	5,506
Natural Gas	35,295	42,232	41,063	45,116	43,141
Still Gas	14,248	14,177	13,527	14,132	13,765
Other Pet. Fuels	9,891	6,762	8,458	7,234	8,002
Total	80,812	81,410	81,334	80,939	79,810
Note: Other Pet. Fuels include all the fuels included by EIA as "Other Petroleum Products" with the exception of still gas.					

Table 1-4
Energy Consumption and CO₂ Emissions from the Combustion of Fossil Fuels
Transportation Sector: 1990- 1994

Fuel	Consumption (Trillion Btu)				
	1990	1991	1992	1993	1994
Aviation Gasoline	5.6	5.5	5.3	4.1	4.0
Jet Fuel	534.7	508.1	489.5	504.7	560.1
Distillate Fuel Oil	340.3	328.1	313.6	282.3	315.3
LPG	3.4	2.7	2.4	2.4	3.7
Lubricants	17.4	15.6	15.9	16.2	16.9
Motor Gasoline	1,571.5	1,542.7	1,633.3	1,605.9	1,601.0
Residual Fuel Oil	345.6	264.8	203.0	206.4	240.9
Natural Gas	20.8	19.0	15.2	12.5	12.9
Total	2,839.1	2,686.6	2,678.2	2,634.4	2,754.8

Fuel	CO ₂ Emissions (Thousand Tons)				
	1990	1991	1992	1993	1994
Aviation Gasoline	421	416	404	312	302
Jet Fuel	42,213	40,116	38,651	39,849	44,224
Distillate Fuel Oil	27,175	26,203	25,045	22,541	25,183
LPG	231	188	162	162	251
Lubricants	705	631	643	655	684
Motor Gasoline	122,077	119,843	126,879	124,747	124,368
Residual Fuel Oil	29,728	22,778	17,461	17,757	20,721
Natural Gas	1,209	1,106	884	728	753
Total	223,760	211,281	210,128	206,751	216,488

As shown in Table 1-4, total fuel consumption in the transportation sector declined slightly from 1990 to 1993, with a small increase seen again in 1994. The consumption of motor gasoline behaves somewhat differently, showing a general tendency toward an increase in energy consumption; however, a minor decline in 1993 consumption is still noticeable. It is important to note that the natural gas consumption in the transportation sector reported in Table 1-4 is mainly gas consumed by compressors in natural gas transmission pipelines. As in the industrial sector, only 50 percent of lubricants are assumed to eventually oxidize carbon, releasing CO₂ to the atmosphere.

Electricity Generation Sector

Electricity in California is produced by both utility and non-utility generators. In 1993 and 1994, about 33 percent of in-state generation of electricity came from non-utility generators, which is significantly higher than the 1994 U.S. average of 11.2 percent.¹¹ In this report, the electricity generation sector is defined as being composed of both utility and non-utility generation.

Fuel consumption in the electric utility industry in California, and its associated CO₂ emissions, are presented in Table 1-5. Natural gas predominates, representing approximately 91 percent of fossil fuel consumed in 1990 and, in subsequent years, more than 96 percent. Coal is not burned in in-state power plants owned or operated by electric utilities, and only very small amounts of distillate and residual fuel oil are burned in this subsector.

The EIA maintains a confidential database of the fuel consumed by non-utility generators with a capacity of one megawatt or more. A similar data base, which is also confidential, has been developed by Edison Electric Institute. Comparisons by the EIA of some of the aggregated statistics (such as total fuel consumption and electricity generation) from both data bases has found them to be similar. For this reason, this report has relied on some statistics from the Edison Electric Institute for information not readily available directly from EIA publications.

Non-utility generators burn coal, petroleum, petroleum-derived fuels, and natural gas. In the Pacific region, which includes Alaska, California, Hawaii, Oregon, and Washington, more than 83.5 percent of fossil fuel generation by non-utility generators in 1992, 1993, and 1994 was by natural gas-burning power plants.¹²

To acquire California-specific fuel use data, fuel consumption statistics from non-utility generators were requested from the EIA, and total aggregated natural gas consumption data for in-state non-utility generators from 1990 to 1995 was received. Fuel consumption data for other fuels was withheld to avoid disclosure of proprietary individual company data. Coal and other

petroleum fuel consumption data was inferred from statistics for the Pacific region. The estimated fuel consumption data, other than for natural gas, should be considered with caution, since it is only meant to give an order of magnitude estimate of actual consumption.

According to the Edison Electric Institute,¹³ cogenerators, small power producers, and other non-utility producers contributed 67.44 percent, 30.98 percent and 1.58 percent, respectively, of total non-utility generation in California in 1993. Small power producers are defined as having a production capacity of 80 megawatts or less and using biomass, other waste, renewable resources, or any combination thereof as their primary source of energy. Because of the nature of these resources, small power producers should not contribute substantially to total net CO₂ emissions from non-utility generators, and it was assumed that the bulk of CO₂ emissions from this subsector of the energy system comes from cogenerators. Since cogeneration is defined as the sequential production of electric energy and heat, not all the fuel consumed in cogeneration facilities should be, in theory, allocated to the electricity generation sector. In addition, cogeneration generally consumes less fuel than a parallel operation of an electricity generating unit and a boiler producing an equivalent amount of electricity and heat. For all these reasons, attributing all the CO₂ emissions from cogenerating units to the electricity generation sector overstates its contribution.

Table 1-6 presents historical CO₂ emissions from non-utility generators. From this and the previous table, which provides the historical data on CO₂ emissions from utility generators, it can be concluded that the electricity generation sector contributed approximately 13.2 percent of CO₂ emissions from the combustion of fossil fuels in 1990, steadily increasing to 16.2 percent in 1994.

**Table 1-5
Energy Consumption and CO₂ Emissions from the Combustion of Fossil Fuels
Electric Utilities: 1990-1994**

Fuel	Consumption (Trillion Btu)				
	1990	1991	1992	1993	1994
Distillate Fuel Oil	1.1	0.6	0.7	0.6	0.6
Residual Fuel Oil	45.1	5.9	3.0	20.3	17.9
Natural Gas	471.5	461.6	583.1	480.0	618.7
Bituminous Coal	0.0	0.0	0.0	0.0	0.0
Total	517.6	468.1	586.8	501.0	637.3
Fuel	CO ₂ Emissions (Thousand Tons)				
	1990	1991	1992	1993	1994
Distillate Fuel Oil	88	49	58	51	49
Residual Fuel Oil	3,877	504	261	1,745	1,544
Natural Gas	27,435	26,860	33,929	27,934	36,004
Bituminous Coal	0	0	0	0	0
Total	31,400	27,413	34,247	29,730	37,597

Table 1-6
Energy Consumption and CO₂ Emissions from the Combustion of Fossil Fuels
Non-Utility Generation: 1990-1994

Fuel	Consumption (Trillion Btu)				
	1990	1991	1992	1993	1994
Distillate Fuel Oil					24.8
Natural Gas	321.1	348.1	370.0	439.3	390.1
Bituminous Coal					44.6
Total					459.5

Fuel	CO ₂ Emissions (Thousand Tons)				
	1990	1991	1992	1993	1994
Distillate Fuel Oil	666	655	608	579	588
Natural Gas	18,683	20,254	21,531	25,562	22,702
Bituminous Coal	584	889	1178	1384	1,350
Total	19,933	21,798	23,317	27,525	24,640

HISTORICAL CARBON DIOXIDE EMISSIONS BY FUEL TYPE

Figure 1-1 presents the historical increment/decrement in CO₂ emissions by fuel type compared to 1990 emissions levels. The line labeled "Net Total" in this figure represents the net change from the 1990 baseline in total emissions from the combustion of all the fossil fuels and indicates that CO₂ emissions have declined in the historic period covered in this analysis. Total emissions dropped in 1993, at the end of a contraction period in the state's economy, which was followed by a period of economic expansion from 1993 through 1995.

Figure 1-1
Increment/Decrement in CO₂ Emission by Fuel Type
in California from 1990 TO 1994

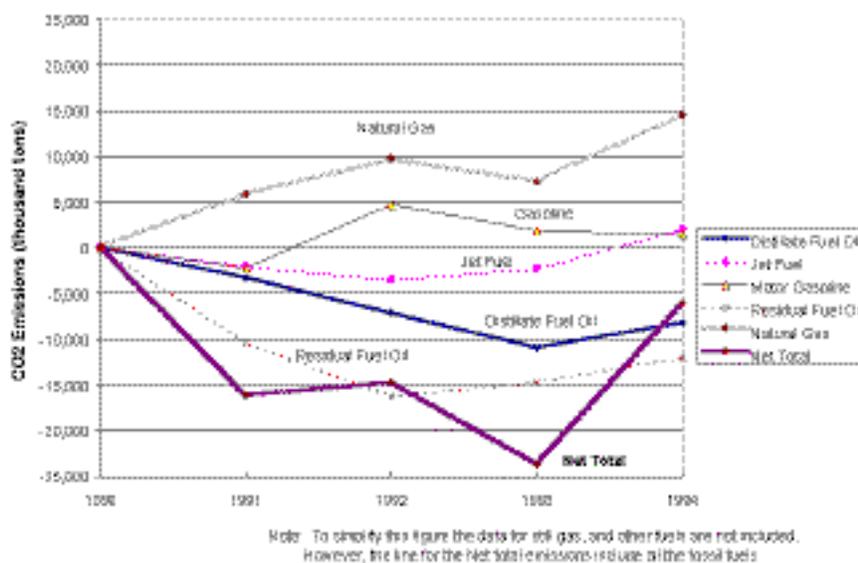
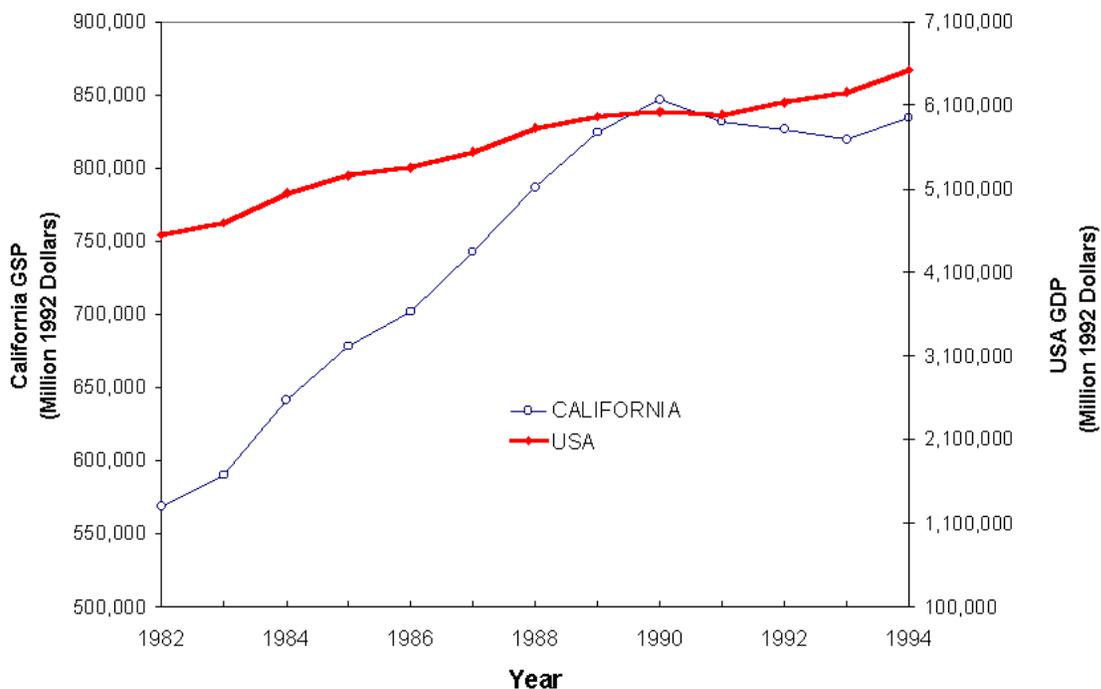


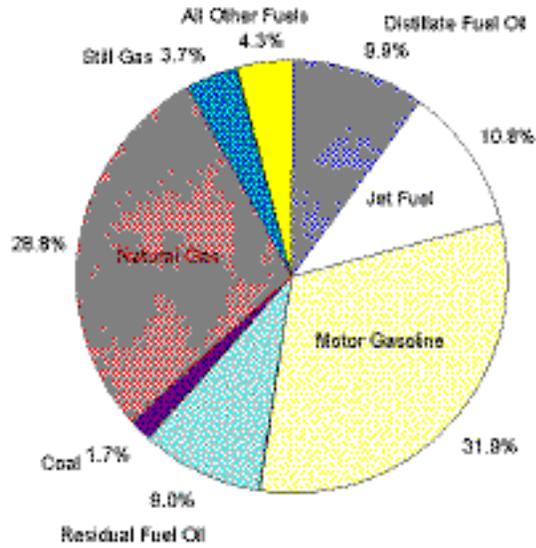
Figure 1-2 shows the historical evolution of the gross state product (GSP) and the national gross domestic product (GDP) up to 1994.¹⁴ Other factors, such as energy efficiency improvements and changes in demographics and weather conditions, may also help explain the observed changes in carbon dioxide emissions in the historical period covered in this analysis. From an examination of Figure 1-1, it is clear that most of the reductions in CO₂ emissions are due to decreases in the use of residual and distillate fuel oil, especially in 1991 and 1992. After 1992, the consumption of residual fuel oil increased significantly, with this trend continuing in 1995, a year after the last year in Figure 1-1. The significant drop in consumption of residual fuel oil in 1992 and 1993 was due to the adoption in 1991 of a new state tax for residual fuel oil sold as a fuel to marine vessels. Although this tax was repealed in July 1992, the new tax law was not effective until January 1993.

Figure 1-2
Gross Domestic Product for the U.S and
Gross State Product for California: 1982-1994

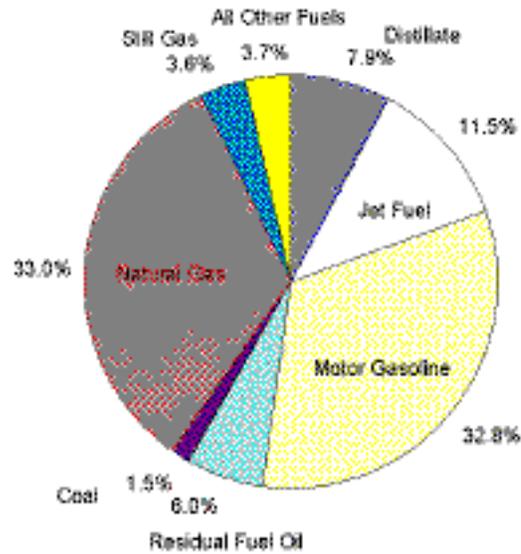


Figures 1-3 and 1-4 present the contribution of CO₂ emissions by fuel type for 1990 and 1994 respectively. Motor gasoline and natural gas contributed more than 60 percent of total CO₂ emissions in California in both years. In 1994, the contribution from natural gas increased from 28.8 percent to 33 percent. It should be noted that the consumption of natural gas in the state, in terms of units of energy, is higher than its contribution to total CO₂ emissions from fossil fuel combustion. For example, natural gas represented 34.6 and 39.1 percent of total energy consumption from fossil fuel combustion in 1990 and 1994 respectively. This apparent discrepancy is easily explained when it is considered that natural gas has a much lower carbon content than other fossil fuels consumed in the state. Table 1-7 presents the historical fossil fuel consumption data, in units of energy, and their corresponding CO₂ emissions.

**Figure 1-3
Percent Contribution of CO₂ Emissions by Fuel Type
California: 1990**



**Figure 1-4
Carbon Dioxide Emissions by Fuel Type
from Combustion of Fossil Fuels: 1994**



**Table 1-7
Fossil Fuel Consumption and CO₂ Emissions by Fuel Type**

Fuel	Consumption (Trillion Btu)				
	1990	1991	1992	1993	1994
Distillate Fuel Oil	481	439	392	344	378
Jet Fuel	535	508	490	505	560
Motor Gasoline	1,598	1,569	1,658	1,621	1,617
Residual Fuel Oil	408	287	218	236	267
Bituminous Coal	65	64	65	57	58
Natural Gas	1,924	2,024	2,089	2,048	2,172
Still Gas	245	244	233	243	237
All Other Fuels	313	263	287	247	262
Total	5,569	5,397	5,432	5,301	5,551
Fuel	CO ₂ Emissions (Thousand Tons)				
Distillate Fuel Oil	38,405	35,079	31,288	27,487	30,200
Jet Fuel	42,213	40,116	38,651	39,849	44,224
Motor Gasoline	124,143	121,849	128,831	125,941	125,586
Residual Fuel Oil	35,098	24,648	18,766	20,345	23,001
Bituminous Coal	6,639	6,507	6,587	5,785	5,899
Natural Gas	111,942	117,773	121,587	119,148	126,399
Still Gas	14,248	14,177	13,527	14,132	13,765
All Other Fuels	16,583	12,954	15,264	12,871	14,069
Total	389,270	373,105	374,499	365,559	383,144
Note: All Other Fuels include: asphalt and road oil, aviation gasoline, kerosene, LPG, lubricants, and "Other Petroleum Fuels" (see Table 1-3).					

HISTORICAL CARBON DIOXIDE EMISSIONS BY SECTOR

Figure 1-5 presents historical CO₂ emissions in California by sector. Transportation contributes the largest amount of CO₂ emissions in the state, representing nearly 57 percent of the total emitted by the combustion of fossil fuels. The second largest contributor is the industrial sector, followed by the residential sector and the electric utilities sub-sector.

Figure 1-5
Carbon Dioxide Emissions by Sector
from the Combustion of Fossil Fuels: 1994

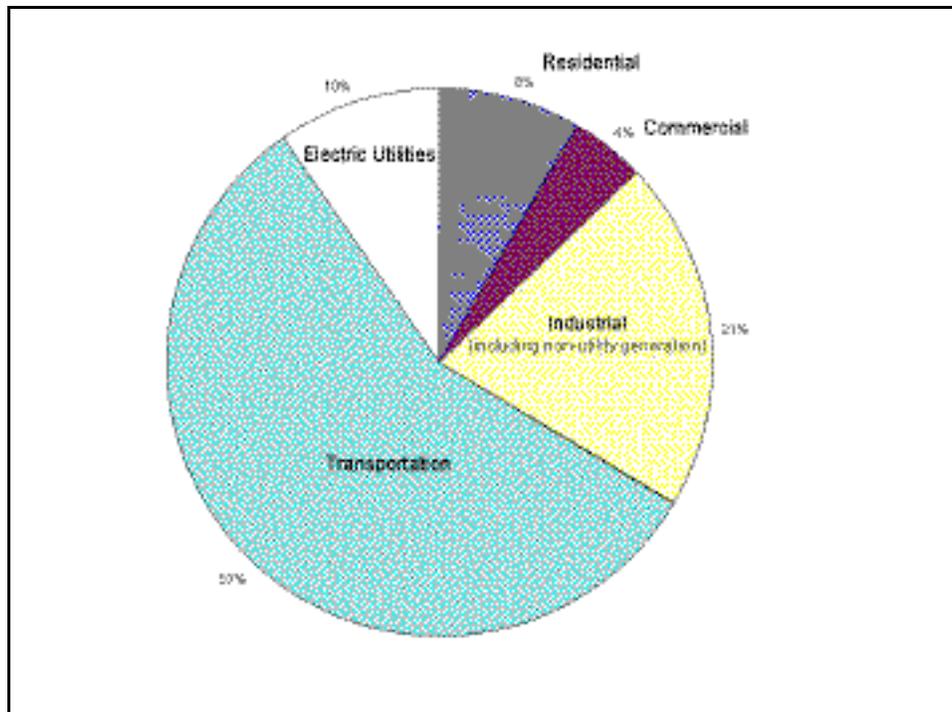
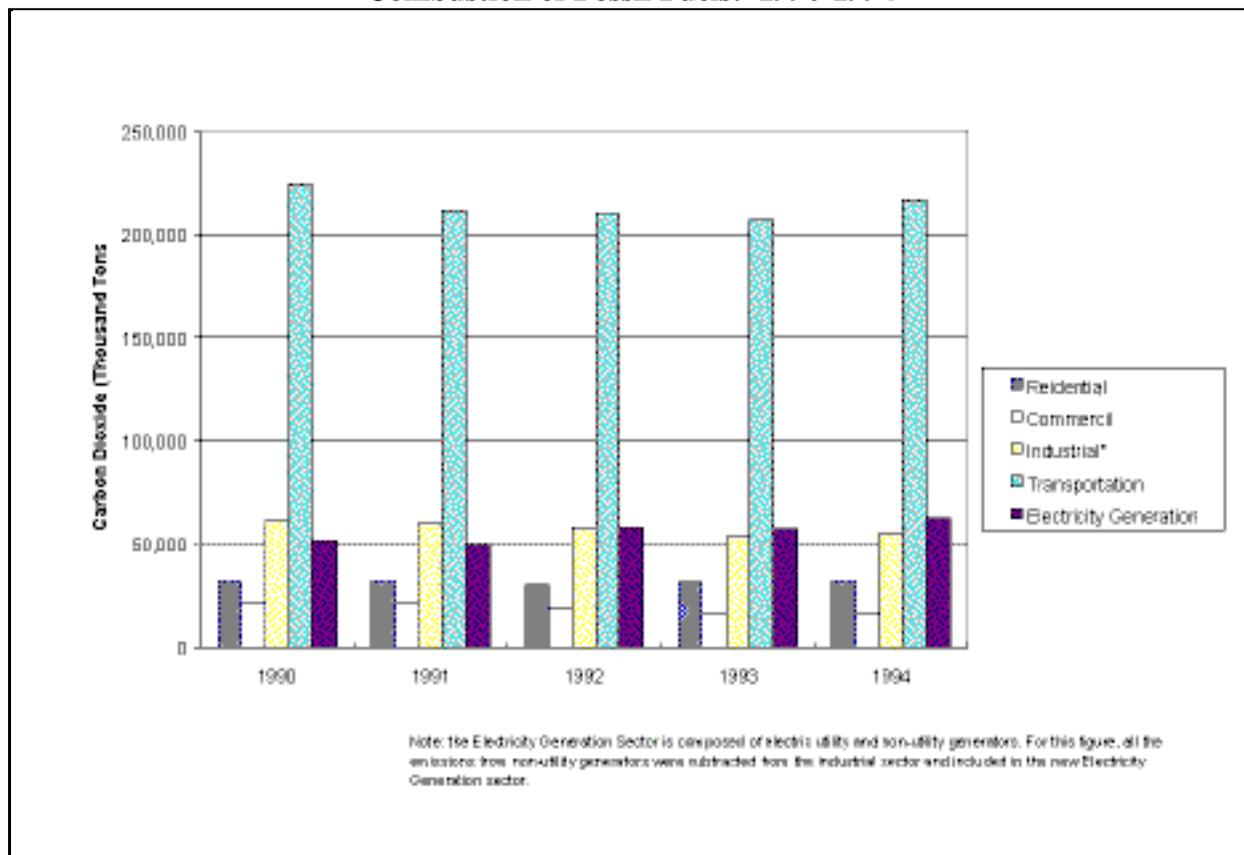


Figure 1-6 shows that, after 1993, the electricity generation sector (utility and non-utility electricity generators) becomes the second largest CO₂-contributing sector, after transportation. This is because non-utility generation, representing a significant portion of industrial sector emissions and a minor portion of commercial sector emissions, is considered part of this new sector.

**Figure 1-6
Contribution by Sector to CO₂ Emissions from
Combustion of Fossil Fuels: 1990-1994**



FORECASTED GREENHOUSE GAS EMISSIONS: 2000, 2005 AND 2010

This section presents the forecast of greenhouse gas emissions for California for the years 2000, 2005, and 2010. This forecast is based on official forecasts of fuel consumption included in the *Commission's 1995 Fuels Report*, which represent approximately 82 percent of the historical fossil fuel consumption in California. Fuels covered in the forecast include natural gas in all energy sectors, motor gasoline, diesel oil, propane, methanol, and aviation jet fuels in the transportation sector.

Gasoline demand is forecasted to stay at about the same level as improvements in fuel economy and substitution of alternative fuels is expected to offset growth in vehicle miles traveled. The forecast

includes fleet average fuel economy growing at about 1 percent annually, due to technology enhancement and material substitution. Along with increased use of compressed natural gas vehicles, the forecast assumes implementation of new light duty vehicles to be electric vehicles after 2002. Diesel demand is forecasted to grow substantially with growth in truck and rail use, to support increased movement of commodities in California and little improvement in fuel efficiency is assumed. Growth in future commercial aviation fuel demand is substantially less than expected growth in number of passengers, due to improvements in fuel use per passenger mile of travel. The forecast includes fuel efficiency growth of 1.8 percent annually, based on retrofit improvements to existing aircraft and continued introduction of more efficient, generally larger aircraft.

For fuels not covered in the *1995 Fuels Reports*, future consumption has been estimated based on the forecast for the Pacific region by the EIA in its *1997 Annual Energy Outlook* and the expected general growth of California's economy. Generally, California consumes more than half of the energy by fuel type in this region. The indicator selected for this task was the non-agricultural wage and salary (W&S) jobs parameter, one of the main economic parameters used by the Commission to forecast future energy consumption. Expected growth for this parameter was obtained from the publication "California Energy Demand: 1995-2015, Volume XII: Economic Projections in Support of Staff's July 1995 Forecast." The use of W&S jobs growth was selected not because future fuel consumption should be directly correlated with this parameter, but mainly because this parameter provides a forecast for fuel consumption sectors not covered in the *1995 Fuels Report* that adequately matches the EIA forecast. Still gas and "all other fuels" in Table 1-9 were forecasted at half the rate of growth of the W&S jobs parameter. Again, this was done to provide a forecast that follows the general trend for these two fuels as presented in the *1997 Annual Energy Outlook*. It is important to emphasize that the forecasting approach presented in this paragraph is only a first-order estimate of future energy consumption, and that using growth of W&S jobs, in general, produces energy consumption estimates in 2010 (for fuels not covered in the *1995 Fuels Report*) that are close to the levels shown for 1990. The only exception is distillate fuel oil, which does not recover from its rapid historical drop in the 1990 to 1994 period and only reaches about 60 percent of the 1990 consumption level in the year 2010.

Table 1-8 presents historical and forecasted fuel consumption levels, and Table 1-9 their associated CO₂ emissions. It should be noted that, for aviation jet fuel, the *1995 Fuels Report* only includes jet fuel used in commercial aviation, while historical data presented in this report includes kerosene-type and naphtha-type jet fuels, which are used for both commercial and military applications. For this reason, the historical jet fuel consumption has been scaled up, using the scaling factors for aviation jet fuel reported in the *1995 Fuels Report*.

Table 1-8							
Historical and Forecasted Fuel Consumption in California (Trillion BTU)							
Fuel	Sectors	1990	1994	1995	2000	2005	2010
Historical Fuel Consumption							
Distillate Fuel Oil	all	480.9	378.2	384.1			
Jet Fuel	all	534.7	560.1				
Motor Gasoline	all	1598.1	1616.7				
Residual Fuel Oil	all	408.0	267.4	325.4			
Bituminous Coal	all	65.3	58.0				
Natural Gas	all	1923.7	2172.1				
Still Gas	all	245.1	236.8				
All Other Fuels	all	313.0	261.9				
Total		5568.8	5551.2				
Fuel Consumption with a 1995 Fuels Report Forecast							
Natural Gas	All	1,923.7	2,172.2		2,230.9	2,413.5	2,602.0
Gasoline	transp.	1,571.5	1,601.0		1,595.2	1,591.9	1,590.7
LPG	transp.	3.4	3.66		5.76	6.04	6.4
Distillate Fuel	transp.	340.3	315.4		351.7	387.5	416.4
Jet Fuel	transp.	534.7	560.1		435.7	449.1	457.0
Subtotal		4373.5	4,652.2				
Fuels Report /Total (%)		79%	84%				
Note: Jet Fuel includes consumption in commercial and military applications. All Other Fuels include: asphalt and road oil, aviation gasoline, kerosene, LPG, lubricants, crude oil, and "Other Petroleum Fuels" (see Table 1-3).							

**Table 1-9
California Historical and Forecasted CO₂ Emissions (Thousand Tons)**

Fuels Consumption With a 1995 Fuel Report Forecast							
	Sectors/Year	1990	1994	1995	2000	2005	2010
Natural Gas	all	111,942	126,399		129,816	140,445	151,414
Gasoline	transp.	122,077	124,368		123,915	123,663	123,566
LPG	transp.	231	251		395	414	441
Distillate Fuel	transp.	27,175	25,183		28,086	30,946	33,255
Jet Fuel	transp.	42,213	44,224		42,561	43,853	45,145
Subtotal		303,639	320,426		324,773	339,321	353,821
Fuel Consumption Without a 1995 Fuels Report Forecast							
Distillate Fuel Oil	all - transp.	11,230	5,017		5,791	6,202	6,642
Motor Gasoline	all - transp.	2,065	1,218		1,406	1,506	1,613
Residual Fuel Oil	all	35,098	23,001	27,997	31,553	33,791	36,188
Bituminous Coal	all	6,639	5,899		6,809	7,077	7,688
Still Gas	all	14,248	13,765		14,795	15,313	15,848
All other Fuels	all- LPG transp.	16,351	13,818		14,852	15,372	15,909
Subtotal		85,631	62,718		75,206	79,260	83,888
Total		389,270	383,144		402,170	421,993	437,709

Note: All other fuels include: asphalt and road oil, aviation gasoline, kerosene, LPG, lubricants, and "Other Petroleum Fuels" (see Table 1-3).

CONCLUSIONS AND RECOMMENDATIONS

Carbon dioxide emissions in California have shown a downward trend from the baseline year of 1990, reaching their lowest levels in 1993. In 1994, CO₂ emissions from the combustion of fossil fuels increased, but remained slightly below 1990 levels. Most of the reductions were due to the state of the economy and the significant reduction in the use of residual fuel oil in marine vessels and, to a minor degree, in the use of distillate fuel oil. These conditions were temporary, and CO₂ emissions are expected to increase in the future.

Forecasted CO₂ emissions are shown in Figure 1-7. As can be seen from this figure and Table 1-9, emissions are expected to increase by 12.4 percent over 1990 emission levels by the year 2010. This is a modest growth rate, due in part to a forecasted slight decrease in the consumption of motor gasoline in the state and to the increased penetration of natural gas as the fuel of choice in the state. As previously indicated, natural gas has a significantly lower carbon content than other fossil fuels. One strategy to reduce CO₂ emissions considered in different studies is fuel switching to fuels with lower carbon content, such as natural gas. California, for all sectors other than transportation, has been moving in this direction, and this trend is expected to continue in the future.

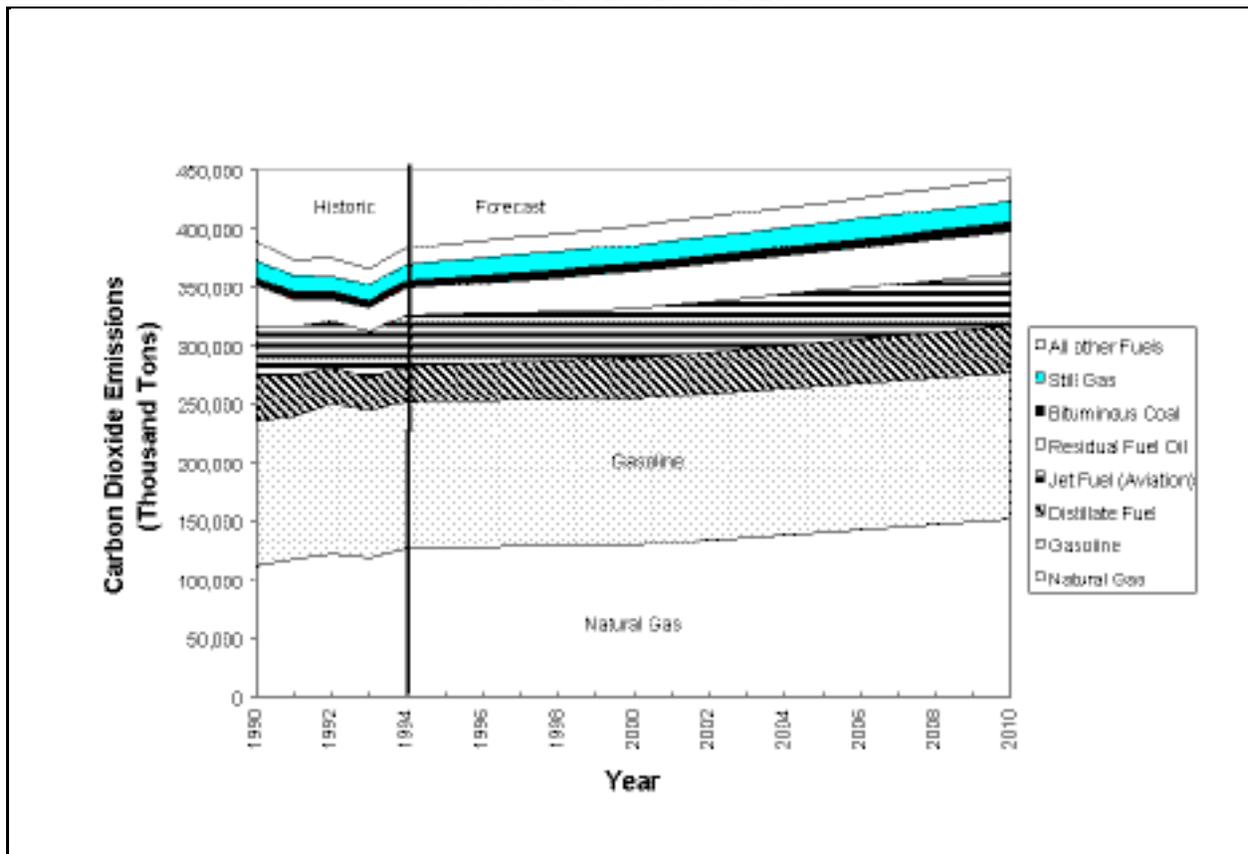
According to the Intergovernmental Panel on Climate Change (IPCC)'s emission inventories guidelines,¹⁵ consumption of fuel in international transport should not be counted in national inventories. At the national level, the U.S. Environmental Protection Agency has also directed states preparing inventories not to include this type of fuel consumption. However, information on disaggregated fuel consumption for national and international transport was unobtainable. This is particularly troublesome in the case of residual fuel oil, which is sold mostly to marine vessels, since, as previously discussed, this fuel has been responsible for a significant portion of the changes in the historical CO₂ emissions in the state. A new guideline being reviewed by the IPCC may require that fuels sold for international transport be included as part of the inventory of the country selling that fuel.

In the future, the Commission should include in its Fuels Report a forecast of some minor fuel consumption categories that have been shown in the historical inventory to be extremely important in determining changes in total CO₂ emissions in the state, including residual fuel oil for marine vessels and distillate fuel oil in sectors other than transportation.

The California Air Resource Board (ARB) mandated the use of a new reformulated gasoline in the state, starting in 1996. The carbon content of this fuel differs from previous gasoline fuels used in the state as the result of an increase in oxygen content and the reduction in the content of aromatic compounds, such as benzene. Representative data on the carbon content and higher heating value

for reformulated gas is needed in order to calculate the emission factor for CO₂. Some preliminary data from a study conducted prior to the actual introduction of reformulated gasoline indicates that the carbon content per gallon goes down and the resulting CO₂ emissions per gallon goes from about 19.6 pounds in conventional gasoline to about 19.0 in reformulated gasoline.¹⁶ However, carbon dioxide emissions per mile travelled may remain the same for both types of gasoline, due to the lower heat of combustion content in reformulated gasoline. The level of uncertainty in the forecast may not warrant a better estimation of CO₂ emissions per unit of energy consumed at this time. This situation will change once historical gasoline consumption is available for 1995 and beyond. In future updates to this inventory, changes in the CO₂ emission factors for reformulated motor gasoline will be determined.

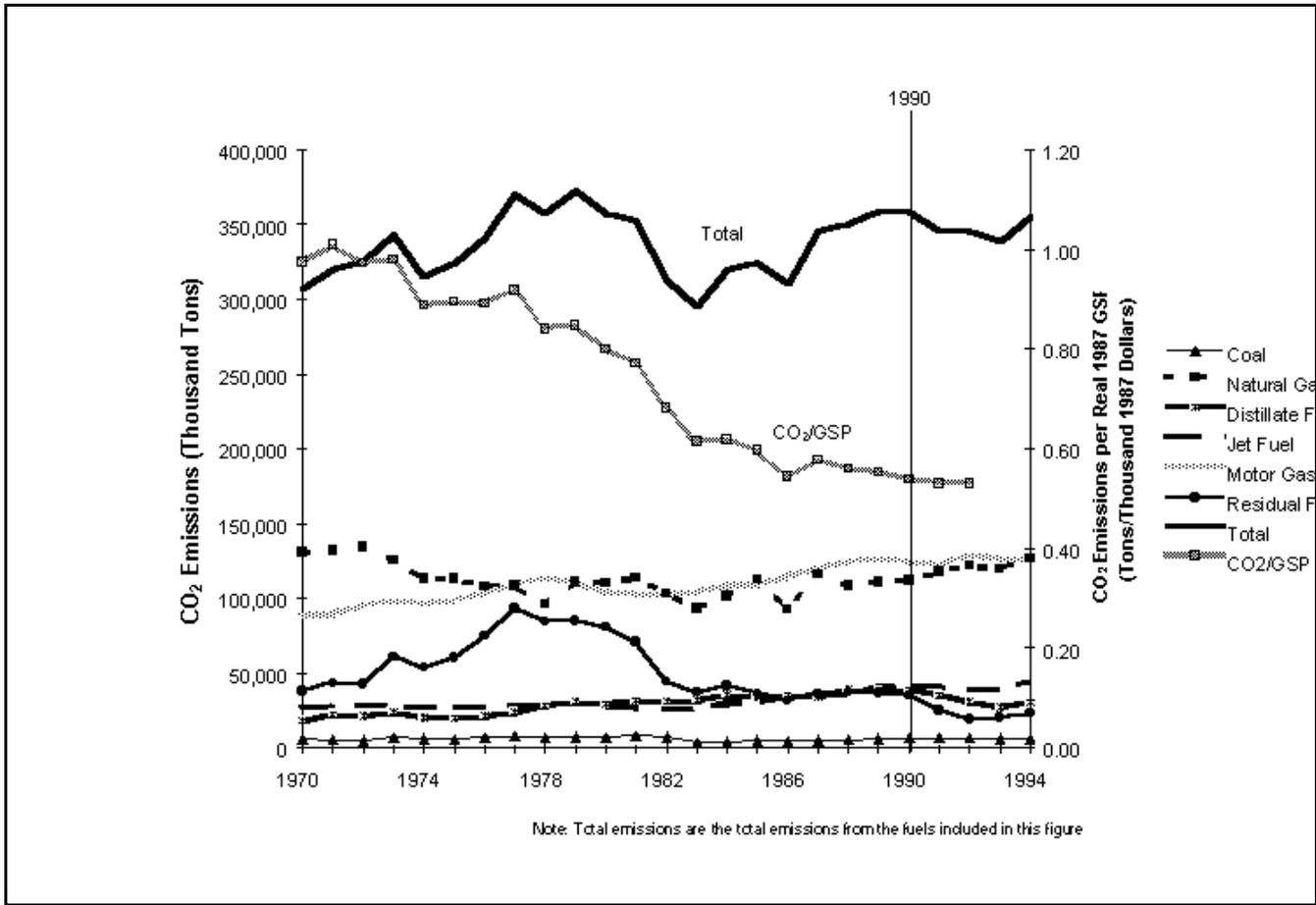
Figure 1-7
Carbon Dioxide Emissions from Combustion of
Fossil Fuels: 1990-2010



The California Integrated Waste Management Board (IWMB) is aggressively pursuing a used-oil recycling program. Future updates to this inventory will use recycling data from the IWMB, which should improve the treatment of lubricant oils.

Finally, as shown in Figure 1-8 carbon dioxide emissions in 1990 were close to the historical peak emissions observed in the late seventies, and therefore, from California's perspective, 1990 is a good baseline year.

Figure 1-8
Carbon Dioxide Emissions by Fuel-Type and per Unit of Gross State Product: 1970-1994



ENDNOTES

1. California Energy Commission, *1995 Fuels Report*, December 1995.
2. Energy Information Center. Historical California Fuel Consumption data in electronic form obtained from <http://www.eia.doe.gov>.
3. California Energy Commission, *1991 Fuels Report*, 1991.
4. Fuel consumption data from EIA are reported on a High Heating Value (HHV) basis; therefore, caution should be exercised when comparing the EIA data with other data sources, which may calculate fuel consumption based on Low Heating Value (LHV).
5. U.S. Department of Commerce, Historical Climatology Series 5-1. Heating Degree Days Weighted by Population. National Climatic Data Center.
6. Stamets, Leigh, California Energy Commission, Longer term statistical analyses do show a correlation between natural gas consumption and heating degree days, personal communication, 1997.
7. Memorandum from Jim Fore to Guido Franco, Fuel Resources Office, California Energy Commission, January 9, 1997.
8. U. S. Environmental Protection Agency, *Methodologies for Estimating Greenhouse Gas Emissions*, second edition, State Workbook, June 1995. Office of Policy, Planning and Evaluation.
9. Energy Information Administration, *Fuel Oil and Kerosene Sales*, 1995. Table 11.
10. Energy Information Administration, *Fuel Oil and Kerosene Sales*, 1995. Table 5.
11. Edison Electric Institute, *1994 Capacity and Generation of Non-Utility Sources of Energy*, November 1995. Pages 26, 27, and 3.
12. Energy Information Administration, *Electric Power Annual 1994*, Volume II. Table 57.
13. Edison Electric Institute, *1994 Capacity and Generation of Non-Utility Sources of Energy*, November 1995. Tables 18 and 19.
14. Gross State Product: New Estimates for 1993-94 and Revised Estimates for 1977-92, Bureau of Economic Analysis, Regional Economic Analysis Division, U.S. Department of Commerce, June 1997.

15. Intergovernmental Panel on Climate Change, Organization for Economic Cooperation and Development, *IPCC Guidelines for National Greenhouse Gas Inventories*, 1994. Paris, France.
16. Personal communication from Tom MacDonald, California Energy Commission.

Chapter 2

GREENHOUSE GAS EMISSIONS FROM PRODUCTION PROCESSES

INTRODUCTION

In addition to being emitted during the combustion of fossil fuels, greenhouse gases are emitted as a by-product of various non-energy related activities. A typical example is the cement producing process, where carbon dioxide is released from limestone during its calcination in cement kilns.

This chapter estimates non-energy related emissions from the following processes: cement production, lime production, and limestone consumption. These three processes were responsible for more than 97 percent of carbon dioxide emissions from production processes in 1990, and most likely will continue to be the dominant sources of CO₂ emissions from production processes in the state.

HISTORICAL EMISSIONS: 1990-1994

Cement Production

Table 2-1 presents the historical CO₂ emissions from cement manufacturing. The amount of carbon dioxide released from cement kilns was calculated assuming that 0.507 tons of carbon dioxide are released for every ton of clinker produced.

Year	Clinker (thousand tons)	CO ₂ Emissions (thousand tons)
1990	9,840	4,989
1991	9,020	4,573
1992	9,480	4,806
1993	8,840	4,482
1994	10,050	5,095

Source: Mineral Yearbook, Metals and Minerals Volume, 1991-1994. Bureau of Mines, U.S. Department of the Interior

Lime Manufacturing

Table 2-2 presents historical emissions from the production of lime in the state, which were calculated assuming that for every ton of lime produced 0.785 tons of carbon dioxide are released to the atmosphere.

Year	Lime (thousand tons)	CO ₂ Emissions (thousand tons)
1990	345	271
1991	307	241
1992	280	220
1993	212	166
1994	223	175

Source: Mineral Yearbook, Metals and Minerals Volume, 1991-1994. Bureau of Mines, U.S. Department of the Interior

Carbon Dioxide Emissions From Limestone Consumption

Table 2-3 presents Carbon Dioxide emissions from Limestone (Calcite and Dolomite) Consumption.

Year	Limestone (thousand tons)	Dolomite (thousand tons)	CO ₂ Emissions (thousand tons)
1990 ^a	20,062	131	8,890
1991	20,062	131	8,890
1992 ^a	19,738	180	8,771
1993	19,738	180	8,771
1994	25,630	229	11,386

Source: Mineral Yearbook, Metals and Minerals Volume, 1991-1994. Bureau of Mines, U.S. Department of the Interior.
^a Limestone consumption prior to 1993 was reported every other year. Therefore, consumption in 1990 and 1992 are based on estimated consumption for 1991 and 1993 respectively.

Carbon dioxide is released to the atmosphere when limestone (calcite and dolomite) is consumed in different manufacturing processes. Approximately 0.44 tons and 0.477 tons of carbon dioxide are produced per ton of calcite and dolomite consumed, respectively.

FORECASTED EMISSIONS: 2000, 2005, 2010

Table 2-4 presents the forecasted CO₂ emissions from cement and lime manufacturing, and limestone consumption. The forecasted emissions were derived using the following assumptions: a) the "Production Indices" (PI) adopted for ER96 for Standard Industrial Classification (SIC) code 3241¹ provides the growth factors for cement production (this SIC code covers establishments primarily engaged in manufacturing hydraulic cement, including portland, natural, masonry, and pozzolana cements); b) the PIC for SIC 3274 provides the same information for lime manufacturing; however, ER 96 does not provide direct forecasting for this SIC code. Since the emissions from this process are relatively minor, future emissions are kept constant and equal to the historical average from 1990 through 1994; and c) limestone consumption was assumed to be directly related to the state production of limestone and therefore related to SIC 1240.²

	2000	2005	2010
Cement Production	5,082	7,683	8,163
Lime Manufacturing	215	215	215
Limestone Consumption	12,333	17,176	18,234

CONCLUSIONS AND RECOMMENDATIONS

Carbon dioxide emissions from cement production and limestone consumption have been increasing with time, and this trend is continued in the forecast period covered by this analysis. By the year 2000, carbon dioxide emissions from cement production and lime manufacturing will increase by about 60 and 100 percent, respectively, as compared to their 1990 emission levels.

END NOTES

1. "Production Indices" (PI) are in terms of physical units, e.g., tons of cement. The PI multiplied by the base year production gives the estimated future production. These indices are in Table 6-4 in California Energy Demand: 1995-2015, Volume II: Electricity Demand Forecasting Methods. Staff Report. California Energy Commission, July 1995.
2. SIC code 1240 covers industries engaged in mining or quarrying crushed and broken limestone.

Chapter 3

METHANE EMISSIONS FROM THE OIL AND NATURAL GAS SYSTEMS

INTRODUCTION

This section presents the estimated historical and forecasted methane emissions from oil and natural gas systems in California. The methods used in this section to estimate emissions are described in *1990 California Greenhouse Gas Emissions Inventory, Technical Appendices, Chapter 3*; this section only discusses the minor modifications to the methods needed to estimate historical and forecasted emissions. In addition, this section presents only a summary of the final results and some intermediate calculations that may be needed to understand changes to the methods. The electronic files containing the raw data, calculations, and full explanation of the assumptions used are available upon request.

HISTORICAL EMISSIONS: 1990-1995

Methane Emissions From The Oil System

Methane emissions from the oil system, presented in Table 3-1, are relatively minor. For this reason, the calculations are based on the order-of-magnitude emission factors included in the EPA Workbook¹ and highly aggregated activity data, such as the amount of crude oil tankered to California from out-of-state sources. The data shows a decrease in the amount of methane released to the atmosphere from 1990 to 1995. This reduction in methane emissions

	1990	1991	1992	1993	1994	1995
Oil Production	6,282	6,282	6,236	6,156	6,172	6,291
Oil transportation (tankered)	1,815	1,748	1,676	1,657	1,745	1,619
Oil Refining	3,509	3,444	3,347	3,384	3,353	3,236
Storage Tanks	629	617	600	606	601	580
TOTAL	12,236	12,091	11,860	11,804	11,870	11,727

Note: The amount of crude oil tankered and processed in California was obtained from the PIIRA data base². The information on crude oil production came from the Annual Report of the State Oil&Gas Supervisors³.

from 1990 to 1995 from oil production, refining, and storage is reasonable because of a decrease in the amount of crude oil transported, stored and processed in California and air quality rules and regulations aimed at reducing fugitive emissions of non-methane volatile organic compounds (NMVOCs), which also reduce fugitive methane emissions. However, because of the relatively high level of uncertainty in the emission factors used in the calculations, the decreasing trend in emissions should be viewed with caution. Further refinement of the calculations to include the impact from these rules and regulations is not warranted at this time, since this is minor source of methane emissions.

Methane Emissions From The Natural Gas System

Table 3-2 presents the estimated methane emissions from the natural gas system in California. A few simplifying assumptions are made due to the lack of reliable new data. For example, the numbers of heaters, separators, and dehydrators were held constant with the numbers estimated for 1990.

		1990	1991	1992	1993	1994
Field Production		20,098	20,083	19,627	19,364	19,402
Processing		1,653	1,592	1,583	1,592	1,529
Inj/Withdrawal		1,399	1,280	1,592	1,427	1,506
Transmission		32,130	31,403	32,458	35,273	34,855
Distribution		43,520	44,301	44,809	45,235	45,445
Engine Exhaust	Production	5,592	7,232	6,481	4,142	4,518
	Processing	2,232	2,190	2,246	1,990	1,792
	STD ^a IC eng.	7,118	7,182	5,551	4,783	3,819
	STD Gas Turbines	74	56	48	32	53
TOTAL		113,815	115,321	114,395	113,839	112,918

^a STD = storage, transmissions and distribution

FORECASTED EMISSIONS: 1995-2010

Methane Emissions From The Oil System

Methane emissions from the state's oil system (Table 3-3) were estimated using a simple linear extrapolation from historical data. The extrapolation suggests a minor decrease in emissions with time, due to the apparent reductions in the amount of crude oil produced in California and processed in state refineries. A reduction in emissions seems plausible, even if there is an increase of crude oil produced or processed in California, since some existing and new air quality rules and regulations will also result in reducing fugitive methane emissions, as mentioned previously.

Year	Emissions (short tons)
2000	11,232
2005	10,766
2010	10,300

Note: Linear extrapolations from historical estimated emissions included in Table 3-1.

Methane Emissions From The Natural Gas System

Methane emissions from the natural gas system were forecasted from 1994, the most recent year with historical data. Emissions were calculated using two parameters:

1) the Domestic Provision Ratio (DPR), the ratio of forecasted natural gas production in California in a given year to the same production during 1994; and, 2) the Total Consumption Ratio (TCR), or the ratio of forecasted fuel consumption in a given year to 1994 state natural gas consumption. Table 3-4 presents the DPR/TCRs and data used for their derivations.

The DPR was used to forecast emissions originating from activities that are related to natural gas production in the state. The TCR was used to forecast emissions from activities related to the total natural gas consumed in the state. Table 3-5 presents the forecasted methane emissions from the California natural gas system. The column "Scale Factor" in this table indicates what factor was used to scale-up future emissions from the 1994 base year.

Table 3-4				
Domestic Provision Ratio (DPR)				
Total Consumption Ratio (TCR)				
	1994	2000	2005	2010
	Base year			
Nat. gas production (TCF/year)	0.298	0.277	0.300	0.440
Total Consumption(MMCF/day)	5,817	5,940	6,426	6,928
DPR		0.93	1.01	1.47
TCR		1.02	1.10	1.19
<i>Note: Production and Consumption forecasted data for 2,000; 2005; and 2010 comes from the 1995 Natural Gas Market Outlook⁴ publication.</i>				

CONCLUSIONS AND RECOMMENDATIONS

Methane emissions from the natural gas system are an order of magnitude higher than emissions from California's oil system; however, as shown in the 1990 Inventory, emissions from the natural gas system, although not a major source of methane in California, are significant. Several improvements to the estimated emissions from both the oil and gas systems can still be implemented to obtain more realistic estimates of emissions.

To improve emissions estimates for the oil system, the emission inventory system developed by the California Air Resources Board (ARB) to estimate NMVOC could be used, together with information on the emission profile typical of fugitive emissions for this sector, to obtain the ratio of methane to NMVOC.

For natural gas, further estimates should rely on a joint study by EPA and the Gas Research Institute (GRI) to improve the estimation of methane emissions from the U.S. natural gas system,⁵ which is soon to be released. This study indicates that previous estimates at the national level were underestimating emissions by approximately a factor of two. Most of this underestimation is due principally to incorrect estimates of fugitive emissions from gathering, transmission, and distribution pipelines based on studies done in California, which the new study found much lower than for leaks from typical cast iron pipes found in other states. For this reason, the new EPA/GRI methods should not significantly change the estimated emissions for California. However, for consistency, future California inventory updates will include changes to accommodate new information developed during the EPA/GRI study that may be relevant for the state, and other changes approved by the IPPC.

Table 3-5
Forecasted Methane Emissions from the Natural Gas System
(Short Tons)

		Scale Factor	1994	2000	2005	2010
Field Production		DPR	19,402	18,037	19,520	28,604
Processing		DPR	1,529	1,422	1,538	2,254
Inj/Withdrawal		TCR	1,506	1,538	1,664	1,794
Transmission		TCR	34,855	35,590	38,502	41,509
Distribution		TCR	45,445	46,403	50,200	54,122
Engine Exhaust	Production	DPR	4,518	4,200	4,546	6,661
	Processing	DPR	1,792	1,666	1,803	2,642
	STD ^a I.C. engines	TCR	3,819	3,899	4,218	4,548
	STD gas turbines	TCR	53	54	58	63
TOTAL			112,918	112,809	122,050	142,197
^a STD = storage, transmission, and distribution						

ENDNOTES

1. U.S. Environmental Protection Agency, *State Workbook, Methodologies for Estimating Greenhouse Gas Emissions*, June 1997. Second Edition. Office of Policy, Planning, and Evaluation. State Outreach Program.
2. California Energy Commission, Petroleum Industry Information Reporting Act (PIIRA) Database.
3. California Department of Conservation, Division of Oil and Gas, Annual Report of the State Oil & Gas Supervisors.
4. California Energy Commission, 1995 Natural Gas Outlook, October 1995.
5. Energy Information Administration, *Emissions of Greenhouse Gases in the United States, 1995*, October 1996. p. 23.

Chapter 4

METHANE EMISSIONS FROM COAL MINING

INTRODUCTION

Methane and coal are formed together during coalification, a process in which vegetation is converted by geological and biological forces into coal. Methane emissions from coal mines are heavily dependent on the geological characteristics and history of the coalbed. Factors such as coal rank (which relates to heating value and sulfur content), depth and permeability affect the amount and distribution of methane in the coalbed and surrounding strata, which in turn determine the quantity and rate of methane release during mining. In addition, the type (underground or surface mining) and rate of mining, as well as the geometry of the mine, may affect methane release.

Because methane creates a safety hazard in underground mines, substantial research has been done to determine ways of predicting and controlling its emissions into mine working areas. However, the same can not be said for surface mining (also called strip mining), in which methane emissions are released directly into the atmosphere, and do not cause a safety hazard.

As pressure is reduced during mining, methane is released from the seam being mined and from the strata around it. In addition to the rank and depth of the coal, the amount of disturbance to the surrounding strata as a result of mining activities may also affect methane emissions. The amount of methane released by mining activities can exceed the amount of gas contained in the mined coal by as much as 3 to 9 times.¹

Coal is produced in California by surface mining only and associated methane emissions are not required to be monitored. Thus, few measurements are currently available on surface mine methane emissions. The U.S. EPA's Office of Research and Development has recently undertaken a field measurement study of methane emissions from surface mines, but that information is not available at this time.¹

Some methane remains in the coal after it is removed from the mine, and it can be emitted over the following days as the coal is transported, processed and stored. The greatest releases occur when coal is crushed, sized, and dried in preparation for industrial or utility uses.

METHODOLOGY

To estimate the emissions from coal mining, the EPA suggests the following methodology:¹

- Obtain the annual coal production from surface and underground mines.
- Calculate the range of possible methane emissions from underground mines.
- Calculate the range of possible methane emissions from surface mines.
- Calculate the range of possible post-coal mining emissions.
- Calculate the range of possible total coal mining emissions.
- Calculate the average total coal mining emissions.
- Calculate the total methane recovered for energy purposes.
- Subtract the recovered methane from the total produced.

The EPA's emission coefficients for methane from both mining and post-mining operations are presented in Table 4-1.

Table 4-1 Methane Emission Coefficient U.S. Environmental Protection Agency		
	Emission Coefficient (cubic feet of methane/ton of coal)	
	Low	High
Underground Mines	50	150
Surface Mines	3	10
Post-Mining	10	16
Underground		
Surface	0.8	1.3

CALIFORNIA EMISSION ESTIMATES: 1990-2010

The total methane emissions from coal mining for California in 1990 is 9.52 million tons, as shown in Table 4-2. The data for this table was taken from the Quarterly Coal Report for October-November 1990.² This report shows the annual totals for 1990, as well as previous years. It also shows that California has only one active coal mine. Due to this, and the fact that methane emissions from this source are not significant in California, staff has chosen to assume that the methane emissions of future years will not be significantly different from those of 1990.

Table 4-2
Methane Emissions from Coal Mining Operations in California
1990-2010

	Coal Production (Million Tons)	Emission Coefficients (Cubic Feet/Ton)		Methane Emitted (Million Cubic Feet)	
		Low	High	Low	High
Underground Mines	0	50	150	0	0
Surface Mines	0.061	3	10	0.183	0.61
Post-Mining (Underground)	0	10	16	0	0
Post-Mining (Surface)	0.061	0.8	1.3	.0488	.0793
Subtotals				0.232	0.690
Averages				0.461	
Methane Recovery				0	
Total Methane (Million Cubic Feet)				0.461	
Total Methane (Tons)				9.52	
see end note ²					
see end note ¹					
<i>The conversion factor from million cubic feet of methane to tons of methane is 20.66 ton/mmCF.</i>					

CONCLUSIONS AND RECOMMENDATIONS

As described in the introduction, there are significant uncertainties associated with this simplistic approach to calculating methane emissions from coal mining. The methodology uses an average emission factor (for both direct mining and post-mining impacts) based on limited data for the majority of the Western States as well as data from other countries (England and Canada). However, since this is not a large source of methane emissions for California, the relative accuracy of the methodology used is not a major concern.

ENDNOTES

1. U.S. Environmental Protection Agency, *State Workbook, Methodologies for Estimating Greenhouse Gas Emissions*, June 1995. Second edition, Office of Policy, Planning and Evaluation, State and Local Outreach Program.
2. U.S. Department of Energy, *State Coal Profiles*, January 1994. Energy Information Administration, Office of Coal, Nuclear, Electric and Alternative Fuels.

Chapter 5

METHANE EMISSIONS FROM MUNICIPAL SOLID WASTE LANDFILLS

INTRODUCTION

Landfill gas (LFG) is formed as a result of the decomposition of organic waste in an anaerobic environment. It contains primarily methane (CH₄) and carbon dioxide (CO₂). The landfill gas is either emitted directly to the atmosphere or is recovered and combusted. This chapter covers only the methane portion of landfill gas emissions based on earlier work done by the California Energy Commission (Energy Commission) in conjunction with the California Integrated Waste Management Board (CIWMB). That work generally involved researching records at the CIWMB and estimating 1990 waste in place figures for active California landfills.¹ This same analysis was used to estimate waste in place tonnages for 1991 through 1995. The method for estimating methane emissions from landfills involves first determining the tonnage of waste in place in a given year, and then estimate the methane recovery that will likely take place in that year.

HISTORIC EMISSIONS: 1990 AND 1995

Table 5-1, see next page, is based on estimates made of the waste in place in 1990 in California landfills, and the known waste disposal rates at these landfills between 1990 and 1995.²

FORECAST EMISSIONS: 2000, 2005, 2010

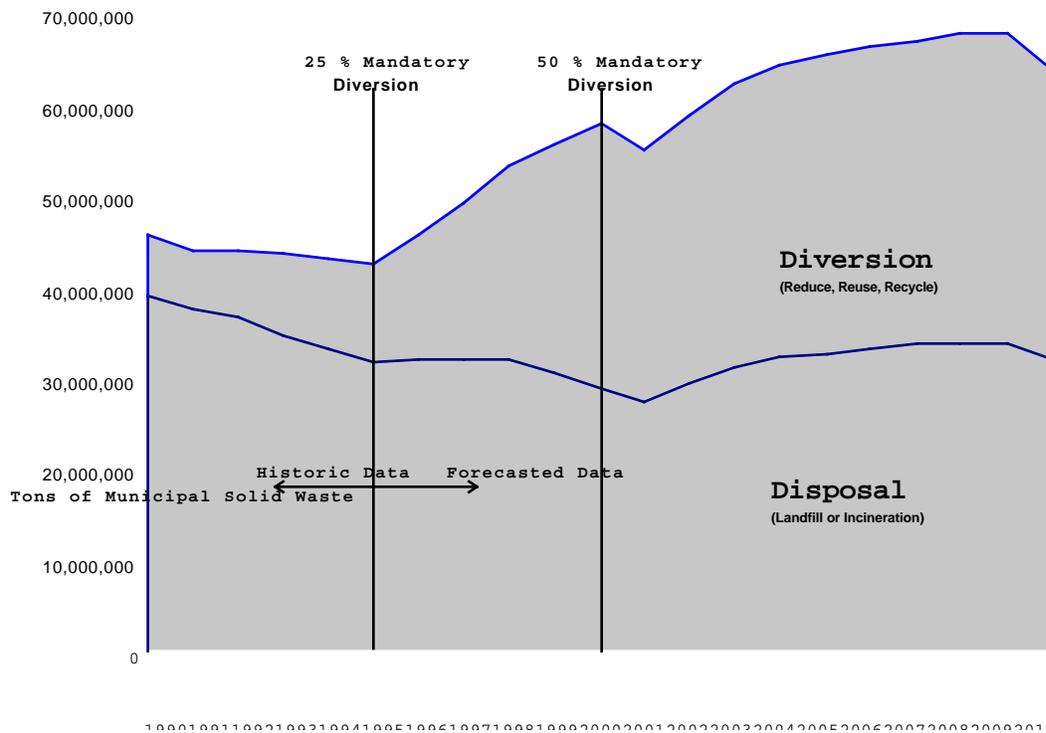
Assumptions For Forecasting The California Waste Stream

According to the California Integrated Waste Management Act of 1989, by 1995 California cities and counties are to achieve a 25 percent landfill diversion rate (which has been achieved)³ and by 2000 they are to achieve a 50 percent landfill diversion rate. These diversion rates were incorporated into the forecast shown in Figure 5-1, by assuming that reasonable progress would be made from 1995 to 2000. In other words, we assumed that the 25 percent diversion rate would increase by 5 percent a year until 2000 when it would reach 50 percent diversion. From 2000 to 2010, the 50 percent diversion rate is held constant while population and the economy continue to change. The diversion amount (actual tons) is

Table 5-1
Methane Emissions from Landfills
1990 thru 1995

Factor	1990	1991	1992	1993	1994	1995
Waste in place (Million Tons of MSW) ¹	914	953	991	1,027	1,062	1,095
Large Landfills (86%) (Million Tons of MSW)	786	820	852	883	913	942
Small Landfills (14%) (Million Tons of MSW)	128	133	139	144	149	153
Methane Emissions large landfills (Tons of Methane)	1,275,209	1,316,492	1,356,228	1,395,066	1,431,747	1,466,893
Methane Emissions(Tons of Methane) Small Landfills	266,114	277,455	288,370	299,040	309,116	318,771
Methane Emissions Industrial Landfills (Tons of Methane) (7% of both small and large landfills) ⁴	107,893	111,576	115,122	118,587	121,860	124,996
Subtotal (Tons of Methane) (gross Methane Generated)	1,649,216	1,705,523	1,759,720	1,812,693	1,862,723	1,910,661
Landfill gas Recovery (Tons of Methane)	333,684	327,038	307,684	301,038	287,747	275,038
Landfill gas Oxidation (10% reduction) (Tons of Methane) ³	131,553	137,849	145,204	151,165	157,498	163,562
Total Methane Emissions from Landfills (Tons of Methane)	1,183,979	1,240,637	1,306,832	1,360,489	1,417,478	1,521,403

**Figure 5-1
California Municipal Solid Waste Stream Forecast**



calculated based on the 1990 municipal solid waste (MSW) stream, with allowances for population⁵ and changes in the local economy⁶ including employment, retail sales and home construction.

Forecasting Landfill Gas Recovery

Federal and California Regulations Affecting Landfill Gas Emissions

In March of 1996, the United States Environmental Protection Agency (EPA) issued final rules regulating MSW landfill gas emissions in their New Source Performance Standards (NSPS) and Emission Guidelines (EG) for both new and existing landfills. These rules require affected landfills with design capacities of at least 2.5 megagrams (Mg) or 2.5 million cubic meters (cm²) to file a design capacity report. Landfills over this size are required to calculate the non-methane

organic compound (NMOC) emissions. Those that emit more than 50 Mg/yr (55 tons/yr) of NMOC are required to install controls to 98 percent effectiveness by weight.⁷ According to EPA,⁸ the new rules will only affect 4 percent of the largest existing landfills and 5 percent of all proposed landfills nationwide. Concurrently with the final rules, EPA started the Landfill Methane Outreach Program. The program is a public-private sector initiative directed at reducing barriers to landfill gas recovery and use through coordinated efforts of states, electric utilities, developers, equipment manufacturers, financial institutions, landfill owner/operators, and consultants. The program specifically encourages landfill owner/operators to install landfill gas recovery systems by identifying the potential to produce energy and by overcoming regulatory barriers at the federal, state and local levels.

Local air district rules and regulations in California are not, for the most part, as restrictive on landfill gas emissions as the new EPA rule. For example, the Bay Area Air Quality Management District (BAAQMD) does not regulate landfills under 1 million tons of waste in place, does not require a landfill gas collection system to be installed, and restricts only methane emissions to 1,000 ppm @ 3% O₂.⁹ The San Joaquin Valley Unified Air Pollution Control District is similar to the BAAQMD, except that they restrict total organic compounds (TOC) to 1,000 ppm @ 3% O₂.¹⁰ However, the South Coast Air Quality Management District (SCAQMD) has existing rules that force landfill operators to install landfill gas collection systems and restrict TOC emissions to an average of 50 ppm with a maximum of 500 ppm @ 3% O₂.¹¹ In addition to their current rules, SCAQMD is currently in the process of increasing the emission controls on landfills for volatile organic compounds (VOC). They predict that through these measures they can reduce VOC emissions by 1.0 tons per day by 2006 and extending out through 2010.¹² It is not unusual for other California air districts to follow the example of the SCAQMD, as they try to meet EPA ambient air quality standards.

Landfill Gas Recovery and Control Trends in the United States and California

The technology has become a recognized control measure for methane and NMOC, as well as an economically feasible energy source. The trends for landfill gas recovery in the United States from 1984 to 1994 suggest that the effectiveness and reliability of the technology has developed to the point where smaller landfills are willing to employ them for purely economic benefit. However, growth in the number of planned or existing landfill gas recovery systems in the western United States has not been as high as in other areas of the United States. This suggests that the economic motives for landfill gas recovery installation have not been favorable in the western United States. Therefore, it is reasonable to assume that the overall trend of increased new and planned landfill gas recovery systems for the United States will be higher than that of California. In 1994, there were 128 landfill gas-to-energy facilities operational plus 79 more which were planned to begin construction, for a total of 212 in the United States. Of the 212

facilities in the United States, 56 were located in California (approximately 26 percent, the largest portion of any other state), 42 were operational and 14 were planned to begin construction.

There are at least two new regional landfills and several municipal landfills being proposed for California. New landfills must control landfill gas mitigation under federal and state law, and are difficult to site due to the stringent regulations (federal, state and local) and adverse public opinion. The two regional landfills are being proposed on local Native American property, so that they would only answer to the federal laws, not state and local.¹³ Therefore, these regional landfills have a much higher probability of being developed in the near future.

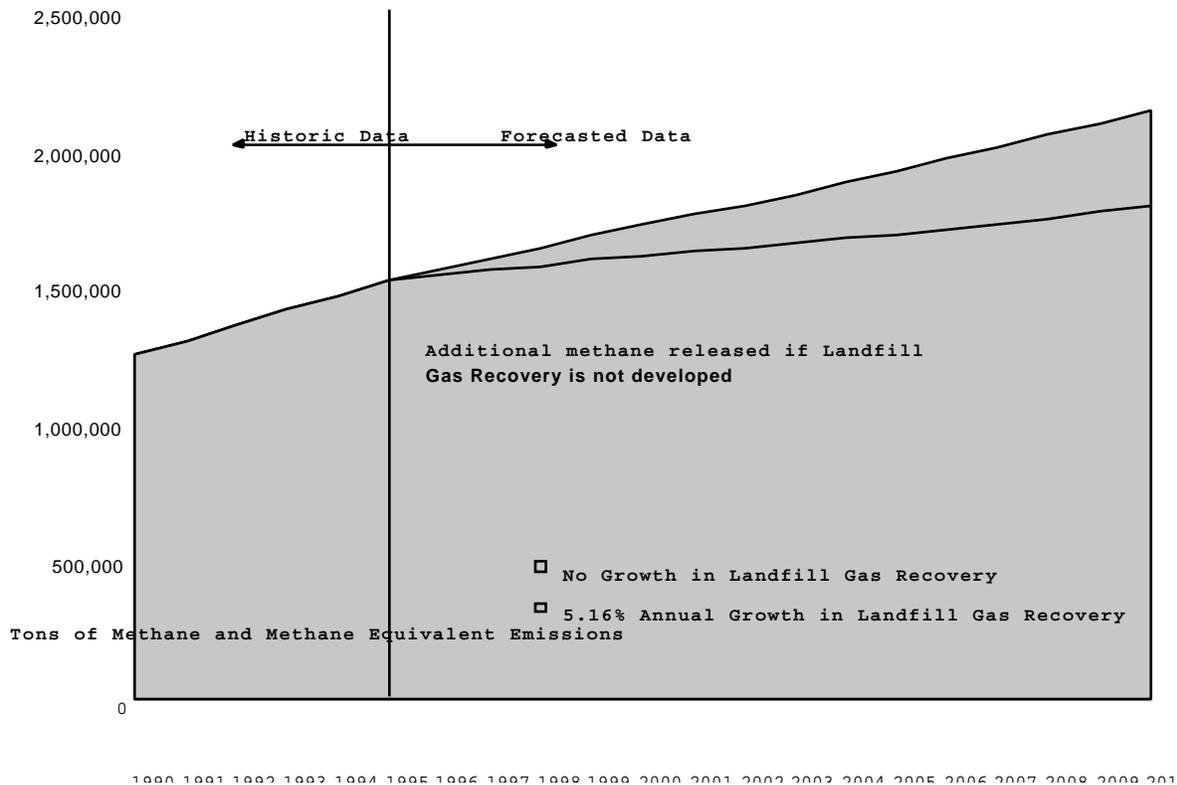
Assumptions for Forecasting Landfill Gas Recovery

We assumed that methane recovery would increase due to EPA and local air district rules and regulations, improvement in the technology, and favorable economic conditions. In 1990, 51 landfills did some type of LFG recovery,¹⁴ 42 of them were, by EPA definition, large (over 1 million tons of MSW on site). By 1995, the number of landfills with LFG recovery was 42. So, from 1990 to 1995 we assumed a steady decrease in LFG recovery from 51 to 42. From 1995 to 2010 we assumed that the remaining large landfills (there are 95 large landfills currently active in California) will have LFG recovery capabilities similar to those already existing. We also assumed that a proportional amount of small landfills (less than 1 million ton on site) would also add LFG recovery by 2010. This would increase their number from 9 to 20, for a total of 114 landfills with LFG recovery by 2010. This worked out to roughly a 5.16 percent increase per year in LFG recovered assuming average recovery rates and no improvements in recovery technology. Comparatively, the United States, as a whole, has increased LFG recovery approximately 14.7 percent per year from 1984 to 1994, and is expected to increase similarly in the coming years.¹⁵ Therefore, a 5.16 percent increase per year seems reasonable for California.

In an effort to capture a range of possibilities, an alternative future of no new LFG recovery systems in California was assumed. It was also assumed that those landfills that had LFG recovery would continue with that recovery through 2010. However, to compare the total environmental impacts of methane and CO₂¹⁶ from LFG, we used a conversion factor for carbon dioxide to methane of 21 CO₂/CH₄.¹⁷ Using this conversion factor, we graphed (Figure 5-2) the methane equivalent emission of both combusted and release LFG for the two possible futures of LFG recovery. For example, one option for LFG recovery is that all large landfills will install LFG recovery systems by 2010 (see discussion above). To calculate the methane-equivalent of this option, four things were considered: the methane released (not recovered) in LFG emitted from landfills; the CO₂ released in LFG emitted from landfills; the CO₂ emitted from the LFG that was recovered from landfills; and the CO₂ credit for displacing the generation of electric power by utility fossil fuel power plants.¹⁸

Figure 5-2 shows the effects of the methane emissions from landfills of these two possible futures of landfill gas recovery in California.

**Figure 5-2
Effects of Methane Recovery Futures
ON METHANE EMISSIONS FROM CALIFORNIA LANDFILLS**



Resulting Forecast for 2000, 2005 and 2010

Table 5-2 incorporates the assumptions for waste generation and recycling, and the growth in methane recovery discussed above. Table 5-2 shows that the future diversion and methane recovery might eventually reduce the methane emissions from California landfills below the 1992 levels by 2010. Based on these findings, it is our opinion that the current trends in methane recovery and recycling significantly reduce methane emissions from landfills in California. However, these are gross estimations from which concrete conclusions can not be drawn.

Table 5-2 Methane Emissions from Landfills 2000, 2005, 2010			
Factor	2000	2005	2010
Waste in place (Million Tons of MSW)	1,253	1,402	1,569
Large Landfills (86%) (Million Tons of MSW)	1,078	1,205	1,349
Small Landfills (14%) (Million Tons of MSW)	175	196	220
Methane Emissions large landfills (Tons of Methane)	1,634,136	1,792,005	1,968,945
Methane Emissions(Tons of Methane) Small Landfills	364,715	408,082	456,689
Methane Emissions Industrial Landfills (Tons of Methane) (7% of small + large) ³	139,920	154,006	169,794
Subtotal (Tons of Methane) (gross Methane Generated)	2,138,771	2,354,094	2,595,429
Landfill gas Recovery (Tons of Methane)	438,266	595,431	752,596
Landfill gas Oxidation (10% reduction) (Tons of Methane) ³	170,050	175,866	184,283
Total Methane Emissions from Landfills (Tons of Methane)	1,530,454	1,582,796	1,658,550

CONCLUSIONS AND RECOMMENDATIONS

Depending on the assumptions regarding methane recovery and diversion that are made, annual methane emissions from landfills could increase by as much as 250,000 tons or more. This is about equal to the emissions of the next largest source (manure management, see Chapter 7 of this appendix). As long as methane recovery continues to be installed as a method of emissions control at large landfills, and the current diversion requirements are satisfied, the methane emissions from landfills may be controlled to reasonable levels by 2010.

ENDNOTES

1. California Energy Commission, *Inventory and Analysis of California Municipal Solid Waste Landfills*. March 1996. Draft.
2. California Integrated Waste Management Board, *Toward Ensuring Adequate Landfill Capacity*, April 1995. Draft.
3. California Integrated Waste Management Board, *Integrated Waste Management Board 1995 Annual Report, The Quiet Revolution in Waste Management*, April 1996.
4. California Energy Commission, *California Greenhouse Gas Emission Inventory, 1990*, September 1996. Technical Appendix, Chapter 5.
5. California Department of Finance, *Projected total population of California counties: 1990 to 2040*, May 1993.
6. UCLA-BFP Forecast, *The California Long-Term Outlook: Projections to 2010*, September 1996. Table 6. California Nondurables Manufacturing Employment, Leather component (SIC31).
7. United States Environmental Protection Agency, *Clean Air Act Amendments, March 1996*, March 1996a. 40 CFR PARTS 9, 51, 52, AND 60, Standards of Performance for New Stationary Sources and Guidelines for Control of Existing Sources: Municipal Solid Waste Landfills.
8. United States Environmental Protection Agency, *EPA Announces Rule Significantly Reduces SMOG and Cancer-Causing Toxics from Landfills*, March 1996b. Carol M. Browner, EPA Administrator.
9. Bay Area Air Quality Management District, *Regulation 834, Waste Disposal Sites*, June 1994. Regulates landfill gas emissions for landfills with 1,000,000 tons or more of waste in place.
10. San Joaquin Valley Unified Air Pollution Control District, *Regulation 4642 Solid Waste Disposal Sites*, July 1995. Regulates the TOC emissions from a landfill to 1000 ppmv @ 3% O₂.
11. South Coast Air Quality Management District, *Regulation 1150.1, 1150.2*, 1985. Regulate the total organic compounds (TOC emissions from a landfill, either operational or closed, to no more than 500 ppm @ 15% O₂.

12. South Coast Air Quality Management District, *Draft 1997 Air Quality Management Plan*, August 1996.
13. Mikles, James, *The Sacramento Bee*, January 1997. p. B1. Tribe Facing Opposition to Plan to Build Landfill.
14. Governmental Advisory Associates, *1989-1990 Methane Recovery Landfill Yearbook*, August 1993.
15. Government Advisory Associates, *1994-1995 Methane Recovery Landfill Yearbook*, September 1994.
16. Recall that landfill gas is 50 percent methane and 50 percent CO₂.
17. Energy Information Administration, *Emissions of Greenhouse Gases in the United States 1995*, October 1996. Energy Information Administration, Office of Integrated Analysis and Forecasting.
18. Based on an analysis by CEC staff of filings at the Department of Energy on the use of utility (SCE, PG&E and SDG&E) fossil fuel fired power plants from 1984 to 1995, the most appropriate carbon credit for displacing utility generate power is 149 metric tons of carbon equivalent per gigawatt-hour.

Chapter 6

METHANE EMISSIONS FROM DOMESTICATED ANIMALS

INTRODUCTION

Methane is a natural byproduct of animal digestion. During digestion, methane is produced through a process referred to as enteric fermentation, in which microbes that reside in animal digestive systems break down food consumed by the animal.¹ We will discuss the historic and forecasted methane emissions from domesticated animals in California, focusing on ruminants² (i.e., cattle, sheep and goats). For a discussion of methane emissions from manure management systems, which will not be discussed here, the reader is referred to Chapter 7 of the 1990 Inventory.³

HISTORIC EMISSIONS: 1990 TO 1994

The historic methane emissions for domesticated animals presented in Table 6-1 for 1990 to 1994, are based on animal population data from the California Department of Food and Agriculture⁴ and methane emission factors prepared by the United States Environmental Protection Agency.⁵ The data for 1995 was not available at the time of this writing. Both the population of domesticated animals and the related methane emissions remain relatively constant during this time period. The methane emissions from the cattle population are clearly the overwhelming component, constituting about 97 percent of any annual methane emissions from domesticated animals.

**Table 6-1
Methane Emissions from Domesticated Animals**

Animal Type	Methane Emissions and Associated Populations				
	1990	1991	1992	1993	1994
	(tons of CH ₄ , 1,000 Head)	(tons of CH ₄ , 1,000 Head)	(tons of CH ₄ , 1,000 Head)	(tons of CH ₄ , 1,000 Head)	(tons of CH ₄ , 1000 Head)
Mature Dairy Cows	146,500 1,115	151,000 1,150	152,500 1,160	153,500 1,170	156,000 1190
Mature Beef Cows	71,000 935	67,000 880	64,500 850	62,500 820	63,000 830
Replacement Dairy Cows	35,500 525	36,000 535	36,500 540	37,500 560	40,500 600
Replacement Beef Cows	11,000 155	10,500 145	10,000 140	10,000 140	10,000 140
Weanling System (Calves under 500 lbs)	26,500 1,020	26,000 1,015	24,000 920	24,000 930	25,500 980
Yearling System (Other Heifers)	10,000 195	9,500 185	10,000 190	9,000 170	8,500 160
Bulls and Steers	94,000 855	76,000 690	77,000 700	78,000 710	71,500 650
Sheep	9,000 1,000	9,000 1,015	9,000 995	8,000 895	7,500 840
Hogs & Pigs	320 195	355 215	415 250	395 240	395 240
Horses	2,660 134	2,570 130	2,475 125	2,380 120	2,285 115
Goats	175 32	180 33	185 34	190 35	195 36
Mules & Asses	75 3	75 3	80 3	80 3	85 3
Total Methane Emissions (tons)	406,500	388,000	386,000	385,500	385,500

FORECAST EMISSIONS: 1995 TO 2010

A forecast for domesticated animal populations was not available in preparing this report. A forecast for the overall agriculture sector⁶ predicts no significant change in population from 1985 through 2010. Therefore, we assume that the average domestic animal population which existed from 1985 through 1994 will continue through 2010. This average and the resulting methane emissions are presented in Table 6-2. Not surprisingly, emissions from cattle comprise the clear majority of methane emissions (97 percent) from domesticated animals.

Table 6-2 Average Annual Methane Emissions from Domesticated Animals for 1995, 2000, 2005 and 2010		
Animal Type	Population	Methane Emissions
	(1,000 Head)	(tons CH₄)
Mature Dairy Cows	1,109	145,500
Mature Beef Cows	912	69,500
Replacement Dairy Cows	515	34,500
Replacement Beef Cows	154	11,000
Weanling System (Calves under 500 lbs)	1,018	26,500
Yearling System (Other Heifers)	186	10,000
Bulls and Steers	806	88,500
Sheep	977	8,500
Hogs & Pigs	161	265
Horses	137	2,710
Goats	31	170
Mules & Asses	3	75
Total		397,000

CONCLUSIONS AND RECOMMENDATIONS

The major historic and likely future producers of the methane emissions are cattle, and more specifically, Mature Dairy Cows. Cattle produce 97 percent of the methane emissions from domesticated animals, while Mature Dairy Cows produce 37 percent of the total emissions. Therefore, reduction measures for methane emissions from domesticated animals should focus on Mature Dairy Cows and the cattle industry in general. For the purposes of methane emission control, areas of research should include feed modification that would produce less gas, such as adding poultry manure to cattle feed, or population control by acts of legislation, such as Pennsylvania's Nutrient Management Act of 1993.⁷ The Act calls for farms with more than 1,000 pounds of animals (approximately two cows) per acre to draft a plan that will identify the best management practices that prevent nutrient releases to the environment.

ENDNOTES

1. California Energy Commission, *California Greenhouse Gas Emission Inventory, 1990*. September 1996. Technical Appendix, Chapter 6.
2. Ruminants are animals that possess a rumen, or large "fore-stomach," in which a significant amount of methane producing fermentation occurs.
3. California Energy Commission, *California Greenhouse Gas Emission Inventory, 1990*, September, 1996. Technical Appendix, Chapter 7
4. California Department of Food and Agriculture, *California Agricultural Statistics, 1993*, November 1994. Compiled by Agricultural Statistics Services.
5. United States Environmental Protection Agency, *State Workbook, Methodologies for Estimating Greenhouse Gas Emissions, second edition*, June 1995. EPA Office of Policy, Planning and Evaluation, State and Local Outreach Program.
6. UCLA-BFP Forecast, *The California Long-Term Outlook: Projections to 2010*, September 1996. Table 6. California Nondurables Manufacturing Employment, Leather component (SIC31).
7. Pelley, Janet, *Environmental Science and Technology*, November 1996. vol. 30, p. 529A. States tackle animal waste problem to improve water quality.

Chapter 7

METHANE EMISSIONS FROM MANURE MANAGEMENT

INTRODUCTION

When animal manure decomposes in an anaerobic (oxygen free) environment, decomposition of the organic material in the manure produces methane. The way in which the manure is managed is the most important factor affecting the amount of methane produced, since certain types of storage and treatment systems promote an oxygen-free environment.¹ The estimated methane emissions from manure management systems are based on domesticated animal population data² and the type of management system. In this section we intend to present an estimate of methane emissions from manure management and some areas for research of potential mitigation.

HISTORIC EMISSIONS: 1990 TO 1994

Table 7-1 presents the estimated methane emissions for 1990 through 1994, based on the historic data available at the time of this writing. The major contributor is anaerobic lagoon manure management, constituting 75 percent of the total methane emissions from manure management. Anaerobic lagoons primarily handle manure from the dairy cow population.

Table 7-1
Summary of Annual Methane Emissions from
Manure Management Systems
1990 - 1994

Management Type	1990 Methane Emissions (Tons)	1991 Methane Emissions (Tons)	1992 Methane Emissions (Tons)	1993 Methane Emissions (Tons)	1994 Methane Emissions (Tons)
Pasture/Range	6,097	5,698	5,734	5,350	5,337
Daily Spread	0	0	0	0	0
Solid Storage	0	0	0	0	0
Drylot	768	706	719	671	667
Deep Pit Stacks	443	416	390	363	429
Litter	28,603	28,868	27,052	25,136	25,542
Paddock	135	131	126	122	133
Liquid/Slurry	461	434	406	379	448
Anaerobic Lagoon	216,384	222,600	226,019	227,668	228,809
Other	37,736	38,527	38,663	38,800	39,728
TOTAL	290,626	297,381	299,108	298,489	301,093

FORECAST EMISSIONS: 1995 TO 2010

A forecast of domestic animal populations was not available from any source. A forecast³ of the overall agriculture sector predicts no significant change through 2010. Therefore, we assume that the average domestic animal population from 1985 through 1994 will continue through 2010. The animal populations for anaerobic lagoons are higher in the forecasted years than for any of the years shown (1990 to 1994) due to the fact that most domestic animal populations peaked in 1985. We further assume that there are no significant changes in related manure management or emission controls. This is presented in Table 7-2 for the years 1995 through 2010.

Table 7-2 Average Annual Methane Emissions from Manure Management Systems for 1995, 2000, 2005 and 2010	
Management Type	Methane Emissions (Tons)
Pasture/Range	5,849
Daily Spread	0
Solid Storage	0
Drylot	734
Deep Pit Stacks	429
Litter	25,542
Paddock	133
Liquid/Slurry	448
Anaerobic Lagoon	229,411
Other	39,913
TOTAL	302,458

CONCLUSIONS AND RECOMMENDATIONS

If a methane emission reduction is sought in the area of manure management, the most logical place to start is the dairy cow anaerobic lagoons. There are currently no known methane recovery facilities for anaerobic lagoons in California. However, the necessary technology can be adapted from existing technology at municipal waste water treatment plants.⁴ This would have to be investigated to determine the economic viability and market penetration of the eventual product gas. Other areas of research potential might be feed modification that would reduce the nutrient content of the animal waste, such as adding poultry manure to cattle feed, or waste management by acts of legislation, such as Pennsylvania's Nutrient Management Act of 1993.⁵ The Act calls for farms with more than 1,000 pounds of animals (approximately two cows) per acre to draft a plan that will identify the best management practices that prevent nutrient releases to the environment.

ENDNOTES

1. California Energy Commission, *California Greenhouse Gas Emission Inventory. 1990*. September 1996. Technical Appendix, Chapter 7.
2. California Department of Food and Agriculture, *California Agricultural Statistics, 1993*, November 1994. Compiled by Agricultural Statistics Services.
3. UCLA-BFP Forecast, *The California Long-Term Outlook: Projections to 2010*, September 1996. Table 6. California Nondurables Manufacturing Employment, Leather component (SIC31).
4. California Energy Commission, *1991 Biomass Resource Assessment Report for California*, December 1992.
5. Pelley, Janet, *Environmental Science and Technology*, November 1996. vol. 30, p. 529A. States tackle animal waste problem to improve water quality.

Chapter 8

METHANE EMISSIONS FROM FLOODED RICE FIELDS

INTRODUCTION

When rice fields are flooded, anaerobic conditions in the soil develop, and methane is produced through anaerobic decomposition of soil organic matter. However, not all of the methane is oxidized by bacteria in the soil. Some is leached away as dissolved methane in flood water that percolates through the field. The remaining non-oxidized methane is transported from the submerged soil to the atmosphere primarily by diffusive transport through the rice plants. Non-flooded rice fields, such as dry upland rice fields, do not produce significant quantities of methane. Additionally, deepwater or floating rice fields (greater than 3.3 feet deep), are not believed to produce significant quantities of methane¹. Accordingly only flooded, non-deepwater rice fields are taken into account in this inventory and forecast.

HISTORICAL METHANE EMISSIONS: 1990 TO 1995

Table 8-1 shows the historic methane emissions from 1990 to 1995. The first section shows the acreage of rice planted² and the corresponding three year average. The next section of Table 8-1 shows the low and high estimate of the length of the growing season³ and the corresponding 1,000 acre-days per year (the three year average times the days per year, divided by 1,000). The last section shows the low and high estimate of methane emission rates⁴ and the corresponding annual methane emissions.

**TABLE 8-1
HISTORIC METHANE EMISSIONS FROM FLOODED RICE FIELDS**

Year	1989	1990	1991	1992	1993	1994	1995	1996
Acreage Planted²	415,000	400,000	351,000	396,000	440,000	487,000	467,000	500,000 ⁵
3-yr Average	--	388,667	382,333	395,667	441,000	464,667	484,667	--
Length of Growing Season	Days / Year³	Average 1,000 Acre-day / Year						
Low Estimate	123	47,806	47,027	48,667	54,243	57,154	59,614	--
High Estimate	153	59,466	58,497	60,537	67,473	71,094	74,154	--
Daily Emissions Rate	Lbs Methane / 1,000 Acre-day⁴	Tons Methane / Year						
Low Estimate	473	11,300	11,100	11,500	12,800	13,500	14,100	--
High Estimate	2,677	79,600	78,300	81,000	90,300	95,100	99,200	--

FORECAST METHANE EMISSIONS: 2000, 2005 AND 2010

No traditional forecast exists of future rice field acreage. We assumed that future rice field acreage would not rise above 550,000 and would not fall below 440,000 acres⁵ from 1997 through 2010. This corresponds to a low estimate of 12,800 and a high estimate of 113,000 tons of methane per year.

CONCLUSIONS AND RECOMMENDATIONS

The highest projected methane emission from flooded rice fields is 113,000. This is one-third the methane emissions from manure management (Chapter 7), one-fourth the methane emissions from domesticated animals (Chapter 6) and one-tenth the methane emissions from municipal solid waste landfills (Chapter 5). Therefore, we recommend that reductions in anthropogenic methane emissions be sought in any of these other three areas prior to flooded rice fields.

END NOTES

1. California Energy Commission, *California Greenhouse Gas Emission Inventory, 1990*, September 1996. Technical Appendix, Chapter 8.
2. California Department of Food and Agriculture, *California Agricultural Resource Directory including Agricultural Production and Export Statistics for 1995*, 1995. Compiled by Agricultural Statistics Services.
3. United States Environmental Protection Agency, *State Workbook, Methodologies for Estimating Greenhouse Gas Emissions, second edition*, June 1995. EPA Office of Policy, Planning and Evaluation, State and Local Outreach Program.
4. Cicerone, R. J. and Shetter, J., *Sources of Atmospheric Methane: Measurements in Rice Paddies and a Discussion*, August 1981. *Journal of Geophysical Research*, vol. 86, No.C8, pp. 7203-7209.
5. Huffman, W., *Record of Conversation between William Huffman of the Farmers Rights Co-op and Joseph Loyer of California Energy Commission*. January 1997.

Chapter 9

NITROUS OXIDE EMISSIONS FROM AGRICULTURAL SOIL MANAGEMENT

INTRODUCTION

Nitrous oxide (N_2O) is produced naturally in soils through the microbial process of denitrification and nitrification.¹ A number of anthropogenic activities add nitrogen to soils, thereby increasing the amount of nitrogen available for nitrification and denitrification, and ultimately the amount of N_2O emitted. These activities include the application of fertilizers, atmospheric deposition, and the cultivation of nitrogen-fixing crops.² Due to the high uncertainty of effects of other sources, only N_2O emissions from fertilizer use are included in this inventory. The methodology for determining the N_2O emissions from agricultural soil management practices (as described in the California Greenhouse Gas Emission Inventory, 1990³) uses the nitrogen content of fertilizing material used in the California agriculture.

HISTORICAL EMISSIONS: 1990 THROUGH 1994

This analysis uses a three year average of the nitrogen content of fertilizing material used in the agricultural sector, based on data from the Department of Food and Agriculture's Fertilizing Materials Tonnage Report.⁴ Historic data from 1989 through 1995 are used to calculate the three year averages for 1990 through 1994. Table 9-1 shows the historic nitrogen tonnage in the second column, the three year averages in the third column, the percent nitrogen that will be oxidized to N_2O (this is held constant at 1.17 percent) in the fourth column, and the corresponding N_2O emissions for the years 1990 through 1994 in the fifth column (the ratio of the molecular weight of N_2O to N_2 , or 44/28).

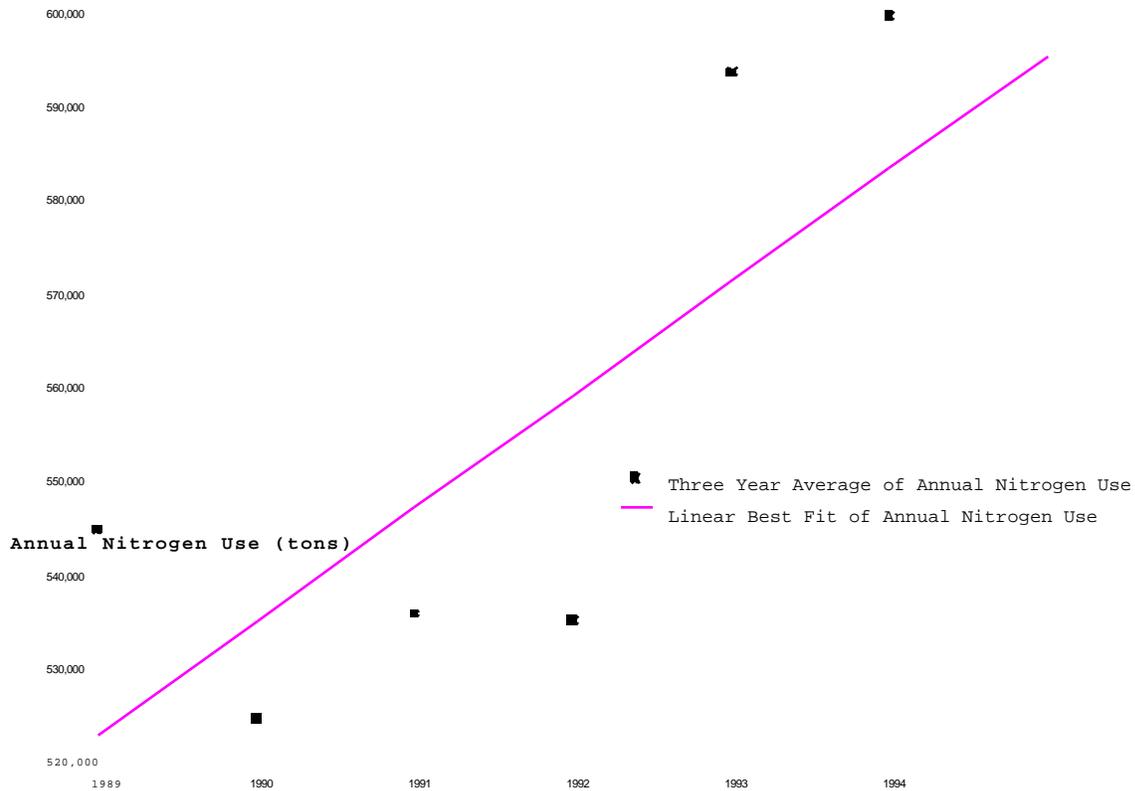
**TABLE 9-1
ANNUAL NITROUS OXIDE EMISSIONS
FROM AGRICULTURAL SOIL MANAGEMENT
1990 THROUGH 1994**

Year	Annual Nitrogen Use (Tons)	3-year Annual Average Nitrogen Use (Tons)	Nitrogen that will be oxidized to N₂O (Tons)	N₂O Emissions (Tons)
1989	558,638	--	--	--
1990	555,309	544,201	6,367	10,006
1991	518,656	524,017	6,131	9,634
1992	498,085	535,235	6,262	9,841
1993	588,965	534,479	6,253	9,827
1994	516,387	593,058	6,939	10,904
1995	673,821	--	--	--

FORECASTED EMISSIONS: 1995, 2000, 2005 AND 2010

The nitrogen content of fertilizing material used in the agricultural sector was forecasted, using a linear "best fit" to the existing data from 1989 through 1995. Figure 9-1 compares the linear equation to the actual data from which it was developed.

**FIGURE 9-1
COMPARISON OF LINEAR BEST FIT TO ACTUAL NITROGEN TONNAGE USE**



This linear equation was applied to determine the annual nitrogen use for the years 1996, 2000, 2005 and 2010. A standard methodology was followed to determine the N₂O emissions for 1995, but not for 2000, 2005 or 2010. For 1995, the three year average was used because two years of actual documented data (1994 and 1995) was available, and only one year of forecasted data (1996). However, for the years 2000, 2005 and 2010 only forecasted data was available. Furthermore, that forecasted data is based on a linear equation, which, when averaged in this manner, results in the value for the year in question. For example, if the forecasted values for 1999, 2000 and 2001 are averaged (these values are 643,055, 655,127 and 667,199), the same value will be obtained as for the year 2000 (655,127). The established methodology is then applied and the nitrous oxide emissions calculated for 1995, 2000, 2005 and 2010. These emissions are presented in Table 9-2. In Table 9-2, the forecasted annual nitrogen use (the second column) for 1996, 2000, 2005 and 2010 are in *italic* to highlight the fact that this is forecasted data, not actual data. The third column in Table 9-2 has only one value for 1995. This

is because 1995 is the only year of interest for doing a three year average, as discussed above. The fourth and fifth columns are the same as in Table 9-1.

TABLE 9-2 ANNUAL NITROUS OXIDE EMISSIONS FROM AGRICULTURAL SOIL MANAGEMENT 1995, 2000, 2005 and 2010				
Year	Annual Nitrogen Use (Tons)	3-year Annual Average Nitrogen Use (Tons)	Nitrogen that will be oxidized to N₂O (Tons)	N₂O Emissions (Tons)
1994	516,387	--	--	--
1995	673,821	599,016	7,008	11,013
1996	606,839	--	--	--
2000	655,127	--	7,665	12,267
2005	715,487	--	8,371	13,155
2010	775,846	--	9,077	14,264

END NOTES

1. Denitrification is the process by which nitrates or nitrites are reduced by bacteria and which results in the escape of nitrogen into the air. Nitrification is the process by which bacteria and other microorganisms oxidize ammonium salts to nitrites, and further oxidize nitrites to nitrates.
2. Methods to estimate N₂O emissions due to atmospheric deposition and nitrogen-fixing crops are not included at this time for two reasons: these emission sources are highly uncertain, and activity data are not readily available.
3. California Energy Commission, *California Greenhouse Gas Emission Inventory, 1990*, September 1996. Technical Appendix, Chapter 9.
4. California Department of Food and Agriculture, *Fertilizing Materials, Tonnage Report, 1995*. Annual Reports from 1989 to 1995, California Department of Food and Agriculture, Feed, Fertilizer and Livestock Drugs.

Chapter 10

CARBON DIOXIDE EMISSIONS FROM FORESTRY MANAGEMENT PRACTICES

INTRODUCTION

Forests are complex ecosystems with several interrelated components, each of which acts as a carbon storage pool. These include living trees, standing dead trees, roots, stems, branches and foliage, soil, woody debris and tree litter, and understory vegetation such as shrubs and bushes.

Changes in forests and other woody biomass stocks due to human interactions include commercial management and logging for forest products, replanting after logging or other timber forest removal, the harvest of fuelwood, the establishment and operation of forest plantations, and planting trees in urban and suburban locations.

AVERAGE ANNUAL INVENTORY, HARVEST, AND NET GROWTH PROJECTIONS¹

Growth and harvest rates are monitored by several different organizations including the U.S. Forest Service, the California Department of Forestry and Fire Protection, the Pacific Northwest Research Station Forest Inventory and Assessment, forestry industry associations, and private landowners.

Predicting exact levels of timber supply cannot be done with certainty because of complex interactions among economic, social, and physical factors. Because of the uncertainty of future events, information in the following tables is based on what different forestland owners would do with respect to projected allowable sale quantities presented in draft national forest plans, and social, demographic, and economic trends.

The tables are taken from *California's Forests and Rangelands: Growing Conflict Over Changing Use*; Forest and Rangeland Resources Assessment Program, California Department of Forestry, July 1988 (FRRAP). These tables represent the average annual inventory, harvest, and net growth projections for California for the period of 1980 through 2010 (net annual growth is defined as total growth minus losses to fire, insects, and disease). The projections for the decade 1980 through 1990 indicate that harvest will exceed growth by 163,077 million board feet; for the

decade 1990 through 2000 harvest will exceed growth by 255,358 million board feet; for the decade 2000 through 2010 growth will exceed harvest by 103,614 million board feet. Although projections indicate that harvest would exceed growth, this is not necessarily the case based on 1977 regulations regarding harvesting on private lands, as stated in Title 14, California Code of Regulations, Chapters 4 and 4.5 (California Forest Practice Rules, California Department of Forestry and Fire Protection).

AVERAGE ANNUAL INVENTORY (MILLION BOARD FEET)					
Period	Other Public	Industry	NIPF	USFS	Total
1980-1990	9,662,354	45,730,473	38,288,227	119,082,633	212,763,657
1990-2000	11,258,772	38,113,580	43,673,234	118,382,749	211,428,303
2000-2010	12,967,529	31,897,095	49,447,952	116,169,275	210,481,808
Source: FRRAP					

AVERAGE ANNUAL HARVEST (MILLION BOARD FEET)					
Period	Other Public	Industry	NIPF	USFS	Total
1980-1990	46,372	1,781,682	265,118	1,816,862	3,910,034
1990-2000	45,309	1,677,399	283,725	1,916,136	3,922,569
2000-2010	64,074	1,362,588	298,761	1,974,819	3,700,242
Source: FRRAP					

AVERAGE ANNUAL GROWTH (MILLION BOARD FEET)					
Period	Other Public	Industry	NIPF	USFS	Total
1980-1990	197,387	1,020,258	782,448	1,746,873	3,746,957
1990-2000	213,579	915,443	843,400	1,694,788	3,667,211
2000-2010	237,557	881,248	298,761	1,791,019	3,803,856
Source: FRRAP					

CONCLUSIONS AND RECOMMENDATIONS

Information to update the 1991 Global Climate Change report has been difficult to obtain; when information is available it is incomplete. Because of the difficulty in obtaining accurate data on changes in forest and other woody biomass stocks, forest and grassland conversion, abandonment of managed lands, growth rate, carbon fraction, conversion/expansion ratio, aboveground biomass density, and soil carbon content, no quantifiable data on California forestry and carbon sequestration has been developed for this report.

Staff conversations with staff at the California Department of Forestry and Fire Protection support staff's conclusions regarding the complexity of estimating carbon emissions from forestry practices because of incomplete or inadequate data. Department of Forestry and Fire Protection staff states that predicting exact levels of timber supply (and subsequent sequestering capability) cannot be done with certainty because of new regulations on private harvesting, environmental controls, and residual requirements that are implemented over time. Because of environmental regulations regarding harvesting, some forest areas in California will have greater carbon sequestering capability than others.²

In addition to the above, the complex interactions among economic, social, and physical factors make it difficult to obtain exact data. The most important changes in land use affecting the carbon budget are those that increase or reduce forest land. Since forests experiencing net growth will sequester CO₂ from the atmosphere as part of the growing process, any buildup of forest biomass will reduce the buildup of atmospheric CO₂.³

There are many uncertainties associated with the emissions from forest and land use changes due to the complexity of estimating these emissions and incomplete or inadequate data. The U.S. Department of Agriculture, Forest Service, in cooperation with the American Forestry Association and other Federal agencies, has been studying the potential for forestry strategies to mitigate the effects of global warming since 1991. The major objective of this research has been to understand the prospective changes in carbon storage in forests and wood products from converting lands to plantation forests and from alternative forest management strategies. Research on carbon storage is part of a larger effort to develop a carbon budget model of U.S. forests and to integrate the model with the existing forest sector model used by the U.S. Forest Service. The integrated forest sector model will have the capability of analyzing the potential impacts of trends in U.S. forest resources on the global carbon cycle, assessing the effects of global change on forest resources and society, and assessing the effects of mitigation and adaptation responses to global change on forest resources, the global carbon cycle, and society.⁴

In addition to the work undertaken by the USDA Forest Service, the American Forestry Association, and other Federal agencies, more California-based research needs to be done in the areas of forest management practices and land use change to determine the extent of carbon sequestering capabilities of forests, rangelands, grasslands, and urban tree planting.

END NOTES

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2. Ahlstrom, Gerald A., Ph.D., Department of Forestry and Fire Protection. Conversation with staff on March 10 and 26, 1997.
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Hall, Daniel, A., *The Extent and Status of State Policies Concerning Greenhouse Gas Emissions and Mitigation in the Energy Sector*, January 1977. The Pacific Forest Trust.

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Chapter 11 _____

GREENHOUSE GAS EMISSIONS FROM BURNING OF AGRICULTURAL CROP WASTES

INTRODUCTION

Considerable quantities of agricultural crop wastes are produced each year in California. Open field burning of such wastes is a common practice. Other common cropwaste disposal methods include plowing cropwaste into the soil, composting disposal into landfills, or use as fuel.

Open burning of agricultural wastes releases the following greenhouse gases: carbon dioxide, (CO₂), methane, and nitrous oxide (N₂O). Burning of agricultural wastes is not considered a net carbon dioxide source, because the carbon released as carbon dioxide during burning is reabsorbed during the next growing season through the photosynthesis process. For this reason, we will report carbon dioxide emissions in this chapter but not count them as part of the state historical and forecasted inventories.

HISTORICAL EMISSIONS

All the historical emissions are calculated using the method developed by the University of California at Davis¹. This method involves: 1) multiplying the production area in acres by its respective "Residue Yield" to obtain the amount of residue produced; 2) multiplying the residue amount by the "Burn Fraction" to obtain the amount of residue actually burned on the field. This quantity, when multiplied by appropriate emission factors, provides the estimated amount of emissions from this type of operations. The parameters used in this chapter for the different crops are presented in Table 11-1. The parameters are California specific and were developed from surveys done in the state and actual emission testing in a wind tunnel constructed specifically to measure the emission of pollutants from simulated open burning practices in California.

Table 11-2 presents the historical emissions from 1990 through 1994. The six crops reported in Table 11-2 produce about 97 percent of all the agricultural biomass burned in the state, exclusive of prescribed forest burns and wildfires.² The same table indicates that emissions have remained

almost constant, with the only exception being a downward trend in the emissions from rice production. The reason for this trend is the implementation of the Rice

TABLE 11-1 PARAMETERS USED TO ESTIMATE THE AMOUNT OF WASTE BURNED IN CALIFORNIA AND EMISSION FACTORS						
	Almonds	Walnuts	Wheat	Barley	Corn	Rice
Burn Fraction (%)	84	95	1	7	3	99
Residue Yield (ton/ha dry basis)	1.89	1.49	3.66	2.51	9.06	6.75
EF ^a -CH ₄	0.12	0.16	0.18	0.25	0.18	0.08
EF-CO ₂	183.38	164.29	117.49	117.22	131.37	117.16
EF-N ₂ O ^b	0.36	0.34	0.23	0.27	0.18	0.28
^a EF = Emission Factor (% of fuel, dry basis) Source: see end note 3 ^b The emission factor for N ₂ O is calculated by multiplying the emission factor for NO _x (see end note 3) by 0.058, which is the ratio of emission factor for N ₂ O to NO _x provided in Table D11-2 in the EPA Workbook. ³						

Straw Burning Act of 1991, which mandates a reduction in rice straw burning by the year 2000, using the schedule shown in Table 11-3. Table 11-3 also presents the actual historical phasedown in rice straw burning for 1992 through 1994, which constantly exceeded what is required by the Rice Straw Burning Act.

FORECASTED EMISSIONS: 2000, 2005 AND 2010

As discussed above, the greenhouse gas emissions originating from open burning of agricultural crop wastes remained practically constant from 1990 through 1995, with rice straw being the sole exception. To forecast emissions for 2000, 2005, and 2010, it was assumed that the future emissions for almonds, walnuts, barley, corn, and wheat will be equal to their historical average emissions. For rice, full compliance with the requirements of the Rice Straw Burning Reduction Act of 1991 was assumed. Therefore, after the year 2000, only 25 percent of the 428,200 historical planted rice acreage will be open burned. Using these assumptions, the total emissions from open burning of agricultural wastes for the years 2000 through 2010 are 1,030; 1,227,670; and 148 tons of CH₄, CO₂, and N₂O, respectively.

**TABLE 11-2
HISTORICAL EMISSIONS FROM AGRICULTURAL RESIDUE BURNING: 1990-1995
(TONS)**

Crop	Compound/Year	1990	1991	1992	1993	1994	1995
Almonds	CH ₄	310	329	327	322	335	343
	CO ₂	486,165	515,766	511,762	504,697	525,069	538,022
	N ₂ O	55.5	59.1	58.6	57.8	60.1	61.6
Walnuts	CH ₄	171	182	180	180	176	180
	CO ₂	171,114	182,220	180,006	180,744	175,949	180,375
	N ₂ O	20.4	21.8	21.5	21.6	21.1	21.6
Wheat	CH ₄	180	143	190	175	193	193
	CO ₂	116,040	92,455	122,891	113,129	124,422	124,422
	N ₂ O	13.3	10.6	14.1	13.0	14.3	14.3
Barley	CH ₄	44	42	40	44	51	46
	CO ₂	21,044	20,004	19,170	20,837	24,171	21,671
	N ₂ O	2.8	2.7	2.6	2.8	3.3	2.9
Corn	CH ₄	73	64	72	77	81	84
	CO ₂	55,146	47,685	54,187	57,800	60,690	62,857
	N ₂ O	4.4	3.8	4.4	4.6	4.9	5.1
Rice	CH ₄	855	731	717	673	632	486
	CO ₂	1,300,354	1,112,051	1,091,521	1,024,608	961,246	739,783
	N ₂ O	180	154	151	142	133	103
TOTAL	CH ₄	1,633	1,491	1,527	1,472	1,467	1,332
	CO ₂	2,149,863	1,970,181	1,979,538	1,901,815	1,871,547	1,667,131
	N ₂ O	276	252	253	242	237	208

The 1990 Emissions taken from the 1990 California Greenhouse Emissions Inventory.⁴

**TABLE 11-3
PLANTED RICE ACREAGE ALLOWED TO BURN AND ACTUAL PLANTED ACREAGE BURNED
IN THE SACRAMENTO VALLEY^a**

Year	Planted Acreage that can be burned (%)	Actual planted acreage burned (%)
1992	90	87
1993	80	73.5
1994	70	62.3
1995	60	
1996	50	
1997	38	
1998	25	
1999	25	
2000 and thereafter	25% or 125,000 acres in the Sacramento Valley, whichever is less	

Source: Report of the Advisory Committee on Alternatives to Rice Straw Burning.³

^a Approximately 95 percent of the areas planted with rice in the state are located in the Sacramento Valley.

CONCLUSIONS AND RECOMMENDATIONS

The Rice Straw Burning Act of 1991 will have the unintended effect of significantly reducing future emissions of CH₄ and N₂O emissions from open burning of agricultural wastes in California. However, the alternative disposal or use of the rice straw will also create emissions. For example, CH₄ and N₂O will also be emitted if rice straw is used as a fuel in a biomass facility or if it is allowed to decompose in the field. The net effect on emissions is not certain. However, future updates to this inventory should strive to determine if a net reduction in emissions would actually occur.

END NOTES

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2. Jenkins, B.M., Turn, S., Primary Atmospheric Pollutants from Agricultural Burning: Emission Rate Determinations from Wind Tunnel Simulations, June 1994. International Summer Meeting Sponsored by ASAE, Kansas City, Kansas.
3. U.S. Environmental Protection Agency, *State Workbook: Methodologies for Estimating Greenhouse Gas Emissions*, January 1995. Second Edition, Office of Policy, Planning and Evaluation.
4. California Energy Commission, *1990 California Greenhouse Emissions Inventory*, 1997.
5. California Air Resources Board, Report of the Advisory Committee on Alternatives to Rice Straw Burning, December 1995.

Chapter 12

METHANE EMISSIONS FROM MUNICIPAL WASTEWATER

INTRODUCTION

Industrial and municipal wastewater, treated or not, can produce methane emissions. Wastewater can be treated using aerobic and/or anaerobic technologies, or if untreated, can degrade under either aerobic or anaerobic conditions.¹ The method used for determining methane emissions from municipal wastewater in this report relies on state population data received from the California Department of Finance.²

HISTORICAL EMISSIONS 1990-1995 AND FORECASTED EMISSIONS TO 2010

Historical and forecasted emissions are presented together. The population data on which the emission estimates are based is backcast to 1970 and forecasted to 2040. Figure 12-1 presents a graph of the associated uncontrolled methane emissions from 1990 to 2010, marking 1995, 2000 and 2005. Table 12-1 shows the uncontrolled methane emissions for the years 1990 through 2010 in agreement with Figure 12-1. From the Table and the Figure it can be seen that methane emissions grow linearly (as does the population data).

Although this analysis assumes that no methane is recovered, methane recovery systems are in operation at California municipal wastewater treatment facilities. Unfortunately, extensive research is required to determine how many there are, how effective they are, where they are located, or how much sewage they process. This research is not possible at this time due to staff and time constraints. Because this forecast is based on population data and not the actual bacteria loading in the water, it is difficult to draw any conclusions about methane emissions reduction options at this time.

**FIGURE 12-1
METHANE EMISSIONS FROM MUNICIPAL WASTEWATER
1990 TO 2010**

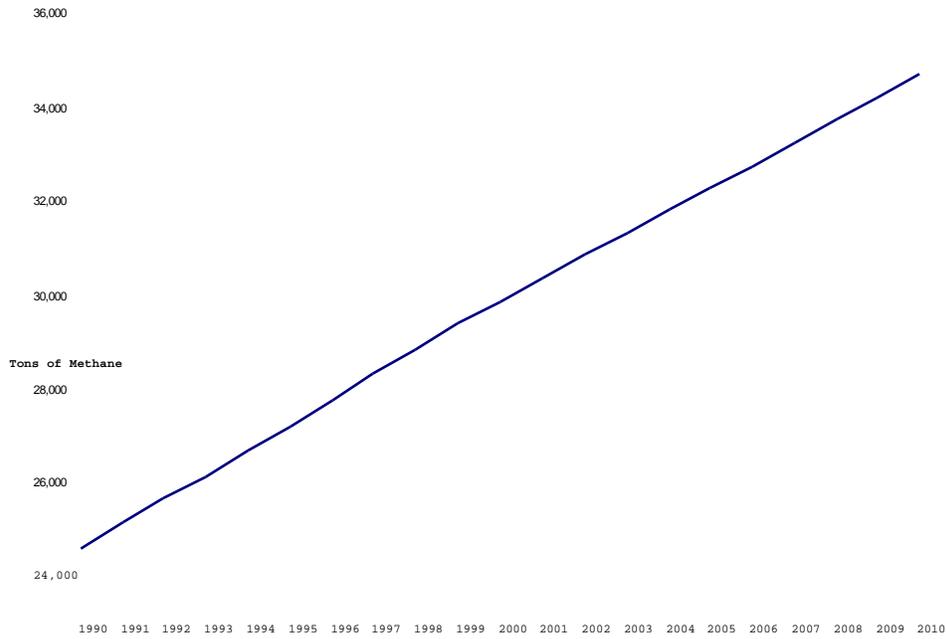


TABLE 12-1 METHANE EMISSIONS FROM MUNICIPAL WASTEWATER 1990 THROUGH 1995 INCLUDING 2000, 2005 AND 2010	
Year	Tons of Methane
1990	24,500
1991	25,000
1992	25,600
1993	26,100
1994	26,600
1995	27,100
2000	29,800
2005	32,200
2010	34,600

CONCLUSIONS AND RECOMMENDATIONS

The methane emissions from municipal wastewater are small in comparison with the methane emissions from manure management (Chapter 7), domesticated animals (Chapter 6), municipal solid waste landfills (Chapter 5) or even flooded rice fields (Chapter 8). However, this source is more likely to be controllable because of existing wastewater treatment facilities in California. More research needs to be done to determine the extent of methane recovery from municipal wastewater that is already implemented and what additional recovery is feasible.

END NOTES

1. California Energy Commission (CEC), *California Greenhouse Gas Emission Inventory, 1990*, September 1996. Technical Appendix, Chapter 12.
2. California Department of Finance, *Projected total population of California counties: 1990 to 2040*, May 1993.

Chapter 13

OTHER GREENHOUSE GAS EMISSIONS FROM MOBILE SOURCE COMBUSTION

This chapter reports emissions of methane (CH₄) and nitrous oxide (N₂O) from mobile source combustion. Carbon dioxide emissions are reported in Chapter 1. There is a great level of uncertainty on the emission levels from this sector due to the numerous and complex factors affecting those emissions. In that context, the estimates presented in this chapter represent only a first order approximation of the level of importance of these emissions as compared to the emissions from other sectors.

HISTORICAL EMISSIONS

CH₄ and N₂O emissions were calculated by multiplying fuel consumption data by the emission factors provided in the EPA State Workbook.¹ The emission factors are differentiated by vehicle type (e.g., passenger cars, heavy-duty trucks), fuel type (e.g., diesel, gasoline, LPG), and emission control system (e.g., uncontrolled, non-catalysts control, three-way catalysts). However, the available fuel consumption data did not match the level of disaggregation needed for the emission factors. To overcome this problem, the following was done: a) in cases where the activity level data per vehicle type was not disaggregated by control technology, we used average emission factors; b) for medium-duty gasoline trucks, as defined by the California Air Resources Board, the emission factors for light-duty trucks, as defined by the Environmental Protection Agency, were used; and, c) vehicles using LPG were assumed to be heavy-duty vehicles. Table 13-1 presents the level of disaggregation used in the calculations and their respective emission factors.

Emissions from on-road vehicles dominate the emissions from the mobile sector. For this reason, and also due to lack of information for non-road vehicles, emissions from non-road vehicles were estimated as a constant fraction of the emissions from the on-road vehicles. These fractions were 0.023 and 0.096 for N₂O and CH₄, respectively, which were determined in the 1990 California Greenhouse Emissions Inventory.² Tables 13-2 and 13-3 present the estimated emissions from the mobile sector that were calculated using the assumptions and emission factors discussed above.

TABLE 13-1 CH ₄ AND N ₂ O EMISSION FACTORS (EF) FOR ON-ROAD FUEL CONSUMPTION			
Vehicle type	Fuel/Control System	EF N ₂ O (lb/MMBtu)	EF CH ₄ (lb/MMBtu)
Light-Duty Passengers	Gas/Non	0.002	0.069
	Gas/Cat	0.019	0.027
	Diesel	0.004	0.004
Light-Duty Trucks (< 6000 lbs)	Gas/Non	0.002	0.059
	Gas/Cat	0.018	0.029
	Diesel	0.004	0.004
Medium Duty Trucks 1 (6001 to 1400 lbs)	Gas/Non	0.002	0.059
	Gas/Cat	0.018	0.029
	Diesel	0.004	0.004
Heavy-Duty Trucks (> 14001 lbs)	Gas/Non	0.001	0.044
	Gas/Cat	0.001	0.022
	Diesel	0.004	0.018
Urban Buses	Diesel	0.004	0.018
Motorcycles	Gas	0.002	0.221
Trucks	LPG	na	0.044
Gas= gasoline, Non= non-catalysts, Cat=three-way catalysts.			

FORECASTED EMISSIONS: 2000, 2005 AND 2010

Nitrous oxide and methane emissions from the mobile sector were forecasted using disaggregated fuel consumption data from the Motor Vehicle Emissions Inventory Computer Model.³ As seen in Table 13-4, nitrous oxide emissions increase with time, while methane emissions remain practically constant. This is the result of reduction over time in the use of light-duty, medium-duty, and heavy-duty trucks without catalysts, and their almost complete elimination from California roadways in the year 2010. The fully-controlled replacement vehicles will be equipped with three-way catalysts, which produce an order of magnitude increase in emissions of nitrous oxides, in comparison to vehicles without such emission controls (see Table 13-1), which explains why emissions go up with time. Methane emissions remain practically constant because any increase in emissions from increased fuel consumption is offset by emission reductions from the steady elimination of vehicles without emission control equipment.

**TABLE 13-2
NITROUS OXIDE EMISSIONS FROM THE MOBILE SECTOR: 1990-1995
(TONS)**

		1990	1991	1992	1993	1994	1995
Light-Duty	Gas/Non	113	97	83	75	66	59
Passengers	Gas/Cat	7,421	7,513	7,390	7,614	7,702	7,786
	Diesel	32	27	23	20	17	14
Light-Duty	Gas/Non	47	39	32	27	23	19
Trucks	Gas/Cat	3,365	3,466	3,427	3,639	3,693	3,748
	Diesel	15	13	11	10	9	7
Medium	Gas/Non	83	71	59	51	43	37
Duty Trucks	Gas/Cat	719	976	1,093	1,280	1,423	1,558
	Diesel	70	78	83	95	103	109
Heavy-Duty	Gas/Non	15	13	11	9	8	7
Trucks	Gas/Cat	1	2	3	4	5	6
	Diesel	501	500	483	509	514	519
Urban Buses	Diesel	15	15	15	15	15	15
Motorcycles	Gas	3	3	3	3	3	3
Trucks	LPG	na	na	na	na	na	na
Total On-Road		12,401	12,814	12,716	13,353	13,624	13,888
Total Mobile Sector ^a		12,692	13,115	13,015	13,667	13,944	14,214

^a Total N₂O emissions are equal to 1.0235 times the total on-road emissions.

TABLE 13-3 METHANE EMISSION FROM THE MOBILE SECTOR: 1990-1995 (TONS)							
		1990	1991	1992	1993	1994	1995
Light-Duty Passengers	Gas/Non	3,909	3,348	2,868	2,581	2,290	2,033
	Gas/Cat	10,389	10,518	10,346	10,660	10,783	10,901
	Diesel	34	29	25	22	18	15
Light-Duty Trucks	Gas/Non	1,390	1,161	936	811	667	551
	Gas/Cat	5,385	5,545	5,483	5,822	5,909	5,996
	Diesel	15	13	11	10	9	7
Medium Duty Trucks	Gas/Non	2,440	2,087	1,729	1,512	1,281	1,083
	Gas/Cat	1,150	1,561	1,749	2,048	2,276	2,493
	Diesel	70	78	83	95	103	109
Heavy-Duty Trucks	Gas/Non	664	572	472	413	352	298
	Gas/Cat	21	47	72	98	120	137
	Diesel	2,297	2,293	2,214	2,332	2,357	2,380
Urban Buses	Diesel	68	68	68	69	69	70
Motorcycles	Gas	318	328	323	338	343	348
Trucks	LPG	na	na	na	na	na	na
Total On-Road		28,151	27,651	26,380	26,811	26,575	26,422
Total Mobile Sector ^a		31,135	30,582	29,176	29,653	29,392	29,223

^a Total CH₄ emissions are equal to 1.106 times the total on-road emissions.

**TABLE 13-4
FORECASTED NITROUS OXIDE AND METHANE EMISSION
FROM THE MOBILE SECTOR: 2000, 2005, 2010
(TONS)**

		2000		2005		2010	
		N ₂ O	CH ₄	N ₂ O	CH ₄	N ₂ O	CH ₄
Light-Duty Passengers	Gas/Non	29	1,002	11	364	1	30
	Gas/Cat	8,097	11,336	8,597	12,035	9,002	12,603
	Diesel	6	6	3	3	1	2
Light-Duty Trucks	Gas/Non	2	57	0	0	0	0
	Gas/Cat	4,083	6,533	4,633	7,413	5,239	8,383
	Diesel	3	3	1	1	0	0
Medium Duty Trucks	Gas/Non	16	485	7	217	2	54
	Gas/Cat	2,127	3,403	2,594	4,150	2,987	4,779
	Diesel	134	134	154	154	173	173
Heavy-Duty Trucks	Gas/Non	3	115	1	37	0	14
	Gas/Cat	9	200	11	237	12	267
	Diesel	535	2,454	565	2,590	621	2,847
Urban Buses	Diesel	15	70	15	69	15	70
Motorcycles	Gas	3	378	4	414	4	454
Trucks	LPG	na	na	na	na	na	na
Total On-Road		15,063	26,176	16,595	27,684	18,059	29,675
Total Mobile Sector ^a		15,417	28,951	16,985	30,619	18,483	32,821

^a Total N₂O and CH₄ emissions are equal to 1.0235 and 1.106 times their total on-road emissions respectively.

CONCLUSIONS AND RECOMMENDATIONS

This chapter presents an order of magnitude estimate of emissions. Several areas of uncertainty exist that preclude a more accurate estimate of the emission levels associated with the mobile sector. However, since nitrous oxide and methane emissions from this sector appear to be relatively minor, the emissions presented in this chapter should be adequate for the present inventory.

END NOTES

1. U.S. Environmental Protection Agency, *State Workbook, Methodologies for Estimating Greenhouse Gas Emissions*, January 1995. Office of Policy and Evaluation, State and Local Outreach Program.
2. See Table 13-2 in 1990 California Greenhouse Emissions Inventory. California Energy Commission.
3. Motor Vehicle Emissions Inventory Computer Model. Scenario Title: MVE17g, Emission Factors Scenario. Model MVE17g version 1.0. California Air Resources Board.

Chapter 14

NITROUS OXIDE AND METHANE EMISSIONS FROM STATIONARY COMBUSTION

This chapter reports emissions of nitrous oxide (N₂O) and methane (CH₄) from stationary combustion sources. These estimates are order of magnitude calculations that serve the purpose of providing an understanding of their importance in the total inventory of greenhouse gas emissions in the state.

HISTORICAL EMISSIONS: 1990-1994

All of the N₂O and CH₄ emission factors for stationary combustion were obtained from the "State Workbook: Methodologies for Estimating Greenhouse Gas Emissions", and the "Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-1993." Both documents were prepared by the U.S. EPA. Tables 14-1 and 14-2 document the factors used in this chapter.

Table 14-3 presents the historical N₂O and CH₄ emissions which were derived using the emission factors included in Tables 14-1 and 14-2 and the fossil fuel consumption data included in Chapter 1 in this document. In addition, the Energy Information Administration (EIA) provides wood consumption data for the residential, commercial, and industrial sectors.¹ Since the data from EIA provides the combined wood consumption from the commercial and residential sector, the CH₄ emission factor for wood combustion is an average of the emission factors reported in Table 14-1 for the two sectors. "Wood" consumption data for the industrial sector includes wood and waste consumption.

FUTURE EMISSIONS: 2000, 2005 AND 2010

In theory, future emissions should be calculated using the expected future consumption data and the emission factors discussed above. However, the high level of uncertainty associated with these emission factors detracts from the accuracy of such future emissions estimates. In addition, the contribution from stationary combustion to the total state inventory for both nitrous oxide and methane is relatively small. For these two reasons, at this time, future emissions for both

greenhouse gases are assumed to be equal to the historical average for the period 1990 through 1994, as shown in Table 14-3.

TABLE 14-1 METHANE EMISSION FACTORS FOR STATIONARY COMBUSTION BY SECTOR AND FUEL TYPE (lb/MMBtu)			
Residential Sector		Electric Utilities	
Distillate Fuel Oil	0.0110	Distillate Fuel Oil	0.0001
Kerosene	0.0112	Residual Fuel	0.0015
LPG	0.0021	Bituminous Coal	0.0013
Bituminous Coal	na	Natural Gas: Boilers	0.0002
Natural Gas	0.0021	Natural Gas: Turbines	0.0124
Wood	0.1640	Industrial Sector	
Commercial Sector		Distillate Fuel Oil	0.0064
Distillate Fuel	0.0013	Kerosene	0.0064
Kerosene	0.0013	LPG	0.0029
LPG	0.0025	Crude Oil	0.0064
Residual Fuel	0.0035	Residual Fuel Oil	0.0064
Bituminous Coal	0.0221	Still Gas	0.0029
Natural Gas	0.0025	Bituminous Coal	0.0053
Wood	0.0331	Natural Gas	0.0029
		Wood	0.0331
Source: Tables D14-2 to D14-6 in the EPA State Workbook ²			

CONCLUSIONS AND RECOMMENDATIONS

This chapter presents only an order of magnitude estimation of nitrous oxide and methane emissions from stationary combustion. This order of magnitude estimation is adequate, at this time, due to the lack of more accurate emission factors and the relatively small contribution of nitrous oxide and methane emissions from stationary combustion to the total state emissions inventory.

TABLE 14-2 GENERIC N₂O EMISSION FACTORS FOR STATIONARY FUEL COMBUSTION (lb/MMBtu)	
Coal	0.00325
Gas	0.00023
Oil	0.00139
Wood	0.00998
Source: EPA, 1994 ³	

TABLE 14-3 N₂O AND CH₄ EMISSIONS FROM STATIONARY COMBUSTION						
Year	N ₂ O Emissions (tons)			CH ₄ Emissions (tons)		
	Fossil Fuels	Wood	Total	Fossil Fuels	Wood	Total
1990	524	957	1,499	3,078	5,314	8,392
1991	483	991	1,474	3,103	5,476	8,579
1992	464	1,042	1,506	3,008	5,759	8,767
1993	439	983	1,421	3,001	5,213	8,214
1994	453	999	1,452	3,030	5,230	8,260
2000, 2005, 2010			1,470			8,442

END NOTES

1. Energy Information Administration, *State Energy Data Report 1994*, 1994. Data for California in electronic form found in file Ca94b.xls.
2. U.S. Environmental Protection Agency, *State Workbook: Methodologies for Estimating Greenhouse Gas Emissions*, January 1995. Second Edition, U.S. Environmental Protection Agency, Office of Policy, Planning and Evaluation.