California's Greenhouse Gas Emissions and Trends over the Past Decade

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ABSTRACT

In August 2000, the California Legislature mandated that the California Energy Commission (CEC) update California's state-level inventory of greenhouse gas (GHG) emissions by January 1, 2002. This paper discusses the results of this inventory development effort, including (a) the process of harmonization with data and research results from other California state agencies and institutions, (b) trends in California's GHG emissions from 1990-2000, and (c) ongoing efforts to improve and refine these emission estimates for a revised inventory (expected to be completed in late 2002). Previous GHG inventories for the state of California suggested that emissions remained relatively stable from 1990-1994. The results presented here extend the time series to 1999 and include estimates for several previously omitted source categories, including several types of industrial processes, various agricultural sources, and wastewater treatment. In addition, the inventory employs emission estimation methodologies that are consistent with the Emission Inventory Improvement Program guidance, the *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-1999*, and the Intergovernmental Panel on Climate Change (IPCC) guidance. By late summer 2002, CEC plans to further improve the data sources, emission factors, and methods to include emissions estimates for the year 2000, and to reflect 2000 IPCC Good Practice Guidance, methods from the *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2000*, and results of ongoing research funded by the CEC.

INTRODUCTION

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

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

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

- **Statewide:** The inventory includes estimates of emissions across the state of California.
- **Sectors:** The inventory estimates emissions from five major sectors – Energy, Industrial Processes, Agriculture, Forestry, and Waste.
- **Thirty GHG Sources:** The inventory provides emissions from thirty sources of emissions and sinks. There are several sources for which data were not available at the state level; however, estimates of emissions from some of these sources may be improved or developed for subsequent inventories as data become available.
- **Six GHGs:** The inventory captures emissions of six GHGs: CO_2, CH_4, N_2O, PFCs, HFCs, and SF_6.
- **Time Series:** The inventory includes emissions for a ten-year period from 1990 through 1999.

The methods used to develop estimates for this inventory are consistent with the *Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories*[1] and with the *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-1999*.[2] Where possible, data from state agencies were used to develop emission estimates. In cases where state agencies were unable to provide the necessary data, estimates reflect state-level data that was collected by states but reported at a national level.

INVENTORY DEVELOPMENT

The California inventory project began with a kickoff meeting at the California Energy Commission in late September. At the kickoff meeting, the project team (ICF Consulting and Sonoma Technology, Inc. [STI]) presented the proposed approach to representatives of state agencies, agreed on sources for inclusion in the inventory, requested data from state representatives, and adopted an aggressive (four-month) schedule for completing the inventory.

Data collection began immediately, with the in-state sources collected by STI. State entities that provided data are listed below, followed by a brief description of the type of data they provided.

- California Air Resources Board provided activity data for on-road mobile sources, which were extracted from EMFAC2000.
- California Department of Food and Agriculture provided data on fertilizer consumption.
- California Department of Forestry and Fire Protection provided information about carbon sequestration by forests.
- California Public Utilities Commission provided information about gas pipelines.
- California Integrated Waste Management Board provided data on waste disposal in landfills.
- California State Horseman's Association provided information about horse populations.
- California Department of Conservation, Division of Oil, Gas, and Geothermal Resources provided information about oil and gas production rates and wells.
- California waste incineration facilities individually provided annual quantities of waste processed.

- University of California at Davis, Agricultural Extension Office, provided estimates of livestock populations and typical animal mass.
- California Rice Commission provided acres of rice cultivated and harvested.
- California Department of Mines provided information on coal mine production and closures.
- The California office of the USDA Natural Resources Conservation Service provided information on histosol cultivation.

As data became available, ICF developed protocols to document data sources and emission estimation methods. In some cases, we filled in data gaps with state-level data available at the federal level. We chose the most appropriate method for estimating emissions from one of three sources:

- *Revised 1996 Intergovernmental Panel on Climate Change (IPCC) Guidelines for National Greenhouse Gas Inventories*,
- Emission Inventory Improvement Program (EIIP), Volume VIII, *Estimating Greenhouse Gas Emissions*, and
- *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-1999*.

Where possible, we used California-specific emission factors. In many cases, however, we had to rely on national or regional default emission factors. Once the protocols were approved by the CEC, we developed estimates of emissions and reported the results in the draft *Inventory of California Greenhouse Gas Emissions and Sinks: 1990-1999*.

SUMMARY OF GREENHOUSE GAS EMISSIONS IN CALIFORNIA

Gross GHG emissions in California (i.e., emissions from all sources, without accounting for removals by sinks) increased approximately one percent from 425 million metric tons of carbon dioxide equivalent ($MMTCO_2$ Eq.) to 428 $MMTCO_2$ Eq. from 1990 to 1999 (Table 1). Carbon dioxide emissions from the combustion of fossil fuels accounted for the majority (more than 80 percent) of emissions throughout the period. Emissions from landfills and agricultural soil management each represented roughly three percent of annual emissions and were responsible for the majority of state methane and nitrous oxide emissions, respectively. Substitutes for ozone-depleting substances were the fastest growing source of emissions, increasing from roughly 0.1 $MMTCO_2$ Eq. in 1990 to 7.0 $MMTCO_2$ Eq. in 1999. This dramatic increase was due to the penetration of substitutes to ozone-depleting chemicals in the middle to late 1990s in response to the terms of the Montreal Protocol, an international treaty to reduce the emissions of ozone-depleting chemicals.

Land-use change and forestry activities in California resulted in net carbon sequestration from this sector. However, annual carbon removals from the atmosphere in the state decreased from more than 25 $MMTCO_2$ Eq. in 1990 to slightly less than 19 $MMTCO_2$ Eq. in 1999, offsetting six and four percent of gross GHG emissions, respectively.

Carbon dioxide emissions from fossil fuel combustion, cement production, and other sources dominated the emission profile in California throughout the ten-year period and accounted for 85 percent of gross emissions in 1999. Methane and nitrous oxide accounted for approximately seven and six percent of gross 1999 emissions, respectively. HFCs, PFCs and SF_6 accounted for the remaining two percent of gross 1999 emissions.

Table 1. California Greenhouse Gas Emissions and Sinks: 1990-1999 ($MMTCO_2$ Eq.).

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

Note: Emission totals in the “Carbon Dioxide” row exclude soils and forests. The emission estimates in this table have not been adjusted to account for emissions from bunker fuels, as those estimates are incomplete and highly uncertain.

EMISSIONS TRENDS AND CONTRIBUTING FACTORS

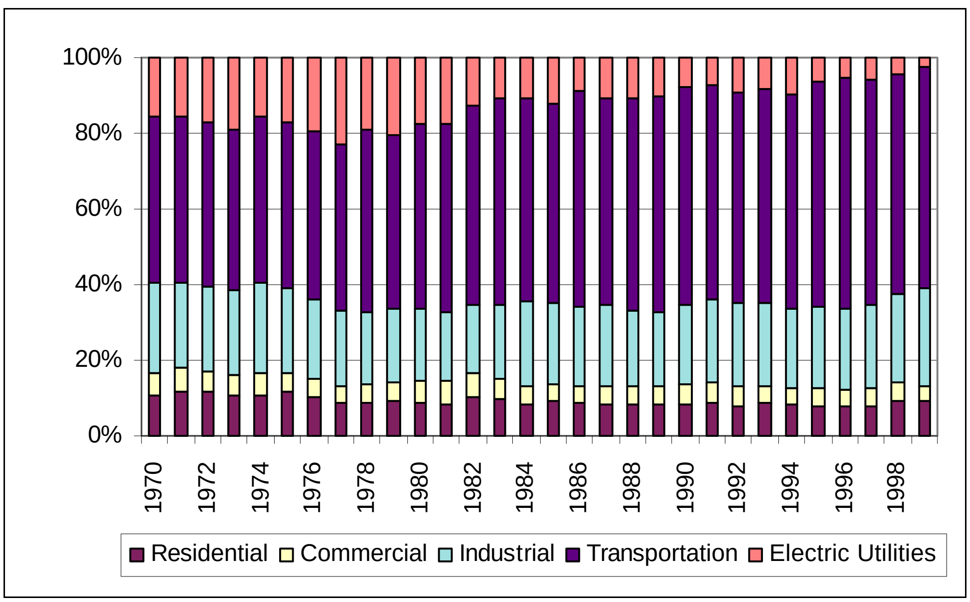
Net GHG emissions in California (i.e., emissions minus sequestration) increased approximately two percent from 399 $MMTCO_2$ Eq. in 1990 to 409 $MMTCO_2$ Eq. in 1999. Although California’s emissions of GHGs are increasing, the California trend is far more gradual than the national trend. Gross and net emissions in California increased one percent and two percent over the ten-year period, respectively, as compared to national increases of 12 percent and 16 percent. California’s gradual emission trend during the 1990s reflects the influences of California’s energy and air quality policies and a number of other underlying factors. The trend in CO_2 emissions from fossil fuel combustion from 1970 through 1999 is described below, with particular emphasis on the period from 1990 through 1999. This discussion is followed by a summary of the factors contributing to the trend in California’s GHG emissions.

Trends in Carbon Dioxide Emissions from Fossil Fuel Combustion in California from 1970 through 1999

Examination of a longer time period, from 1970 to 1999, provides an effective historical context for more recent, post-1990 emissions trends. Within this period, the trends and factors that affect emissions from 1990 to 1999 are emphasized because 1990 is the base year for the emission inventory and is the most common base year for GHG accounting efforts. California's emissions have remained relatively flat from 1970 through 1999. Emissions peaked in 1979 at approximately 400 $MMTCO_2$ Eq., and have remained below this level through 1999.

The relative importance of the energy end-use sectors with respect to total emissions has changed over time. Figure 1 shows the percentage that each sector contributed to total CO_2 emissions from fossil fuel combustion in each year. As shown in the figure, from 1970 to 1999 the contribution of the transportation sector increased from 42 percent in 1970 to 59 percent in 1999. The contribution of the transportation sector peaked in 1996 at about 61 percent. Also shown in Figure 1, the electric utility sector's share of emissions has declined. Energy and environmental policies drive this decline in part. However, sales of fossil-fuel electric power plants by electric utilities to industrial entities drive much of the apparent late-1990s decline in the emissions from the electric utilities sector. When such sales occur, the associated emissions simply transfer to the industrial sector from the electric utilities sector.

Figure 1. Changing mix of emissions by sector: CO_2 emissions in California from fossil fuel combustion.

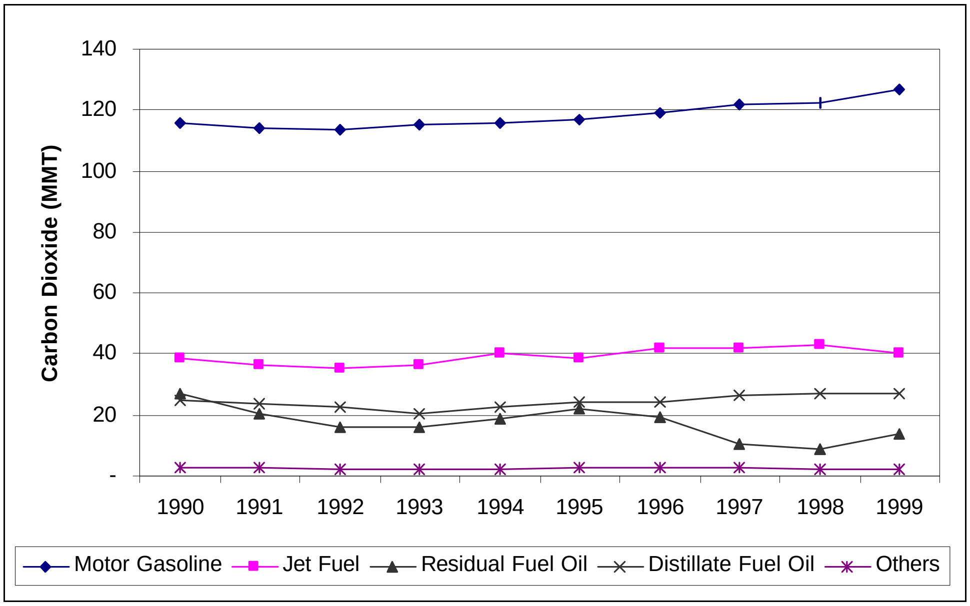


Shifts in fuels use underlie shifts in the contributions of each energy end-use sector to total emissions. Emissions from transportation fuels (motor gasoline and jet fuel) increased from 1970 to 1999. The emissions patterns for natural gas and residual fuel oil are more complex. In the early 1970s, natural gas emissions declined while residual fuel oil emissions increased rapidly. At that time, these fuels were interchangeable in many industrial applications, including electricity production. After the second oil price shock in the 1970s, the use of residual fuel oil declined significantly. To some extent, natural gas was the replacement fuel. Because natural gas has a lower carbon content than residual fuel oil, the switch helped to mitigate post-1970s CO_2 emissions.

During the period from 1990 through 1999, total CO_2 emissions from fossil fuel combustion first declined slightly and then increased. Total 1999 emissions estimates are about 0.5 percent less than

1990 estimates. As mentioned previously, the apparent rapid decline in emissions from electric utilities was due to transfers of ownership (and corresponding emissions) from utilities to non-utilities. Transportation emissions, the largest sector, mirror the trend in overall CO_2 emissions. Although the trend for the transportation sector is flat, emissions from combustion of motor gasoline are on the rise. As shown in Figure 2, emissions from motor gasoline increased by about 9 percent from 1990 to 1999. Emissions from residual fuel oil in the transportation sector declined significantly over the same period, which caused the total emissions from the sector to remain relatively flat. The factors contributing to this decline in transportation-related residual fuel oil emissions are discussed further below.

Figure 2. CO_2 emissions from fossil fuel combustion in the transportation sector by fuel type: 1990-1999.



Economic and Population Growth

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

In California, CO_2 emissions from fossil fuel combustion tracked economic and population growth in the early 1970s. Following the oil price shocks in the 1970s, and the resulting dislocations in the energy sector, the linkage between these emissions and economic growth appears to have de-coupled in the 1980s. This de-coupling is evidenced by the decline in emissions from 1979 through 1983 while the economy (measured as Gross State Product, GSP) and population grew. Emissions remained flat through 1986 and then started to grow slightly through the end of the decade. Economic and population growth both outpaced the growth in emissions during this period. In the early 1990s, the state economy contracted, and emissions declined. However, in the late 1990s, the economic boom in California was not accompanied by a commensurate increase in CO_2 emissions from fossil fuel combustion.

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

Structural changes to the California economy may have contributed to the reduction in emissions per unit of GSP. For the period 1990 to 1999, five sectors and sub-sectors of the state economy accounted for 75 percent of the state's economic growth. As shown in Table 2, these portions of the economy grew at a combined rate of 41 percent during this period. The remainder of the state economy grew at 13.9 percent, for an overall growth during the period of 27.8 percent (approximately 2.8 percent per year on average). As a result of their faster growth rates, these sectors comprised 56.6 percent of state GSP in 1999, up from 51.3 percent in 1990. These faster-growing sectors and sub-sectors of the economy have lower-than-average energy intensities. Consequently, the pattern of economic growth during the 1990s probably contributed to the decline in CO_2 emissions per unit of GSP. However, the extent of this impact has not been quantified.

Table 2. Growth rates for the fastest growing sectors in California: 1990-1999.

Sector or Sub-sector of the State Economy	Growth from 1990-1999	Portion of State GSP Growth from 1990-1999
Manufacturing – Industrial Machinery*	233%	11.5%
Manufacturing – Electronic Equipment	366%	16.5%
Manufacturing – Misc. Electronic Equipment and Instruments	169%	15.9%
Finance, Insurance, and Real Estate	15.3%	13.0%
Services	23.3%	18.8%
Total	41.1%	75.7%

Source: Bureau of Economic Analysis, 2001[3]
* This sub-sector includes the manufacture of computers (SIC 35: industrial and commercial machinery and computer equipment).

Energy Efficiency Policies

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

Under the auspices of the California Public Utilities Commission (CPUC), California's electric and gas utilities have undertaken significant efforts to improve the efficiency of electricity and natural gas use among residential and non-residential customers. From 1977 to 1995, the state's electric utilities spent a cumulative total of about \$125 per capita (1998 dollars) on energy efficiency programs for the industrial and commercial sectors.

The California Energy Commission recently conducted a retrospective analysis of the impact of past efficiency measures on in-state energy consumption as required by Sections 44 and 45 of Assembly Bill 1105 (Chapter 67, Statues of 1999).[4,5] This report, "A Proposal for a New Millennium," provides a comprehensive analysis of the energy savings of past energy efficiency programs that began in the mid-1970s. By 1990, energy efficiency efforts saved over 20,000 MWh per year and by 1999, energy efficiency savings approached 35,000 MWh per year. These savings are approximately 10 to 15 percent of the annual electricity consumption in the state. In the absence of these savings, additional electricity either would have been produced in-state or imported from other states. By preventing increases in electricity production during the 1990s, these savings helped moderate California's CO_2 emissions to a growth rate of only one percent from 1990 and 1999. Overall, energy savings, which include electricity savings, reduced California's GHG emissions by 7.1 $MMTCO_2$ Eq. Between 1990 and 1999.

Energy Supply and Environmental Policies

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

Air quality regulations that limit NO_x emissions favor the use of natural gas over residual fuel oil or other petroleum product in the industrial, commercial, and electric utility sectors. A secondary benefit of these regulations is a net reduction in GHG emissions, which primarily is due to the lower carbon content of natural gas relative to petroleum fuels.

California has been the national leader in the development of non-utility electric power generation. In 1991, non-utility generators in California and Texas produced about 53,000 and 49,000 GWh of electricity respectively, and together represented about 41 percent of the nation's non-utility electricity production. By establishing standard contracts, the CPUC was instrumental in the development of non-utility generation in California. Cogeneration has contributed the largest proportion of the non-utility generation. In 1997, the state's cogeneration power plants produced about 23.4 percent of the total in-state electricity generation. This compares favorably to a 9.5 percent contribution by cogeneration to total U.S. electricity generation for the same year. In addition, much of the non-utility generation is from renewable resources—California non-utility production of solar, wind, and geothermal resources has been higher than production of these resources in any other state. The substantial growth in these sources of electricity, primarily through the early 1990s, was an important factor that limited growth in CO_2 emissions from fossil fuel combustion.

California's reliance on nuclear energy and hydropower has also affected the trend in state GHG emissions. The increased reliance on nuclear energy in California constrained CO_2 emissions from the combustion of fossil fuels. Nuclear power generated less than 10,000 GWh per year from 1975 to 1983 and increased to almost constant levels of about 30,000 GWh per year after 1988. Since nuclear power does not emit CO_2 to the atmosphere, this increase helped to reduce the growth in emissions. Because nuclear power generation did not increase significantly in the 1990s, nuclear power had no appreciable impact on the emissions trend during the period from 1990 through 1999. In contrast, decreased water supply in 1990 led to corresponding increases in production at other types of power plants (mostly natural gas-fired plants). As a result, below-average hydropower production in 1990 is associated with emissions of 8.2 $MMTCO_2$ Eq. Hydro production increased after 1992, which moderated the effects of increased electricity generation on California's GHG inventory.

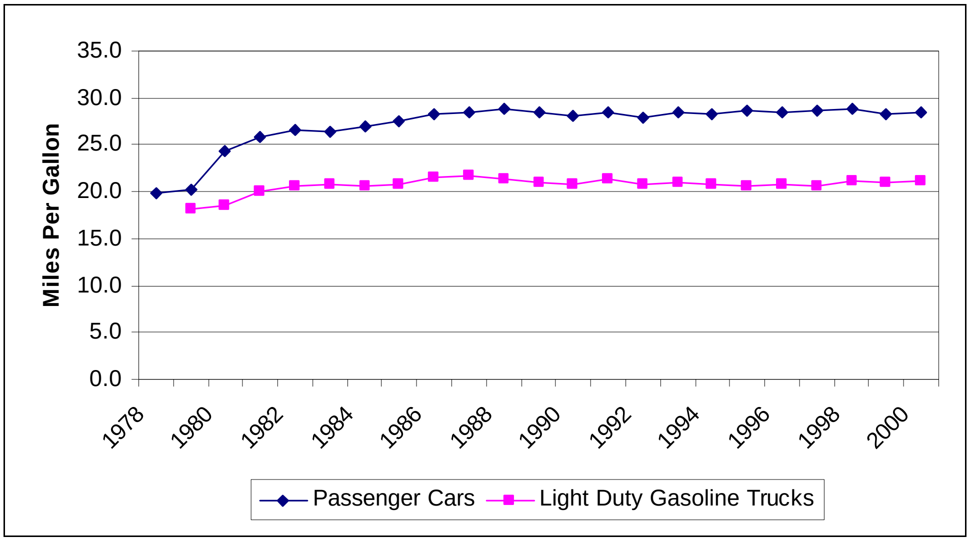
Transportation Issues

The trend in CO_2 emissions from fossil fuel combustion in the transportation sector was influenced by several inter-related factors. The largest source of emissions in this sector is from motor gasoline, which is used primarily in passenger cars and light-duty trucks (which include sport utility vehicles). Increases in vehicle miles traveled (VMT) for passenger cars and light duty trucks have driven increases in the use of motor gasoline. Counterbalancing the increases in VMT have been improvements in fuel economy.

Figure 3 shows that the fuel economy of new passenger cars sold in the U.S. increased substantially from 1978 through 1983, and then steadily through 1988, after which time it leveled off. Improvements were also realized in new light duty trucks although these improvements were smaller.

The improvements in fuel economy were the result of the corporate average fuel economy (CAFE) standards promulgated at the federal level.

Figure 3. Fuel economy of new vehicles by year sold: total U.S.



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

The CO_2 emission estimates for the transportation sector are also influenced by emissions from bunker fuels. According to the guidance for national- and state-level inventories, emissions from bunker fuels are to be estimated but not attributed to the national- or state-level totals. However, bunker fuels were not excluded from the California inventory due to data problems. As described in the inventory, bunker fuel data for the aviation sector were not available, and bunker fuel data obtained for marine vessels appeared to be inconsistent with state-wide fuel consumption data.

Nearly all of the residual fuel oil consumed in California in the 1990s was used for marine vessels. Emissions from residual fuel oil declined in 1991 and 1992, and then again in 1990. By 1999, CO_2 emissions from residual fuel oil in the transportation sector had declined 50 percent relative to 1990 levels, or about 13 $MMTCO_2$ Eq.

The initial drop in consumption of residual fuel oil in 1991 and 1992 may have been due to the adoption in 1991 of a new state tax on residual fuel oil sold as a fuel to marine vessels.[6] This tax was repealed in July 1992, with the repeal taking effect in January 1993. It is unclear why residual fuel oil sales did not recover after 1993. A possible explanation is that residual fuel oil production declined as the result of refinery modernizations that were required for the state reformulated gasoline program. The modernizations increased refineries' capacity to break down heavy petroleum compounds into lighter hydrocarbons, reducing the need to produce fuels with perhaps lower commercial value, such as residual fuel oil. This explanation is supported by an observed decrease in residual fuel oil production at the national level. According to the EIA, the federal Clean Air Act of 1990 "mandated reduction in various pollutants in fuels and in emissions from stationary sources. To produce these fuels required costly upgrades to refineries, which increased the costs of all petroleum products. These upgrades have also substantially reduced the amount of residual fuel oil that is produced, which tends to increase the price as well".[7]

Whatever the causes of the declines in the consumption of residual fuel oil in marine vessels in California in the 1990s, the impact on emissions from the transportation sector are clear. Without the reduction in residual fuel oil emissions, the CO_2 emissions from the transportation sector would have increased by about 8 percent from 1990 to 1999, rather than less than 1 percent. Consequently, it would be useful to understand the portion of the residual fuel oil emissions reduction that is associated with bunker fuels in order to better understand in-state emissions trends.

The U.S. Bureau of Transportation Statistics reports that in 1997, nearly 24 million metric tons were shipped from California ports to domestic destinations. This figure includes transfers to Alaska, intra-state commerce, Hawaii, the Pacific Northwest, the South Central region, and the Pacific Islands by tankers and barges. The foreign trade from California for the same year was roughly 43 million metric tons.[8] About 85 percent of the foreign trade (by tonnage) is to the Far East.[8] Since on average, more fuel may be needed for travel to foreign ports than to domestic ports, the share of fuel used for international transport should be higher than what can be estimated from just looking at the relative tonnage shipped to domestic and foreign ports. Informal contacts with firms selling residual fuel oil suggest that most of the fuel is used for international transport.[9] This view is confirmed by the limited data available for estimating these bunker fuel quantities. A rough estimate puts the bunker fuel emissions at about 21.8 and 10.6 $MMTCO_2$ Eq. for 1990 and 1999, respectively. After subtracting out the preliminary emission estimates for marine bunker fuels from state totals, California's total gross and net emissions in 1999 are about 3.4 and 5.5 higher than in 1990, respectively.

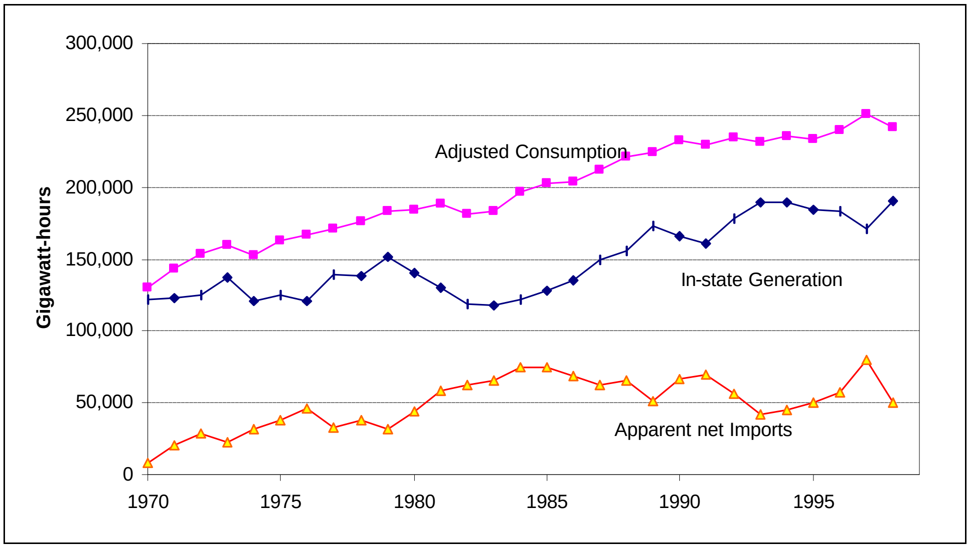
Although it was not possible to obtain an estimate of the proportion of jet fuel used for international air transport, it is reasonable to assume that that the amount of jet fuel used for international transport has increased over the past decade. Thus, if it were deducted from both the 1990 and 1999 emissions, it would be expected to reduce the overall growth in emissions somewhat.

Electricity Imports

The trend in CO_2 emissions from the combustion of fossil fuels indicated by the results of the draft inventory is also influenced by the fact that California has increased its dependence on imported electricity since the early 1970s. By convention, emissions associated with electricity produced in other states are excluded from state GHG inventories.[10]

Figure 4 presents the amount of electricity consumed in California as reported in a draft California Energy Commission Staff Report.[11] This figure also presents the amount of in-state electricity generation as reported by the Energy Information Administration, which includes generators with an installed capacity of at least 1 MW. The total generation figure includes non-utility generation starting in 1983, which, as discussed earlier, is an important source of electricity in California. Data on non-utility generation prior to 1983 are not available. However, it is believed that non-utility generation, which includes self-generation, was minimal before the 1980s (prior to the effects of the Public Utility Regulatory Policies Act).

Figure 4. In-state electricity generation, electricity consumption, and apparent net import of electricity to California.



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

It is difficult to estimate the emissions associated with these electricity imports, particularly for the beginning of the period (the mid-1970s) due to a lack of data on energy transactions. If it is assumed that emissions from out-of-state power plants in the mid-1970s had the same emissions rate as those of the mid-1990s (about 800 metric tons of CO_2 per GWh),[12] then annual out-of-state emissions to supply California electricity would have increased by about 16 $MMTCO_2$ Eq. over that period. This represents about 5 percent of California's CO_2 emissions in the 1990s. However, it is important to note that if these out-of-state power plants were subject to California rules and regulations, they most likely would have been natural gas burning units with lower CO_2 emissions rates.

The California Department of Finance publishes information on imported electricity in their annual California Statistical Abstract based on data provided by the CEC. The data breaks out the electricity imports that are generated by out-of-state power plants that are owned by California utilities. Using these data, and assumptions about emissions per GWh for imported electricity from the Pacific Northwest and Pacific Southwest, it is estimated that the CO_2 emissions associated with the imported electricity is on the order of 67.5 $MMTCO_2$ Eq. in 1990 and 73 $MMTCO_2$ Eq. in 1999. While these emissions would increase the total state inventory, they do not significantly influence the trend in emissions during the 1990s because they increase by only 5.5 $MMTCO_2$ Eq., or less than 2 percent of annual emissions from fossil fuel combustion.

Other Contributing Factors

Although CO_2 emissions from fossil fuel combustion dominate the state GHG emissions inventory, trends in the emissions of other gases and sources are significant during the 1990 to 1999 period. In particular, emissions of compounds that replaced stratospheric ozone-depleting substances increased by 7 $MMTCO_2$ Eq. from 1990 to 1999. This is one of the largest increases of any individual emissions source over this period. The 7 $MMTCO_2$ Eq. decline in the annual rate of carbon sequestration (sinks) also contributes to increased net emissions over the 1990 to 1999 period.

As a result of requirements to control emissions of volatile organic compounds (VOCs), CH_4 emissions from landfills were reduced through the implementation of landfill gas recovery/combustion systems. In some cases, these systems are used for energy generation. Emissions from landfills were reduced from 17 $MMTCO_2$ Eq. in 1990 to about 13 $MMTCO_2$ Eq. in 1999. Policies requiring the diversion of organic wastes from landfills also helped to reduce CH_4 emissions from landfills by reducing the amount of waste in landfills that is available to degrade into CH_4. The impacts of these waste diversion policies on CH_4 emissions have not been quantified.

Nitrous oxide (N_2O) emissions from gasoline passenger vehicles and light duty trucks have also been influenced by environmental control policies. Estimates in the inventory reflect the increase in N_2O emissions associated with the early catalyst technologies for controlling VOC. Subsequent improved catalysts (Tier 1 and LEV) have reduced N_2O emissions. As a result of the penetration of the new control technologies into the vehicle fleet, the N_2O emissions from gasoline vehicles declined by about 0.6 $MMTCO_2$ Eq. between 1990 and 1999.

Summary of These Factors on Emissions Trends

The overall impacts of policies and socioeconomic factors on emissions and emissions trends are summarized in Table 3. As shown in the table, the many of the factors discussed above reduced emissions in both 1990 and 1999. In contrast, the inclusion of bunker fuels from the inventory produces a positive bias in the emissions estimates for both years. Electricity imports were the largest determinant factor in emissions estimates for these two years.

For those factors that have been quantified, the emission trend from 1990 to 1999 is reduced by approximately 36 $MMTCO_2$ Eq. In other words, were it not for these factors, gross emissions in California would have increased by about 36 $MMTCO_2$ Eq., or about 8 percent from 1990 to 1999 as opposed to the 1 percent and 2 percent rise in gross and net emissions, respectively, excluding bunker fuels. Although not quantified, the impact of the cogeneration and renewable resources policies are probably significant, both in terms of their impacts on emissions in 1990 and 1999, and their impact on the emissions trend during this period.

LESSONS LEARNED AND POTENTIAL IMPROVEMENTS

The CEC is currently undertaking several efforts to improve GHG accounting in the state. Short-term activities will include revising the *California Inventory of Greenhouse Gas Emission and Sinks: 1990-1999* to reflect (1) a detailed analysis of imported electricity currently being conducted by researchers at Lawrence Berkley National Laboratory, (2) improved data and methods for several sources, including bunker fuels; (3) estimates of emissions through the year 2000, and (4) analyses of the uncertainties associated with emission estimates. The Commission is also in the process of drafting a long-range research plan for improving the quality of activity data and methods used to estimate state emissions.

Table 3. Summary impact of policies and other factors on emissions: 1990-1999.

Policies and Other Factors Affecting Emissions	Impacts on Emissions Inventory ($MMTCO_2$ Eq.) 1990	Impacts on Emissions Inventory ($MMTCO_2$ Eq.) 1999	Impacts on Emissions Growth, 1990-1999 ($MMTCO_2$ Eq.)
Energy Efficiency Policies and Standards	-15.5	-22.6	-7.1
NO_x and VOC Emissions Controls and Conversion to Natural Gas	Not Quantified. Fuel switching began in the 1980s for economic reasons.		Reduced the rate of emissions growth.
Cogeneration and Renewable Resources	Not quantified. Reduced emissions.		Reduced the rate of emissions growth.
Below Average Hydro Power in 1990	+8.2	Not Applicable	-8.2
Electricity Imports	-67.5	-73.0	-5.5
Federal Vehicle Fuel Economy Standards	Not quantified. Reduced emissions.		Reduced the rate of emissions growth.
Bunker Fuel Emissions	+21.8	+10.6	-11.2
VOC Emissions Controls from Landfills	0.0	-4.0	-4.0

Note: Negative values indicate that the policy or factor reduced emissions or reduced the growth in emissions from 1990 to 1999. All values are in $MMTCO_2$ Eq.

DISCLAIMER

This paper reports the authors' findings and does not necessarily reflect the views and policies of the California Energy Commission.

REFERENCES

1. Intergovernmental Panel on Climate Change. *Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories*, Houghton, J.T.; Meira Filho, L.G.; Lim, B.; Treanton, K.; Mamaty, I.; Bonduki, Y.; Griggs, D.J.; Callender, B.A. (Eds.); Intergovernmental Panel on Climate Change, Organization for Economic Co-Operation and Development, International Energy Agency, Paris, France. 1997.

2. U.S. Environmental Protection Agency. *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-1999*, U.S. Environmental Protection Agency, Washington, DC, April 2001; EPA 236-R-01-001.

3. Bureau of Economic Analysis. “Regional Accounts Data: Gross State Product Data”; Internet site maintained by the Bureau of Economic Analysis, U.S. Department of Commerce, Washington, D.C. Last updated June 2001.
(Available at http://www.bea.doc.gov/.)

4. California Energy Commission. “The Energy Efficiency Public Goods Charge Report, Technical Appendix A, A Proposal for a New Millennium”; Report P400-99-020 prepared by the California Energy Commission, Sacramento, CA. December 1999.

5. Marshall, L., Smith, D. November 2001. California Energy Commission, Sacramento, CA, *data provided through personal communication*.

6. Franco, G., Loyer, J. "Historical and Forecasted GHG Emissions Inventories for California" ; In *Proceedings of a Specialty Conference, Emission Inventory: Planning for the Future, Volume 1*; Air and Waste Management Association and U.S. Environmental Protection Agency: Research Triangle Park, NC, October 28-30, 1997.

7. Energy Information Administration. "Fuel Oil and Kerosene Sales 1995"; Report DOE/EIA-0535(96), Prepared by the Energy Office of Oil and Gas, Information Administration, U.S. Department of Energy, Washington, D.C. August 1996.
(Available for download, http://www.eia.doe.gov/pub/oil_gas/petroleum/data_publications/fuel_oil_and_kerosene_sales/historical/1995/foks_1995.html

8. U.S. Department of Transportation. "Maritime Trade & Transportation 1999"; Report BTS99-02U.S., prepared by the U.S. Coast Guard, Maritime Administration, Bureau of Transportation Statistics, U.S. Department of Transportation, Washington, D.C. 1999.

9. Metz, D. January 2002. California Energy Commission, Sacramento, CA, *personal communications*.

10. Emission Inventory Improvement Program (EIIP). "EIIP Volume VIII, Estimating Greenhouse Gas Emissions"; From the EIIP Guidance Document Series prepared by the Emission Inventory Improvement Program. October 1999.
(Available for download, http://www.epa.gov/ttn/chief/eiip/techreport/volume08/index.html.)

11. "2002-2012 Electricity Outlook Report"; Report P700-01-004, Staff draft report prepared by the California Energy Commission, Sacramento, CA. November 2001.

12. California Energy Commission. "Fuel-Resources Profiles of Electricity Generation and Related CO_2 Emissions for the State of California"; Report prepared by the California Energy Commission, Sacramento, CA. February 19, 1998.