Title
Spatial Disaggregation of CO2 Emissions for the State of California

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Spatial Disaggregation of CO_2 Emissions for the State of California

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Executive Summary

This report allocates California's 2004 statewide carbon dioxide (CO_2) emissions from fuel combustion[1] to the 58 counties in the state. The total emissions are allocated to counties using several different methods, based on the availability of data for each sector. Data on natural gas use in all sectors are available by county. Fuel consumption by power and combined heat and power generation plants is available for individual plants. Bottom-up models were used to distribute statewide fuel sales-based CO_2 emissions by county for on-road vehicles, aircraft, and watercraft. All other sources of CO_2 emissions were allocated to counties based on surrogates for activity. CO_2 emissions by sector were estimated for each county, as well as for the South Coast Air Basin. It is important to note that emissions from some sources, notably electricity generation, were allocated to counties based on where the emissions were generated, rather than where the electricity was actually consumed. In addition, several sources of CO_2 emissions, such as electricity generated in and imported from other states and international marine bunker fuels, were not included in the analysis. California Air Resource Board (CARB) does not include CO_2 emissions from interstate and international air travel, in the official California greenhouse gas (GHG) inventory, so those emissions were allocated to counties for informational purposes only. Los Angeles County is responsible for by far the largest CO_2 emissions from combustion in the state: 83 Million metric tonnes (Mt), or 24% of total CO_2 emissions in California, more than twice that of the next county (Kern, with 38 Mt, or 11% of statewide emissions). The South Coast Air Basin accounts for 122 $MtCO_2$, or 35% of all emissions from fuel combustion in the state. The distribution of emissions by sector varies considerably by county, with on-road motor vehicles dominating most counties, but large stationary sources and rail travel dominating in other counties.

The CO_2 emissions data by county and source are available upon request.

[1] This represents about 75% of total emissions. In this report only CO_2 emissions from fuel combustion are considered, which corresponds to the Intergovernmental Panel Climate Change (IPCC) main source category 1A. Emissions from IPCC categories 2 to 5: Industrial and Product Use; Agriculture, Forestry, and Other Land-Use; and Waste are not included in the spatial disaggregation. See Section 1.1. fro further information.

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List of Abbreviations and Acronyms

ATC	Available Transfer Capability
BTS	Bureau of Transportation Statistics
CALEB	California Energy Balance Database
CARB	California Air Resources Board
CEC	California Energy Commission
CHP	Combined Heat and Power
CO_2	Carbon Dioxide
EEA	European Environment Agency
EIA	Energy Information Administration
EMFAC	CARB emissions model for calculating on-road vehicle emissions
FHWA	Federal Highway Administration
GHG	Greenhouse Gas
IPCC	Intergovernmental Panel on Climate Change
kW	Kilowatt
LBNL	Lawrence Berkeley National Laboratory
LPG	Liquefied petroleum gas
MW	Megawatt
Mt	Million metric tonne
NAICS	North American Industry Classification System
PCA	Portland Cement Association
SCAB	South Coast Air Basin
SCAQMD	South Coast Air Quality Management District
SEDS	State Energy Data System
Tbtu	Trillion British Thermal Unit
UNFCCC	United Nations Framework Convention on Climate Change
TEOR	Thermally enhanced oil recovery
TRB	Transportation Research Board
AAR	Association of American Railroads
FRA	Federal Railroad Administration
TWh	Terawatt hour

1. Introduction

Central to any study of climate change is the development of an emission inventory that identifies and quantifies the primary anthropogenic sources and sinks of greenhouse gas (GHG) emissions. Carbon dioxide (CO_2) emissions from fossil fuel combustion accounted for 86% of total California's GHG emissions in 2004. CO_2 emissions are well characterized at the State level; however no estimates exist at a more disaggregated spatial level, such as by county or air basin.

In September 2006 the California legislature passed Assembly Bill 32 (AB 32) the California Global Warming Solutions Act of 2006, which caps California GHG at 1990 levels by 2020. In order to effectively implement the cap, AB 32 directs the California Air Resources Board (CARB) to determine the statewide GHG level in 1990 and approve in a public hearing the 2020 limit equivalent to that level. In 2005, Lawrence Berkeley National Laboratory (LBNL) developed the California Energy Balance (CALEB) database which manages highly disaggregated data on energy supply, transformation, and end-use consumption for each type of energy commodity from 1990 to the most recent year available, in the form of an energy balance (Murtishaw et al., 2005). The CALEB database has since been used by CARB to construct the latest version of the California GHG Inventory.

This report provides an alternative view of emissions by showing where in California the major sources of emissions are located. Emissions for each individual county are estimated, based on where fossil fuel is consumed rather than where energy services are provided. For example, in the case of electricity, we allocate energy use to the counties in which electricity generation occurs, rather than the counties in which electricity is ultimately consumed. This report indicates where the major sources of CO_2 emissions in the state are located, in order to provide policy-makers information on the geographical ramifications of possible CO_2 emission reduction strategies.

The second part of the report provides an estimation of the CO_2 emission inventory for the South Coast Air Basin (SCAB). The SCAB covers a substantial part of southern California and is the source of a significant fraction of California's CO_2 emissions. Two of the three largest marine ports in California, much of the state's refinery facilities, significant stationary sources, as well as 43% of the population, are located within the SCAB. Understanding the SCAB CO_2 emission profile, finding ways of validating these on a sector-by-sector basis, and providing a validation approach to the statewide GHG emission inventory through disaggregation is an important step in building AB32 GHG emissions inventory baselines and projections. This report provides the necessary disaggregated sector-by-sector information that can then be evaluated using information from local sources.

2. Methodology

2.1 CO_2 Emissions

The estimates of CO_2 emissions from fuel combustion calculated in this report follow the Intergovernmental Panel on Climate Change's (IPCC's) *Revised 1996 IPCC Guidelines for*

National Greenhouse Gas Inventories (IPCC, 1996). The IPCC Guidelines allow Parties under the United Nations Framework Convention on Climate Change (UNFCCC) to estimate and report on national inventories of anthropogenic GHG emissions and removal. Inventories are divided according to six source categories: *Energy, Industrial Processes and Product Use, Agriculture, Forestry and Other Land-Use, and Waste Sectors* (see Table 1).

Table 1. IPCC main source categories

1- Energy
1- A- Fuel Combustion Activities
1- B- Fugitive Emissions from Fuels
1- C- Carbon Dioxide Transport and Storage
2- Industrial Processes and Product Use
3- Agriculture, Forestry and Other Land Use
5- Waste
6- Other
Memo Items:
International Aviation Bunkers
International Marine Bunkers
CO_2 Emissions from Biomass

Source: IPCC, 2006

The category Energy is itself divided into three sub-categories. The first sub-category refers to GHG emissions from fuel combustion activities, the second sub-category to fugitive emissions from fuels and third refers to carbon dioxide (CO_2) capture and storage sequestration (CCS). Emissions estimated in this report are related to the first subcategory only: emissions from fuel combustion activities and only CO_2 emissions are considered. This comprises the most significant contributor to GHG emissions. For example, in 2004, CO_2 emissions from fuel combustion in California accounted for 86% of total emissions (CARB, 2007). Fugitive emissions from fuels refer to intentional or unintentional releases of gases occurring during the production, processing, transport, storage, or use of fuels (e.g., methane emissions from coal mining). These emissions are not included in this report. It is important to note that CO_2 emissions resulting from electricity generation are accounted in the "electric sector" and not in the end use sectors where the electricity is ultimately consumed.

2.2 Bottom-up versus Top-down Approach

There are three main approaches to estimate CO_2 emissions. One method consists of gathering data on fuel sales by activity for each county. For example, county level data on natural gas consumption by sector of activity were gathered from the California Energy Commission (CEC), which collects data from utilities and other large suppliers. The CO_2 emissions are then calculated based on reported data of natural gas consumption, and hence are very precise. However, this level of detail is not available for every fuel type or for each sectoral activity. For example, petroleum fuel sold in California is not reported by end use consumption. In this case, it is necessary to survey major consumers. For example, the U.S. Energy Information Administration (EIA) requires that all utility and non-utility electric generating plants in the United States with a nameplate rating of 1 megawatt (1000 kW) and above that are connected to the electric grid submit their energy consumption through a monthly questionnaire (EIA-

906) (EIA, 2007a). The information that the EIA collects is available for each individual plant. In this case, it is also possible to estimate precisely the CO_2 emissions associated with the energy consumption for each plant in each county.

When this type of consumption survey is not available or plant-level data are kept confidential, then two methods exist to estimate emissions at the county level. The first method consists of constructing a bottom-up approach where end use consumption is estimated based on detailed information about the consumers. For example, emissions from on-road vehicles were based on CARB's EMission FACtors model (Eslinger, 2008) (CARB, 2008), where emission rates are multiplied by vehicle counts and activity data provided by the regional transportation agencies to calculate various emission inventories (county, air basin, etc.). The estimated fuel use by county are then scaled so that the sum of the county fuel consumption equals the statewide fuel sales data in the GHG inventory. The second method, which is less precise, consists of allocating statewide emissions to counties based on county-level activity data. For example, in the case of coal consumption by cement plants, only the state level emissions are made publicly available. Therefore, emissions at the plant level were estimated based on the capacity of production of each cement plant in California. This last approach is a quick approximation that needs to be taken with precaution. Estimates for these sectors at the county level are associated with large uncertainties range.

Hence, the accuracy of resulting CO_2 emission estimates at the county level varies by fuel type.

Table 2 summarizes the different data sources and methods used in this report. Natural gas and fuel used for electricity and heat generation, which represent 37% of the state's CO_2 emissions, are rather precise. Emissions from on-road vehicles, marine and aviation, however, are based on bottom-up models that provide a good approximation. Finally, end uses such as cement manufacture, petroleum refining, and rail travel are the least accurate, since they are estimated based on county-level activity data. Different methodologies are used for each sector, reflecting differences in data availability.

Table 2. Methods used to allocate CO_2 emissions to counties, by sector and fuel

Sector	Method	Source	Share of total CO_2
	Sales data and consumer survey		
Residential: Natural Gas	Sales data	CEC (2007)	8%
Commercial: Natural Gas	Sales data	CEC (2007)	3%
Industry: Natural Gas	Sales data	CEC (2007)	5%
Agriculture: Natural Gas	Sales data	CEC (2007)	0%
Mining: Natural Gas	Sales data	U.S. EIA (2007a)	4%
Electricity & CHP Plants	Consumer Survey	U.S. EIA (2007a)	17%
	Hybrid (combined Bottom-Up & Top-Down)		
On-road vehicles	CARB EMFAC model & sales data	CARB (2008)	48%
Aviation	LBNL estimate of fuel used by intrastate aircraft & sales data	US BTS (2007), EEA (2006)	1%
	Bottom-Up		
Marine	CARB Model	(Alexis, 2008)	1%
	Top-down		
Refineries: Petroleum & Natural Gas	Production capacity of individual refineries	U.S. EIA (2007b)	9%
Industry: Petroleum	Value of manufacturing shipments	US Census (2008)	1%
Commercial: Petroleum	Sales value of accommodation and food services, wholesale and retail trade	US Census (2008)	0%
Agriculture: Petroleum	Area of irrigated land	CA Water and Land Use (2004)	2%
Cement: Coal and Petroleum	Clinker capacity of individual plants	van Oss, H.G., 2007 and PCA (2004)	1%
Rail	Rail miles	FRA (2007)	1%

2.3 Geographical Boundary

In this report, we estimate CO_2 emissions by county and for the SCAB. We present absolute emission levels by sector, fuel type, and county, as well as levels per capita and per square mile. There are 58 counties in California, each with a different land area and population density. California is also divided geographically into air basins for the purpose of managing regional air quality. An air basin generally has similar meteorological and geographic conditions throughout. There are 15 air basins in California. Appendix 1 provides a map of the counties and air basins in California.

Per capita emissions by county are calculated to show emissions in the county relative to the population density. The counties with the highest population densities tend to have the largest absolute emissions. However, some of these counties have the lowest CO_2 emissions per capita, because high population density supports mass transit, which has lower emissions per passenger-mile than light-duty vehicles. In addition, high density development supports other modes of transport, such as walking, bike riding, etc., that have essentially no CO_2 emissions. As mentioned previously, in this report CO_2 emissions from electricity are allocated to the county in which they were generated, not to the county in which the services they provide (lighting, heating/cooling, etc.) were used. Throughout this report we show data in terms of absolute emission levels in thousand metric tonne (kt) and in terms of emissions per capita.

The SCAB includes all of Orange County and the non-desert portions of Los Angeles, Riverside, and San Bernardino counties. The South Coast Air Quality Management District (SCAQMD) is the agency responsible for attaining state and federal clean air standards in the SCAB. The SCAB and the SCAQMD are not exactly the same area; the district includes the basin plus non-urbanized areas in three counties. However emission sources operating in the non-urbanized area are negligible, so we defined the SCAB as the set of zip codes in the district.

3. Overview

This report allocates California's 2004 emissions of 353 MtCO_2 to the 58 counties in California by sector. The CARB official 2004 inventory includes 480 Mt of GHGs, of which 350 Mt are CO_2 emissions from combustion of fossil fuels. Table 3 shows the sum of the LBNL estimate of emissions by county, by IPCC category, and compares it with the most recent CARB inventory for 2004 (CARB, 2008). Both sets of numbers compared in the table exclude 61 Mt CO_2 emissions from electricity generated in other states and imported into California, as well as 19 Mt from domestic US aviation, 13 Mt from international aviation, and 11 Mt from international shipping. Figure 1 shows the distribution of statewide CO_2 emissions by fuel and sector; following CARB convention, emissions from domestic and international air travel, and international shipping, are excluded from Figure 1.

Table 3. Comparison of CO_2 emissions from CARB inventory and LBNL estimate, by sector

IPCC categories	CARB inventory	LBNL estimate	Difference (LBNL/CARB)
Total GHG (MMTCO_2-e/yr)	479.7		
Total CO_2 (MMTCO_2/yr)	425.7		
1A - Fuel Combustion Activities	410.5		
Without Imports	349.8	352.5	0.8%
1A1 - Energy Industries	105.2	104.9	-0.3%
1A2 - Manufacturing Industries and Construction	19.3	23.3	17.2%
1A3 - Transport	177.7	178.5	0.7%
1A4 - Other Sectors	45.9	45.7	-0.2%
1A5 - Non-Specified	2.2	-	

Figure 1. 2004 California CO_2 emissions by fuel and sector

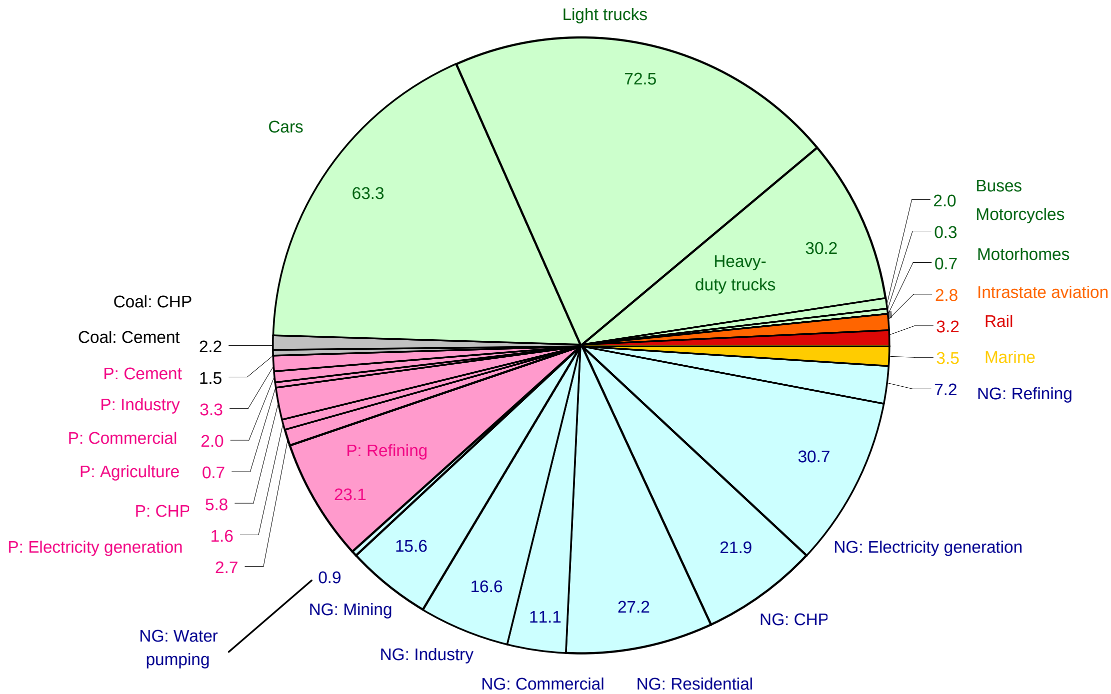


Figure 2 shows LBNL's allocation of CO_2 emissions by sector and county. Los Angeles County has by far the largest CO_2 emissions (83 Mt, 24% of state total), more than twice that of the next county (Kern County, 38 Mt, 11% of state total).

Figure 2. 2004 CO_2 emissions by sector and county

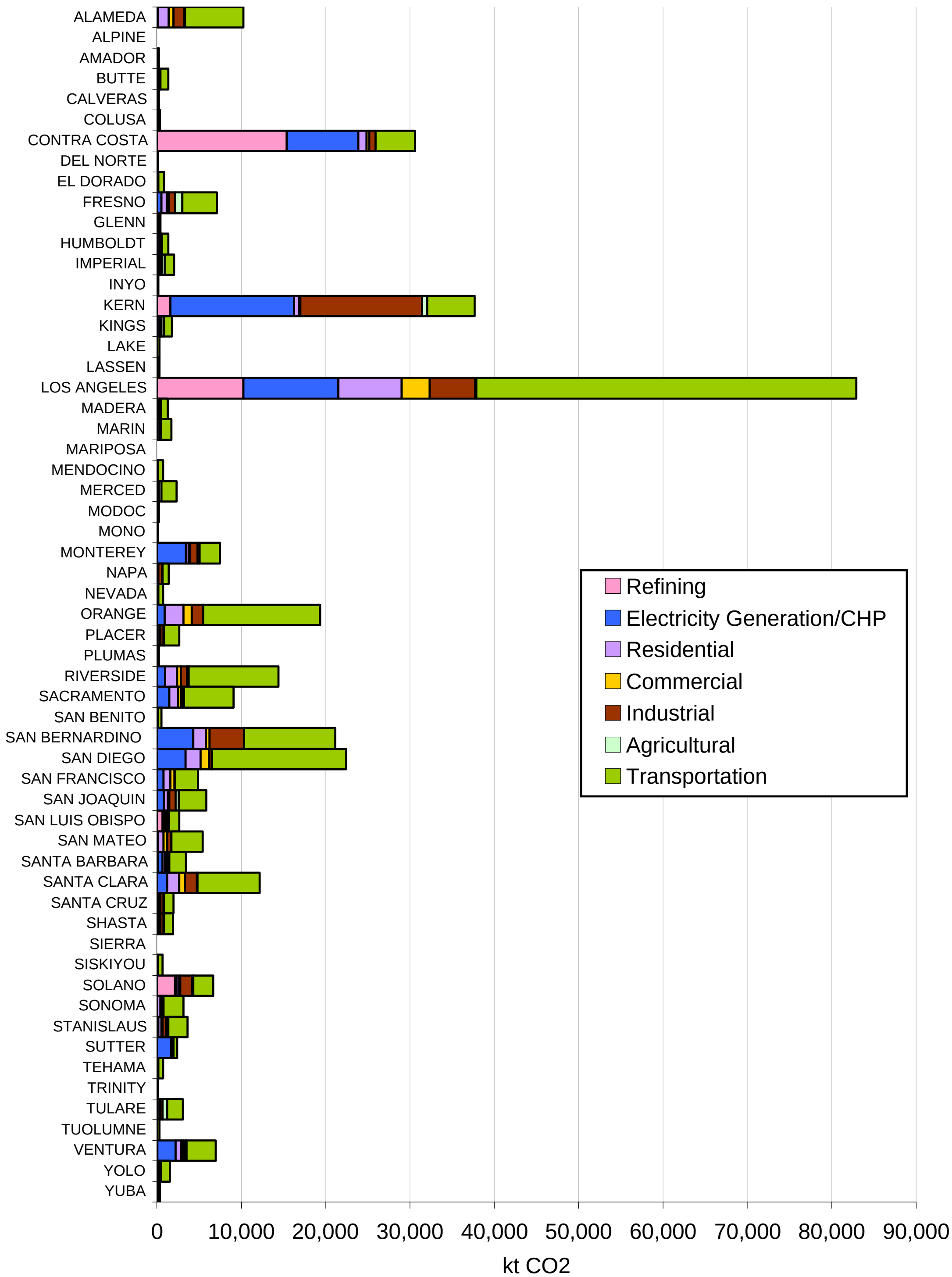


Figure 3 shows the sectoral distribution of CO_2 emissions by county. Transportation accounts for a large fraction of CO_2 emissions in most counties, more than 90% in some rural counties (Calaveras, Del Norte, Inyo, Lake, Mariposa, Trinity, and Tuolumne Counties). However, large stationary sources burning natural gas and petroleum are large sources in a few counties:

petroleum refining in Contra Costa and Solano Counties, electricity generation in Contra Costa, Kern, Monterey, Sutter, and Ventura Counties, industry in Kern and Napa Counties, and agriculture in Colusa, Modoc, and Sierra Counties.

Figure 3. Sectoral distribution of 2004 CO_2 emissions, by county

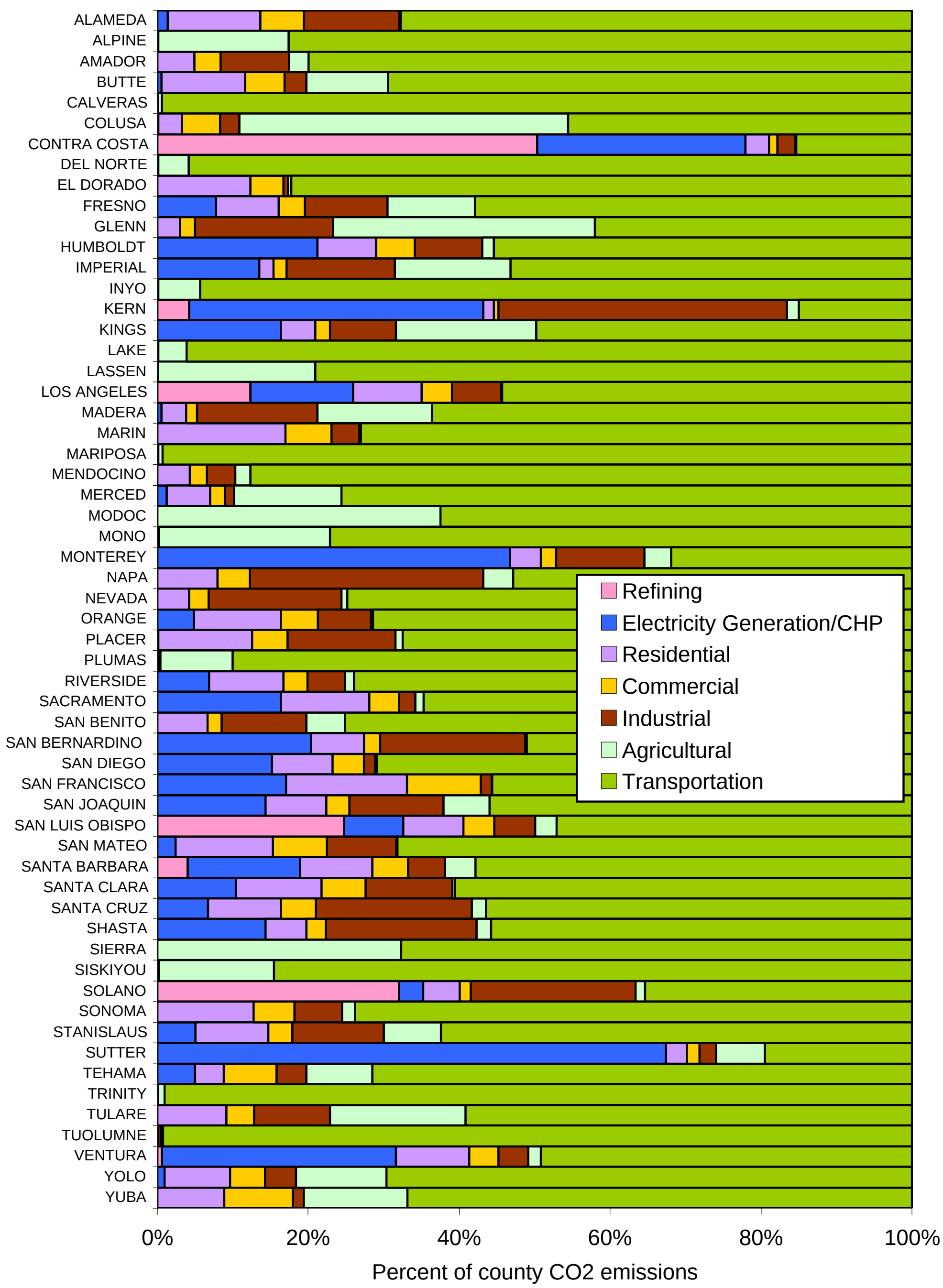
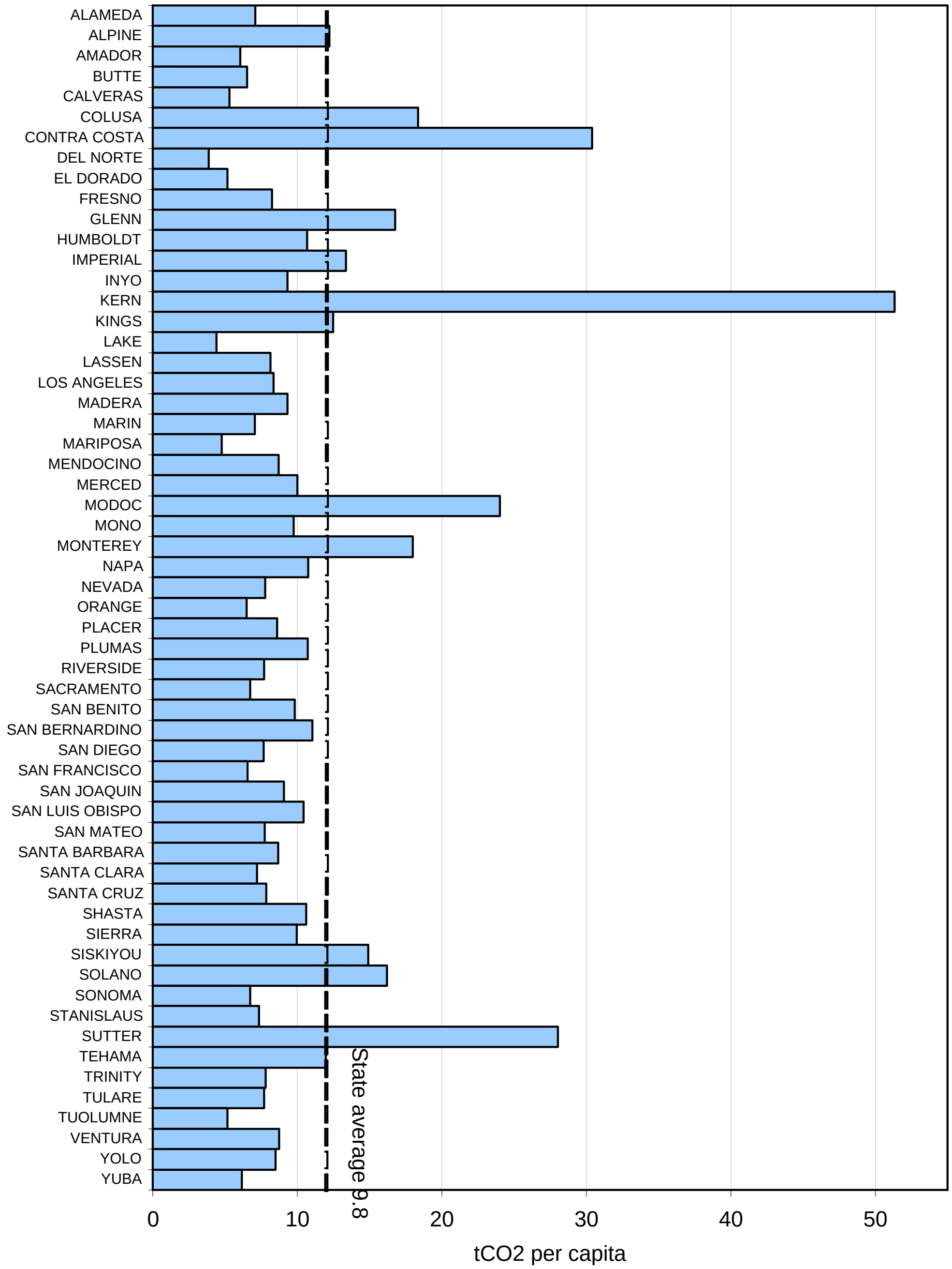


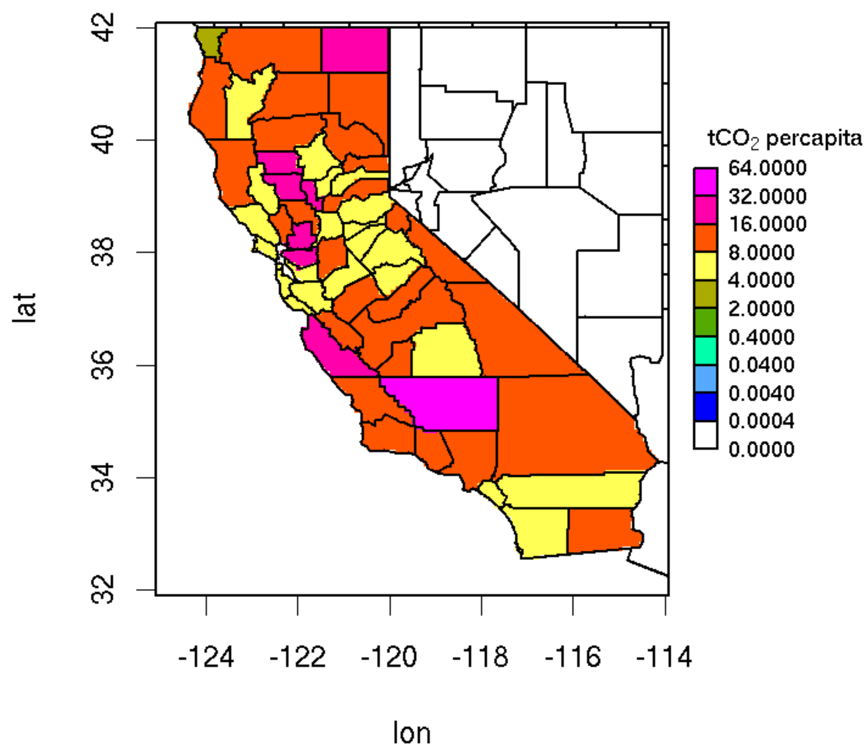
Figure 4 shows total CO_2 emissions per capita. Statewide CO_2 emissions are 9.8 tonnes per capita; however, several counties, such as Kern, Modoc, Contra Costa, and Sutter Counties, have much higher per capita CO_2 emissions. San Francisco, Sacramento and Orange Counties are among the most populated counties in California, but have very low emissions per capita.

Figure 4. Per capita CO_2 emissions (tonnes per capita) by county



Map 1 shows graphically the per capita emissions from Figure 4 above. Urban counties tend to have lower per capita emissions than rural counties.

Map 1. Per capita CO_2 emissions from fossil fuel combustion, by county



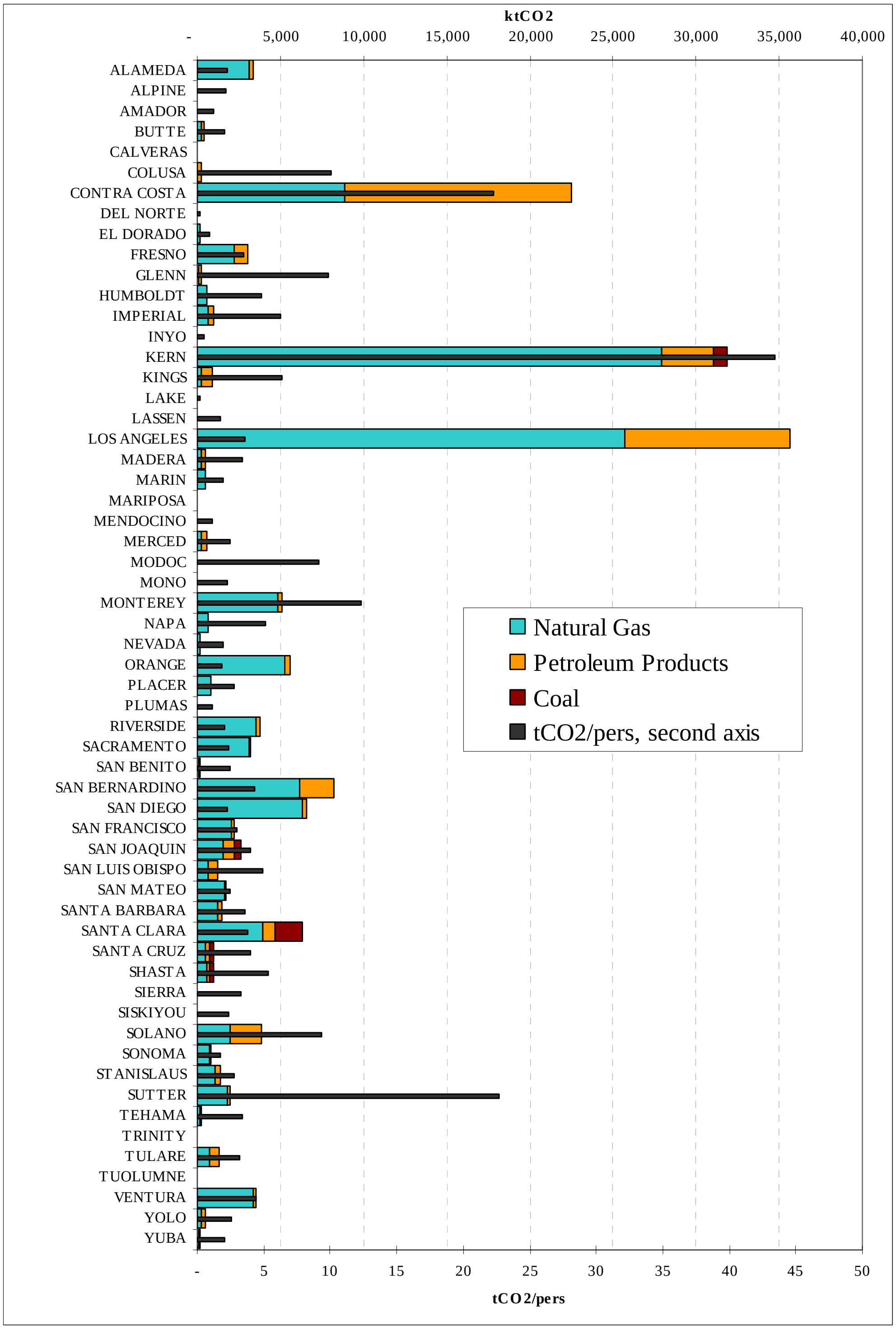
4. Stationary source emissions

4.1 Overview

The major source of energy-related emissions from stationary sources in California is natural gas used by electric and combined heat and power (CHP) plants, industrial plants, and consumers in residential and commercial buildings. The second major source of stationary source emissions is petroleum products used mostly by refineries and by CHP plants. Finally, coal consumption in cement plants is a small source of CO_2 emissions. Natural gas consumption represents 74% of the stationary CO_2 emissions, followed by petroleum products with a 24% share, while coal represents only 2%. Figure 6 shows the CO_2 emissions from stationary sources disaggregated to the county level. Los Angeles, Kern, and Contra Costa Counties are the largest sources of CO_2 emissions from stationary sources. In the case of Los Angeles, this is largely explained by its population and its size as CO_2 emissions per capita in Los Angeles County are only 3.6 tonnes of CO_2 per person, which is less than the state level of 4.79 tonnes CO_2 per person. High emissions in Kern County are due to oil extraction activity, while high emissions in Contra Costa County are due to both refinery activity and population density.

On the other hand, because of its small population, Sutter County has the second highest per capita CO_2 emission rate from stationary sources (24 tonnes per person) despite having a small absolute level of stationary source CO_2 emissions (1,970 kilotonnes CO_2).

Figure 5. Absolute and per capita CO_2 emissions by stationary sources, by fuel type and county



The following sections show, for each type of fuel, CO_2 emissions by major sector of activity. The different sources of data are discussed as well as the methodology used to allocate to the county level when data at this level were not available.

4.2 Natural Gas

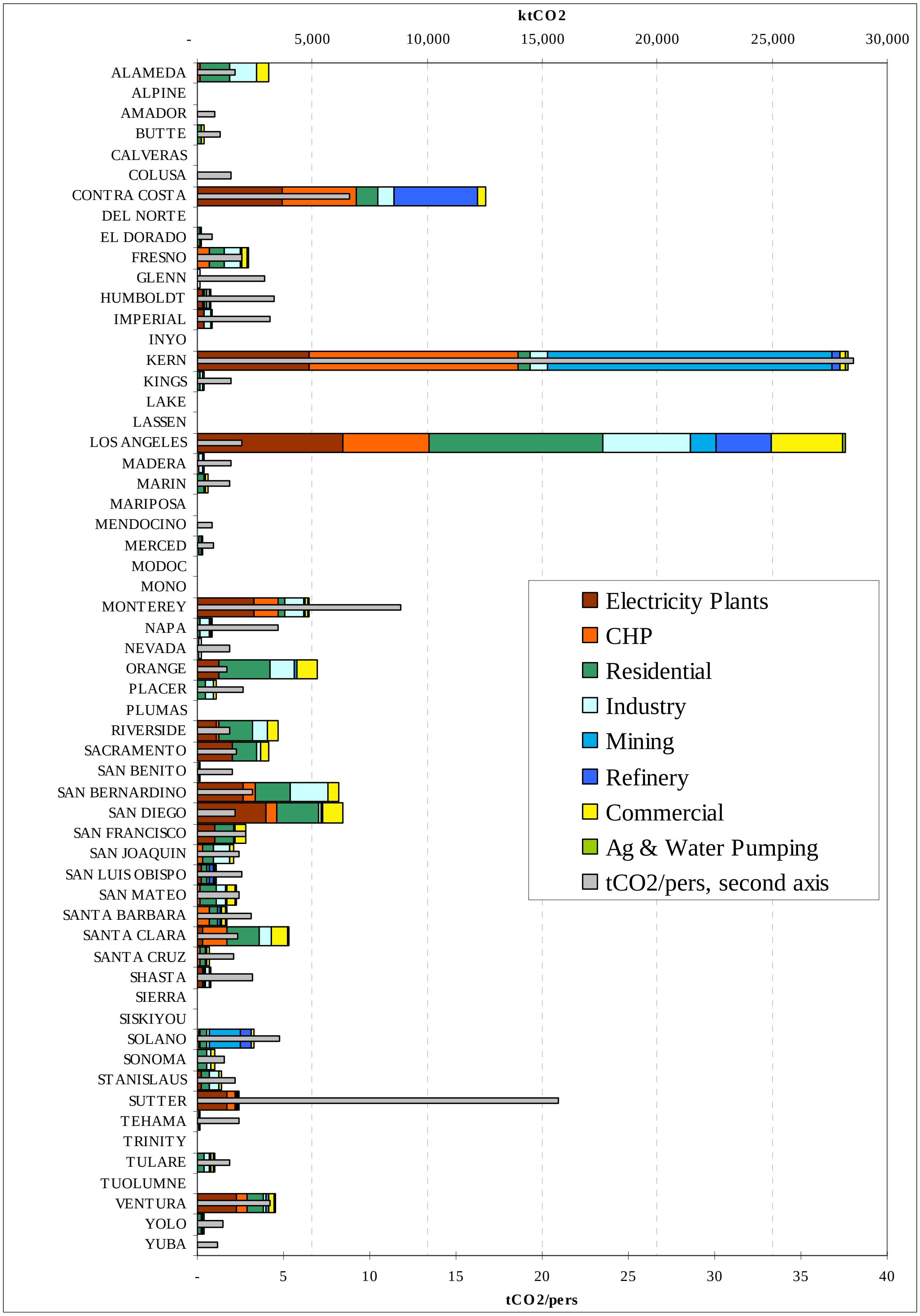
4.2.1 Overview

CO_2 emissions resulting from natural gas consumption are mostly concentrated in the most populous counties of California. The counties in two basins, SCAB and the San Francisco Bay Area Air Basin, have the highest CO_2 concentrations. This reflects the fact that natural gas is consumed by the population directly as well as to produce refined products and goods that are directed to the population. About a third of natural gas consumption is used in residential (22%) and commercial (9%) buildings, for space conditioning comfort, cooking and other end uses. Natural gas consumption is also largely used to generate electricity (25%) as well as for the cogeneration of heat and power (18%), which tend to be located in close proximity to the population areas. Finally, another quarter of natural gas is used by the industry (13%) and mining (13%) sectors. Industries also tend to be located not too far from population areas, while mining activity is highly concentrated in Kern County. Kern County accounts for 80% of emission related to natural gas consumption in the mining sector; Solano and Los Angeles counties, each account for 9% and 7% respectively.

Figure 6 shows absolute emissions (wide bars, top scale) and emissions per capita (narrow bars, bottom scale), by county. Kern County has the largest CO_2 emissions from natural gas combustion, closely followed by Los Angeles County. However, the sources in these two counties are very different: mining activity (44%) and combined heat-power (32%) are the largest sources of natural gas CO_2 emissions in Kern County, while electricity generation (29%) and residential end uses (25%) are the largest sources of natural gas CO_2 in Los Angeles. Kern County is home to several oil fields that are using thermal recovery to extract oil. Thermally enhanced oil recovery (TEOR) is a process whereby heavy oil is heated, usually by steam or hot water injection, to make it more fluid to pump from the reservoir. This extraction process uses large quantities of natural gas imported from Wyoming through a pipeline. In 2004, oil from Kern County accounted for over 69% of the state's total oil production, which represents approximately a quarter of the total California oil consumption (Sheridan, 2006).

CO_2 emissions from natural gas combustion per capita vary widely by county. Los Angeles County, which has a large source of CO_2 emissions, has low CO_2 emission per capita because of its large population. In contrast, because of its small population, Sutter County has the second highest per capita CO_2 emission rate from natural gas combustion, despite having a small absolute level of natural gas CO_2 emissions. Sutter County is home to several natural gas power and CHP plants operated by Calpine Corporation; the electricity generated by these plants is sold both within and outside of the county.

Figure 6. Absolute and per capita CO_2 emissions from natural gas combustion by stationary sources, by sector and county



4.2.2 Data Sources

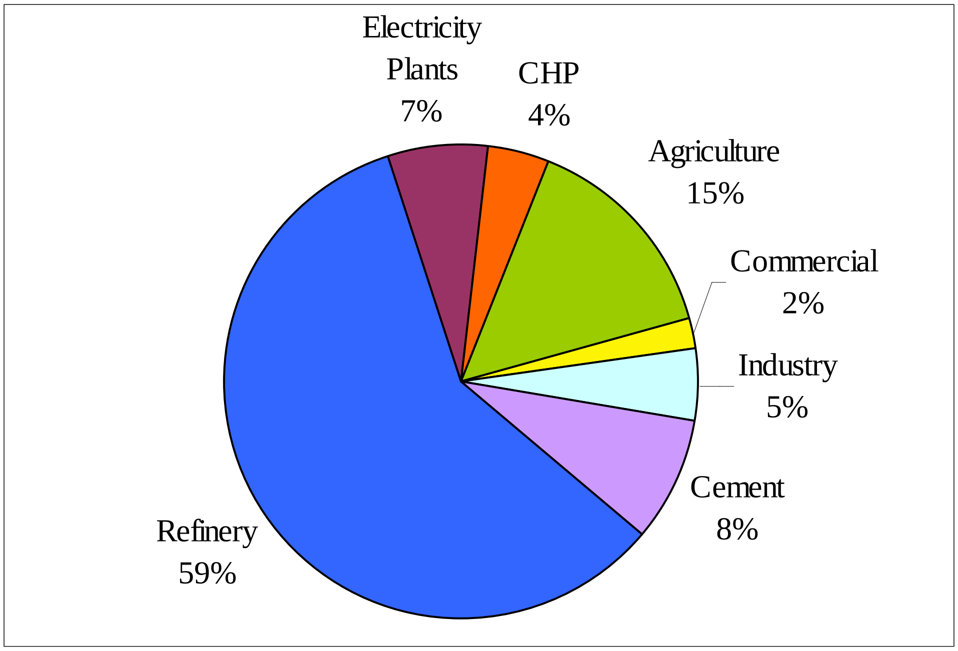
Data on natural gas consumption at the county level are available for each end use sector (electricity, cogeneration, residential, commercial, industry, mining and agricultural water pumping). These data are collected by the California Energy Commission (CEC, 2007) from California gas utilities (both investor-owned and publicly-owned utilities) and gas producers for own use. The major sectors are residential, commercial, industry, mining, and agriculture and water pumping. The industry sector includes natural gas used in refineries, while the mining sector includes natural gas used in oil and gas extraction. However, natural gas used for electricity generation and for electricity and heat cogeneration is not included in this data set. To include natural gas consumption for these uses, data on fuel consumption by provider type were obtained from the EIA's *EIA-906 and EIA-920 Databases* (U.S. EIA, 2007a). The EIA collects the information through two questionnaires: EIA-906 for electric power plants and EIA-920 for CHP facilities.[2] The databases provide plant-level data on generation, fuel consumption, stocks, and fuel heat content from utility and non-utility power plants.

[2] EIA data include only electric power plants or CHP facilities with capacity higher than 1 MW, but the Commission does collect some data on all plants of 100 kW capacity or greater. Although there are over 200 plants in California in the 100 kW to 1 MW range, their total capacity comprises well less than one percent of the State's total generating capacity.

4.3 Petroleum

4.3.1 Overview

Figure 7. CO_2 emissions from petroleum product combustion by stationary sources, by sector

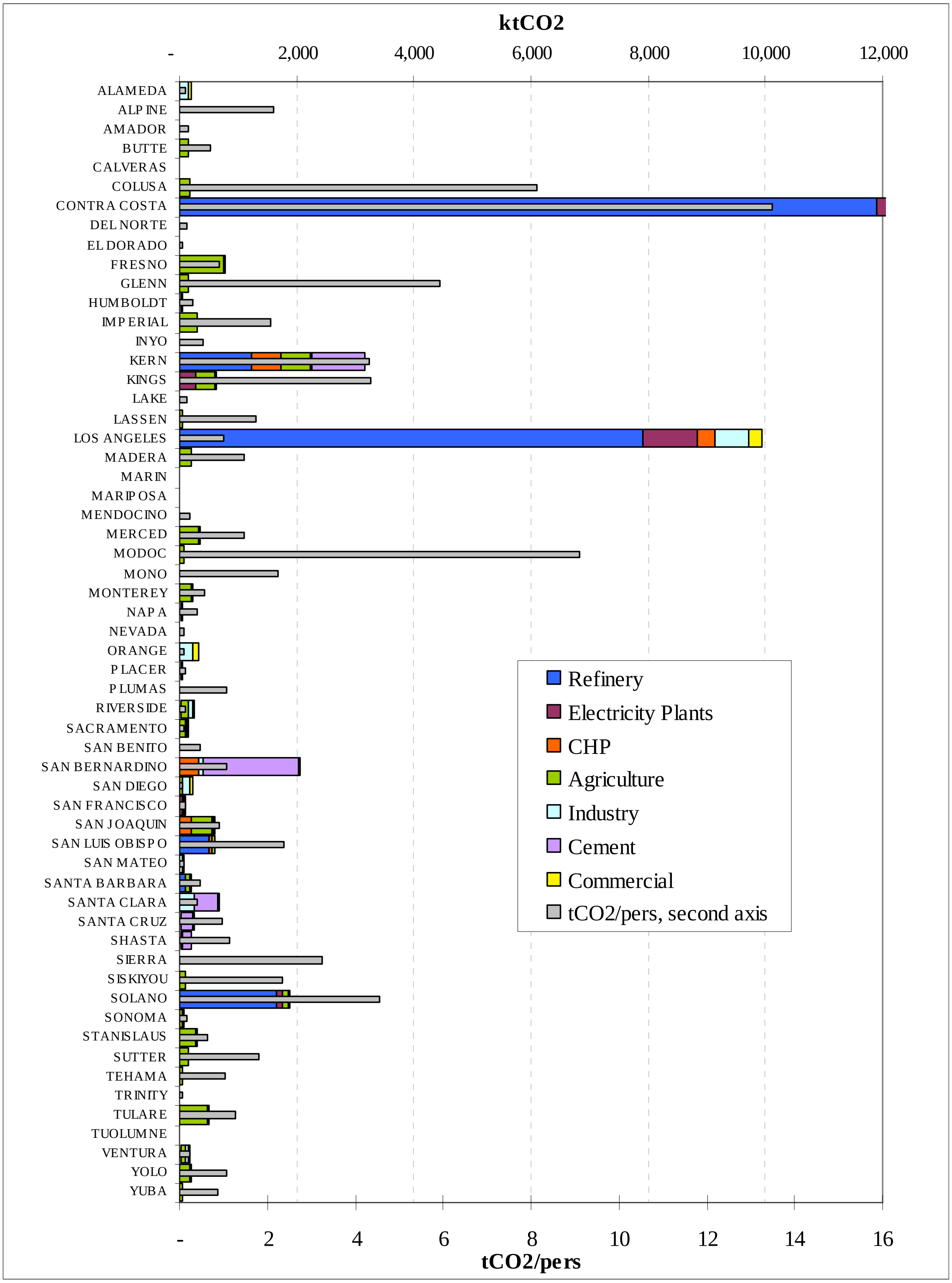


Petroleum products consist of various types of oil-refined products, including: Distillate Fuel Oil (#1, 2, and 4), Residual Fuel Oil (#5 and 6), Petroleum Coke, liquefied petroleum gas (LPG) (average for fuel use), Motor Gasoline, Jet Fuel, Still Gas and Kerosene. About 85% of the petroleum products are consumed in the transport sector, which results in emissions from mobile sources (discussed in Section 5). The remaining 15% of petroleum emissions are from stationary sources: refineries (60%), agriculture (15%), cement (8%), electricity (7%), diverse industries (5%), cogeneration (4%) and the commercial sector (2%), as shown in Figure 7.

CO_2 emissions from refineries are highly concentrated (see Appendix 2), with only two counties representing 85% of total CO_2 emission from refineries: Contra Costa County represents more than half (51%) and Los Angeles represents 34%. Emissions from petroleum fuel consumption by cements plants are mostly concentrated in San Bernardino; about 12 of the 18 cement kilns located in California are in San Bernardino County. Figure 9 shows the disaggregation of CO_2 emissions from petroleum combustion by stationary sources, at the county level. Contra Costa, Los Angeles, Solano and Kern Counties are the counties with the most emissions, due principally to the location of refineries in their area. Kern County is also the location of CHP and cement plants.

In terms of CO_2 emission per capita, Contra Costa County has a high rate, mostly due to the refineries' own consumption of petroleum products. Modoc and Colusa Counties also have high levels of CO_2 emissions per capita, due to large areas of irrigated agriculture land and limited population.

Figure 8. Absolute and per capita CO_2 emissions from petroleum product combustion by stationary sources, by sector and county



4.3.2 Data Sources

Data on consumption of petroleum products in the State is the most challenging to gather, because there are many diverse products and the distribution system is managed by many operators, rather than a few large utilities that are not required to identify how the petroleum that is sold is used.

Consumption of own energy from refineries is collected by the CEC through the M13 form (CEC, 2006). Only the data at the state level was available to us; therefore, we disaggregated the total state consumption for each petroleum product by the production capacity of individual refineries, available from the EIA (U.S. EIA, 2007b). Note that this represents a rough estimation.

For electricity and CHP plants, data from the EIA's EIA-906 and EIA-920 databases (U.S. EIA, 2007a) are available at the plant level and was aggregated at the county level.

The EIA collect data on distillate fuel oil, residual fuel oil, and kerosene sales through a survey form EIA-821, "Annual Fuel Oil and Kerosene Sales Report" (U.S. EIA, 2006). The data collected provides state-level data on end-use sales including volumes for residential, commercial, industrial, and agricultural uses. Data on stationary source energy use for California are small - 89 thousand British thermal units (Tbtu). The state total was allocated to counties using surrogates for each end use sector. Data for farming were allocated based on irrigated land area by county, available from California Water and Land Use (2004). Industry energy use was allocated using the 2002 manufacturing value of shipments for North American Industry Classification System (NAICS) categories 31-33 (U.S. Census Bureau, 2008), while energy use in the commercial sector was allocated using the sales value of accommodation and food services (NAICS 72), wholesale trade (NAICS 42) and retail trade (NAICS 44-45), using payroll 2002 information (U.S. Census Bureau, 2008).

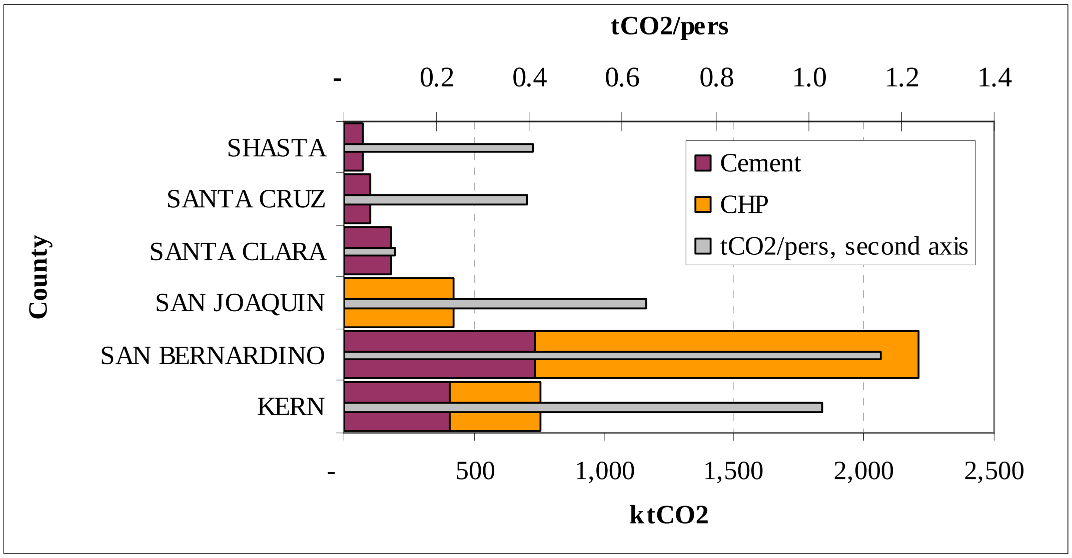
Finally, the Federal Highway Administration (FHWA) publishes consumption of motor gasoline used by the industrial, commercial and agriculture sectors. We used the same methodology to disaggregate this consumption as described above for data on distillate fuel oil, residual fuel oil, and kerosene.

4.4 Coal

4.4.1 Overview

About 70 Tbtu (74 PJ) of coal is consumed annually in California, which represents less than 1% of all fossil fuel consumed in the state, and about 2% of emissions from combustion of fossil fuel by stationary sources. The two sectors responsible for this consumption are the electricity generation and combined heat and power generation (CHP) sector, and the cement sector. The county of San Bernardino, where 12 of the 18 cement plants in California are located, has the most absolute and per capita emissions from coal combustion. In terms of CO_2 emissions per capita, San Bernardino County is closely followed by Kern County (Figure 10). Large industrial activities are located in San Bernardino. Moreover, the county possesses a large cogeneration plant owned by "IMC Chemicals Inc" which uses more than a third of all coal used for cogeneration in California.

Figure 9. Absolute and per capita CO_2 emissions from coal combustion by stationary sources, by sector and county



4.4.2 Data Sources

Data on coal consumption from the cement sector in California is available from U.S. Geological Survey (van Oss, 2007). Allocation at the county level was done by using the clinker capacity for each plant located in California. Information on the activity of individual plants was available from the Portland Cement Association (PCA, 2004). Note that this represents a rough estimation.

Data on coal consumption for CHP is available from the EIA's *EIA-906 and EIA-920 Databases* (U.S. EIA, 2007a). This source provides data at the plant level.

5. Mobile Sources

Mobile sources account for 179 Mt CO_2 statewide; on-road vehicles account for nearly all (95%) of these emissions, with only a small fraction from intrastate aviation, rail, and marine. Map 6 shows the geographical distribution of CO_2 emissions from mobile sources.

5.1 On-road vehicles

5.1.1 Overview

On-road vehicles (cars, trucks, buses, motorcycles, and motor homes) accounted for 169 Mt CO_2 in 2004. Figure 11 indicates that Los Angeles County had by far the largest share of CO_2 emissions from motor vehicles (25%), followed by San Diego (9.1%), Orange (8.0%), Riverside (6.2%), and San Bernardino Counties (6.1%). Statewide, 37% of transport CO_2

emissions come from passenger cars, 30% from light-duty trucks, and 31% from medium- and heavy-duty trucks, as shown in Figure 12.

Figure 10. CO_2 emissions from on-road vehicles, by county and vehicle type

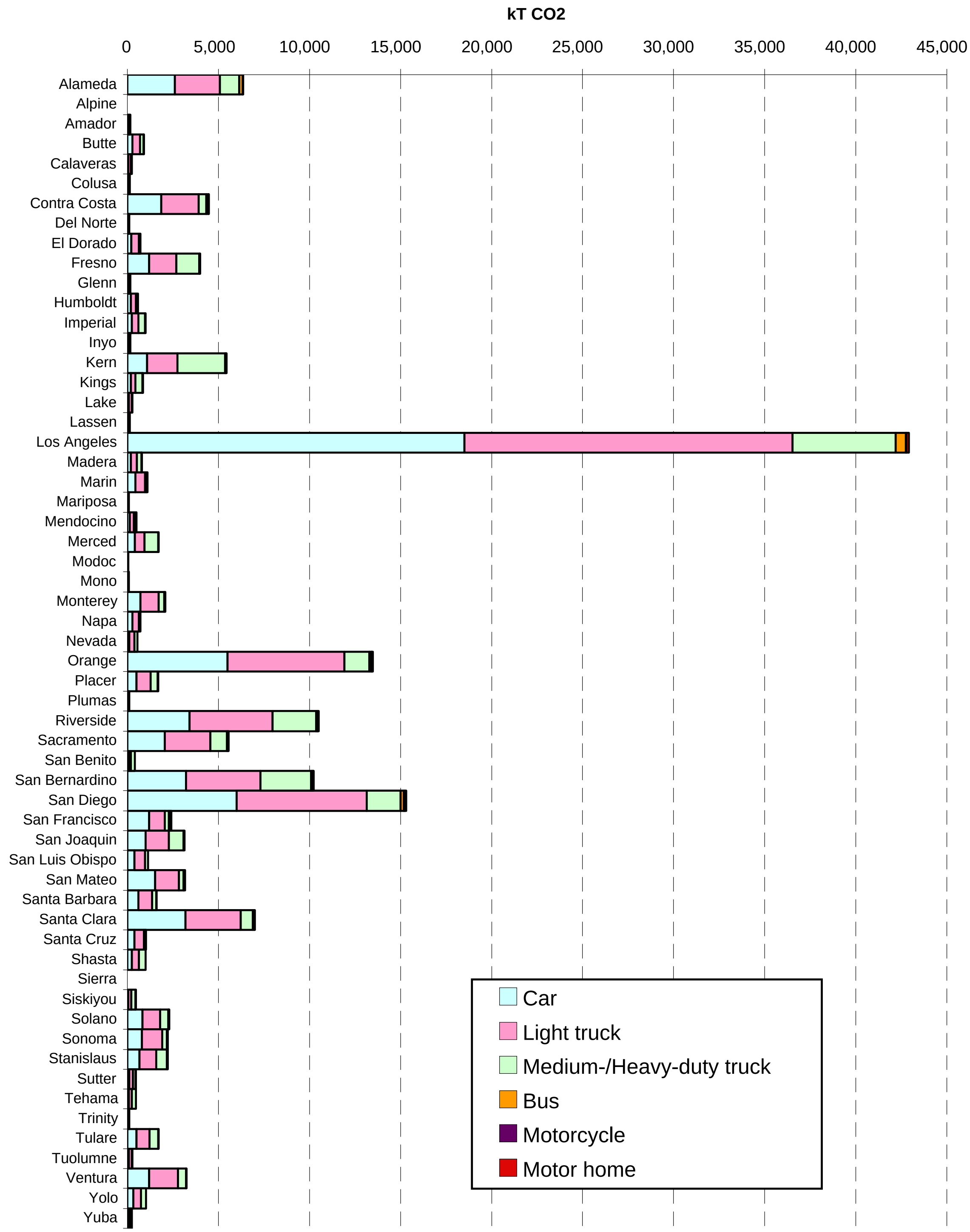
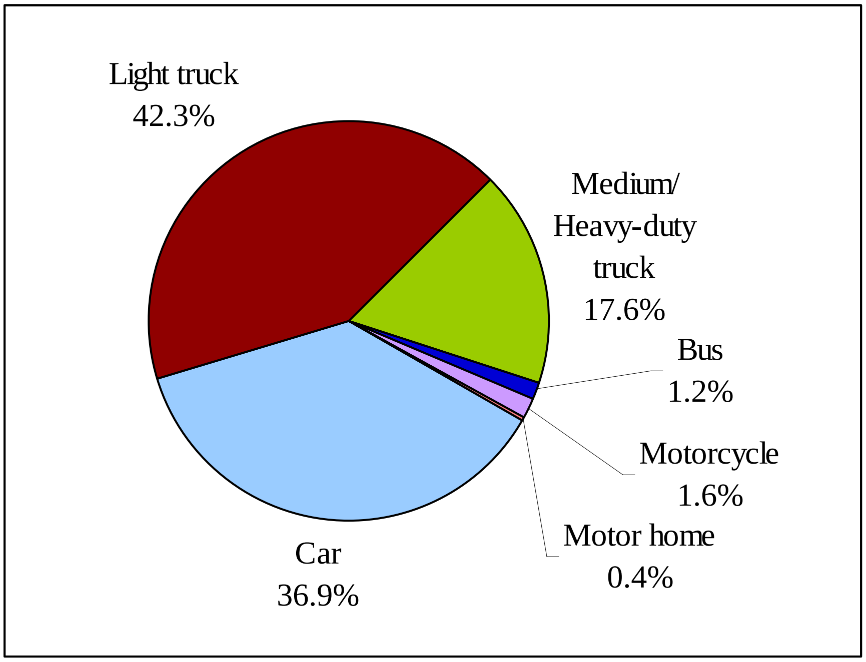


Figure 11. California CO_2 emissions from on-road vehicles, by vehicle type



5.1.2 Data Sources

2004 CO_2 emissions were calculated according to vehicle type and county based on the combination of using EMFAC2007 mobile source emission modeling system outputs and Bureau of Equalization fuel sales data for 2004. This calculation methodology is based on CARB's GHG inventory calculation procedures outlined in the inventory technical support document (Eslinger, 2008). This method scales EMFAC outputs according to reported sales of gasoline by on-road vehicles (which are 6.2% lower than EMFAC), and sales of diesel (5.1% higher than EMFAC), Using this method, total fuel consumed is scaled to match total fuel sales within the state of California.

5.2 Aviation

5.2.1 Overview

The IPCC Guidelines for preparing a GHG inventory require the inclusion of GHGs from domestic aviation; GHGs from international flights are to be listed separately but not included in the official inventory. There is no clear guidance as to which flights US states should include when estimating their emissions inventories, although the Transportation Research Board has commissioned a study to provide guidance on this issue (TRB ACRP 02-06). The CARB CO_2 inventory for California includes the emissions only from flights with origins and destinations in California (intrastate flights); emissions from flights from California to other US (interstate, or domestic, flights) and international destinations are reported, but not included in the inventory. Table 4 shows the magnitude of emissions from domestic and international flights, which currently are not included in the official CO_2 inventory. Including all flights from California to other states would raise the aviation share of the total inventory from 0.6% to 4.4%, while including all international flights from California would raise the share to 6.8%. Clearly the decision on whether or not to include domestic or international flights in the inventory has an impact on the size of the total inventory, as well as the portion attributable to aviation. Following CARB's convention, we allocate CO_2 emissions not only from intrastate flights, but also from domestic and international flights, to counties in California. However, only emissions from intrastate flights are included in the totals in this report.

Table 4. Impact of including domestic and international flights on California 2004 CO_2 emission inventory

Destination	Aviation CO_2 emissions (million metric tonnes)	Cumulative aviation CO_2 emissions (million metric tonnes)	Total CO_2 emissions (million metric tonnes)	Percent aviation of inventory
Intrastate	2.8	2.8	484.4	0.6%
Domestic	19.2	22.0	503.6	4.4%
International	13.3	35.4	517.0	6.8%

In the fuel inventory LBNL prepared for the CEC (Murtishaw et al., 2005) we developed a bottom-up fuel use model for commercial aircraft in California. This model was used to allocate total jet fuel sales, and CO_2 emissions, to intrastate, domestic, and international flights. The data we used to develop this inventory also allow for the disaggregation of California jet fuel and CO_2 emissions to the airport where each flight originated; fuel sales and CO_2 by airport can then be aggregated into counties and air basins. The CARB inventory includes 0.2 Mt CO_2 emissions from small private aircraft that burn aviation gasoline; this source represents 7% of all CO_2 emissions from California intrastate flights. We were not able to identify data on the distribution of small private aircraft, so we have not allocated the CO_2 from aviation gasoline to counties.

Table 5 lists California airports by the county in which they are located. Table 6 shows the allocation of commercial CO_2 emissions by county and type of flight. Figure 13 shows the allocation of CO_2 emissions by flight type, for the eight counties with the most air traffic taking off from California airports. CO_2 emissions from intrastate flights are fairly evenly distributed among airports in these eight counties; however, airports in Los Angeles and San Mateo Counties account for 60% of all CO_2 of domestic US flights, and virtually all of the CO_2 emitted by international flights.

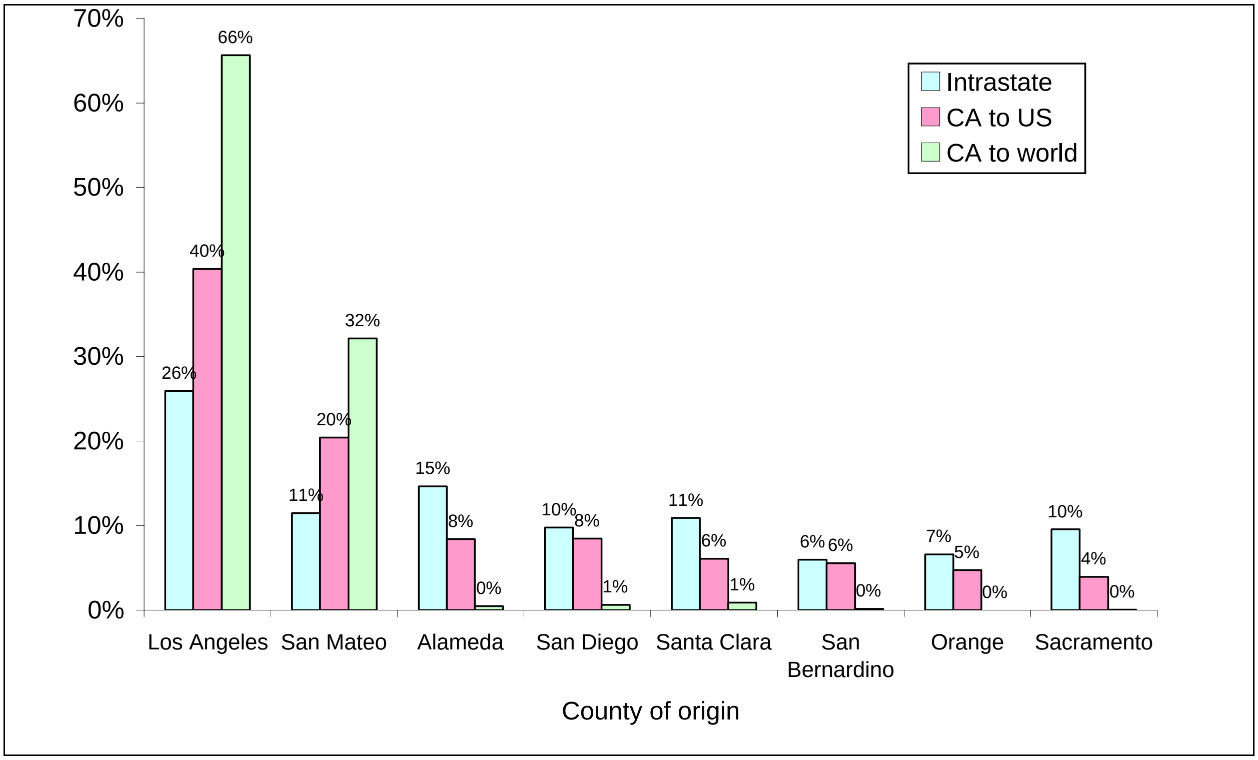
Table 5. California airports by county

County	Airports
Alameda	OAK, LVK
Butte	CIC
Del Norte	CEC
Fresno	FAT
Humboldt	EKA, ACV
Imperial	NJK, IPL
Kern	BFL, RQK, IYK
Los Angeles	LAX, LGB, BUR, JZL, SMO, PMD, WJF
Merced	MCE
Monterey	MRY
Orange	SNA
Riverside	PSP, RIV
Sacramento	SMF, MHR
San Bernardino	ONT, VCV, SBD
San Diego	SAN, CLD, NZY, NKX, SDM
San Joaquin	SCK
San Luis Obispo	PRB, SBP
San Mateo	SFO
Santa Barbara	SBA, SMX, VBG, LPC
Santa Clara	SJC, NUQ
Shasta	RDD
Solano	SUU
Stanislaus	MOD
Tulare	VIS
Ventura	FQB, NTD, OXR

Table 6. Allocation of 2004 California aircraft CO_2 emissions to counties, by type of flight

County	Distribution of 2003 jet fuel use			Allocation of 2004 commercial jet fuel CO_2 (thousand tonnes)		
	Intrastate	Domestic	International	Intrastate	Domestic	International
Los Angeles	25.9%	40.3%	65.6%	719	7,758	8,760
San Mateo	11.5%	20.4%	32.2%	318	3,927	4,291
Alameda	14.6%	8.4%	0.5%	406	1,621	62
San Diego	9.8%	8.4%	0.6%	271	1,624	80
Santa Clara	10.9%	6.1%	0.9%	303	1,164	119
San Bernardino	6.0%	5.5%	0.2%	165	1,064	21
Orange	6.6%	4.7%	0.0%	182	913	0
Sacramento	9.5%	3.9%	0.1%	265	759	9
Fresno	1.2%	0.7%	0.0%	33	135	0
Riverside	0.9%	0.6%	0.0%	24	122	3
Santa Barbara	1.3%	0.4%	0.0%	35	72	0
Others	1.9%	0.4%	0.0%	53	74	0
Total	100%	100%	100%	2,775	19,235	13,345

Figure 12. CO_2 emissions from aircraft, by county of origin and type of flight



5.2.2 Data Sources

We derived a bottom-up inventory of aviation fuel use using aircraft activity data from the U.S. Bureau of Transportation Statistics (BTS), and fuel burn rates from the European Environmental Agency (EEA, 2006). The BTS *Air Carriers: T-100 Segment* data series (U.S. BTS, 2004) provides the airport code and name for each flight originating in California. Each California airport was assigned to a county and air basin, and the fuel consumed by each flight originating in California was calculated by flight type, county, and air basin. We then allocated total CO_2 emissions from commercial aviation in the CARB inventory (35.4 Mt) to flight type and county, based on the bottom-up inventory of fuel use.

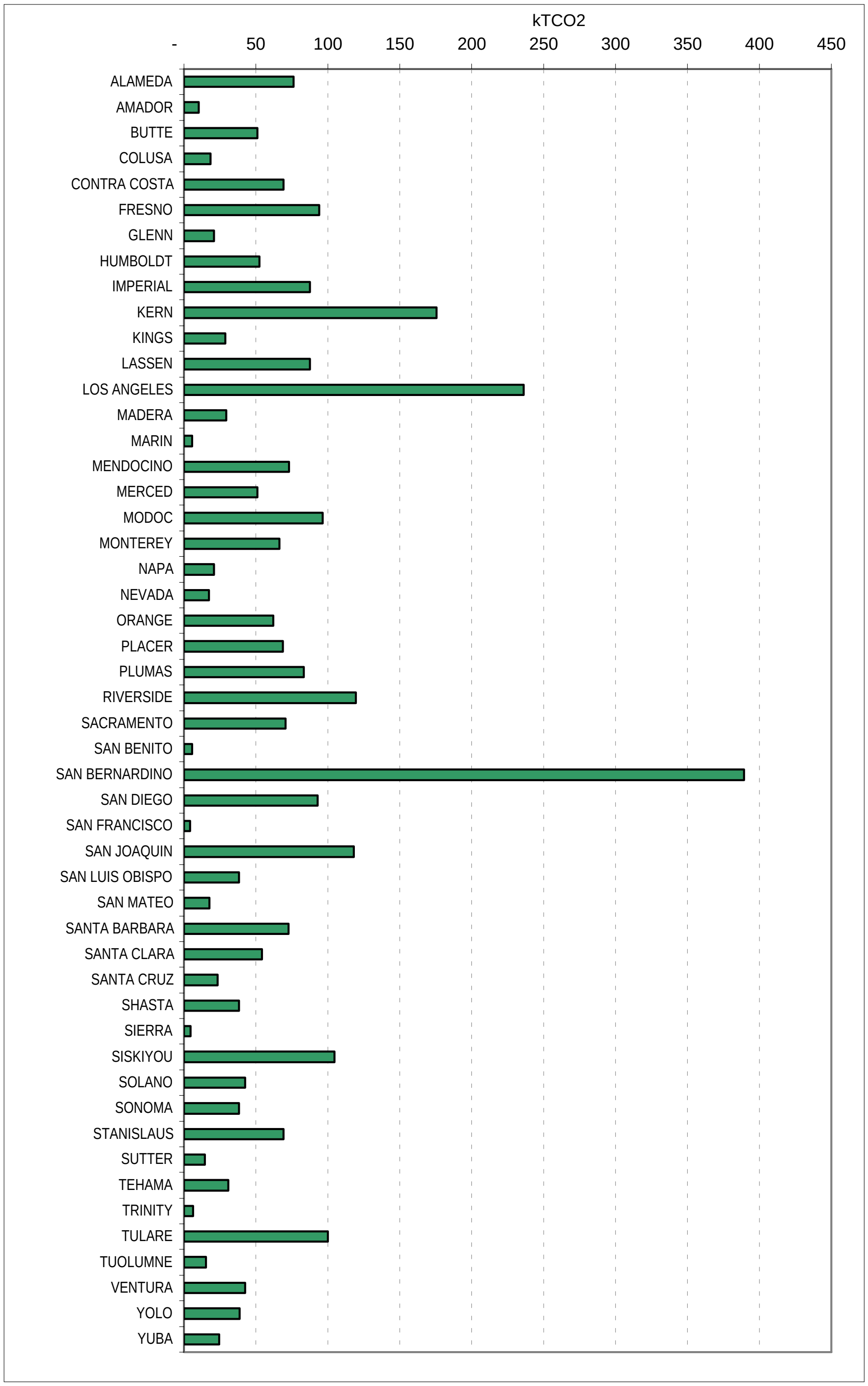
5.3 Rail

5.3.1 Overview

CO_2 emissions from railway activity represent less than 1% of total CO_2 emissions from fuel combustion (CARB, 2007). There are about 7,368 miles of railroad operated in California (not including abandoned railroad). Approximately 70% is operated for freight, and two main companies, the Burlington Northern and Santa Fe Railway Corporation, and Union Pacific Railroad Corporation, represent 76% of rail activity, while the rest is operated by local railroads (AAR, 2002). Passenger rail activity is mostly intercity train service operated by Amtrak; local commuter transit represents about 15% of the passenger railroads in California.

Figure 14 shows the distribution of CO_2 emissions from railroad activity, by county. Although railroad activity is less than 1% of total CO_2 statewide, it accounts for over 20% of CO_2 in some rural counties (Lassen, Modoc, and Plumas Counties), and is the single largest source of CO_2 (42%) in Modoc County.

Figure 13. CO_2 emissions from railroad activity, by county



5.3.2 Data Sources

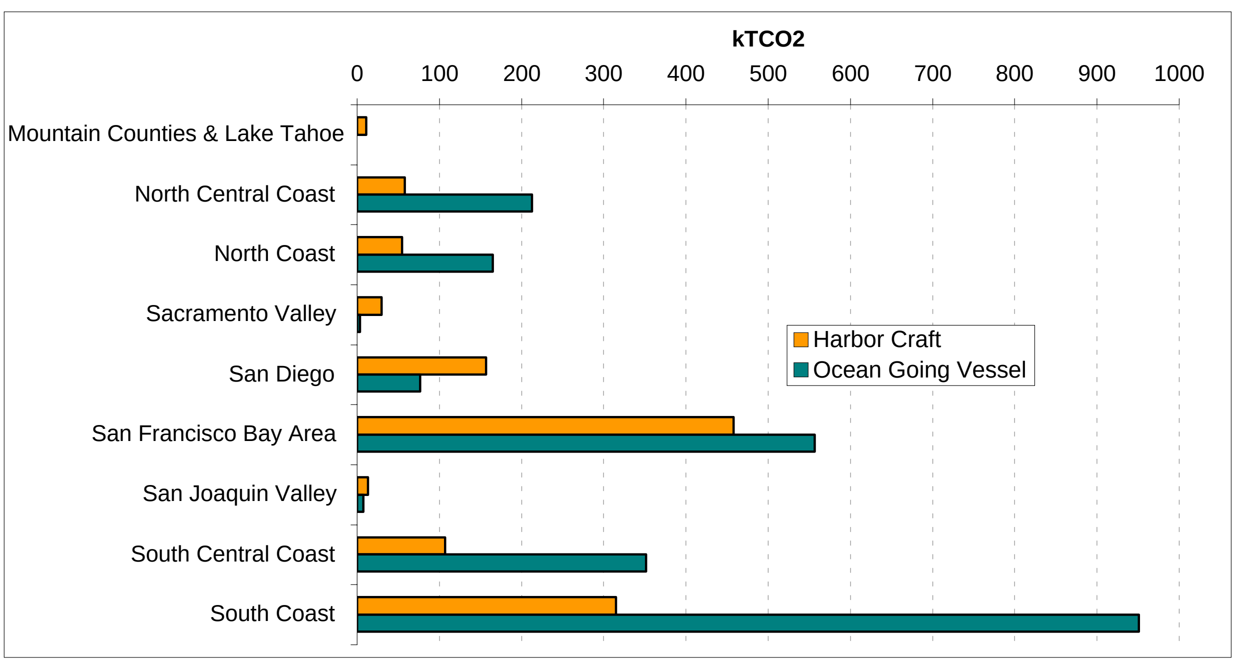
No data are available at the county level on fuel used for rail activity. Therefore, we allocated the statewide estimate of CO_2 emissions from fuel used for rail transport to counties based on the mileage of all railway (including heavy, intercity commuter, and local commuter) by county. Hence, this does not account for intensity of traffic by county. Mileage per county was taken from the Federal Railroad Administration (FRA, 2007).

5.4 Marine

5.4.1 Overview

CO_2 emissions from watercraft represent less than 1% of total CO_2 emissions from fuel combustion (CARB, 2007). Waterborne navigation is divided into two sub categories: ocean-going vessels and harbor craft. Ocean-going vessels include many different type of watercraft such as container ships that move goods in containers, tankers that move liquids like petroleum products, as well as other types of watercraft. Emissions from ocean-going vessels represent two-thirds of total waterborne navigation emissions, while harbor craft account for the remainder. Harbor craft includes vessels used for commercial and leisure purposes or to support public services. These vessels generally operate within California coastal waters and inland waterways. Figure 15 shows emissions from both activities at the air basin level. The two basins with the largest share of emissions are the South Coast and the San Francisco Bay Area Air Basins, mostly due to large amount of shipping activity at these two major ports.

Figure 14. CO_2 emissions from marine activity, by air basin



5.4.2 Data Sources

Data on CO_2 emissions from ocean-going vessels at the county level and from harbor craft at the air district level were estimated and provided by CARB (Alexis, 2008). CARB staffs have developed a consistent methodology to estimate emissions from harbor craft (CARB, 2007b) and ocean-going vessels (CARB, 2005). To estimate California harbor craft and ocean-going vessel emissions by region, data on vessel type and engine information were collected by CARB through detailed surveys. Emissions were then estimated by multiplying number of engines in each engine category and in each region by average emissions per engine.

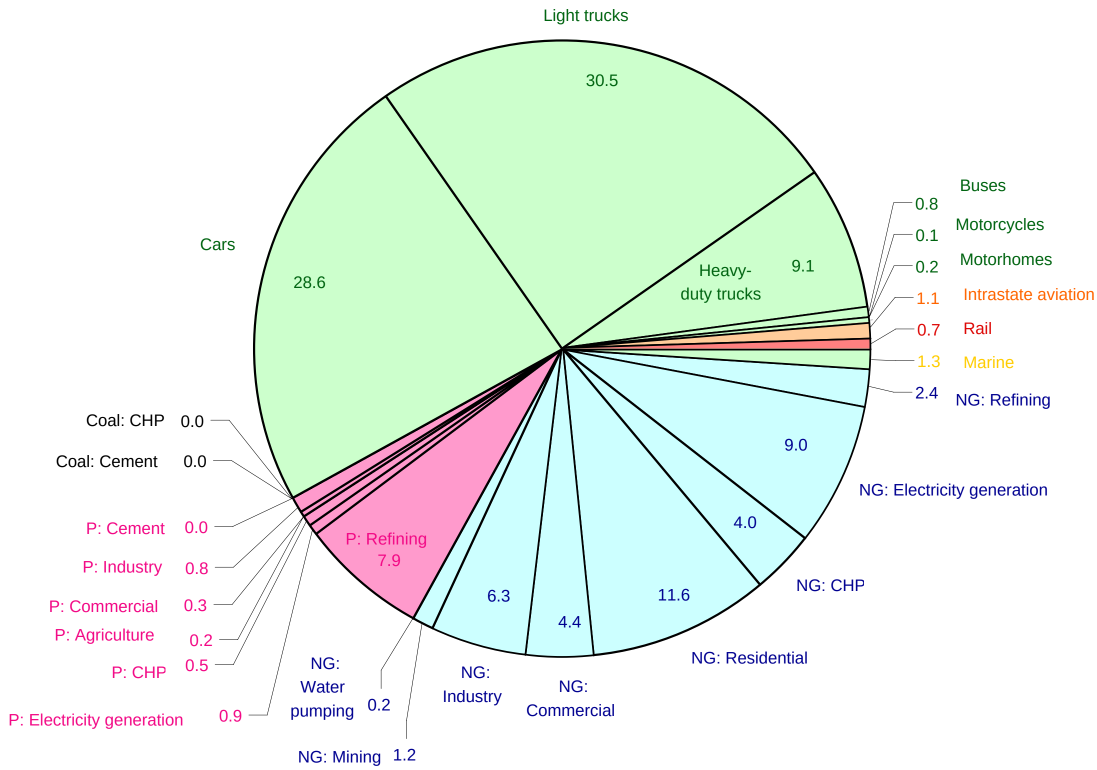
6. CO_2 emissions in the South Coast Air Basin

The South Coast Air Basin (SCAB) includes all of Orange County and the non-desert portions of Los Angeles, Riverside, and San Bernardino Counties. For some sectors (residential, commercial, industrial, agricultural, and rail transportation) we used population distribution by zip code to allocate emissions to the South Coast, Mojave Desert, and Antelope Valley Air Basins. Population by zip code is available from the Census Bureau (2002), and the zip codes that make up each air management district are available from ARB (2008). The SCAB covers an area of 6,745 square miles with a population of 15.2 million. About 70% of the population of San Bernardino County is included in the SCAB, while 88% and 93% of the population of Riverside and Los Angeles Counties, respectively, are in the SCAB.

In the case of large energy users (refineries, electricity generation, heat and power cogeneration, and cement production), the exact location of individual plants is available. There are ten refineries and two cement plants located in the SCAB; three additional cement plants in San Bernardino County are within the boundary of the Mojave Desert Basin. The EIA database for electric generation and CHP plants (U.S. EIA 2007a) does not provide the zip code of each individual plant. We determined that the three CHP plants using coal in San Bernardino County are all located outside of the SCAB.

The SCAB accounted for 122 Mt CO_2 emissions in 2004, or 35% of the statewide total. Figure 16 indicates the distribution of CO_2 emissions in the SCAB by fuel and sector; the distribution is quite similar to that of the state, although 59% of the CO_2 emissions in the SCAB come from mobile sources, as opposed to only half of statewide CO_2 emissions.

Figure 15. 2004 South Coast Air Basin CO_2 emissions by fuel and sector

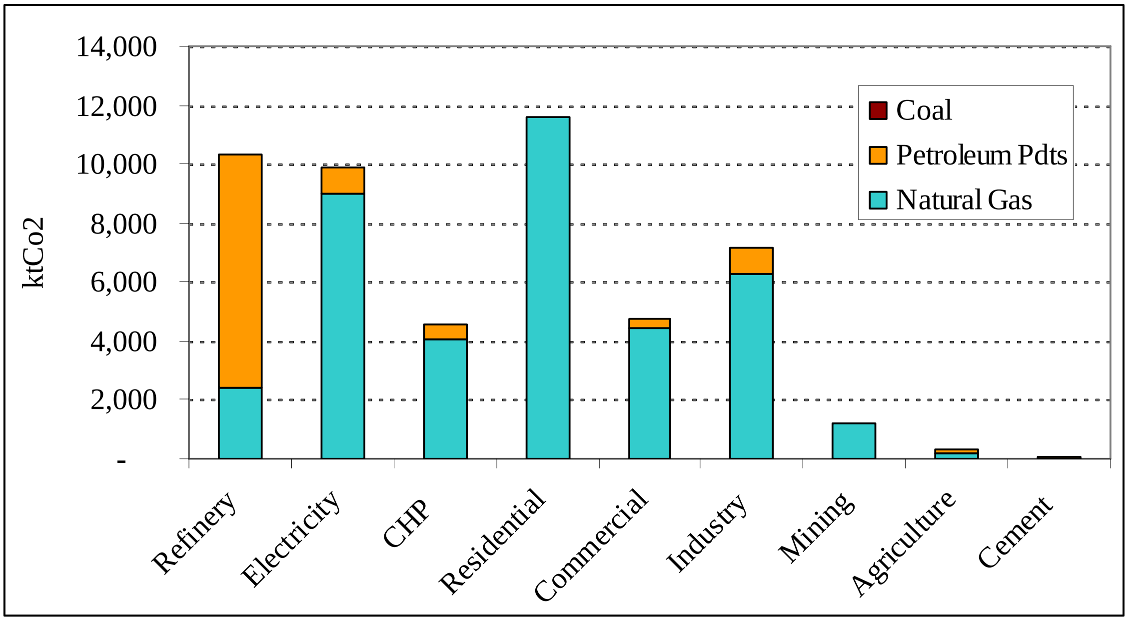


6.1 Stationary sources

Stationary sources accounted for 50 Mt, or 41% of total CO_2 emissions in the SCAB. Figure 17 shows the distribution of stationary source emissions in the SCAB by sector and fuel type. The major source of CO_2 emissions from stationary sources is the use of natural gas by households. As pointed out earlier, the SCAB has a very high population density; almost half (43%) of California's total population is concentrated in this basin. The second and third largest sources of stationary source emissions in the SCAB are the refinery and electricity generation sectors. Both sectors are responding to the great demand of SCAB residents to fuel their cars and turn on appliances such as air conditioners.

Natural gas accounts for 79% of the CO_2 emissions from stationary sources in the SCAB. Most of the remaining CO_2 emissions from stationary sources come from the combustion of petroleum products, mostly in the refinery sector. Consumption of coal, by contrast, is insignificant. Overall, stationary source CO_2 emissions in the SCAB represent about a third of the state total emissions from stationary sources.

Figure 16. SCAB CO_2 emissions by stationary sources, by sector and fuel type

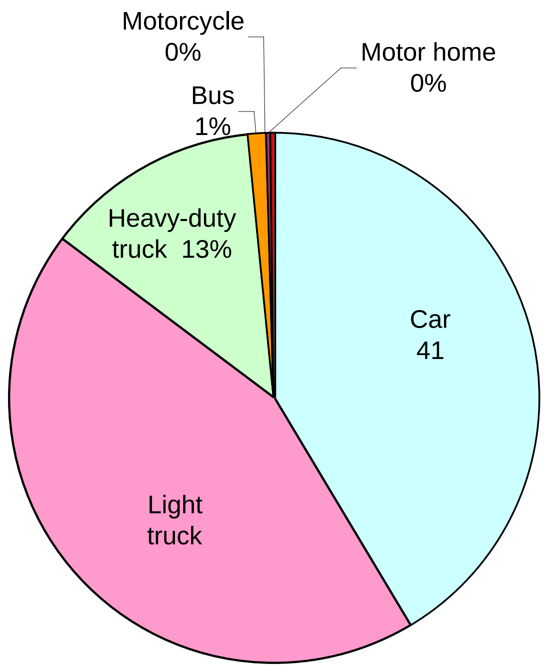


6.2 Mobile Sources

6.2.1 On-road vehicles

The EMFAC2007 mobile source emission modeling system provides CO_2 emissions by air basins. Figure 18 shows the distribution of the 69 Mt CO_2 emissions from on-road vehicles in the SCAB by vehicle type. The SCAB accounts for 41% of statewide CO_2 emissions from on-road vehicles.

Figure 17. SCAB CO_2 emissions from on-road vehicles, by vehicle type



6.2.2 Aviation

Table 7 shows California airports by county and air basin. Note that some counties span more than one air basin. For example, a portion of San Bernardino county is in the South Coast basin, while the remainder is in the Mojave Desert basin; the Victorville airport (VCV) is in the Mojave Desert basin. The basin in which each airport is located was determined by entering the airport zip code into CARB's basin locator website[3].

[3] http://www.arb.ca.gov/app/dislookup/dislookup.php

Table 7. California airports by air basin and county

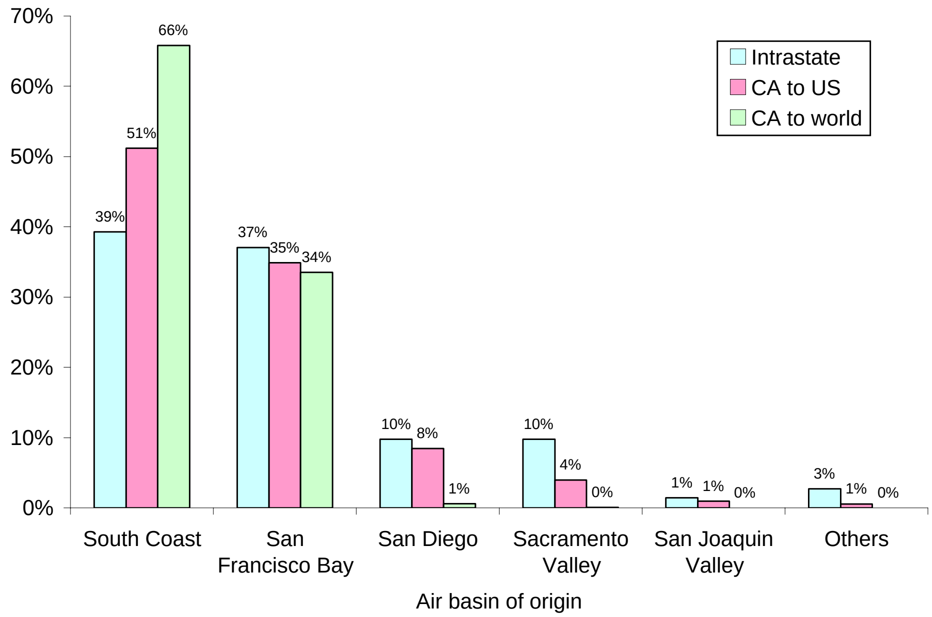
Basin	County	Airports
South Coast	Los Angeles Orange Riverside San Bernardino	LAX, LGB, BUR, JZL, SMO SNA PSP, RIV ONT, SBD
Bay Area	San Mateo Alameda Santa Clara Solano	SFO OAK, LVK SJC, NUQ SUU
San Diego	San Diego	SAN, CLD, NZY, NKX, SDM
Sacramento Valley	Sacramento Butte Shasta	SMF, MHR CIC RDD
San Joaquin Valley	Fresno Kern Merced San Joaquin Stanislaus Tulare	FAT BFL MCE SCK MOD VIS
South Central Coast	Santa Barbara Ventura San Luis Obispo	SBA, SMX, VBG, LPC FQB, NTD, OXR PRB, SBP
Mojave Desert	Los Angeles Kern San Bernardino	PMD, WJF RQK, IYK VCV
North Coast	Humboldt Del Norte	EKA, ACV CEC
North Central Coast	Monterey	MRY
Salton Sea	Imperial	NJK, IPL

Table 8 and Figure 19 show the CO_2 emissions allocated to the air basin in which the flight originated. They indicate that airports in the South Coast air basin account for 40% of the CO_2 emitted throughout California by intrastate flights, half of the CO_2 emitted by domestic flights, and two-thirds of the CO_2 emitted by international flights.

Table 8. CO_2 emissions by aircraft, by air basins and type of flight

Air basin	Distribution of 2003 jet fuel use			Allocation of 2004 commercial jet fuel CO_2 (thousand tonnes)		
	Intrastate	Domestic	International	Intrastate	Domestic	International
South Coast	39.3%	51.2%	65.8%	1,090	9,853	8,783
San Francisco Bay	37.0%	34.9%	33.5%	1,028	6,713	4,473
San Diego County	9.8%	8.4%	0.6%	271	1,624	80
Sacramento Valley	9.8%	4.0%	0.1%	271	761	9
San Joaquin Valley	1.4%	0.9%	0.0%	39	178	0
South Central Coast	1.6%	0.4%	0.0%	45	83	0
Others	1.1%	0.1%	0.0%	30	22	0
Total	100%	100%	100%	2,775	19,235	13,345

Figure 18. CO_2 emissions by aircraft, by air basin of origin and type of flight



6.2.3 Rail

For CO_2 emissions from railroads, we simply added the estimated rail emissions for Los Angeles, Orange, San Bernardino, and Riverside Counties. The SCAB had 0.8 Mt of CO_2 emissions from rail activity, which accounts for 26% of rail emissions statewide.

6.2.4 Marine

CARB estimates that marine activity in the SCAB accounts for 1.3 Mt of CO_2 emissions, 36% of California's marine emissions.

7. CO_2 emissions from electricity generation versus end-use

The 2006 IPCC guidelines call for CO_2 emissions to be reported according to source of emissions and sector categories. This internationally recognized framework allows jurisdictions across the world to display their emissions inventories in a harmonized and transparent manner. However, as climate policy develops locally, alternative and more complex methods are needed to report sources of emissions. For example, the CARB inventory includes CO_2 emissions from electricity imports, which are not required by the IPCC guidelines. Similarly, it is possible to allocate CO_2 emissions from electricity generation to the ultimate end users of the electricity, rather than to the county in which it is generated. In this section we provide a preliminary analysis of the distribution of electricity CO_2 emissions by the county of use rather than by the county of generation.

Figure 19 shows total CO_2 emissions from electricity generation in California, by the county in which the electricity is generated.

Figure 20 shows the distribution of electricity generation by fuel type and county. No CO_2 from fuel combustion is emitted from electricity generation using nuclear, geothermal, hydro, and other renewable resources (wind, solar, etc.), as can be seen by comparing Figures 20 and 19. For example, San Luis Obispo County generates 15 terrawatt hours (TWh) of electricity from nuclear facilities (Figure 20); however, this electricity generation results in zero CO_2 emissions (Figure 19; the small CO_2 emissions from electricity generation in San Luis Obispo County comes from less than 0.4 TWh of electricity generated there using natural gas). Natural gas is the most common fuel type used to generate electricity in the state, followed by nuclear and hydro. There is very little in-state electricity generated using coal combustion; however, almost half of the electricity imported into California comes from coal combustion (CEC, 2007).

Figure 19. 2004 CO_2 emissions from electricity generation, by county

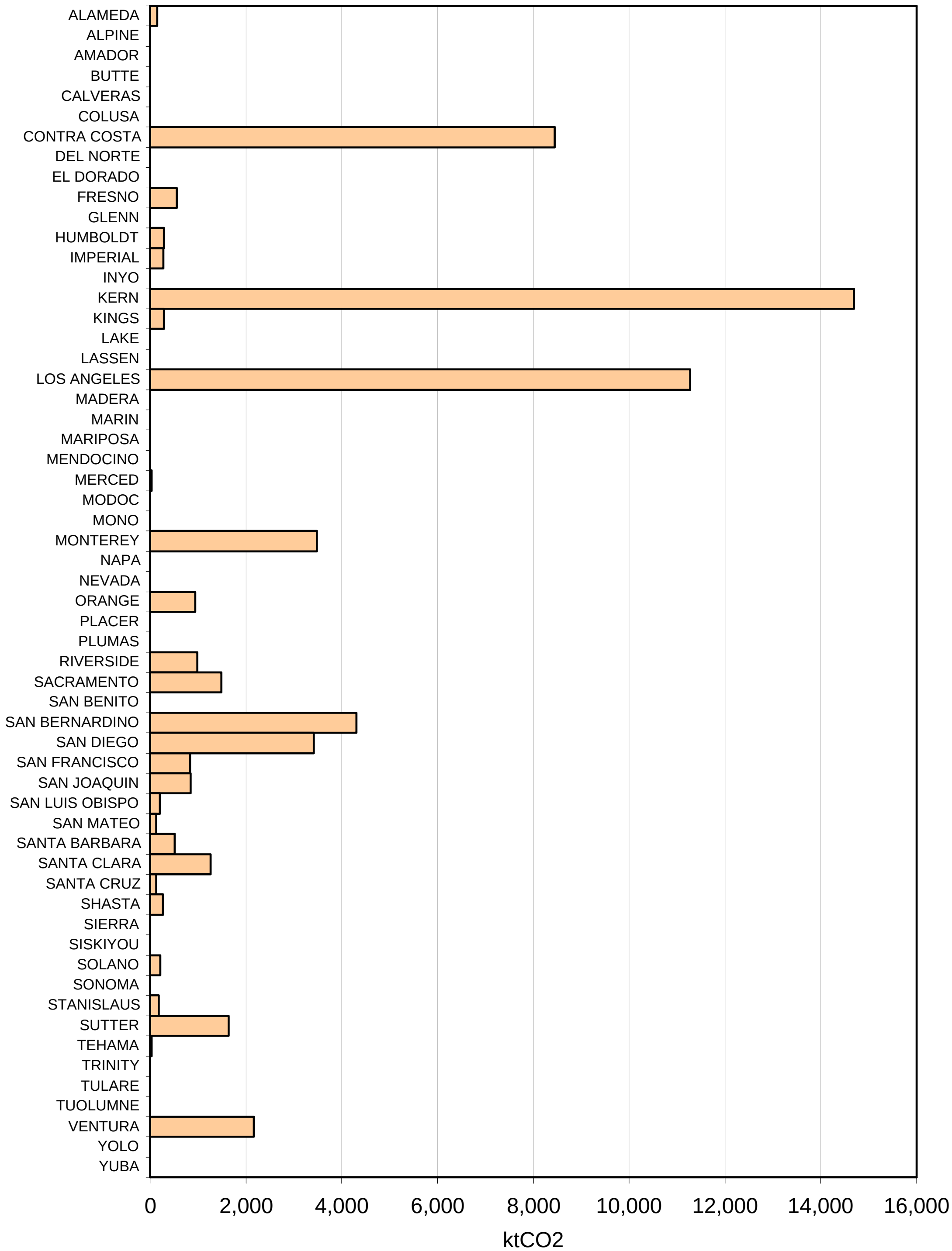
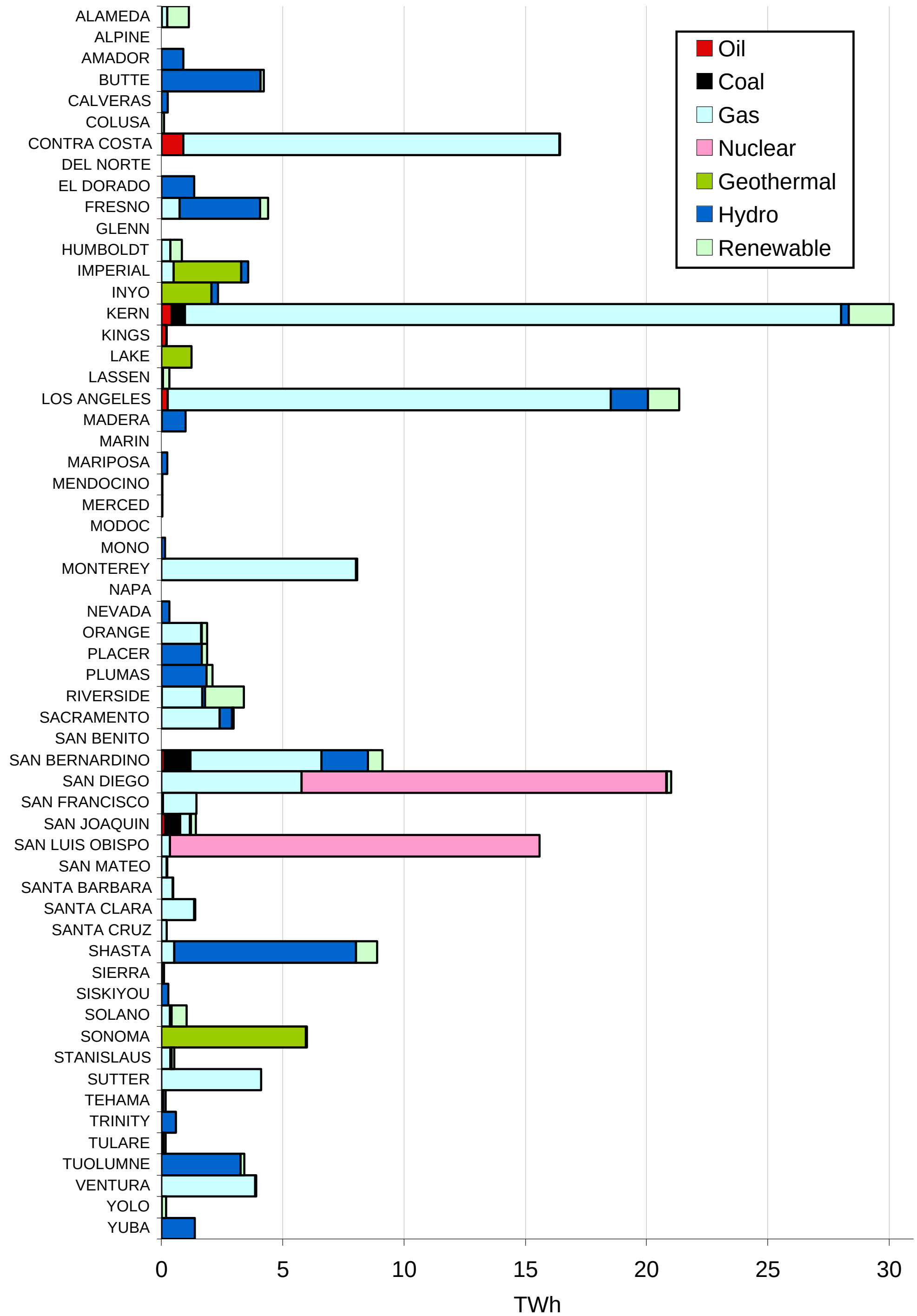


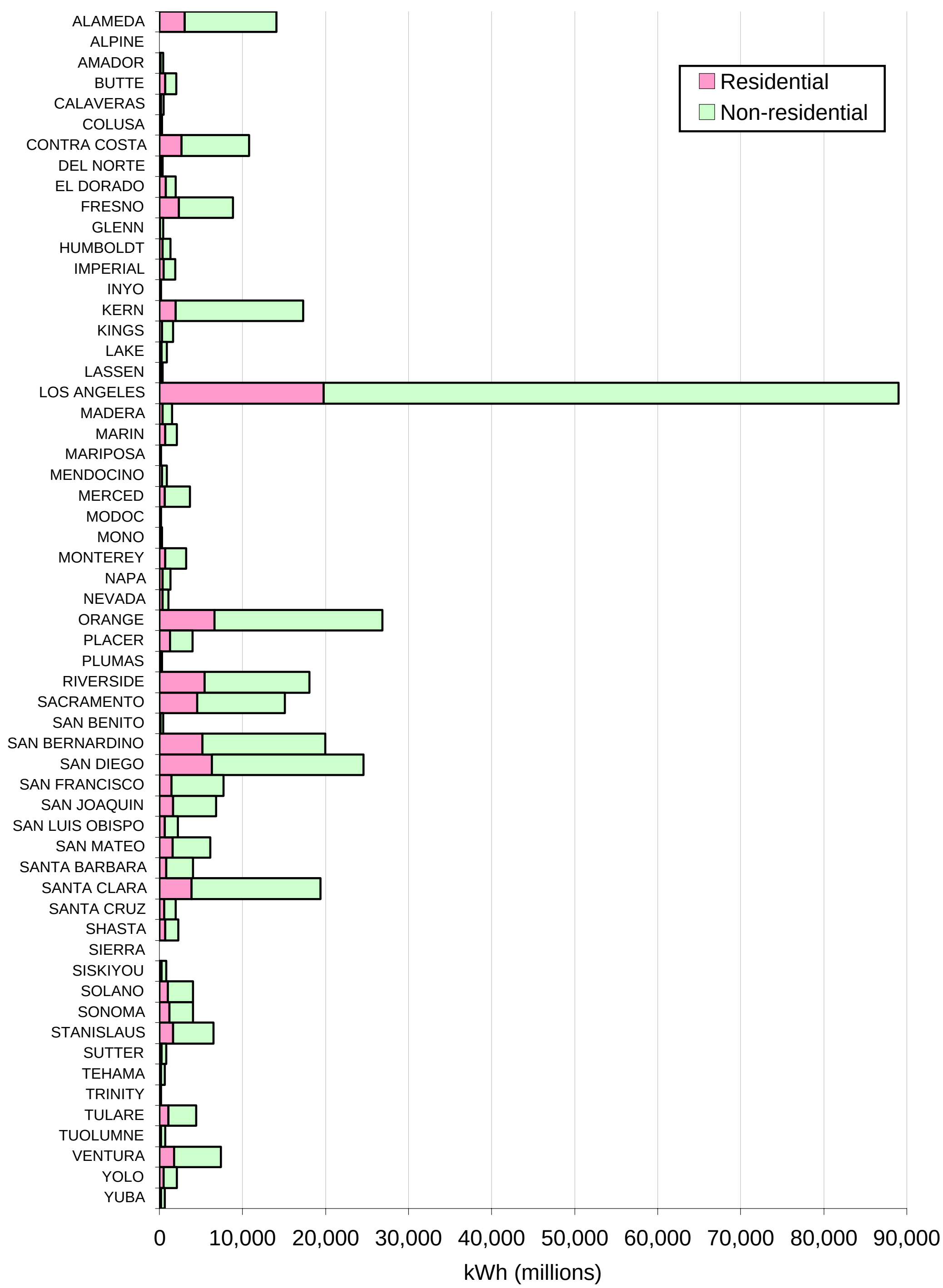
Figure 20. 2004 electricity generation, by fuel type and county



The CEC provides total electricity use by county, for both residential and non-residential customers (CEC, 2008). The CEC electricity consumption figures include the roughly 25% of electricity that is generated outside of California and imported into the state (CEC, 2007). Figure 21 shows the distribution of electricity use, including imports, for residential and non-residential end-uses, by the county in which the electricity is ultimately used. Comparison of

Figure 20 and Figure 21 indicate that in some counties the electricity generated is much larger than the electricity used in that county; Kern, Contra Costa, Monterey and Sutter Counties are net exporters of in-state-generated electricity to other areas of the state, whereas urban counties such as Alameda, Orange, Riverside, Sacramento, and Santa Clara Counties, and to a lesser extent Los Angeles County, are net importers of in-state-generated electricity.

Figure 21. 2005 electricity consumption, by sector and county



As indicated in Figure 20, the electric utilities that serve each county use a different mix of fuels to generate electricity for their customers. In addition, the amount of electricity imported, as well as the mix of fuels used to generate that electricity, also varies by utility service area.

Retail electricity providers are required to disclose to the CEC and to their consumers the power mix of the electricity that they provide through the power content label; however, this information is not compiled for all providers and is not readily available through a single source. CEC does not report county electricity use by fuel type, or by the fraction that is imported from other states. It may be possible to aggregate counties into utility service areas, in order to estimate electricity use by fuel type and therefore CO_2 emissions from electricity use by county; however, such an analysis is outside the scope of the current project.

A reallocation of CO_2 emissions from counties where electricity is produced to counties where electricity is consumed will dramatically change the distribution of emissions by county. For example, net electricity exporters, such as Contra Costa, Kern, Monterey, and Sutter Counties, that generate electricity at a per capita rate several times the state average (Figure 22) will have per capita electricity use rates much closer to the state average (Figure 23).

Figure 22. 2004 fossil fuel electricity generation per capita, by fossil fuel type and county

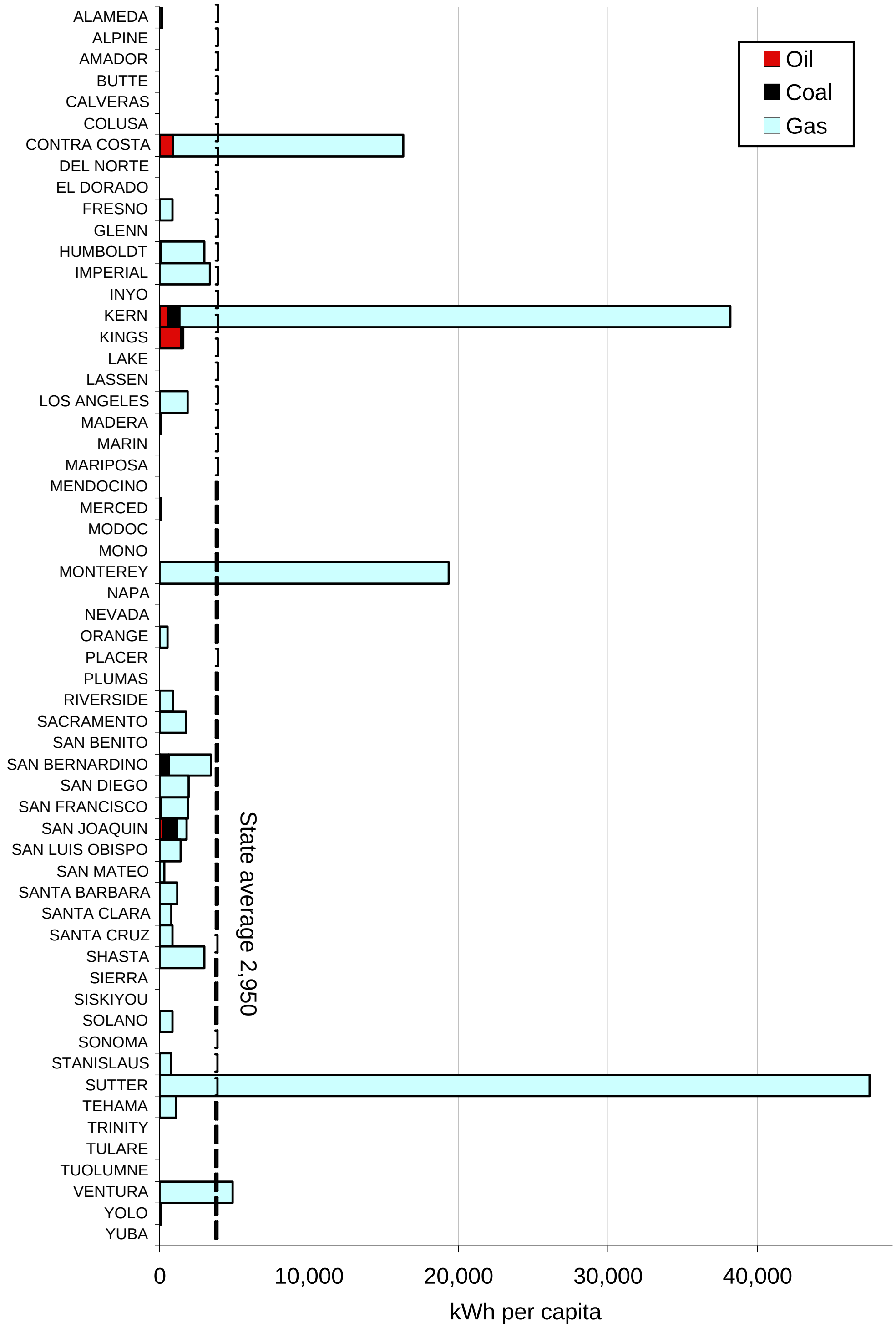
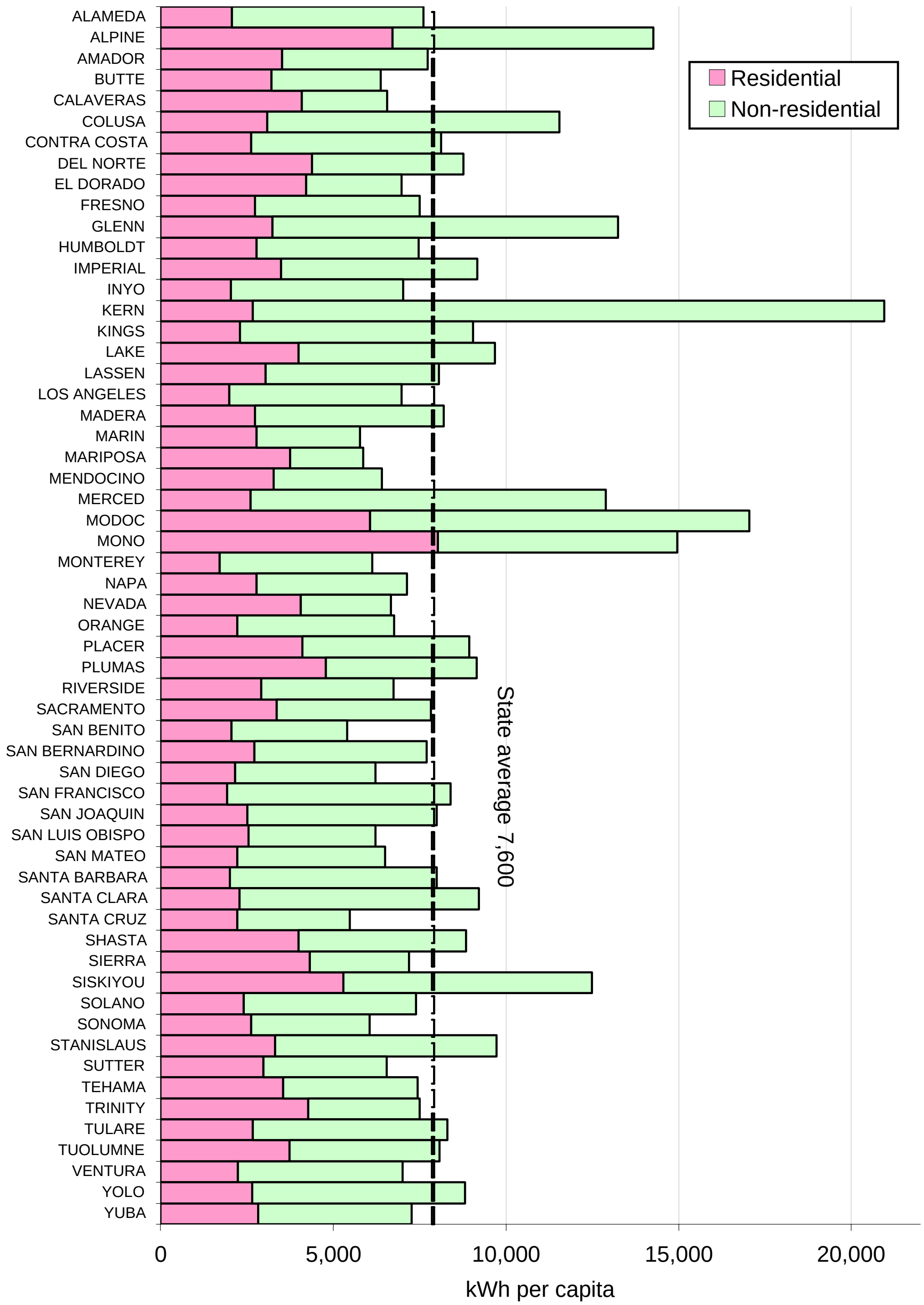


Figure 23. 2005 electricity consumption per capita, by sector and county



8. Conclusion

This report allocates CO_2 emissions from fuel combustion in California to the 58 counties in the state, with a difference of 0.8% compared to the official California GHG inventory estimated by CARB (CARB, 2008). CO_2 emissions from fuel combustion comprise the most significant contributor to GHG emissions, accounting for 86% of total emissions in California in 2004 (CARB, 2008). The largest uncertainties with the allocation methods concern petroleum CO_2 emissions from stationary sources, which account for 15% of total statewide emissions. The sources in this sector are refineries (petroleum and natural gas), industry (petroleum), commercial (petroleum), agriculture (petroleum), and cement (petroleum). We used various indicators to allocate statewide emissions from these sources to counties. Coal consumption by cement plants represents another source of uncertainty, as their emissions were allocated according to the plant capacity. Another source of uncertainty is fuel use by rail activity, which we allocated to counties by track miles. Mandatory GHG reporting requirements proposed by CARB (and to be approved in the next few months) will help improve estimates of CO_2 emissions from large industrial sources and commercial activity by ensuring a rigorous and consistent accounting and verification procedure. The reporting regulations will require annual reporting from the largest facilities in the state, which account for 94% of GHG emissions from industrial and commercial stationary sources in California.

9. Acknowledgments

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Appendices

Appendix 1. California air basins and counties

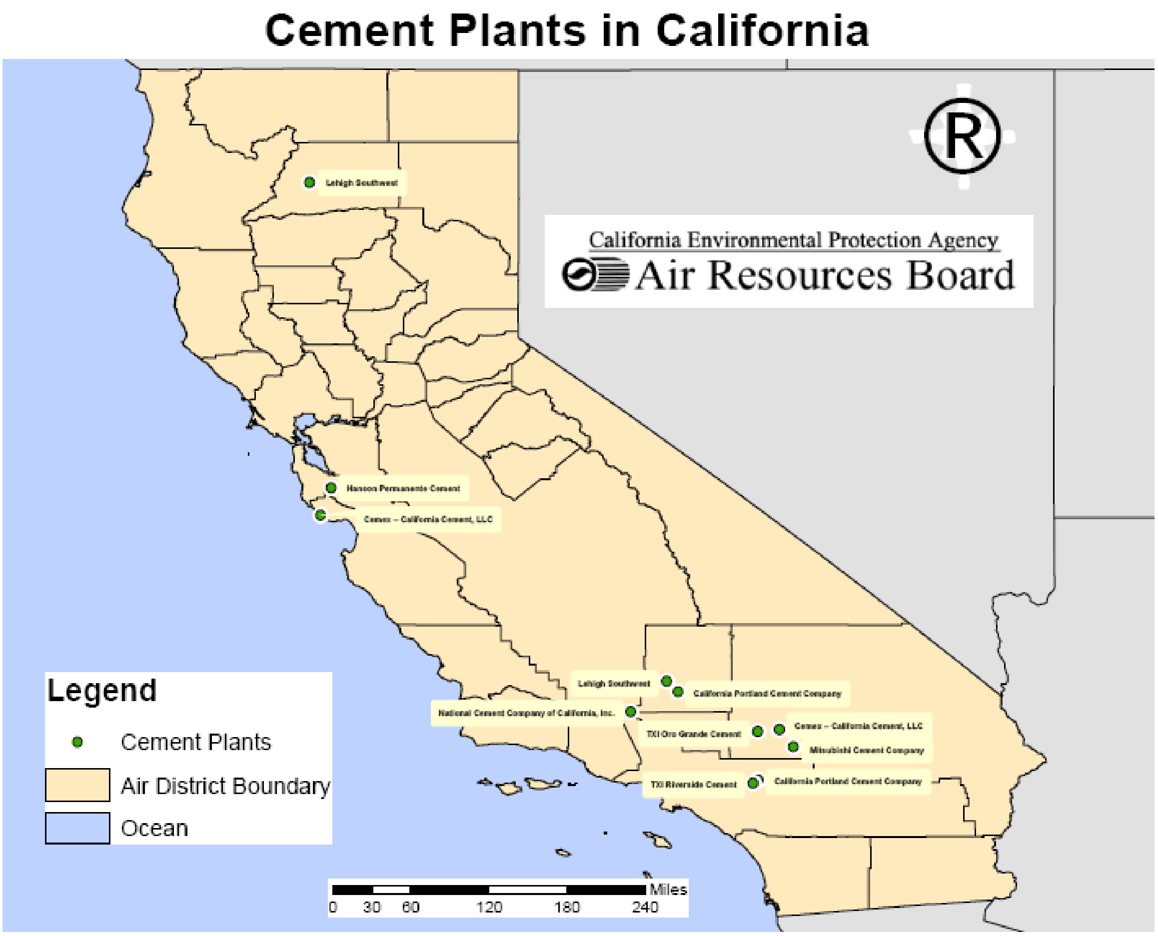
http://www.capcoa.org/maps.php

Appendix 2. Oil refinery locations in California

http://www.energy.ca.gov/maps/refinery_locations.html

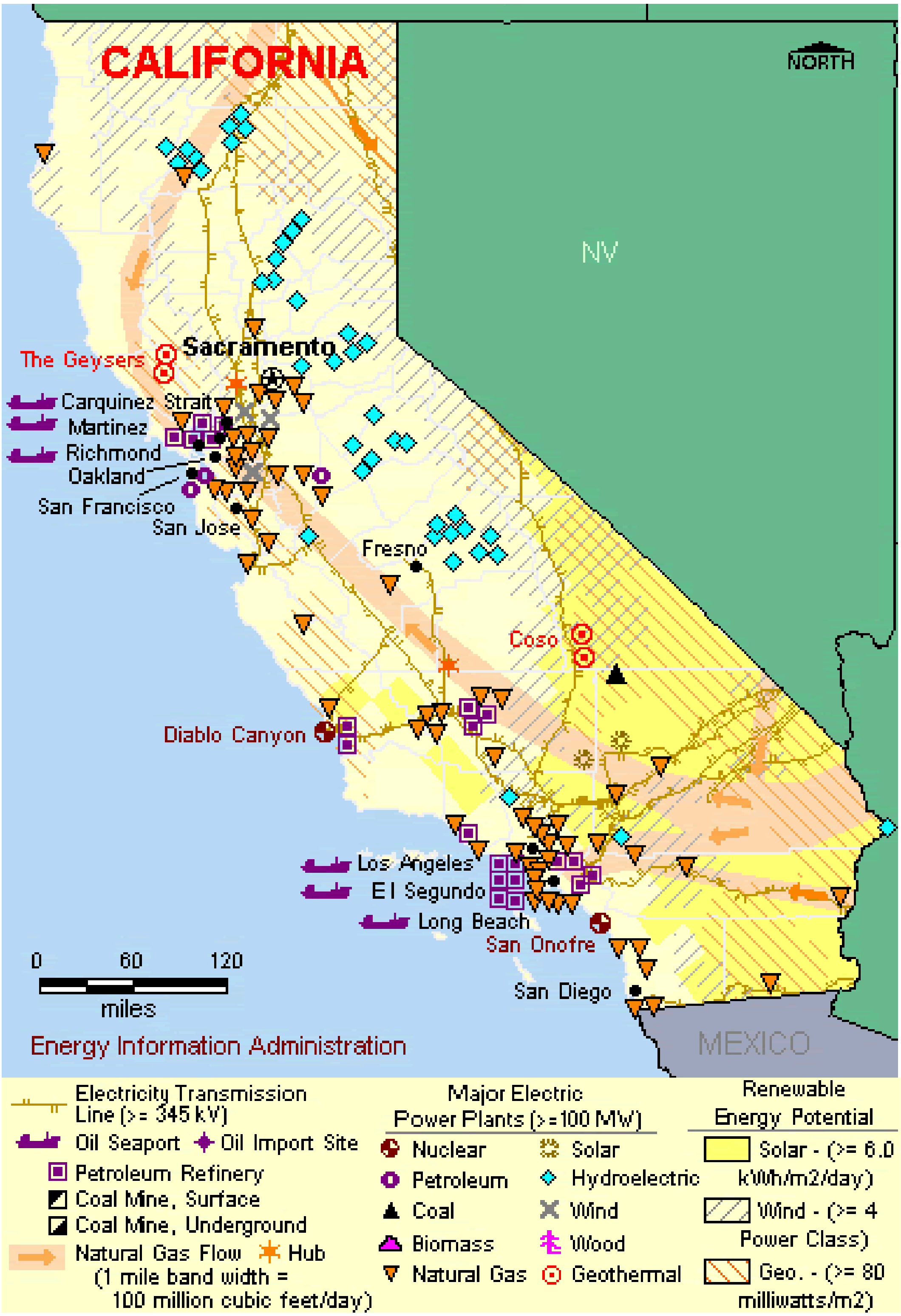
Source : CEC,. 2005. http://www.energy.ca.gov/maps/refinery_locations.html

Appendix 3. Cement Plants in California



Source : ARB

Appendix 4. Map of California main energy activities



Source: U.S. EIA, http://tonto.eia.doe.gov/state/