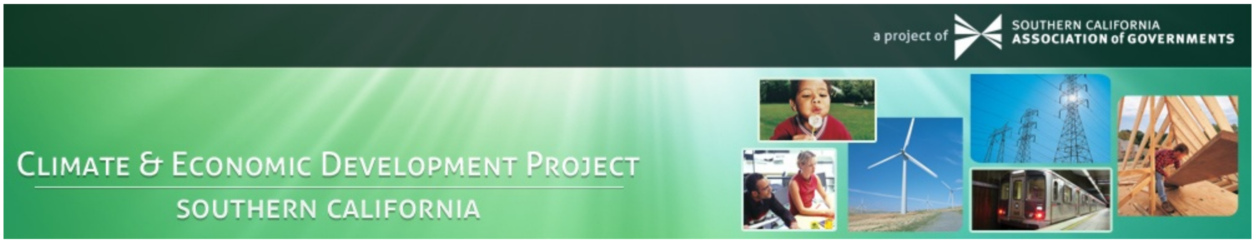

Final
Southern California Association of Governments (SCAG)

Regional Greenhouse Gas Emissions Inventory and Reference Case Projections, 1990-2035

May 30, 2012

Prepared by:

THE CENTER FOR CLIMATE STRATEGIES

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**This inventory and forecast has been prepared with the most up-to-date information and should not be compared to any previous analysis at this time.*

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Executive Summary

The Center for Climate Strategies (CCS) prepared this report for the Southern California Association of Governments (SCAG). The report presents an assessment of the region's anthropogenic greenhouse gas (GHG) emissions and sinks (carbon storage) from 1990 to 2035. This preliminary draft inventory and forecast served as a starting point to assist the Climate and Economic Development Project (CEDP) Project Stakeholders Committee (PSC), as well as the Technical Work Groups (TWGs) of the PSC, with an initial comprehensive understanding of SCAG's current and possible future GHG emissions, and thereby informed the identification and analysis of policy options for mitigating GHG emissions.[1] The PSC and TWGs have reviewed, discussed, and evaluated the draft inventory and methodologies as well as alternative data and approaches for improving the draft GHG inventory and forecast. Staff from California's Air Resources Board also provided significant review of and comments on the draft inventory and forecast. The inventory and forecast as well as this report have been revised to address the comments provided and approved by the PSC.

Emissions and Reference Case Projections (Business-as-Usual)

SCAG's anthropogenic GHG emissions and anthropogenic sinks (carbon storage) were estimated for the period from 1990 to 2035. The reference case or Business As Usual (BAU) forecast illustrates what emissions are expected to be in the absence of additional policies beyond what is already planned. Historical GHG emission estimates (1990 through 2008)[2] were developed using a set of generally accepted principles and guidelines for State GHG emissions inventories, relying to the extent possible on SCAG-specific data and inputs when it was possible to do so. The reference case projections (2009-2035) are based on a compilation of various projections of vehicle miles traveled (VMT), electricity generation, fuel use, and other GHG-emitting activities in the SCAG region, along with a set of simple, transparent assumptions described in the appendices of this report. Figure ES-1 illustrates the 6-county geographic area that this inventory covers.

The inventory and projections cover the six types of gases included in the U.S. Greenhouse Gas Inventory: carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), hydrofluorocarbons (HFCs), perfluorocarbons (PFCs), and sulfur hexafluoride (SF_6). Emissions of these GHGs are presented using a common metric, CO_2 equivalence (CO_2e), which indicates the relative contribution of each gas, per unit mass, to global average radiative forcing on a global warming potential (GWP) weighted basis.[3]

[1] "Draft Southern California Association of Governments (SCAG) Regional Greenhouse Gas Emissions Inventory and Reference Case Projections, 1990-2035," prepared by the Center for Climate Strategies for SCAG, August 2010.
[2] The last year of available historical data varies by sector; ranging from 2005 to 2008.
[3] Changes in the atmospheric concentrations of GHGs can alter the balance of energy transfers between the atmosphere, space, land, and the oceans. A gauge of these changes is called radiative forcing, which is a simple measure of changes in the energy available to the Earth-atmosphere system (IPCC, 2001). Holding everything else constant, increases in GHG concentrations in the atmosphere will produce positive radiative forcing (i.e., a net increase in the absorption of energy by the Earth), see: Boucher, O., et al. "Radiative Forcing of Climate Change."

Figure ES-1. SCAG Region Included in GHG Inventory and Forecast

As shown in Table ES-1 below, activities in the SCAG region accounted for approximately 231 million metric tons (MMt) of gross[4] CO_2e ($MMtCO_2e$) emissions (consumption basis[5]) in 2008, an amount equal to about 3.3% of total U.S. gross GHG emissions.[6] SCAG's gross GHG emissions are rising at a slower rate than those of the nation as a whole. From 1990 to 2008, SCAG's gross GHG emissions increased by about 12% while national emissions rose by 14%. The growth in SCAG's emissions from 1990 to 2008 is primarily associated with the

Chapter 6 in Climate Change 2001: The Scientific Basis. Contribution of Working Group 1 of the Intergovernmental Panel on Climate Change: Cambridge University Press. Cambridge, United Kingdom. Available at: http://www.grida.no/climate/ipcc_tar/wg1/212.htm. Additional background can be found in Appendix I.

[4] Gross emissions exclude GHG emissions removed due to forestry and other land uses and excluding GHG emissions associated with exported electricity. For SCAG, forestry sector emissions are positive so net emissions are equivalent to gross emissions (which is not true for the US as a whole).

[5] "Consumption-basis" here refers to the electricity sector, where emissions are expressed on the basis of the amount of electricity consumed in the SCAG region, instead of on the basis of where that electricity was produced. All other sector emissions are reported on a production (or direct) basis. Production-based emissions are expressed are attributed to the geographic location where the emission/sink occurs.

[6] The national emissions used for these comparisons are based on 2008 emissions from Inventory of US Greenhouse Gas Emissions and Sinks: 1990-2010, April 15, 2012, US EPA #430-R-12-001, http://www.epa.gov/climatechange/emissions/downloads12/US-GHG-Inventory-2012-Main-Text.pdf

transportation sector, the use of ozone-depleting substance (ODS) substitutes used in cooling and refrigeration equipment, the fossil fuel industry, and electricity generation.

Estimates of carbon sinks within SCAG's forests, including urban forests and land use changes, have also been included in this report. The current estimates indicate that about 0.5 $MMtCO_2e$ were stored in SCAG's urban forest biomass in 2008. This leads to net emissions that are nearly the same as gross emissions: 230 $MMtCO_2e$ in SCAG in 2008, an amount equal to 3.9% of total

Table ES-1. SCAG Historical and Reference Case GHG Emissions, by Sector[a]

(Million Metric Tons CO_2e)	1990	2000	2005	2008	2010	2020	2035
Energy Consumption Based	**188.6**	**209.9**	**213.1**	**207.9**	**204.0**	**192.5**	**210.0**
Electricity (Consumption)	**56.3**	**63.3**	**59.3**	**58.0**	**55.0**	**49.1**	**58.1**
Electricity Production (in SCAG Region)	20.4	32.1	16.1	20.9	18.0	21.1	21.3
Coal	*2.80*	*2.73*	*0.70*	*0.90*	*0.93*	*0.93*	*0.93*
Natural Gas	*15.5*	*24.2*	*12.3*	*17.5*	*14.7*	*18.1*	*18.1*
Petroleum	*2.14*	*0.76*	*0.58*	*0.05*	*0.03*	*0.03*	*0.03*
Waste/Biogas	*0.00*	*1.80*	*1.61*	*1.54*	*1.53*	*1.01*	*1.11*
Renewable	*0.00*	*0.01*	*0.30*	*0.31*	*0.31*	*0.47*	*0.55*
Electricity Imports	35.9	31.2	43.2	37.1	37.0	28.0	36.8
Res./Com./Ind. (RCI)	**39.8**	**41.4**	**41.0**	**37.5**	**36.8**	**38.8**	**39.8**
Coal	4.03	2.91	2.86	2.50	2.29	2.66	2.57
Natural Gas	23.0	28.1	28.5	26.6	25.8	26.3	27.6
Oil	12.3	10.1	9.50	8.33	8.57	9.62	9.53
Wood (CH_4 and N_2O)	0.39	0.22	0.15	0.14	0.14	0.15	0.16
Transportation	**75.5**	**85.7**	**93.5**	**92.4**	**91.8**	**83.1**	**89.6**
Onroad Gasoline	61.6	70.0	74.0	72.7	70.7	56.4	54.0
Onroad Diesel	9.18	10.8	14.0	14.5	15.5	19.2	25.7
Marine Vessels	0.92	0.98	1.08	0.97	1.37	2.32	2.92
Rail, Gas, LPG, other	0.79	0.64	1.36	1.26	1.19	1.48	2.46
Jet Fuel & Aviation Gas	3.00	3.28	2.98	2.90	3.04	3.70	4.49
Fossil Fuel Industry	**17.1**	**19.5**	**19.3**	**20.0**	**20.3**	**21.6**	**22.5**
Oil & Gas Prod. - Refining	9.31	12.3	12.3	11.4	11.6	12.3	12.7
Fugitive - Oil Refining	4.70	4.39	4.27	5.23	5.32	5.66	5.84
Fugitive - Gas Refining	3.04	2.83	2.76	3.38	3.42	3.63	3.97
Industrial Processes	**3.8**	**8.6**	**10.6**	**11.0**	**11.4**	**13.0**	**15.1**
Cement Manufacture (CO_2)	2.61	3.07	3.30	3.00	3.17	3.93	4.98
Lime Manufacture (CO_2)	0.11	0.03	0.03	0.02	0.02	0.01	0.00
Semiconductor Manufacturing (HFC, PFC, SF_6)	0.16	0.35	0.22	0.22	0.22	0.22	0.22
ODS Substitutes (HFC, PFC)	0.02	4.17	6.07	6.81	7.00	7.81	8.87
SF_6 Electrical Equipment	0.08	0.04	0.03	0.03	0.03	0.03	0.02
CO_2 Consumption	0.08	0.07	0.06	0.10	0.10	0.11	0.11
Limestone & Dolomite Use (CO_2)	0.07	0.06	0.06	0.06	0.06	0.06	0.06
Soda Ash Use (CO_2)	0.15	0.14	0.14	0.13	0.13	0.13	0.12
Hydrogen Production (CO_2)	0.53	0.65	0.63	0.67	0.67	0.71	0.74
Waste Management	**4.8**	**4.5**	**5.0**	**5.1**	**5.3**	**6.4**	**9.0**
Landfills	3.77	3.38	3.72	3.84	3.99	4.99	7.40
Wastewater Management	1.01	1.16	1.23	1.28	1.30	1.41	1.58
Agriculture	**3.7**	**3.3**	**3.2**	**3.1**	**3.1**	**3.0**	**2.9**
Fuel Combustion	0.33	0.29	0.35	0.36	0.37	0.41	0.46
Enteric Fermentation	1.49	1.10	1.04	0.92	0.88	0.70	0.47
Manure Management	0.94	0.80	0.68	0.61	0.58	0.47	0.33
Ag Burning	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Ag Soils - Livestock	0.18	0.23	0.24	0.25	0.26	0.32	0.41

(Million Metric Tons CO_2e)	1990	2000	2005	2008	2010	2020	2035
Ag Soils - Liming	0.01	0.02	0.02	0.03	0.03	0.04	0.06
Ag Soils - Fertilizer	0.23	0.30	0.37	0.42	0.44	0.57	0.77
Ag Soils - Crops	0.45	0.44	0.39	0.40	0.39	0.35	0.29
Soil Carbon Flux	0.11	0.11	0.11	0.11	0.11	0.11	0.11
Forestry and Land Use	**4.5**	**3.6**	**15.5**	**3.6**	**1.4**	**1.5**	**1.4**
Forested Landscape	4.47	3.48	15.36	3.33	1.32	1.32	1.27
Non-Farm Fertilizer (Settlement Soils)	0.05	0.06	0.08	0.08	0.08	0.09	0.10
Forest Fires (N_2O & CH_4)	1.17	0.03	0.01	0.06	0.14	0.01	0.07
Total Gross Emissions (Consumption Based)	**205.5**	**229.8**	**247.3**	**230.7**	**225.1**	**216.4**	**238.5**
increase relative to 1990		*12%*	*20%*	*12%*	*10%*	*5%*	*16%*
Emissions Sinks	**-0.4**	**-0.5**	**-0.5**	**-0.7**	**-0.5**	**-0.6**	**-0.6**
Urban Forests	-0.43	-0.45	-0.48	-0.67	-0.51	-0.56	-0.64
Net Emissions	**205.0**	**229.3**	**246.8**	**230.2**	**224.6**	**215.8**	**237.8**
increase relative to 1990		*12%*	*20%*	*12%*	*10%*	*5%*	*16%*

[a] Totals may not equal exact sum of subtotals shown in this table due to independent rounding. Consumption-basis refers to the electricity sector only. Transportation sector forecast does not include the effects of recent actions, which are addressed separately in this report.

U.S. net GHG emissions. Other forestry sources in the SCAG region, including the forested landscape, non-farm fertilizer use, and forest fires are estimated to be sources rather than sinks of GHG emissions in the SCAG region.

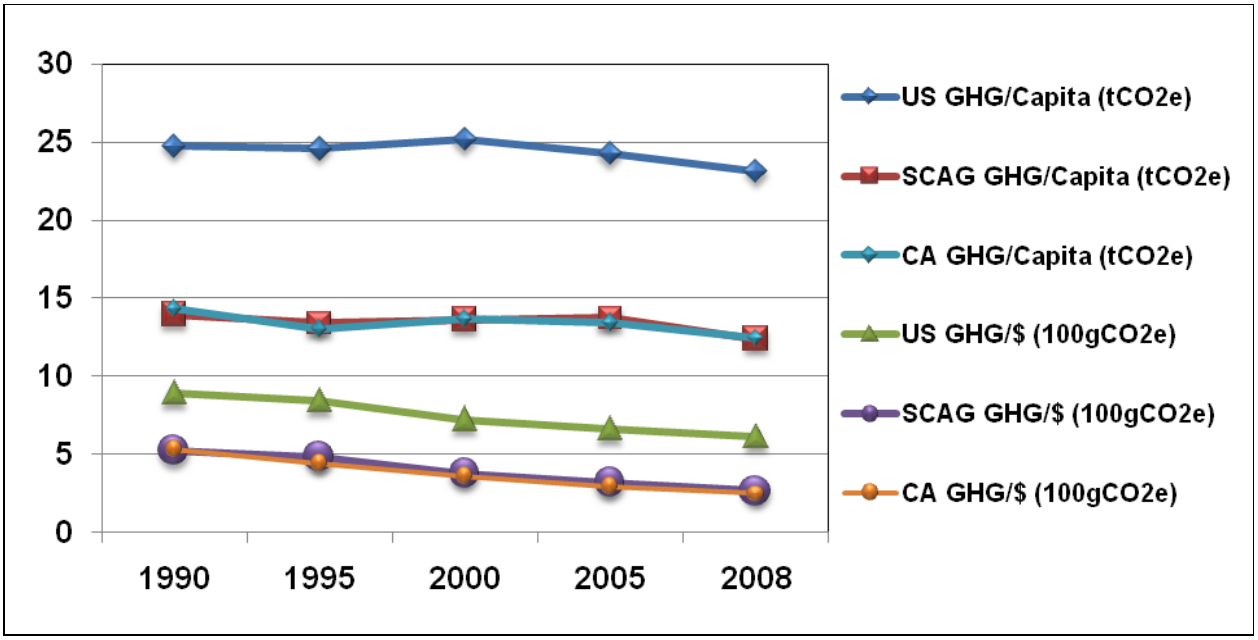
Figure ES-2 illustrates the region's emissions per capita and per unit of economic output, and shows comparable data for California and the US.[7] On a per capita basis, SCAG residents emitted about 14 metric tons (t) CO_2e per person (tCO_2e) in 1990, much lower than the 1990 national per capita emissions of 25 tCO_2e/person and slightly lower than California emissions per capita. Both national and SCAG per capita emissions decreased from 1990 to 2008, by 7% and 11%, respectively. By 2008, SCAG per capita emissions are the same as per capita emissions in California. Like the nation as a whole, SCAG's economic growth exceeded emissions growth throughout the 1990-2008 period, leading to declining estimates of GHG emissions per unit of regional product. From 1990 to 2008, emissions per unit of gross product dropped by 49% in the SCAG region and by 31% nationally.[8] Emissions per unit of gross product are almost identical for both the SCAG region and California throughout the 1990-2008 period.

The principal sources of SCAG's GHG emissions are transportation; electricity consumption; and residential, commercial, and industrial (RCI) fuel use accounting for 40%, 25%, and 16% of SCAG's gross GHG emissions in 2008, respectively.

[7] Historical SCAG population statistics are compiled by SCAG's Economic Development staff from California Department of Finance data. They are available at http://www.scag.ca.gov/economy/econdata.html. The population projections through 2035 used in this report are not available yet at the link listed above. Revised data (updated from 2008 RTP data) were provided by SCAG to CCS on July 30th, 2010.
[8] Based on real gross domestic product (millions of chained 2000 dollars), that excludes the effects of inflation; available from the U.S. Bureau of Economic Analysis (http://www.bea.gov/regional/gsp). The national emissions used for these comparisons are based on 2008 emissions from Inventory of US Greenhouse Gas Emissions and Sinks: 1990-2010, April 15, 2012, US EPA #430-R-12-001, http://www.epa.gov/climatechange/emissions/downloads12/US-GHG-Inventory-2012-Main-Text.pdf

As illustrated in Figure ES-3 and shown numerically in Table ES-1, under the reference case projections, SCAG's gross GHG emissions continue to grow, and are projected to climb to about 238 MMtCO_2e by 2035, reaching 16% above 1990 levels. As shown in Figure ES-4, the waste management sector is projected to be the largest contributor to future emissions growth in the SCAG region, followed by emissions associated with the fossil fuel industry, the use of ODS substitutes used in cooling and refrigeration equipment, and other industrial processes.

Figure ES-2. Historical SCAG, California, and US Gross GHG Emissions, Per Capita and Per Unit Gross Product, 1990-2008



tCO_2e = metric ton carbon dioxide equivalent. g = gram.

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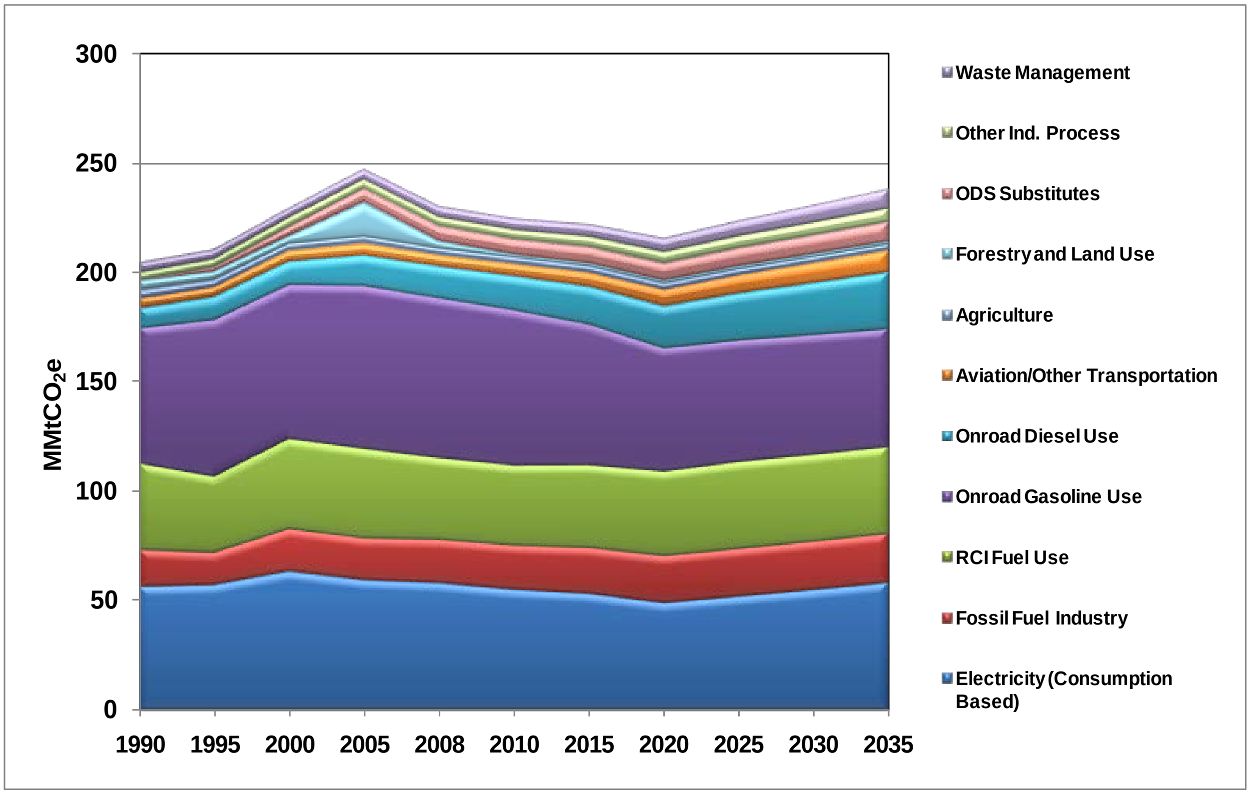
Figure ES-3. SCAG Gross GHG Emissions by Sector, 1990-2035: Historical and Projected



RCI – direct fuel use in residential, commercial, and industrial sectors. ODS – ozone depleting substance. Forecast does not include the effects of recent actions in the Transportation Sector. These are addressed separately in this report.

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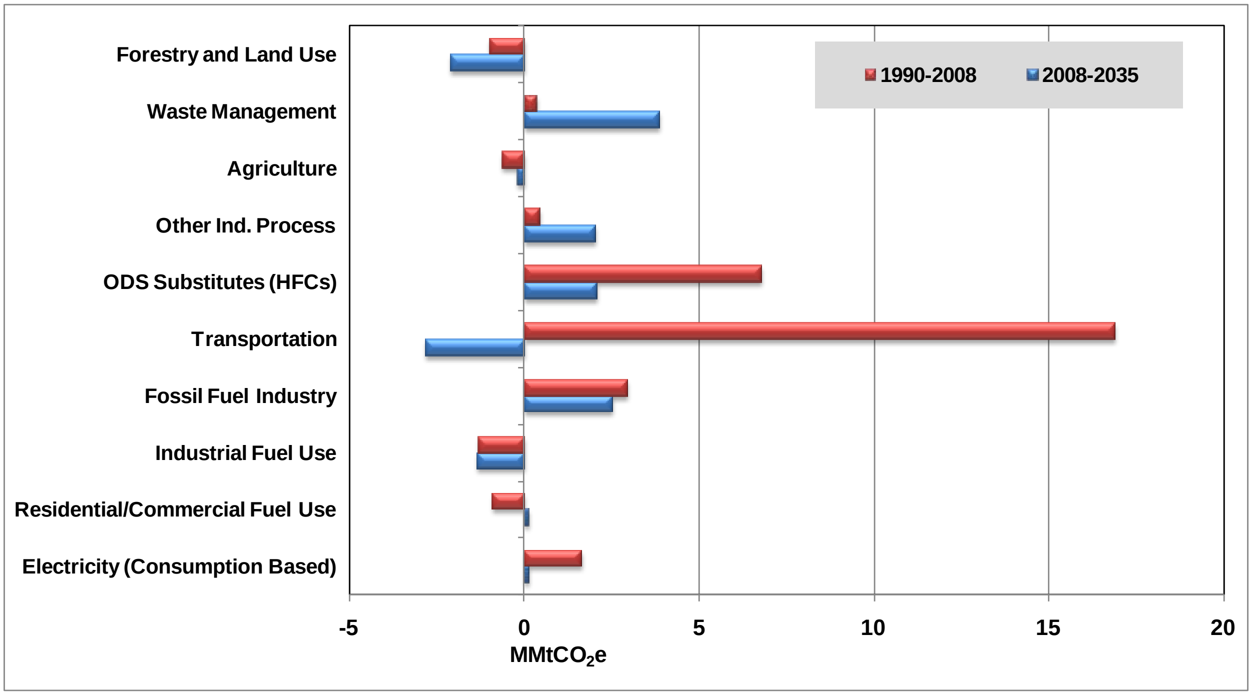
Figure ES-4. Sector Contributions to Gross Emissions Growth in SCAG, 1990-2035: Reference Case Projections (MMtCO_2e Basis)



Residential/Commercial – direct fuel use in residential and commercial sectors. ODS – ozone depleting substance. HFCs – hydrofluorocarbons. Emissions associated with other industrial processes include all of the industries identified in Appendix D except emissions associated with ODS substitutes which are shown separately in this graph because of high expected growth in emissions for ODS substitutes.

Table ES-2 compares gross GHG emissions by sector in California and in the SCAG region in 1990, 2008, and 2020 (latest year of the California Air Resources Board (ARB)'s forecast). The sectors are defined according to ARB's GHG emissions forecast used in the AB 32 Scoping Plan[9, 10,11] (those sectors are different from the ones mentioned above). This table also shows the 6-county SCAG region's contribution to California's total GHG emissions. In 1990, SCAG regional emissions represented 47% of California's gross GHG emissions. While the SCAG region's contribution increased to 48% in 2008, it is projected to slightly decrease to 43% by 2020.

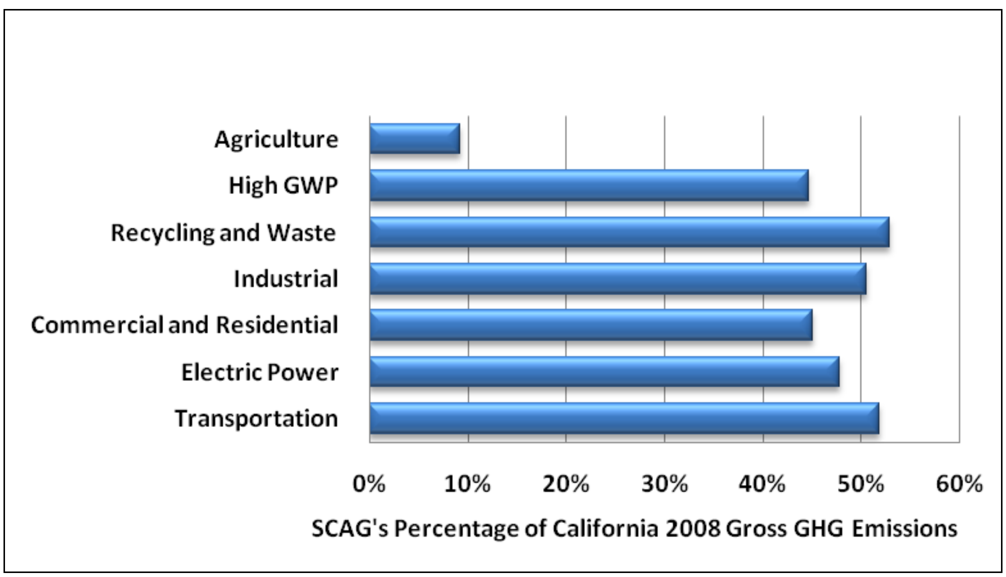
[9]Air Resources Board, Inventory Data Archive - 1990 to 2004 Inventory, November 2007. Available at: http://www.arb.ca.gov/cc/inventory/archive/tables/ghg_inventory_sector_90-04_sum_2007-11-19.pdf
[10]Air Resources Board, Greenhouse Gas Emission Inventory Data – years 2000-2009, October 26, 2011. Available at: http://www.arb.ca.gov/cc/inventory/data/tables/ghg_inventory_scopingplan_00-09_2011-10-26.pdf
[11] Air Resources Board, Greenhouse Gas Inventory - 2020 Emissions Forecast, October 2010. Available at: http://www.arb.ca.gov/cc/inventory/data/forecast.htm

Table ES-2. California and SCAG Gross GHG Emissions by Sector, 1990-2020: Historical and Projected

Sector	Emissions ($MMtCO_2e$)								
	1990			2008			2020		
	CA	SCAG	*SCAG %*	CA	SCAG	*SCAG %*	CA	SCAG	*SCAG %*
Transportation	150.7	75.5	*50%*	178.0	92.4	*52%*	183.9	83.1	*45%*
Electric Power	110.6	56.3	*51%*	121.2	58.0	*48%*	110.3	49.1	*44%*
Commercial / Residential	44.1	19.6	*45%*	41.5	18.7	*45%*	45.3	19.3	*43%*
Industrial	94.8	41.7	*44%*	87.1	44.1	*51%*	91.5	47.4	*52%*
Recycling and Waste	6.3	3.8	*60%*	7.3	3.8	*53%*	8.5	5.0	*59%*
High GWP	3.2	0.3	*8%*	15.8	7.1	*45%*	37.9	8.1	*21%*
Agriculture	23.4	3.7	*16%*	33.7	3.1	*9%*	29.2	3.0	*10%*
Forestry	0.2	4.5	*2390%*	0.2	3.6	*1870%*	0.2	1.5	*739%*
Forestry Net Emissions	-6.7	-0.4	*6%*	-3.8	-0.5	*14%*	0.0	-0.6	*N/A*
Total Gross Emissions	**433.3**	**205.5**	***47%***	**484.7**	**230.7**	***48%***	**506.8**	**216.4**	***43%***
Total Net Emissions	**426.6**	**205.0**	***48%***	**480.9**	**230.2**	***48%***	**506.8**	**215.8**	***43%***

Figure ES-5 illustrates SCAG's contribution to California's total GHG emissions in 2008, for each sector. This figure shows that all sectors do not contribute evenly to California's emissions. While SCAG's total emissions account for 48% of California's total emissions, SCAG's agricultural emissions only represent 9% of California's agricultural emissions. On the other hand, when it comes to emissions related to the transportation sector, SCAG's emissions represent 52% of California's emissions. SCAG's contribution is slightly greater for the recycling and waste sector, with a fraction of 53%.

Figure ES-5. SCAG Region's Contribution to California 2008 Gross GHG Emissions by Sector



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Some data gaps exist in this analysis, particularly for the reference case projections. Key tasks include review and revision of key emissions drivers that will be major determinants of SCAG's future GHG emissions (such as the growth rate assumptions for electricity generation and consumption, transportation fuel use, and RCI fuel use). Appendices A through H provide the detailed methods, data sources, and assumptions for each GHG sector. Also included, are descriptions of significant uncertainties in emissions estimates or methods and suggested next steps for refinement of the inventory and forecast. Appendix I provides background information on GHGs and climate-forcing aerosols.

GHG Reductions from Recent Actions

Two recent actions were identified that have the potential to significantly reduce the reference case forecast of the transportation sector GHG emissions and that could also be quantified within the scope of resources available for this project. These include the California Advanced Clean Car program and the Federal heavy-duty GHG emission standards. During the development of the revised inventory and forecast, sufficient information was identified (e.g. implementation schedules) to estimate GHG emission reductions associated with these two programs. (Note that the GHG emission reductions associated with the California Pavley I vehicle GHG standards and the Low Carbon Fuel Standards were included in the reference case forecast.)

The Advanced Clean Cars program combines the control of smog-causing pollutants and greenhouse gas emissions into a single coordinated package of requirements for model years 2017 through 2025. The new rules will clean up gasoline and diesel-powered cars, and deliver increasing numbers of zero-emission technologies, such as full battery electric cars, newly emerging plug-in hybrid electric vehicles and hydrogen fuel cell cars.[12]

In September 2011 the U.S. EPA and the Department of Transportation's National Highway Traffic Safety Administration (NHTSA) initiated a program to reduce GHG emissions and improve fuel efficiency of vehicles ranging from semi trucks to the largest pickup trucks and vans, as well as all types and sizes of work trucks and buses in between. These federal standards are phased in from the 2014 through 2018 vehicle model years.

The GHG emission reductions projected to be achieved by these recent actions are summarized in Table ES-3. This table shows a total reduction of about 14 $MMtCO_2e$ in 2035 from the business-as-usual reference case emissions, or a 5.9% reduction from the business-as-usual emissions in 2035 for all sectors combined.

[12] "California Air Resources Board Approves Advanced Clean Car Rules," news release # 12-05 from California Air Resources Board, January 27, 2012.

Table ES-3. Emission Reduction Estimates Associated with the Effect of Recent Actions in the SCAG Region

	GHG Reductions ($MMtCO_2e$)		GHG Emissions (MMtCO2e)	
			Business as Usual	With Recent Actions
Sector / Recent Action	**2020**	**2035**	**2035**	**2035**
Transportation			89.6	75.5
California Advanced Clean Cars Program	1.3	11.9		
Federal Heavy-Duty GHG Standards	0.7	2.1		
Total (All Sectors)	**1.96**	**14.1**	**238.5**	**224.4**

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Acronyms and Key Terms

Acronym	Definition
AEO	(EIA) Annual Energy Outlook
Ag	Agriculture
AIM	Affiliated International Management
ARB	(California) Air Resources Board
ARB TSD	ARB Technical GHG Inventory Technical Support Document
ATADS	Air Traffic Activity Data System
BAU	Business-as-usual
bbls	Barrels
BC	Black Carbon*
Bcf	Billion cubic feet
BEA	Bureau of Economic Analysis
BOD	Biochemical Oxygen Demand
BTS	Bureau of Transportation Statistics
BTU	British Thermal Unit
C	Carbon*
$CaCO_3$	Calcium Carbonate
CARB	California Air Resources Board
CCS	Center for Climate Strategies
CEC	California Energy Commission
CEDP	Climate and Economic Development Project
CFCs	Chlorofluorocarbons*
CH_4	Methane*
CHP	Combined Heat and Power
CNG	Compressed Natural Gas
CO	Carbon monoxide*
CO_2	Carbon Dioxide*
CO_2e	Carbon Dioxide equivalent*
COLE	Carbon On-Line Estimator
CRP	Federal Conservation Reserve Program
CWNS	Clean Water Needs Survey
DOT	US Department of Transportation
EC	Elemental Carbon*
EGU	Electricity Generating Unit
EIA	US DOE Energy Information Administration
EIIP	Emissions Inventory Improvement Program
EMFAC	EMission FACtors
EOR	Enhanced Oil Recovery
EPA	(United States) Environmental Protection Agency
Eq.	Equivalent
FAA	Federal Aviation Administration
FHWA	Federal Highway Administration
FIA	Forest Inventory and Analysis

**This inventory and forecast has been prepared with the most up-to-date information and should not be compared to any previous analysis at this time.*

Acronym	Definition
GDP	Gross Domestic Product
Gg	Gigagram
GHG	Greenhouse Gases*
GSP	Gross State Product
GWh	Gigawatt-hour
GWP	Global Warming Potential*
H_2O	Water Vapor
Ha	hectare
HBFC	Hydrobromofluorocarbons
HCFC	Hydrochlorofluorocarbons
HFCs	Hydrofluorocarbons*
IPCC	Intergovernmental Panel on Climate Change*
kg	Kilograms
kWh	Kilowatt-hour
LCFS	Low Carbon Fuel Standard
LF	Landfill
LFG	Landfill gas
LFGTE	Landfill-Gas-to-Energy
LMOP	Landfill Methane Outreach Program
LNG	Liquefied Natural Gas
LPG	Liquefied Petroleum Gas
LTO	Landing and Take-Off
MG	Million Gallons
MGD	Millions Gallons per Day
MMBtu	Million British Thermal Units
MMt	Million Metric tons
$MMtCO_2e$	Million Metric tons of Carbon Dioxide equivalents
MSA	Metropolitan Statistical Area
MSW	Municipal Solid Waste
Mt	Metric tons
MW	Megawatt
MWh	Megawatt-hour
N	Nitrogen
N_2O	Nitrous Oxide*
NAICS	Northern American Industry Classification System
NASS	National Agricultural Statistics Service
NCASI	National Council for Air and Stream Improvement
NEI	National Emissions Inventory (US EPA)
NHTSA	National Highway Traffic Safety Administration
NMVOC	Nonmethane Volatile Organic Compound
NMVOCs	Non-methane Volatile Organic Compounds*
NO	Nitrogen Oxide*
NO_2	Nitrogen Dioxide*
NO_x	Nitrogen Oxides*
O_3	Ozone*

Acronym	Definition
OCS	Pacific Outer Continental Shelf
ODS	Ozone-Depleting Substances*
OH	Hydroxyl Radical
OM	Organic Matter*
OMB	Office of Management and Budget
OPS	Office of Pipeline Safety
PFCs	Perfluorocarbons*
PM	Particulate Matter*
POLA	Port of Los Angeles
POLB	Port of Long Beach
ppb	parts per billion
ppm	parts per million
ppmv	parts per million by volume
ppt	parts per trillion
PSC	Project Stakeholders Committee
PV	Photovoltaic
RCI	Residential, Commercial, and Industrial
RES	Renewable Energy Standard
RITA	Research and Innovative Technology Administration
RPS	Renewable Portfolio Standard
RTP	Regional Transportation Plan
SAR	Second Assessment Report*
SCAG	Southern California Association of Governments
SCAQMD	South Coast Air Quality Management District
SCPPA	Southern California Public Power Authority
SED	State Energy Data
SF_6	Sulfur Hexafluoride*
Sinks	Removals of carbon from the atmosphere, with the carbon stored in forests, soils, landfills, wood structures, or other biomass-related products.
SIT	State GHG Inventory Tool
SO_2	Sulfur Dioxide
SUV	Sport Utility Vehicle
t	Metric Tons
T&D	Transmission and Distribution
TAF	Terminal Area Forecast
TAR	Third Assessment Report*
tCO_2e	Metric Tons Carbon Dioxide Equivalent
THC	Total Hydrocarbons
tN_2O	Metric Tons Nitrous Oxide
TWG	Technical Work Group
UNFCCC	United Nations Framework Convention on Climate Change
US	United States
US DOE	United States Department of Energy
USDA	United States Department of Agriculture

Acronym	Definition
USFS	United States Forest Service
USGS	United States Geological Survey
VMT	Vehicle-Miles Traveled
VOC	Volatile Organic Compound
WW	Wastewater
WWTP	Wastewater Treatment Plant

* See Appendix I for more information.

Summary of Preliminary Findings

Introduction

The Center for Climate Strategies (CCS) prepared this report for the Southern California Association of Governments (SCAG). The report presents an assessment of the region's greenhouse gas (GHG) emissions and anthropogenic sinks (carbon storage) from 1990 to 2035. The preliminary draft inventory and forecast served as a starting point to assist the Climate and Economic Development Project (CEDP) Project Stakeholders Committee (PSC), as well as the Technical Work Groups (TWGs) of the PSC, with an initial comprehensive understanding of SCAG's current and possible future GHG emissions, and thereby informed the upcoming identification and analysis of policy options for mitigating GHG emissions.[13] The PSC and TWGs have reviewed, discussed, and evaluated the draft inventory and methodologies as well as alternative data and approaches for improving the draft GHG inventory and forecast. Staff from California's Air Resources Board have also provided significant review of and comments on the draft inventory and forecast. The inventory and forecast as well as this report have been revised to address the comments provided and approved by the PSC.

Emissions and Reference Case Projections (Business-as-Usual)

SCAG's anthropogenic GHG emissions and anthropogenic sinks (carbon storage) were estimated for the period from 1990 to 2035. The reference case or Business As Usual (BAU) forecast illustrates what emissions are expected to be in the absence of additional policies beyond what is already planned. Historical GHG emission estimates (1990 through 2008)[14] were developed using a set of generally accepted principles and guidelines for State GHG emissions inventories, as described in the "Approach" section below, relying to the extent possible on SCAG-specific data and inputs. The initial reference case projections (2009-2035) are based on a compilation of various projections of electricity generation, fuel use, vehicle miles traveled (VMT), and other GHG-emitting activities for SCAG, along with a set of simple, transparent assumptions described in the appendices of this report.

The inventory and projections cover the six types of gases included in the U.S. Greenhouse Gas Inventory: carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), hydrofluorocarbons (HFCs), perfluorocarbons (PFCs), and sulfur hexafluoride (SF_6). Emissions of these GHGs are presented using a common metric, CO_2 equivalence (CO_2e), which indicates the relative contribution of each gas, per unit mass, to global average radiative forcing on a global warming potential (GWP) weighted basis.[15]

[13] "Draft Southern California Association of Governments (SCAG) Regional Greenhouse Gas Emissions Inventory and Reference Case Projections, 1990-2035," prepared by the Center for Climate Strategies for SCAG, August 2010.
[14] The last year of available historical data varies by sector; ranging from 2005 to 2008.
[15] Changes in the atmospheric concentrations of GHGs can alter the balance of energy transfers between the atmosphere, space, land, and the oceans. A gauge of these changes is called radiative forcing, which is a simple measure of changes in the energy available to the Earth-atmosphere system (IPCC, 2001). Holding everything else constant, increases in GHG concentrations in the atmosphere will produce positive radiative forcing (i.e., a net

It is important to note that the emissions related to the electricity sector reflect the *GHG emissions associated with the electricity sources used to meet SCAG's demands*, corresponding to a consumption-based approach to emissions accounting for this sector (see "Approach" section below). Another way to look at electricity emissions is to consider the *GHG emissions produced by electricity generation facilities in the region.* Appendix A of this report covers both methods of accounting for electricity emissions, but for consistency, all total results are reported using the *consumption-based* electricity emissions. Emission estimates in all other sectors are presented on a production- or direct emissions basis only.

SCAG Greenhouse Gas Emissions: Sources and Trends

Table 1 provides a summary of GHG emissions estimated for the 6-county SCAG region by sector for the years 1990, 2000, 2005, 2008, 2010, 2020, and 2035. Details on the methods and data sources used to construct these estimates are provided in the appendices to this report**.** In the sections below, we discuss GHG emission sources (positive, or *gross*, emissions) and sinks (negative emissions) separately in order to identify trends, projections, and uncertainties clearly for each.

This next section of the report provides a summary of the historical emissions (1990 through 2008), followed by a summary of the reference-case projection-year emissions (2009 through 2035). We also provide a comparison to California's emission inventory, a summary of revisions that have been made to the draft inventory and forecast, reductions to the reference case projections from recent actions, and key uncertainties. Finally, an overview of the general methodology, principles, and guidelines followed for preparing the inventories is provided. Appendices A through H provide the detailed methods, data sources, and assumptions for each GHG sector. Appendix I provides background information on GHGs and climate-forcing aerosols.

increase in the absorption of energy by the Earth), see: Boucher, O., et al. "Radiative Forcing of Climate Change." Chapter 6 in Climate Change 2001: The Scientific Basis. Contribution of Working Group 1 of the Intergovernmental Panel on Climate Change: Cambridge University Press. Cambridge, United Kingdom. Available at: http://www.grida.no/climate/ipcc_tar/wg1/212.htm

Table 1. SCAG Historical and Reference Case GHG Emissions, by Sector[a]

(Million Metric Tons CO_2e)	1990	2000	2005	2008	2010	2020	2035
Energy Consumption Based	**188.6**	**209.9**	**213.1**	**207.9**	**204.0**	**192.5**	**210.0**
Electricity (Consumption)	**56.3**	**63.3**	**59.3**	**58.0**	**55.0**	**49.1**	**58.1**
Electricity Production (in SCAG Region)	20.4	32.1	16.1	20.9	18.0	21.1	21.3
Coal	*2.80*	*2.73*	*0.70*	*0.90*	*0.93*	*0.93*	*0.93*
Natural Gas	*15.5*	*24.2*	*12.3*	*17.5*	*14.7*	*18.1*	*18.1*
Petroleum	*2.14*	*0.76*	*0.58*	*0.05*	*0.03*	*0.03*	*0.03*
Waste/Biogas	*0.00*	*1.80*	*1.61*	*1.54*	*1.53*	*1.01*	*1.11*
Renewable	*0.00*	*0.01*	*0.30*	*0.31*	*0.31*	*0.47*	*0.55*
Electricity Imports	35.9	31.2	43.2	37.1	37.0	28.0	36.8
Res./Com./Ind. (RCI)	**39.8**	**41.4**	**41.0**	**37.5**	**36.8**	**38.8**	**39.8**
Coal	4.03	2.91	2.86	2.50	2.29	2.66	2.57
Natural Gas	23.0	28.1	28.5	26.6	25.8	26.3	27.6
Oil	12.3	10.1	9.50	8.33	8.57	9.62	9.53
Wood (CH_4 and N_2O)	0.39	0.22	0.15	0.14	0.14	0.15	0.16
Transportation	**75.5**	**85.7**	**93.5**	**92.4**	**91.8**	**83.1**	**89.6**
Onroad Gasoline	61.6	70.0	74.0	72.7	70.7	56.4	54.0
Onroad Diesel	9.18	10.8	14.0	14.5	15.5	19.2	25.7
Marine Vessels	0.92	0.98	1.08	0.97	1.37	2.32	2.92
Rail, Gas, LPG, other	0.79	0.64	1.36	1.26	1.19	1.48	2.46
Jet Fuel & Aviation Gas	3.00	3.28	2.98	2.90	3.04	3.70	4.49
Fossil Fuel Industry	**17.1**	**19.5**	**19.3**	**20.0**	**20.3**	**21.6**	**22.5**
Oil & Gas Prod. - Refining	9.31	12.3	12.3	11.4	11.6	12.3	12.7
Fugitive - Oil Refining	4.70	4.39	4.27	5.23	5.32	5.66	5.84
Fugitive - Gas Refining	3.04	2.83	2.76	3.38	3.42	3.63	3.97
Industrial Processes	**3.8**	**8.6**	**10.6**	**11.0**	**11.4**	**13.0**	**15.1**
Cement Manufacture (CO_2)	2.61	3.07	3.30	3.00	3.17	3.93	4.98
Lime Manufacture (CO_2)	0.11	0.03	0.03	0.02	0.02	0.01	0.00
Semiconductor Manufacturing (HFC, PFC, SF_6)	0.16	0.35	0.22	0.22	0.22	0.22	0.22
ODS Substitutes (HFC, PFC)	0.02	4.17	6.07	6.81	7.00	7.81	8.87
SF_6 Electrical Equipment	0.08	0.04	0.03	0.03	0.03	0.03	0.02
CO_2 Consumption	0.08	0.07	0.06	0.10	0.10	0.11	0.11
Limestone & Dolomite Use (CO_2)	0.07	0.06	0.06	0.06	0.06	0.06	0.06
Soda Ash Use (CO_2)	0.15	0.14	0.14	0.13	0.13	0.13	0.12
Hydrogen Production (CO_2)	0.53	0.65	0.63	0.67	0.67	0.71	0.74
Waste Management	**4.8**	**4.5**	**5.0**	**5.1**	**5.3**	**6.4**	**9.0**
Landfills	3.77	3.38	3.72	3.84	3.99	4.99	7.40
Wastewater Management	1.01	1.16	1.23	1.28	1.30	1.41	1.58
Agriculture	**3.7**	**3.3**	**3.2**	**3.1**	**3.1**	**3.0**	**2.9**
Fuel Combustion	0.33	0.29	0.35	0.36	0.37	0.41	0.46
Enteric Fermentation	1.49	1.10	1.04	0.92	0.88	0.70	0.47
Manure Management	0.94	0.80	0.68	0.61	0.58	0.47	0.33
Ag Burning	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Ag Soils - Livestock	0.18	0.23	0.24	0.25	0.26	0.32	0.41
Ag Soils - Liming	0.01	0.02	0.02	0.03	0.03	0.04	0.06
Ag Soils - Fertilizer	0.23	0.30	0.37	0.42	0.44	0.57	0.77
Ag Soils - Crops	0.45	0.44	0.39	0.40	0.39	0.35	0.29
Soil Carbon Flux	0.11	0.11	0.11	0.11	0.11	0.11	0.11
Forestry and Land Use	**4.5**	**3.6**	**15.5**	**3.6**	**1.4**	**1.5**	**1.4**
Forested Landscape	4.47	3.48	15.36	3.33	1.32	1.32	1.27
Non-Farm Fertilizer (Settlement Soils)	0.05	0.06	0.08	0.08	0.08	0.09	0.10
Forest Fires (N_2O & CH_4)	1.17	0.03	0.01	0.06	0.14	0.01	0.07
Total Gross Emissions (Consumption Based)	**205.5**	**229.8**	**247.3**	**230.7**	**225.1**	**216.4**	**238.5**
increase relative to 1990		*12%*	*20%*	*12%*	*10%*	*5%*	*16%*

**This inventory and forecast has been prepared with the most up-to-date information and should not be compared to any previous analysis at this time.*

(Million Metric Tons CO_2e)	1990	2000	2005	2008	2010	2020	2035
Emissions Sinks	**-0.4**	**-0.5**	**-0.5**	**-0.7**	**-0.5**	**-0.6**	**-0.6**
Urban Forests	-0.43	-0.45	-0.48	-0.67	-0.51	-0.56	-0.64
Net Emissions	**205.0**	**229.3**	**246.8**	**230.2**	**224.6**	**215.8**	**237.8**
increase relative to 1990		*12%*	*20%*	*12%*	*10%*	*5%*	*16%*

[a] Totals may not equal exact sum of subtotals shown in this table due to independent rounding. Transportation sector forecast does not include the effects of recent actions, which are addressed separately in this report.

Historical Emissions

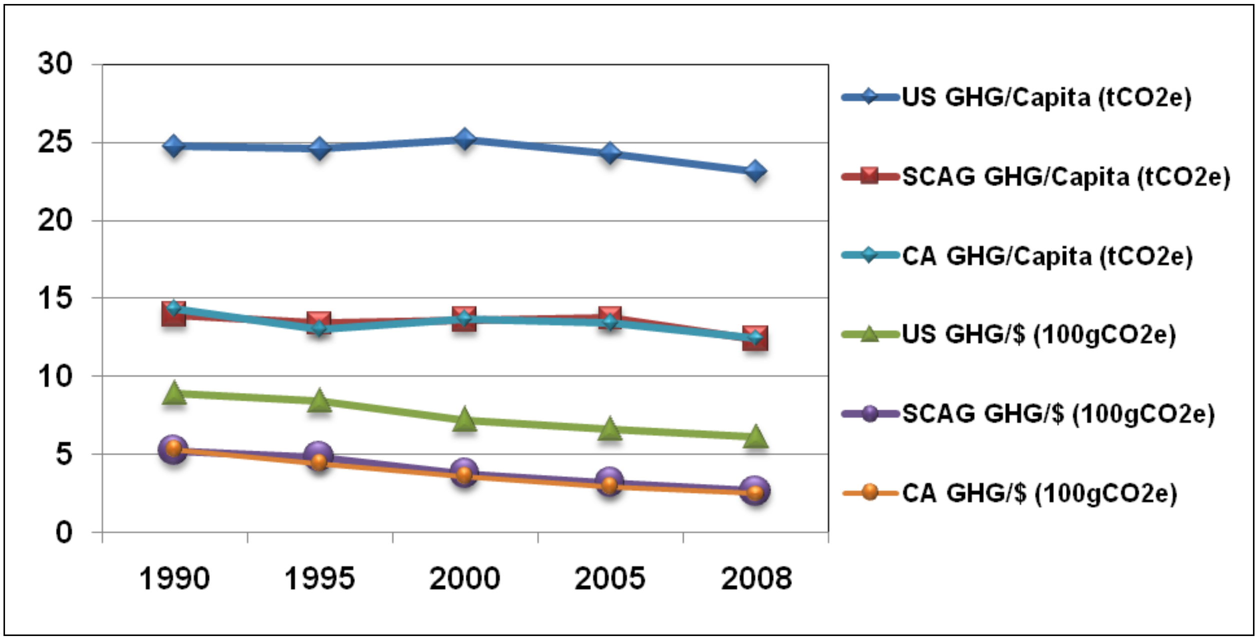
Overview

In 2008, activities in the SCAG region accounted for approximately 231 million metric tons (MMt) of gross[16] CO_2e emissions (consumption basis), an amount equal to about 3.3% of total U.S. gross GHG emissions.[17] SCAG's gross GHG emissions are rising at a slower rate than those of the nation as a whole. From 1990 to 2008, SCAG's gross GHG emissions increased by about 12% while national emissions rose by 14%. The growth in SCAG's emissions from 1990 to 2008 is primarily associated with the transportation sector, the use of ozone-depleting substance (ODS) substitutes used in cooling and refrigeration equipment, the fossil fuel industry, and electricity generation.

Figure 1 illustrates the region's emissions per capita and per unit of economic output, and shows comparable data for California and the US.[18] On a per capita basis, SCAG residents emitted about 14 tCO_2e/person in 1990, much lower than the 1990 national per capita emissions of 25 tCO_2e and slightly lower than California emissions per capita. Both national and SCAG per capita emissions decreased from 1990 to 2008, by 7% and 11%, respectively. By 2008, SCAG per capita emissions are the same as per capita emissions in California. Like the nation as a whole, SCAG's economic growth exceeded emissions growth throughout the 1990-2008 period, leading to declining estimates of GHG emissions per unit of regional product. From 1990 to 2008, emissions per unit of gross product dropped by 49% in the SCAG region and by 31% nationally.[19] Emissions per unit of gross product are almost identical for both the SCAG region and California throughout the 1990-2008 period.

[16] Gross emissions exclude GHG emissions removed due to forestry and other land uses and excluding GHG emissions associated with exported electricity.
[17] The national emissions used for these comparisons are based on 2008 emissions from Inventory of US Greenhouse Gas Emissions and Sinks: 1990-2010, April 15, 2012, US EPA #430-R-12-001, http://www.epa.gov/climatechange/emissions/downloads12/US-GHG-Inventory-2012-Main-Text.pdf
[18] Historical SCAG population statistics are compiled by SCAG's Economic Development staff from California Department of Finance data. They are available at http://www.scag.ca.gov/economy/econdata.html. The population projections through 2035 used in this report are not available yet at the link listed above. Revised data (updated from 2008 RTP data) were provided by SCAG to CCS on July 30th, 2010.
[19] Based on real gross domestic product (millions of chained 2000 dollars), that excludes the effects of inflation; available from the U.S. Bureau of Economic Analysis (http://www.bea.gov/regional/gsp). The national emissions used for these comparisons are based on 2008 emissions from Inventory of US Greenhouse Gas Emissions and Sinks: 1990-2010, April 15, 2012, US EPA #430-R-12-001, http://www.epa.gov/climatechange/emissions/downloads12/US-GHG-Inventory-2012-Main-Text.pdf

Figure 1. Historical SCAG, California, and US Gross GHG Emissions, Per Capita and Per Unit Gross Product, 1990-2008



tCO_2e = metric ton carbon dioxide equivalent; g = gram

Figure 2 compares the contribution of each sector to the total 2008 gross GHG emissions for the SCAG region, California, and the US. In order to compare results with California and the US, the sectors used in Figure 2 are those defined in the California Air Resources Board (ARB)'s GHG emissions forecast used in the AB 32 Scoping Plan.[20] Principal sources of SCAG's GHG emissions are the transportation sector; the residential, commercial, and industrial[21] (RCI) sectors; and the electricity consumption sector accounting for 40%, 27%, and 25% of SCAG's gross GHG emissions in 2008, respectively. In California, the largest contributors are also transportation, RCI, and electricity consumption accounting for 37%, 27%, and 25% of the State's gross GHG emissions in 2008, respectively. Transportation, RCI, and electricity consumption are also the major sectors in the US with respective contributions to the nation's gross GHG emissions in 2008 of 26%, 29%, and 34%.

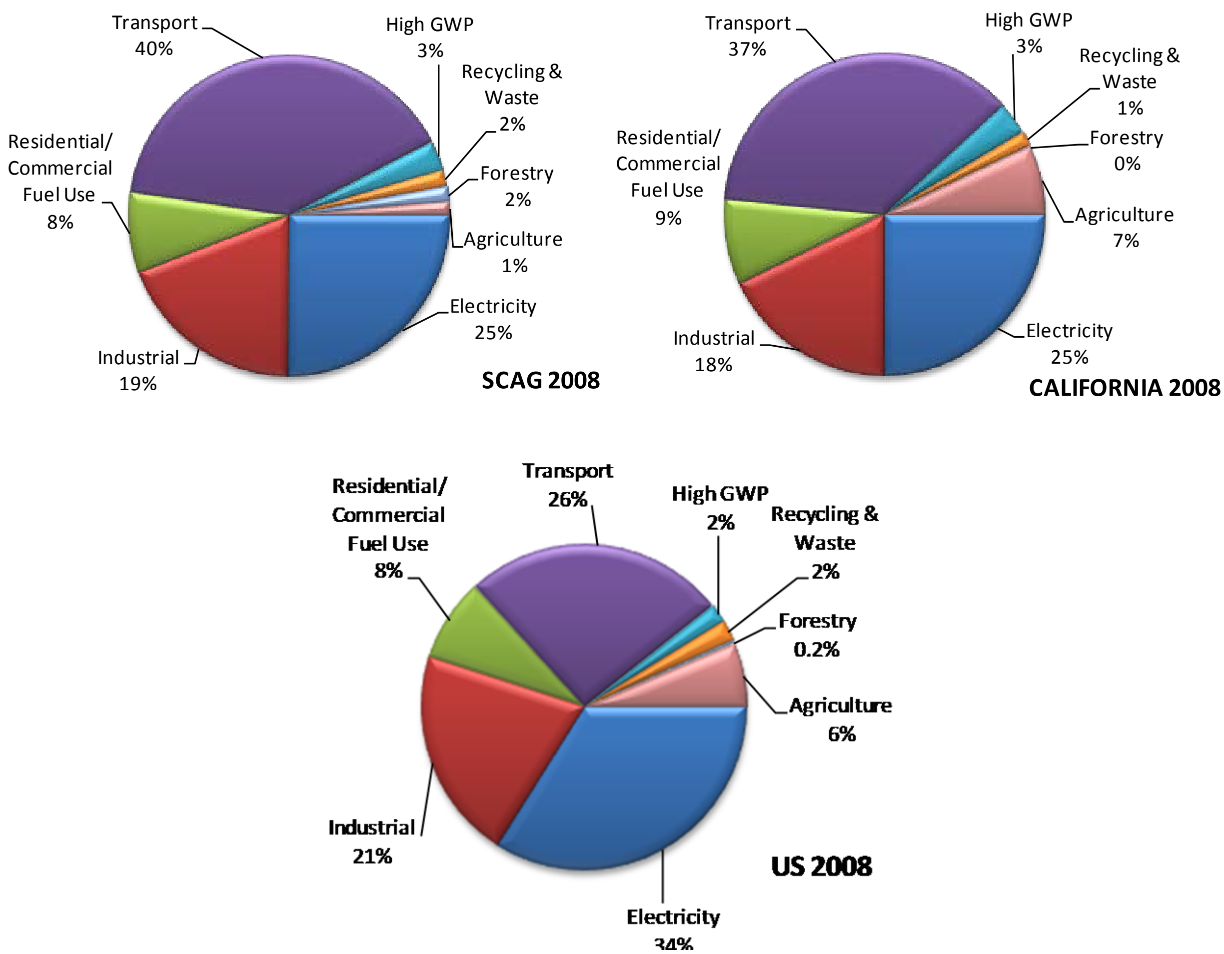
The next largest contributor to SCAG's 2008 gross GHG emissions is the use of HFCs as substitutes for ozone-depleting chlorofluorocarbons (CFCs), which represents 3% of SCAG's gross GHG emissions in 2008. This is followed by the recycling and waste sector and forestry sector, each accounting for 2% of SCAG's 2008 gross GHG emissions. The waste management

[20] Air Resources Board, Greenhouse Gas Emission Forecast for 2020: Data Sources, Methods, and Assumptions, October 2010. Available at: http://www.arb.ca.gov/cc/inventory/data/tables/2020_forecast_methodology_2010-10-28.pdf

[21] The industrial sector as described by ARB includes emissions from industrial fuel use associated with the direct use of fuels as well as industrial processes and fossil fuel industry (excludes High GWP emissions which are from the use of HFCs as substitutes for ozone-depleting chlorofluorocarbons (CFCs)).

sector is dominated by CH_4 emissions from landfills, but also includes emissions from wastewater management. The forestry sector includes emissions from the forested landscape, forest fires including both wildfires and prescribed burns, and non-farm fertilizer usage. Finally, the agriculture sector accounts for 1% of the SCAG region's 2008 gross GHG emissions. The agriculture sector includes emissions from enteric fermentation, manure management, agricultural soils, and agricultural burning.

Figure 2. Gross GHG Emissions by Sector, 2008, SCAG, California, and US



Notes: The sectors in Figure 2 are those described in ARB's GHG emissions forecast used in the AB 32 Scoping Plan[22]. Residential/Commercial Fuel Use = residential and commercial fuel use sectors; emissions for the residential, commercial and industrial fuel use sectors are associated with the direct use of fuels (natural gas, petroleum, coal, and wood) to provide space heating, water heating, process heating, cooking, and other energy end-uses. The commercial sector accounts for emissions associated with the direct use of fuels by, for example, hospitals, schools, government buildings (local, county, and state), and other commercial establishments. The industrial sector as described by ARB includes emissions from industrial fuel use associated with the direct use of fuels as well as

[22] Air Resources Board, Greenhouse Gas Emission Forecast for 2020: Data Sources, Methods, and Assumptions, October 2010. Available at: http://www.arb.ca.gov/cc/inventory/data/tables/2020_forecast_methodology_2010-10-28.pdf

industrial processes and fossil fuel industry (excludes High GWP emissions which are from the use of HFCs as substitutes for ozone-depleting chlorofluorocarbons (CFCs)). The transportation sector accounts for emissions associated with fuel consumption by all on-road and non-highway vehicles. Non-highway vehicles include jet aircraft, gasoline-fueled piston aircraft, railway locomotives, boats, and ships. Emissions from non-highway agricultural and construction equipment are included in the industrial sector. Electricity = electricity generation sector emissions on a consumption basis (including emissions associated with electricity imported from outside of SCAG and excluding emissions associated with electricity exported from SCAG to other regions).

Forestry activities in the SCAG region are estimated to be net producers of GHG emissions in all years. However, urban forestry was estimated to be a small net sink in all years. The current estimates indicate that about 0.5 $MMtCO_2e$ are stored in SCAG's urban forestry biomass in 2008. This leads to *net* emissions that are almost identical to gross emissions of 230 $MMtCO_2e$ in the SCAG region in 2008, an amount equal to 3.9% of total U.S. net GHG emissions.

A Closer Look at the Three Major Sources: Transportation, RCI Fuel Use, and Electricity Consumption,

Transportation Sector

As shown in Figure 2, the transportation sector accounted for about 40% of SCAG's gross GHG emissions in 2008 (about 92 $MMtCO_2e$), which was similar to California's average share of emissions from transportation fuel consumption (37%), but much higher than the national average of 26%. The GHG emissions associated with SCAG's transportation sector increased by 17 $MMtCO_2e$ between 1990 and 2008, accounting for about 67% of the region's net growth in gross GHG emissions in this time period.

From 1990 through 2008, SCAG's GHG emissions from transportation fuel use have risen at an average rate of about 1.1% annually. In 2008, onroad gasoline vehicles accounted for about 79% of transportation GHG emissions. Onroad diesel vehicles accounted for an additional 15% of transportation emissions. Marine vessels, air travel, rail, and other sources (natural gas and liquefied petroleum gas (LPG) fueled-vehicles used in transport applications) accounted for the remaining 6% of transportation emissions. GHG emissions from onroad gasoline use grew 18% between 1990 and 2008. Meanwhile, GHG emissions from onroad diesel use rose 58% during that same period. Emissions associated with rail and marine fuel use increased by about 59% and 6%, respectively from 1990 to 2008, while emissions associated with aviation fuel consumption decreased by 3% in the same period.

During the period from 2008 to 2035, emissions from transportation fuels are projected to decrease at a rate of 0.1% per year. This leads to a decrease of 3 $MMtCO_2e$ in transportation emissions from 2008 to 2035. This decrease is driven by the onroad sector, as all of the other transportation sectors are expected to see increases in GHG emissions from 2008 to 2035. The onroad emissions are generally expected to decline from about 2005 until about 2025, at which point onroad emissions begin to increase again. The decline in GHG emissions from onroad vehicles is primarily due to California's onroad GHG emission standards. Once the majority of the onroad vehicle fleet is comprised of vehicles meeting these lower GHG standards, continuing increases in vehicle miles traveled (VMT) cause the onroad emissions to begin increasing again in the reference case projections.

Residential, Commercial, and Industrial Sectors

Activities in the RCI sectors produce GHG emissions when fuels are combusted to provide space heating, process heating, and other applications (this excludes emissions from industrial processes such as cement production or limestone and dolomite use which are included in the "global industrial sector" described by ARB and illustrated in Figure 2). In 2008, combustion of natural gas, oil, coal, and wood in the RCI sectors contributed about 16% (about 38 $MMtCO_2e$) of SCAG's gross GHG emissions.

If emissions from other industrial emissions are included, as in Figure 2 (industrial processes and fossil fuel industry except high GWP emissions), then the contribution is 27% of SCAG's gross GHG emissions. This is the same as the comparable sector contribution for California, and similar to the contribution of this sector for the nation as a whole (29%).

In 2008, the residential sector's share of total RCI emissions from direct fuel use was 35% (13 $MMtCO_2e$), the commercial sector accounted for 14% (5 $MMtCO_2e$), and the industrial sector's share of total RCI emissions from direct fuel use was 50% (19 $MMtCO_2e$). Overall, emissions for the RCI sectors (excluding those associated with electricity consumption) are expected to increase by 7% between 2008 and 2035 to 36 $MMtCO_2e$. Emissions from the residential sector are projected to increase slightly by 3% from 2008 to 2035, and those from the commercial and industrial sectors are expected to increase by 6% and 8%, respectively, from 2008 to 2035.

Electricity Consumption Sector

In the SCAG region, natural gas is responsible for the majority of electricity generation and GHG emissions from electricity use. Throughout the historical and forecasted periods, SCAG power plants do not generate enough electricity to satisfy the region's demand. The remaining electricity consumed in the SCAG region is assumed to be imported from neighboring regions. As shown in Figure 2, electricity consumption accounted for about 25% of SCAG's gross GHG emissions in 2008 (about 58 $MMtCO_2e$), which was about the same as California average share of emissions from electricity consumption (25%) and lower than the national average of 34%.[23] The GHG emissions associated with SCAG's electricity consumption sector increased by less than 2 $MMtCO_2e$ between 1990 and 2008.

In 2008, emissions associated with SCAG's electricity consumption (58 $MMtCO_2e$) were about 37 $MMtCO_2e$ higher than those associated with electricity production (21 $MMtCO_2e$). The higher level for consumption-based emissions reflects GHG emissions associated with net imports of electricity from other neighboring regions. Projections of electricity consumption for 2008 through 2035 indicate that the SCAG region will remain a net importer of electricity.

[23] For the US as a whole, there is relatively little difference between the emissions from electricity use and emissions from electricity production, as the US imports only about 1% of its electricity, and exports even less.

Emissions from net electricity imports are projected to vary over the 2008-2035 period, from 37 $MMtCO_2e$ in 2008, down to 28 $MMtCO_2e$ in 2020, and back to 37 $MMtCO_2e$ in 2035. Overall, the reference case projection indicates that production-based emissions (associated with electricity generated in-region) will increase by about 0.4 $MMtCO_2e$ from 2008 levels, and consumption-based emissions (associated with electricity consumed in SCAG) will increase by about 0.1 $MMtCO_2e$ from 2008 to 2035.

Consistent with the Renewable Portfolio Standards (RPS) requirement of SB1078 (i.e. 20% RPS by 2020), increasing amounts of renewable generation are assumed to be integrated into the SCAG electric supply system during the forecast period. Growth in natural gas consumption, the dominant primary fuel used for electricity production, is assumed to be offset by a growing amount of renewable generation.

The production-based approach can better reflect the emissions (and emission reductions) associated with generation activities occurring in the SCAG region. These estimates are useful for policy analysis with respect to electricity generation, such as plant efficiency improvements and renewable energy projects.

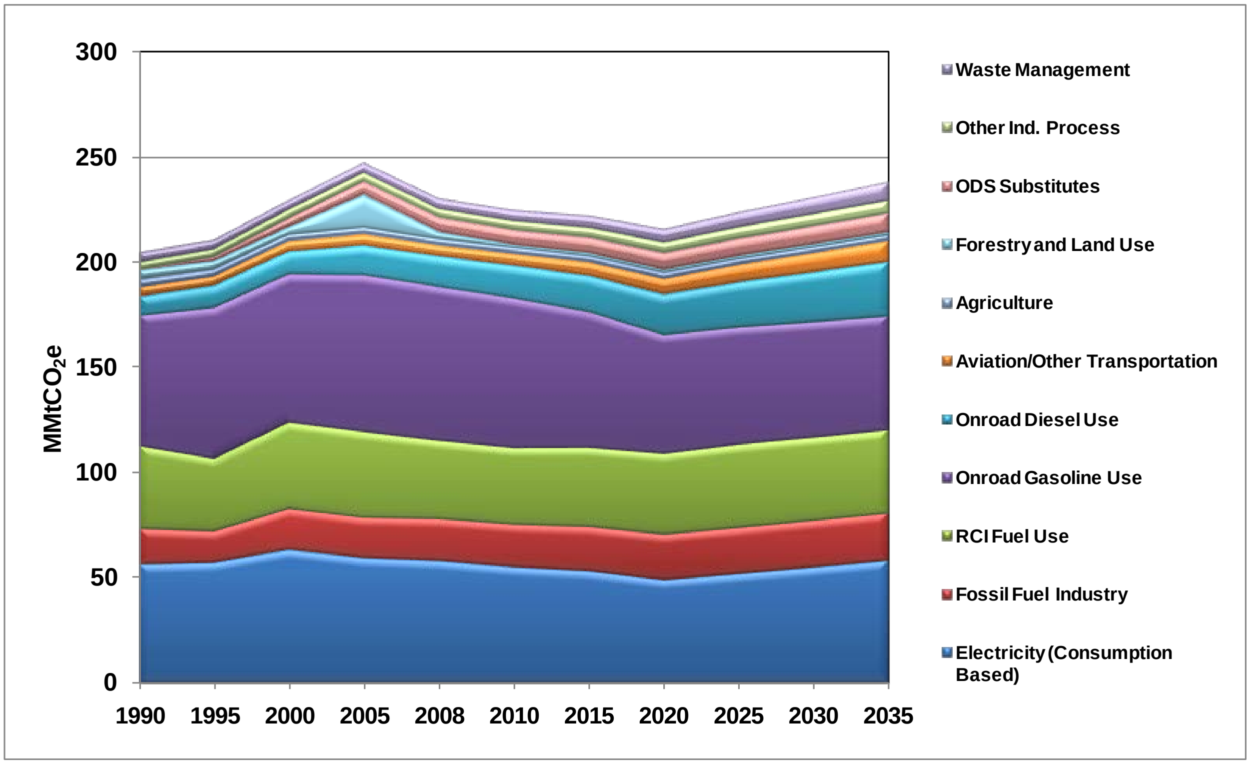
Reference Case Projections (Business as Usual)

Relying on a variety of sources for projections, as noted below and in the appendices, we developed a simple reference case projection of GHG emissions through 2035. As illustrated in Figure 3 and shown numerically in Table 1, under the reference case projections, SCAG's gross GHG emissions begin to decrease during the projection period, but then begin to increase again, reaching 238 $MMtCO_2e$ by 2035, or 16% above 1990 levels. This equates to an annual growth rate of 0.1% per year from 2008 to 2035.

Relative to 2008, the share of emissions by sector in 2035 is relatively unchanged from the emission shares in 2008. The greatest changes occur in the transportation sector's share of emissions, which decreases from 40% in 2008 to 38% in 2035, and in the waste sector's share of gross GHG emissions, which increases from 2% in 2008 to 4% in 2035.

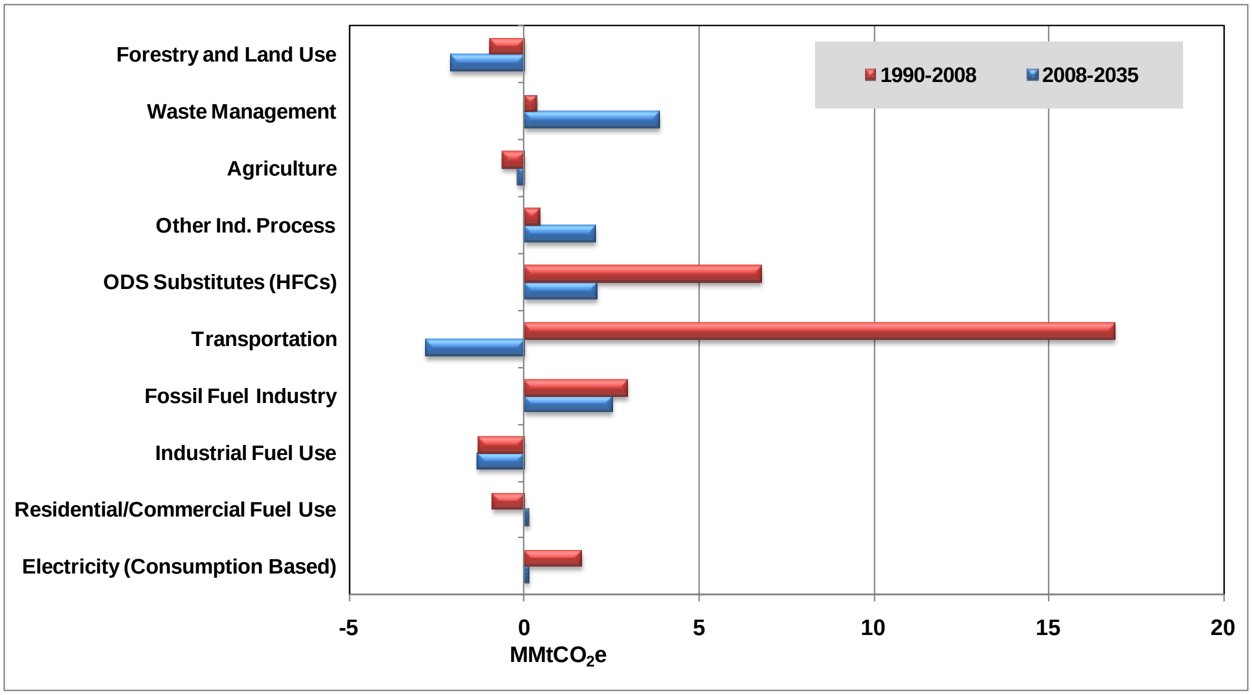
The waste management sector is projected to be the largest contributor to future emissions growth in the SCAG region, as shown in Figure 4. This is followed by the growth in emissions associated with the fossil fuel industry, the use of ODS substitutes used in cooling and refrigeration equipment, and other industrial processes. Table 2 summarizes the growth rates that drive the SCAG reference case projections as well as the sources of these data.

Figure 3. SCAG Gross GHG Emissions by Sector, 1990-2035: Historical and Projected



RCI – direct fuel use in residential, commercial, and industrial sectors. ODS – ozone depleting substance.

Figure 4. Sector Contributions to Gross Emissions Growth in SCAG, 1990-2035: Reference Case Projections (MMtCO_2e Basis)



Residential/Commercial – direct fuel use in residential and commercial sectors. ODS – ozone depleting substance. HFCs – hydrofluorocarbons. Emissions associated with other industrial processes include all of the industries identified in Appendix D except emissions associated with ODS substitutes which are shown separately in this graph because of high expected growth in emissions for ODS substitutes.

Table 2. Key Annual Growth Rates for SCAG, Historical and Projected

Growth Indicator	1990-2008	2008-2035	Sources
Population	1.31%	0.79%	Historical SCAG population statistics are compiled by SCAG's Economic Development staff from California Department of Finance data. They are available at http://www.scag.ca.gov/economy/econdata.html. The population projections through 2035 used in this report are not available yet at the link listed above. Revised data (updated from 2008 RTP data) were provided by SCAG to CCS on July 30th, 2010.
Electricity Sales	1.17%	0.88%	Historical and projected growth rates are based on electricity consumption data in the SCAG region. The methodology used to calculate this electricity consumption is detailed in Appendix A.
Vehicle Miles Traveled	1.76%	0.73%	VMT data provided by SCAG for key years from the Draft 2012 Regional Transportation Plan.

**This inventory and forecast has been prepared with the most up-to-date information and should not be compared to any previous analysis at this time.*

Comparison with California Inventory and Projections

Table 3 compares gross GHG emissions by sector in California and in the SCAG region in 1990, 2008, and 2020 (latest year of the ARB's forecast). The sectors are defined according to ARB's GHG emissions forecast used in the AB 32 Scoping Plan[24] (those sectors are different from the ones mentioned above). This table also shows SCAG's contribution to California's total GHG emissions. In 1990, SCAG's emissions represented 47% of California's gross GHG emissions. While SCAG's contribution increased to 48% in 2008, it is projected to decrease to 43% by 2020. Figure 5 illustrates SCAG's contribution to California's total GHG emissions in 2008, for each sector.

As mentioned above, Table 3 indicates the differences in source contributions between the SCAG region and the State. While SCAG's total emissions account for 48% of California's total emissions, SCAG's agricultural emissions only represent 9% of California's agricultural emissions. On the other hand, when it comes to emissions related to transportation, SCAG's emissions represent 52% of California's emissions. SCAG's contribution is even greater for the recycling and waste sector, with a fraction of 53%. In California, the forestry sector is a net sink of CO_2. However, in the SCAG region, significant losses in forested lands to development (especially in the 1990's) led to significant losses in forest carbon stocks and CO_2 sequestration potential for the region. Hence, the SCAG region's forestry sector is estimated to have been a significant source of GHGs, rather than a sink.

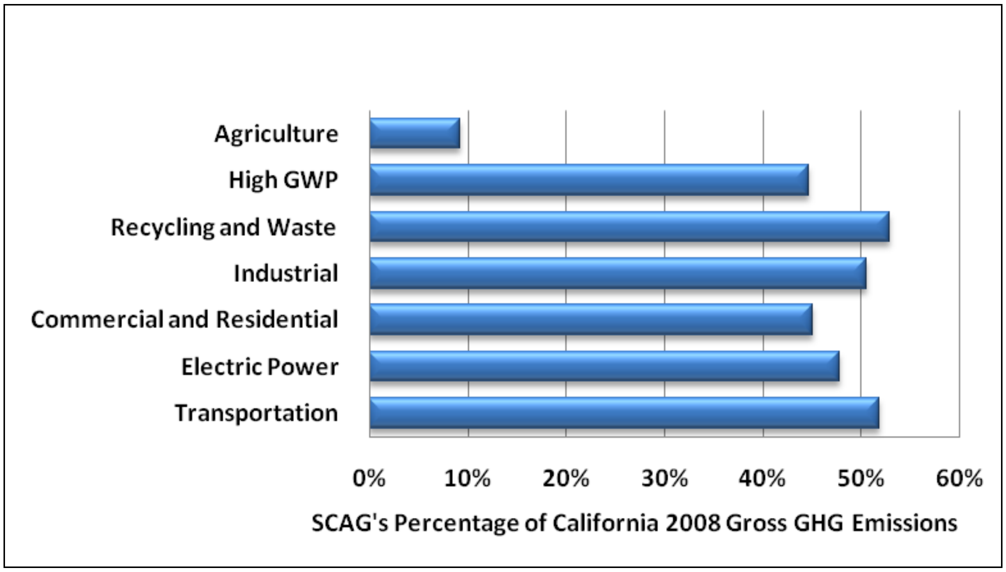
Table 3. California and SCAG Gross GHG Emissions by Sector, 1990-2020: Historical and Projected

Sector	Emissions ($MMtCO_2e$)								
	1990			2008			2020		
	CA	SCAG	*SCAG %*	CA	SCAG	*SCAG %*	CA	SCAG	*SCAG %*
Transportation	150.7	75.5	*50%*	178.0	92.4	*52%*	183.9	83.1	*45%*
Electric Power	110.6	56.3	*51%*	121.2	58.0	*48%*	110.3	49.1	*44%*
Commercial / Residential	44.1	19.6	*45%*	41.5	18.7	*45%*	45.3	19.3	*43%*
Industrial	94.8	41.7	*44%*	87.1	44.1	*51%*	91.5	47.4	*52%*
Recycling and Waste	6.3	3.8	*60%*	7.3	3.8	*53%*	8.5	5.0	*59%*
High GWP	3.2	0.3	*8%*	15.8	7.1	*45%*	37.9	8.1	*21%*
Agriculture	23.4	3.7	*16%*	33.7	3.1	*9%*	29.2	3.0	*10%*
Forestry	0.2	4.5	*2390%*	0.2	3.6	*1870%*	0.2	1.5	*739%*
Forestry Net Emissions	-6.7	-0.4	*6%*	-3.8	-0.5	*14%*	0.0	-0.6	*N/A*
Total Gross Emissions	**433.3**	**205.5**	***47%***	**484.7**	**230.7**	***48%***	**506.8**	**216.4**	***43%***
Total Net Emissions	**426.6**	**205.0**	***48%***	**480.9**	**230.2**	***48%***	**506.8**	**215.8**	***43%***

[1] Industrial emissions in this table include both emissions from industrial fuel use as well as emissions from non-fuel use for industrial processes.

[24] Air Resources Board, Greenhouse Gas Emission Forecast for 2020: Data Sources, Methods, and Assumptions, October 2010. Available at: http://www.arb.ca.gov/cc/inventory/data/tables/2020_forecast_methodology_2010-10-28.pdf

Figure 5. SCAG Region's Contribution to California 2008 Gross GHG Emissions by Sector



PSC Revisions

The following summarizes the revisions approved by the PSC that were made to the inventory and reference case projections, thus explaining the key differences in the GHG inventory and forecast between this report and the initial assessment completed in August 2010:

- Electricity Supply and Use: The GHG emission inventory and forecast for this sector was completely revised, based on comments and feedback from the PSC. See Appendix A for details of the revised methodology.
- Residential, Commercial, and Industrial (RCI) Fuel Combustion: Emissions from natural gas consumption associated with useful thermal output at combined heat and power (CHP) facilities (i.e. fuel consumption at CHP facilities that is not associated with the production of electricity) was added to the commercial and industrial sectors. The allocation of electricity emissions to the RCI sectors in Appendix B was revised to account for revisions to electricity sales.
- Transportation Energy Use: The VMT projections used in calculating the onroad GHG emissions were revised, per an update from SCAG. Additionally, in the draft version of the GHG inventory and forecast, the onroad transportation emissions output from the EMFAC2007 model were adjusted in proportion to the state-level adjustment used by ARB to scale the EMFAC2007 calculated fuel outputs to the state-level fuel consumption. This adjustment was removed in the current version of the inventory and forecast, since it is unclear how EMFAC2007 fuel outputs for the region relate to state-level fuel consumption. Another revision involved adjusting the emissions of CO_2 from gasoline vehicles to account for the ethanol proportion of the fuel (emissions of CO_2 are treated as biogenic and excluded

from the GHG totals). For the nonroad forecasts, SCAG provided train traffic volume forecasts that were used to derive rail growth factors.

- Industrial Processes: The forecast for emissions from cement production were revised to correct the use of an incorrect growth factor.
- Waste Management: The Municipal Wastewater Indirect N_2O emissions and emissions from Industrial Landfills were both removed to avoid possible double-counting of emissions. All landfills in the SCAG region are captured in the ARB data set, and it is assumed that there are no additional landfills that manage only industrial waste.
- Forestry & Land Use: Non-CO_2 emission estimates were added for wildfires. In addition, the estimates for the forested landscape and urban forests were revised to be consistent with SCAG-regional urban growth rates.

Reference Case Projections with Recent Actions

Two recent actions were identified that have the potential to significantly reduce the reference case forecast of the transportation sector GHG emissions and that could also be quantified within the scope of resources available for this project. These include the California Advanced Clean Car program and the Federal heavy-duty GHG emission standards. During the development of the revised inventory and forecast, sufficient information was identified (e.g., implementation schedules) to estimate GHG emission reductions associated with these two programs. (Note that the GHG emission reductions associated with the California Pavley I vehicle GHG standards and the Low Carbon Fuel Standards were included in the reference case forecast.)

The GHG emission reductions projected to be achieved by these recent actions are summarized in Table 4. This table shows a total reduction of about 14 $MMtCO_2e$ in 2035 from the business-as-usual reference case emissions, or a 5.9% reduction from the business-as-usual emissions in 2035 for all sectors combined.

The following provides a brief summary of the components of these two actions that were analyzed as recent actions. Further information on how GHG emission reductions from these programs were estimated can be found in Appendix C.

California Advanced Clean Cars Program: The California Advanced Clean Cars program combines the control of smog-causing pollutants and greenhouse gas emissions into a single coordinated package of requirements for model years 2017 through 2025. The new rules will clean up gasoline and diesel-powered cars, and deliver increasing numbers of zero-emission technologies, such as full battery electric cars, newly emerging plug-in hybrid electric vehicles and hydrogen fuel cell cars. The package will also ensure adequate fueling infrastructure is available for the increasing numbers of hydrogen fuel cell vehicles planned for deployment in California.[25] ARB provided a table of the expected reduction in CO_2 emissions from light and

[25] "California Air Resources Board Approves Advanced Clean Car Rules," news release # 12-05 from California Air Resources Board, January 27, 2012.

medium-duty vehicles by model year as a result of this program. These reductions were applied to the reference case emissions, which included the effects of the Pavley I (California GHG light-duty vehicle standards) and Low Carbon Fuel Standards (LCFS).

Federal Heavy-duty GHG Emission Standards: In September 2011, the U.S. EPA and the Department of Transportation's National Highway Traffic Safety Administration (NHTSA) initiated a program to reduce GHG emissions and improve fuel efficiency of heavy-duty trucks and buses. This program will reduce fuel use and GHG emissions from medium- and heavy-duty vehicles, from semi trucks to the largest pickup trucks and vans, as well as all types and sizes of work trucks and buses in between. The standards are phased in from the 2014 through 2018 vehicle model years. To estimate GHG emission reductions from this program, the percentage reduction by model year and vehicle type, as identified in EPA's Regulatory Impact Assessment[26] were applied to the reference case emissions of the corresponding vehicle types by model year.

Table 4. Emission Reduction Estimates Associated with the Effect of Recent Actions in the SCAG Region

	GHG Reductions ($MMtCO_2e$)		GHG Emissions ($MMtCO_2e$)	
			Business as Usual	With Recent Actions
Sector / Recent Action	**2020**	**2035**	**2035**	**2035**
Transportation			89.6	75.5
California Advanced Clean Cars Program	1.3	11.9		
Federal Heavy-Duty GHG Standards	0.7	2.1		
Total (All Sectors)	**1.96**	**14.1**	**238.5**	**224.4**

Key Uncertainties and Next Steps

Some data gaps exist in this inventory, particularly in the reference case projections. Key tasks for future refinement of this inventory and forecast include review and revision of key drivers, such as the transportation, electricity demand, and RCI fuel use growth rates that will be major determinants of SCAG's future GHG emissions (See Table 2 and Figure 4). These growth rates are driven by uncertain economic, demographic and land use trends (including growth patterns and transportation system impacts), all of which deserve closer review and discussion.

[26] "Final Rulemaking to Establish Greenhouse Gas Emissions Standards and Fuel Efficiency Standards for Medium- and Heavy-Duty Engines and Vehicles," Regulatory Impact Analysis, EPA-420-11-901, USEPA and National Highway Traffic Safety Administration, August 2011.

Approach

The principal goal of compiling the inventories and reference case projections presented in this document is to provide SCAG with a general understanding of its historical, current, and projected (expected) GHG emissions. The following sections explain the general methodology and the general principles and guidelines followed during the development of these GHG inventories for the SCAG region.

General Methodology

We prepared this analysis in consultation with SCAG and California agencies, in particular, with the staff at ARB. The overall goal of this effort is to provide simple and straightforward estimates, with an emphasis on robustness, consistency, and transparency. As a result, we rely on reference forecasts from best available State and regional sources where possible. Where reliable existing forecasts are lacking, we use straightforward spreadsheet analysis and constant growth-rate extrapolations of historical trends rather than complex modeling.

In many cases, we follow the same approach to emissions accounting for historical inventories used by ARB in its State GHG emissions inventory[27] and its guidelines.[28] These inventory guidelines were developed based on the guidelines from the IPCC, the international organization responsible for developing coordinated methods for national GHG inventories.[29] The inventory methods provide flexibility to account for local conditions. The key sources of activity and projection data used are shown in Table 4. Table 4 also provides the descriptions of the data provided by each source and the uses of each data set in this analysis.

General Principles and Guidelines

A key part of this effort involves the establishment and use of a set of generally accepted accounting principles for evaluation of historical and projected GHG emissions, as follows:

- **Transparency:** We report data sources, methods, and key assumptions to allow open review and opportunities for additional revisions later based on input from others. In addition, we report key uncertainties where they exist.
- **Consistency:** To the extent possible, the inventory and projections were designed to be externally consistent with current or likely future systems for State and national GHG emission reporting. We have used ARB's tools for California State inventories and projections as well as EPA's State GHG Inventory Tool, where appropriate, as a starting point. These initial estimates were then augmented and/or revised as needed to conform with a regional inventory and base-case projection needs. For consistency in making reference

[27] Air Resources Board, Greenhouse Gas Emission Inventory Data – years 2000-2008, May 2010.Available at: http://www.arb.ca.gov/cc/inventory/data/tables/ghg_inventory_scopingplan_00-08_2010-05-12.pdf
[28] Air Resources Board, *Documentation of California's Greenhouse Gas Inventory*, June 2010. Available at: http://www.arb.ca.gov/cc/inventory/doc/doc.htm
[29] http://www.ipcc-nggip.iges.or.jp/public/2006gl/index.html

case projections, we define reference case actions for the purposes of projections as those currently in place or reasonably expected over the time period of analysis.

- **Priority of Existing State and Local Data Sources:** In gathering data and in cases where data sources conflicted, we placed highest priority on county and SCAG data and analyses, followed by State and regional sources, with national data or simplified assumptions such as constant linear extrapolation of trends used as defaults where necessary.
- **Priority of Significant Emissions Sources:** In general, activities with relatively small emissions levels may not be reported with the same level of detail as other activities.
- **Comprehensive Coverage of Gases, Sectors, SCAG Activities, and Time Periods:** This analysis aims to comprehensively cover GHG emissions associated with activities in the SCAG region. It covers all six GHGs covered by US and other national inventories: CO_2, CH_4, N_2O, SF_6, HFCs, and PFCs. The inventory estimates are for the year 1990, with subsequent years included up to most recently available data (typically 2008), with projections to 2010, 2015, 2020, 2025, 2030 and 2035.
- **Use of Consumption-Based Emissions Estimates:** To the extent possible, we estimated emissions that are caused by activities that occur in the SCAG region. For example, we reported emissions associated with the electricity consumed in SCAG. The rationale for this method of reporting is that it can more accurately reflect the impact of region-based policy strategies such as energy efficiency on overall GHG emissions, and it resolves double-counting and exclusion problems with multi-emissions issues. This approach can differ from how inventories are compiled, for example, on an in-state (or in-region) production basis, in particular for electricity.

For electricity, we estimate, in addition to the emissions due to fuels combusted at electricity plants within the SCAG region, the emissions related to electricity *consumed* in the SCAG region. This entails accounting for the electricity sources used by SCAG utilities to meet consumer demands. As this analysis is refined in the future, one could also attempt to estimate other sectoral emissions on a consumption basis, such as accounting for emissions from transportation fuel used in SCAG, but purchased out-of-region. In some cases, this can require venturing into the relatively complex terrain of life-cycle analysis. In general, we recommend considering a consumption-based approach where it will significantly improve the estimation of the emissions impact of potential mitigation strategies. For example re-use, recycling, and source reduction can lead to emission reductions resulting from lower energy requirements for material production (such as paper, cardboard, and aluminum), even though production of those materials, and emissions associated with materials production, may not occur within the region.

Table 4. Key Sources for SCAG Data, Inventory Methods, and Growth Rates

Source	Information provided	Use of Information in this Analysis
US EPA State Greenhouse Gas Inventory Tool (SIT)	US EPA SIT is a collection of linked spreadsheets designed to help users develop State GHG inventories. US EPA SIT contains default data for each State for most of the information required for an inventory for years from 1990 to 2008. The SIT methods are based on the methods provided in the Volume VIII document series published by the Emissions Inventory Improvement Program (http://www.epa.gov/ttn/chief/eiip/techreport/volume08/index.html)	Where not indicated otherwise, the framework offered by SIT was used as an organizational structure for SCAG's inventory and forecast for the RCI fuel combustion, industrial processes, agriculture, forestry, and waste. SIT emission factors were updated with data used by ARB for California State inventory (CO_2, CH_4, and N_2O per British thermal unit (Btu) consumed) to calculate energy use emissions. SIT's default State-level activity data (fuel consumption) were also replaced with SCAG county-level activity, when available.
EIA AEO2010	EIA AEO2010 projects energy supply and demand for the US from 2007 to 2035. Energy production and consumption are estimated on a regional basis.	EIA AEO2010 was used to: - forecast changes in fuel use by the RCI sector. - forecast Natural Gas and LPG Vehicles emissions in the Transportation sector. - forecast the demand of petroleum derived products in the Industrial Processes sector.
US DOE Energy Information Administration (EIA) State Energy Data (SED)	EIA SED provides energy use data in each State, annually to 2008 for all RCI sectors and fuels.	When SCAG county-level data were not available, EIA SED was the source for energy use data. State activity data were allocated to SCAG on a population or employment basis for the RCI sector.
US DOE Form EIA-923 Monthly Time Series	Plant-level fuel consumption for combined heat and power (CHP) useful thermal output.	Used to estimate RCI sector CHP emissions for inventory years.
California Energy Commission	Natural gas retail sales.	1990-2008 natural gas sales data by county were used to estimate RCI natural gas consumption. Also used in the electricity sector to estimate total annual retail electricity sales.
US DOE Forms EIA-860A and 860B	Database of annual electric generators for utility and non-utility sources.	Used to determine the locations of electric power stations in the SCAG region.
US DOE Form EIA-906	1990-2010 monthly and annual generation and fuel consumption by power stations.	Used to determine unit-level annual fuel use and net generation of electric power stations in the SCAG region.
Southern California Public Power Authority (SCPPA)	Data on imports by SCAG region	Used imported net generation and emission levels from specified imports from SCPPA AB-32 model for utilities in the SCAG region.
SCAG	VMT data (1990-2008 and 2008-2035), commercial aviation operations forecast, rail line traffic density forecast, and port cargo forecast, and forestry acreage data .	SCAG VMT data and ARB's EMFAC2007 model were used to calculate the inventory emissions. The forecast data were adjusted based on Pavley I and Low Carbon Fuel Standard. Commercial aviation emissions were forecast based on a linear projection of total commercial operations from 2008 to 2035. Commercial marine emissions were based on containerized cargo forecasts for POLA and POLB from SCAG's 2008 Regional Transportation Plan. Rail emissions were forecast based on train traffic volume forecasts from the 2008 RTP. Forestry acreage was used in the forestry calculations.

Source	Information provided	Use of Information in this Analysis
Bureau of Transportation Statistics, Research and Innovative Technology Administration	The BTS database provides data on number of flights by origin, destination, and aircraft type.	Inventory emissions for commercial aviation were estimated based on aircraft operations data from the BTS aviation database.
Federal Aviation Administration, Air Traffic Activity Data System	The Air Traffic Activity Data System (ATADS) contains the official NAS air traffic operations data.	Total operations for each airport were obtained from the FAA ATADS database.
EPA, 2008 National Emission Inventory	Rail length for SCAG counties and California as a whole.	State-level rail diesel consumption from EIA was allocated based on rail length data from 2008 US EPA National Emissions Inventory (NEI) to calculate the inventory emissions.
Federal Aviation Administration, Terminal Area Forecast	General aviation operations forecast.	Aviation gasoline emissions were projected based on forecasts from the FAA's Terminal Area Forecast.
Waterborne Commerce Statistics Center	Waterborne port tonnage data.	Commercial marine vessels emissions were scaled from 2006-2008 data based on port tonnage data from the Army Corp of Engineers' Waterborne Commerce Statistics Center.
Federal Highway Administration's Highway Statistics	State-level marine consumption for 1990-2008.	Emissions associated with recreational marine gasoline consumption were estimated by allocating state-level marine gasoline consumption to the region based on allocation data from ARB's OFFROAD2007 model.
US Department of Transportation (DOT), Office of Pipeline Safety (OPS)	Natural gas transmission pipeline mileage, distribution pipeline mileage, gathering pipeline mileage, number of unprotected and protected steel services, and number of services for 1990–2007.	OPS data entered into SIT to calculate historical emissions. Transmission and distribution pipeline emissions projected based on analysis of historical data.
California Greenhouse Gas Inventory, versions 1 and 3	Emissions from statewide lime production, semi conductor manufacturing, use of ODS substitutes, carbon dioxide consumption, limestone and dolomite consumption, and soda ash consumption.	Emissions were apportioned to the SCAG region using related industry segment economic data (Source: Bureau of Economic Analysis, U.S. Department of Commerce) and population statistics (Source: Population Division, U.S. Census Bureau).
ARB, GHG Tool	Emissions from statewide cement plants, hydrogen plants, and Electric Power T&D Systems activity.	Those data were used as surrogate data for missing inventory years in the California Greenhouse Gas Inventory, versions 1 and 3.
Agricultural Commissioner's Office of SCAG's six counties	Livestock population and crop production estimates	Intervening years for all six counties were interpolated, and then the estimates were summed to get the SCAG total. From this information, estimates of crop production and livestock population in the state were developed for the SCAG region for 1990 to 2006
USDS National Agricultural Statistics Service (NASS)	USDA NASS provides data on the number of farms, land area and average size of farms by county.	Emissions from fertilizer usage, including from manure application, came from the estimate of fertilizer emissions in California, multiplied by the percentage of agricultural acreage in the SCAG region. Nitrogen released by the cultivation of histosols was estimated based on the percentage of California's organic crop acreage located in the SCAG region.

Source	Information provided	Use of Information in this Analysis
ARB 1990-2008 GHG Inventory and 2020 Forecast	Annual CH_4 and N_2O emissions estimates for all landfills in the SCAG region for the years 1990 through 2035 and N_2O emissions that result from the combustion of landfill gas to 2020. Emission factors for the RCI sectors.	These data were used to calculate the inventory and forecast emissions from Solid Waste Management, using a bottom-up procedure. ARB emission factors for the RCI sectors were used in some cases to replace the SIT default emission factors.
Clean Water Needs Survey database	Municipal wastewater flow at wastewater treatment plants in the SCAG region	Emissions from Wastewater Management are based on the amount of wastewater treated in each year municipal in the SCAG region and on the population data provided by SCAG, using a bottom-up approach.
US Forest Service and National Council for Air and Stream Improvement (NCASI) Carbon On-Line Estimator (COLE)	County-level estimates of carbon stocks in forests and carbon sequestration rates	Data are used to estimate net CO_2 sequestration / emissions.
SCAG in conjunction with the United States Geological Survey	County-level estimates of forest acreage and population estimates.	Data are used to estimate net CO_2 sequestration / emissions and forest sequestration, emissions of CH_4 and N_2O from Wildfire and Prescribed Burning Emissions. Emissions from land use were forecasted using population growth projections from SCAG.

Details on the methods and data sources used to construct the inventories and forecasts for each source sector are provided in the following appendices:

- Appendix A. Electricity Supply and Use
- Appendix B. Residential, Commercial, and Industrial (RCI) Fuel Combustion
- Appendix C. Transportation Energy Use
- Appendix D. Industrial Processes
- Appendix E. Fossil Fuel Industries
- Appendix F. Agriculture
- Appendix G. Waste Management
- Appendix H. Forestry & Land Use

Appendix I provides additional background information from the US EPA on GHGs and global warming potential values.

**This inventory and forecast has been prepared with the most up-to-date information and should not be compared to any previous analysis at this time.*

Appendix A. Electricity Supply and Use

Overview

This appendix describes the data sources, key assumptions, and the methodology used to develop an inventory of greenhouse gas (GHG) emissions over the 1990-2010 period associated with the generation of electricity to meet electricity demand in the SCAG region. It also describes the data sources, key assumptions, and methodology used to develop a reference case projection (forecast) of GHG emissions from the base year of 2010 over the 2011-2035 period associated with meeting electricity demand in the region. Specifically, the following topics are covered in this Appendix:

- *GHG Inventory Approach:* This section outlines the basic approach used to assemble the information required to calculate an inventory of GHG emissions.
- *GHG Inventory Data Sources:* This section outlines the data sources used, including links to publicly available data.
- *GHG Inventory Data Limitations:* This section outlines the data gaps that exist and provides an overview of their importance in developing the GHG emission inventory.
- *Approach to Overcome GHG Inventory Data Limitations:* This section outlines an approach to overcome the data gaps and provide plausible estimates of power supply GHG emissions.
- *GHG Forecast Approach:* This section outlines the basic approach used to assemble the information required to calculate a forecast of GHG emissions for the SCAG region.

GHG Inventory Approach

For power generation within the SCAG region, the data used are based upon the availability of fuel use and generation data from the EIA for 1990-2010. The GHG inventory approach follows the steps below:

- Identify all sources of power supply that met retail and on-site electricity demand at CHP facilities in the 6-county SCAG region consisting of Imperial, Los Angeles, Orange, Riverside, San Bernardino, and Ventura counties over the period 1990-2010.
- Assume that electricity from power supply sources located in the SCAG region is consumed within the SCAG region (i.e., no power exports to neighboring counties/states).
- Establish the total annual net generation and fuel use (by fuel type) by regulated utilities during the inventory period.
- Establish the total annual net generation and fuel use (by fuel type) by independent power producers during the inventory period.
- Establish the total annual net generation and fuel use (by fuel type) by industrial/commercial combined heat and power facilities associated with total power generated (i.e., power sold to utilities for the purpose of meeting retail load, plus power used on-site for productive activities) during the inventory period.

**This inventory and forecast has been prepared with the most up-to-date information and should not be compared to any previous analysis at this time.*

- Combine the data above to develop an estimate of the total annual net generation and fuel use (by fuel type) to meet total electric demand within the 6-county SCAG region during the inventory period.
- Multiply the total annual fuel use (by fuel type) to meet total electric demand within the 6-county SCAG region during the inventory period by the appropriate emission factors for CO_2, CH_4, and N_2O to obtain annual emissions of these GHGs within the 6-county SCAG region during the inventory period.
- Apply global warming potentials of 21 for CH_4 and 310 for N_2O to obtain annual CO_2e emissions within the 6-county SCAG region during the inventory period.

For power imports into the SCAG region, the data used are based upon a model developed by the Southern California Public Power Authority (SCPPA).[30] The GHG inventory approach follows the steps below:

- For the 2001-2010 period -
  - ✓ Assume imported net generation and CO_2e emission levels for specified imports from the SCAPPA model.
  - ✓ Assume that annual imported net generation and CO_2e emission levels for unspecified imports is the difference between total net generation from SCAPPA and the sum of in-SCAG net generation and SCAPPA specified imports.

For the 1990-2000 period, an estimate of the GHG intensity is needed because this information is not available from the SCAPPA inputs. A simple parameterization of the ARB inventory data was implemented based on the observed trends in the 2001-2004 period where SCAPPA and ARB results overlap. The proposed approach is briefly summarized in the bullets below:

- Determine the weighted average GHG intensity of specified net generation imports into California for the years 2001-2004, based on the ARB inventory;
- Determine the weighted average GHG intensity of specified net generation imports into the SCAG region for the years 2001-2004, based on the SCAPPA inputs;
- Multiply the ratio of the SCAPPA and ARB weighted averages to the GHG intensity of specified imports into California for the years 1990-2000.

Using the above approach yields an estimate of annual GHG intensities for the SCAG region for each of the years for which data are not available. To obtain annual GHG emissions, these intensities are multiplied by actual annual levels of imported net generation into the SCAG region during the 1990-2000 period.

GHG Inventory Data Sources

The data used to carry out the above steps are available from a variety of data sources as outlined in the bullets below:

[30] Provided to CCS by Cathy Yap at SCPPA, February 7, 2012, File titled “For SCAG modeling 2-7-12 aggr.xls”.

- *Locations* of electric power stations in the 6-county SCAG region are obtained from the sources below. An example of this type of data appears in Annex 1.
  - ✓ 1990-1997: Form EIA-860A Database Annual Electric Generator—Utility (http://www.eia.doe.gov/cneaf/electricity/page/eia860a.html)
  - ✓ 1998-2000: Form EIA-860B Database Annual Electric Generator—Utility (http://www.eia.doe.gov/cneaf/electricity/page/eia860a.html)
  - ✓ 1998-2000: Form EIA-860B Database Annual Electric Generator—Nonutility (http://www.eia.doe.gov/cneaf/electricity/page/eia860b.html)
  - ✓ 2001-2010: Form EIA-860B Database Annual Electric Generator—Utility and Nonutility (http://www.eia.doe.gov/cneaf/electricity/page/eia860.html)
- Total unit-level annual *fuel use* and *net generation* of electric power stations in the 6-county SCAG region are obtained from the sources below. An example of this type of data appears in Annex 2.
  - ✓ 1990-2000: Form EIA-906 Database on monthly/annual generation and fuel consumption by utility power stations (http://www.eia.doe.gov/cneaf/electricity/page/eia906u.html)
  - ✓ 1999-2000: Form EIA-906 Database on monthly/annual generation and fuel consumption by nonutility power stations (http://www.eia.doe.gov/cneaf/electricity/page/eia906nonu.html)
  - ✓ 2001-2010: Form EIA-906 Database on monthly/annual generation and fuel consumption by utility and nonutility power stations (http://www.eia.doe.gov/cneaf/electricity/page/eia906_920.html)
- Total annual retail electricity sales in the 6-county SCAG region are obtained from the sources below. An example of this type of data appears in Annex 3.
  - ✓ 1990-2005: California Energy Commission electricity consumption by county database[31]
  - ✓ 2006-2010: California Energy Commission electricity consumption by county online database (http://www.ecdms.energy.ca.gov/elecbycounty.aspx)
- GHG emission factors are consistent with those used to develop the California GHG emission inventory, as confirmed via communications with ARB.[32]
- CO_2e intensity of imported electricity into the 6 SCAG counties is obtained from the source below. An example of this type of data appears in Annex 4.
  - ✓ 2000-2008: input data from the AB-32 model for the utilities in the SCAG region from SCAPPA.
- Historical transmission and distribution (T&D) losses as a percentage of total electricity production are assumed to be 7.5%, consistent with the State GHG inventory.[33]

[31] CCS obtained these from Andrea Gough, California Energy Commission, email: agough@energy.state.ca.us.
[32] Personal communication from Larry Hunsaker, ARB, in an email to Bill Dougherty, CCS, February 22, 2012.

GHG Inventory Data Limitations

Much, but not all, of the required historical power plant data are available for the period 1990-2008 for the 6-county SCAG region. A summary of data availability and gaps is summarized in Table A1. As can be seen in the table, the following information is either unavailable or cannot be obtained through the channels available:

- *Independent power producer (IPP) data for the period 1990-1997, inclusive:* EIA[34] confirms that these data are not publicly available, likely due to proprietary concerns. To put this gap into perspective, the share of IPP net generation in 2001 was 11% of total net generation in the SCAG region in that year.

Table A1. GHG Inventory Data Availability Summary

			CHP data for facilities located in the 6 SCAG counties				
Time Period	Utility data for power stations located in the 6 SCAG counties	IPP data for power stations located in the 6 SCAG counties	Total electricity generated (on-site use + sales to meet retail load)	sales to utilities to meet retail load ONLY	Electricity sales to the 6 SCAG counties	CO_2e intensity of imported electricity into the 6 SCAG counties	Electricity losses for T&D system located in the 6 SCAG counties
1990-1997	✓	○	○	○	✓	○	✓
1998-2000	✓	✓	✓	✓	✓	○	✓
2001-2008	✓	✓	✓	○	✓	✓	✓

✓ *- data are available*
○ *- data are not available*

- *Combined heat and power (CHP) data for the period 1990-1997, inclusive:* EIA[35] confirms that these data are not publicly available, likely due to proprietary concerns. To put this gap in perspective, the share of CHP net generation in 2001 was 15% of total net generation in the SCAG region in that year.
- *CO_2 intensity of imported electricity into the 6 SCAG counties:* For the inventory period, CO_2 intensity is only available from 2001 to 2008, inclusive.[36] To put this gap in perspective, the share of net generation associated with imported power in 2000 was 74% of total net generation to meet retail electricity load in the SCAG region in that year.

[33] 1990-2000: page 13 of the report entitled: "California's 1990-2004 Greenhouse Gas Emissions Inventory and 1990 Emissions Level - Technical Support Document", available at: http://www.arb.ca.gov/cc/inventory/doc/methods_v1/ghg_inventory_technical_support_document.pdf.
[34] Personal communication from Glenn McGrath of the EIA (202-586-4325).
[35] Ibid.
[36] Note: Additional estimates of CO_2 intensity of imported power are available for the forecast period (i.e., 2009-2020, inclusive).

- *Electricity losses for T&D system located in the 6 SCAG counties:* SCAG-specific T&D losses as a percentage of total net generation for load are unavailable for any year in the inventory period. To put this gap in perspective, electricity losses in the state of California are forecasted by the EIA in AEO2009 to range between 6.9% and 8.9% of total net energy for load in the period 2008 to 2030.

Approach to Overcome GHG Inventory Data Limitations

The bullets below provide an overview of the approach used to overcome the data limitations outlined in the previous section:

- *IPP data for the period 1990-1997, inclusive:* No net generation or fuel use data were collected during this period. No adjustments were made to the inventory to overcome this limitation.
- *CHP facility data for the period 1990-1997, inclusive:* Determine the average heat rate and SCAG net generation share from CHP units relative to California by fuel type for the 3-year period 1998-2000. Develop annual fuel use at CHP facilities in CA on the basis of the CO_2e emissions and CO_2e emission factors from the CA GHG inventory. Multiply the average SCAG share by CA fuel use to obtain fuel use in the period 1990-1997. Finally, multiply SCAG fuel use by the average heat by fuel for the period 1990-1997 to obtain net generation.
- *CO_2 intensity of imported electricity into the 6 SCAG counties for the period 1990-2000, inclusive:* As discussed in the previous section.
- *Electricity losses for the T&D system located in the 6 SCAG counties for the period 1990-2008, inclusive:* As discussed in the previous section.

GHG Forecast Approach – Business-as-Usual Scenario

The approach to establish the GHG emission forecast for power supply is based upon a 2010 base year inventory of power system characteristics (i.e., in-region power stations, out-of-region imports) together with regulations/actions that affect the expansion of the electric sector. The GHG forecast approach for the power sector for the period 2011-2035 follows the steps below:

- Establish an acceptable configuration of SCAG-region power supply for the 2010 base year. This is available from the inventory previously discussed.
- Establish a configuration of imported power from specified and unspecified sources for the 2010 base year. This is available from the SCAPPA model cited previously.
- Establish the annual average retail electricity growth rate for the period 2011-2035. This information is available from the CEC forecast.[37]
- Establish the in-region renewable resource mix for the period 2011-2035 assuming a 20% RPS. This information is available from the CPUC.[38]

[37] Found in the file entitled: "CEC-200-2011-011-SD.pdf" and located at: http://www.energy.ca.gov/2011publications/CEC-200-2011-011/CEC-200-2011-011-SD.pdf.

- Establish the total annual net generation and fuel use (by fuel type) by in-region utilities for the period 2011-2035 based on the assumption that all fossil-fired resources, except natural gas (NG), remain at 2010 levels. NG-fired generation grows at a rate of 2.52% per year in the 2011-2020 period based on a CEC study.[39] In the 2021-2035 period, the NG-fired growth rate is assumed flat as all NG-fired capacity has been added to the system to cope with the increased intermittent renewable generation associated with the 20% RPS. The 20% target remains constant over the 2021-2035 period.
- Establish the total annual net generation and fuel use (by fuel type) by in-region IPPs for the period 2011-2035 based on the assumption that all fossil-fired resources, including natural gas, remain at 2010 levels.
- Establish the total annual net generation and fuel use (by fuel type) by in-region CHP facilities for the period 2011-2035 based on the assumption that all fossil-fired resources, including natural gas, remain at 2010 levels.
- Establish the total annual net generation and CO_2e emissions associated with specified imported power for the period 2011-2020 based on the SCAPPA model cited previously. For the 2021-2035 period, assume specified imported power grows at the average system rate to keep pace with demand growth.
- Establish the total annual net generation and CO_2e emissions associated with unspecified imported power for the period 2011-2020 based on the SCAPPA model cited previously. For the 2021-2035 period, assume unspecified imported power is the difference between total SCAG supply requirements and in-SCAG generation and specified imports.
- Establish the CO_2 intensity of imported power for the period 2011-2020 based on the SCAPPA model cited previously.
- Establish the CO_2 intensity of imported power for the period 2021-2035 based on an extrapolation of SCAPPA trends.
- Establish the losses in percentage terms associated with the T&D system within the 6-county SCAG region based on EIA's AEO2010 estimate for California for the period 2009-2035.
- Multiply the total annual fuel use (by fuel type) to meet retail electric demand within the 6-county SCAG region during the forecast period by the appropriate emission factors for CO_2, CH_4, and N_2O to obtain annual emissions of these GHGs within the 6-county SCAG region during the forecast period.
- Apply global warming potentials of 21 for CH_4 and 310 for N_2O to obtain annual CO_2e emissions within the 6-county SCAG region during the forecast period.

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[38] http://www.cpuc.ca.gov/PUC/energy/Renewables/hot/RPS+Program+Update.htm.
[39] Table 14 (page 30) of the CEC report entitled: "Impact Of Assembly Bill 32 Scoping Plan Electricity Resource Goals On New Natural Gas-Fired Generation" found at: http://www.energy.ca.gov/2009publications/CEC-200-2009-011/CEC-200-2009-011.PDF.

Results

The results of the analysis of the SCAG electricity supply GHG inventory and forecast, based on the approach described above, is available in a spreadsheet entitled: "SCAG Electricity Sector GHG IF.xls". A summary of the contents of the spreadsheet is provided in Annex 5.

The characteristics of the electricity production system in the SCAG region to meet retail electricity load is summarized in Table A2 for the 2010 Base Year. Additional details for this and earlier years in the inventory period are available in the analysis spreadsheets.

Total primary energy consumption associated with electricity generation in the SCAG region is summarized in Figure A1 for the period 1990-2035. Primary energy consumption in the SCAG region is dominated by natural gas in both the inventory and forecast periods.

Total net generation to meet electricity demand in the SCAG region is summarized in Figure A2. Electricity demand is satisfied by power plants and CHP facilities in the SCAG region as well as specified and unspecified imports. Power production within the region is comprised mainly of steam, combustion turbine, and combined cycle units using natural gas.

Consistent with the RPS requirements of SB1078 (i.e., 20% RPS by 2020), increasing amounts of renewable generation are assumed to be integrated into the SCAG electric supply system during the forecast period. Growth in natural gas consumption, the dominant primary fuel used for electricity production, is assumed to be offset by a growing amount of renewable generation. Figure A3 illustrates the shares of renewable generation in the utility/non-utility and imported electricity fuel mix.

As noted earlier, the CO_2e intensity of electricity imports over the 2001-2020 period were obtained from SCAPPA and include the effects of compliance with California's RPS policy under SB1078. Figure A4 illustrates the CO_2e intensity projection of electricity generated to meet electricity demand in the SCAG region.
Total CO_2e emissions associated with electricity production and consumption in the SCAG region are summarized in Figure A5 and Table A3. On a production basis (representing emissions only from SCAG region power plants), emissions were about 18.0 MMtCO_2e in 2010 and are projected to increase to about 21.3 MMtCO_2e in 2035, representing an overall increase of about 18% during this 25-year period. On a consumption basis (representing emissions from all generation sources both within and outside of SCAG to meet electricity demand), emissions were about 55.0 MMtCO_2e in 2010 and are projected to decrease to about 58.1 MMtCO_2e in 2035, representing an overall increase of under 6% during this 25-year period.

Table A2. SCAG region electricity production characteristics, 2010

	Utilities and non-utilities		CHP (total power)		Utilities and IPPs				CHP (total power)					
	Net Generation	Fuel use	Net Generation	Fuel use	Emissions (million tonnes)				Emissions (million tonnes)				Heat Rate (btu/kWh)	
Fuel type	**(MWh)**	**(mmbtu)**	**(MWh)**	**(mmbtu)**	**CO_2**	**CH_4**	**N_2O**	**CO_2e**	**CO_2**	**CH_4**	**N_2O**	**CO_2e**	**Util & nonutils**	**CHP**
Bituminous coal	0	0	1,131,473	9,916,533	0.0000	0.0000	0.0000	0.0000	0.9262	0.0000	0.0000	0.9313	0	8,764
Diesel oil	29,521	315,910	4	24	0.0234	0.0000	0.0000	0.0234	0.0000	0.0000	0.0000	0.0000	10,701	6,000
Geothermal	3,874,490	37,799,526	0	0	0.2846	0.0000	0.0000	0.2846	0.0000	0.0000	0.0000	0.0000	9,756	0
Landfill gas	947,755	12,379,914	38,400	214,886	1.2892	0.0000	0.0001	1.3062	0.0224	0.0000	0.0000	0.0227	13,062	5,596
MSW (biomass)	40,524	612,991	118,818	2,183,887	0.0000	0.0000	0.0000	0.0012	0.0000	0.0001	0.0000	0.0043	15,127	18,380
MSW (fossil)	31,841	481,649	93,357	1,715,907	0.0437	0.0000	0.0000	0.0446	0.1556	0.0001	0.0000	0.1590	15,127	18,380
Natural gas	27,866,456	228,855,955	7,421,129	47,207,469	12.1339	0.0002	0.0000	12.1458	2.5029	0.0000	0.0000	2.5054	8,213	6,361
Other Biomass Gases	104,771	1,249,790	197,738	2,080,887	0.0000	0.0000	0.0000	0.0011	0.0000	0.0001	0.0000	0.0018	11,929	10,523
Other gases	5,237	441,257	1,170,038	6,751,273	0.0260	0.0000	0.0000	0.0261	0.3983	0.0000	0.0000	0.4000	84,258	5,770
Other gases	0	0	211,926	2,083,582	0.0000	0.0000	0.0000	0.0000	0.1552	0.0000	0.0000	0.1557	0	9,832
Petroleum coke	3,966	65,080	0	0	0.0067	0.0000	0.0000	0.0067	0.0000	0.0000	0.0000	0.0000	16,408	0
Solar/PV	725,669	7,079,627	0	0	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	9,756	0
Tire-derived fuels	4,383	74,431	0	0	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	16,983	0
Hydroelectric	2,873,128	25,673,737	0	0	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	8,936	0
Biomass	413,358	6,747,296	0	0	0.0000	0.0002	0.0000	0.0133	0.0000	0.0000	0.0000	0.0000	16,323	0
Waste heat	0	0	295,294	2,880,887	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0	9,756
Wind	1,625,548	15,858,846	0	0	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	9,756	0
Residual oil	0	0	952	5,154	0.0000	0.0000	0.0000	0.0000	0.0004	0.0000	0.0000	0.0004	0	5,412
Total	**38,546,645**	**337,636,009**	**10,679,129**	**75,040,489**	**13.807**	**0.000**	**0.000**	**13.853**	**4.161**	**0.000**	**0.000**	**4.180**	**8,759**	**7,027**

Figure A1. Total Primary Energy Use by SCAG-based electricity generators by fuel type, all years

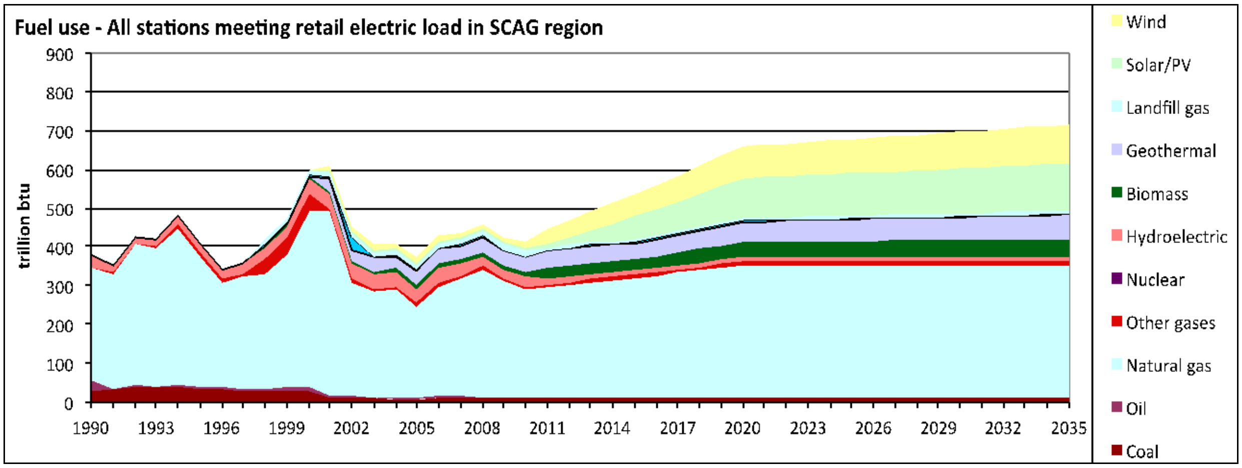
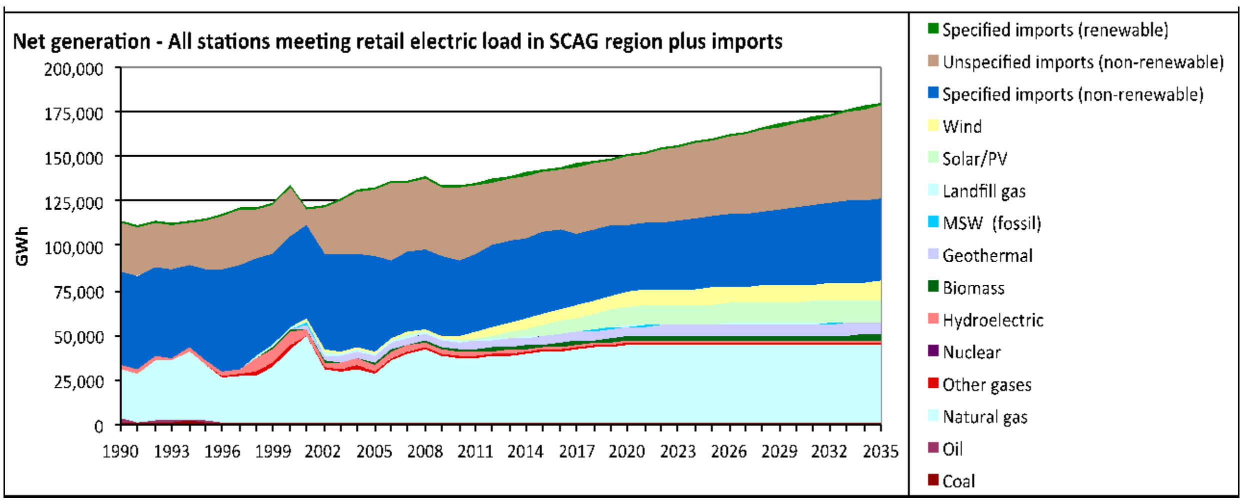


Figure A2. Total Net Generation by fuel type to meet SCAG electricity demand, all years, all sources



**This inventory and forecast has been prepared with the most up-to-date information and should not be compared to any previous analysis at this time.*

Figure A3. Renewable energy generation shares for SCAG utility/non-utility units and imported power, 1990, 2000, 2010, 2020, and 2030

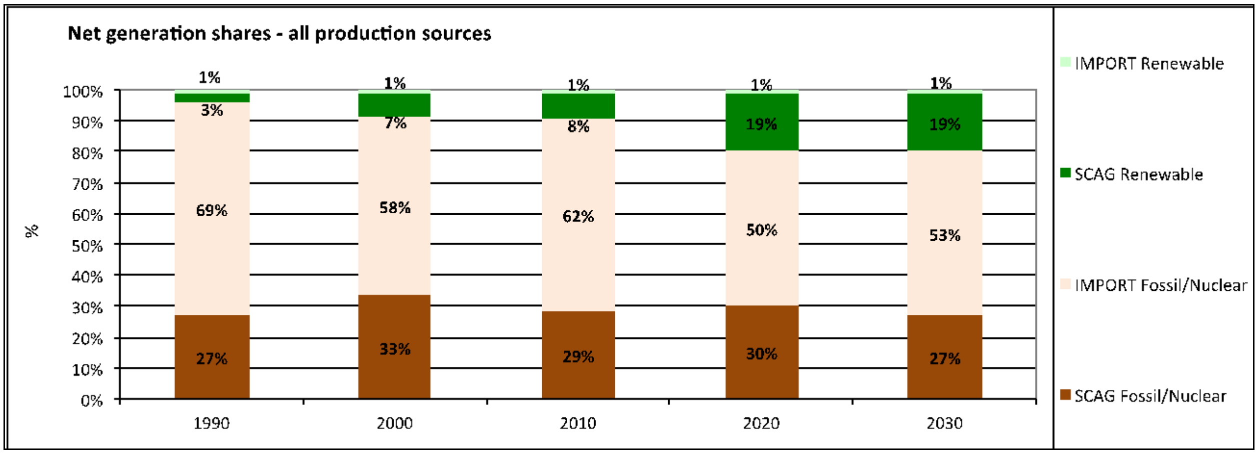


Figure A4. CO2e emission intensity of electricity imports into the SCAG region, all years

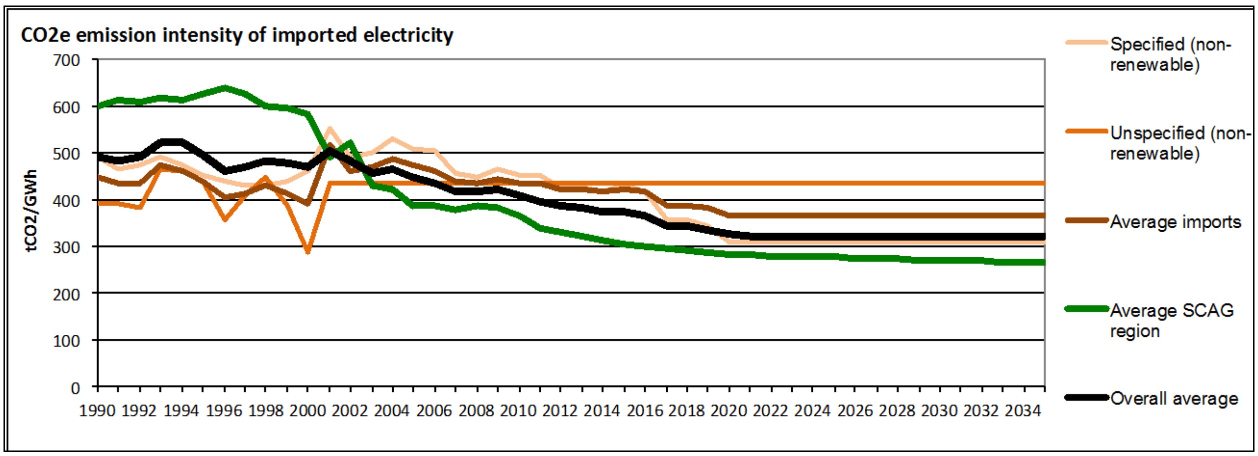


Figure A5. Total GHG Emissions Associated with SCAG total electricity consumption by Fuel Type, all years

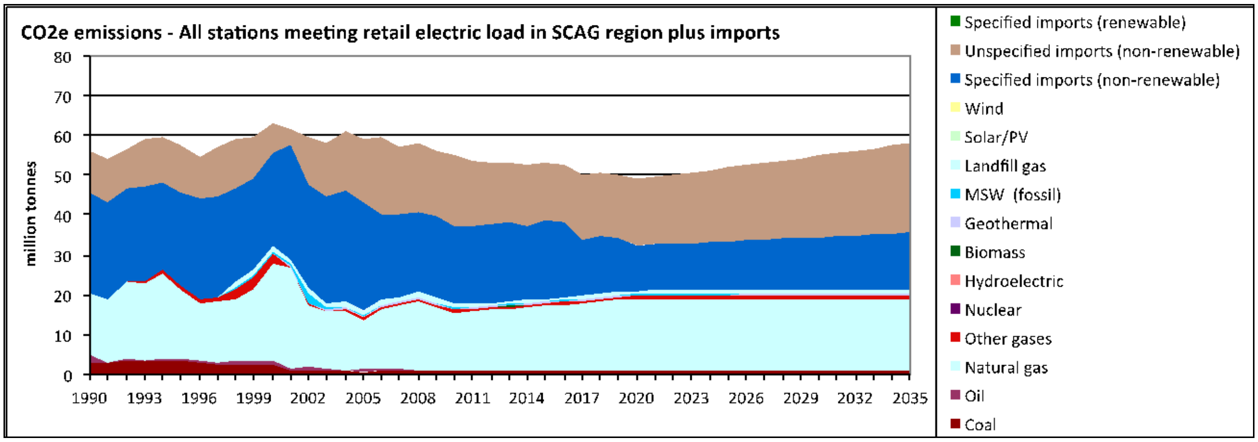


Table A3. Total GHG Emissions Associated with SCAG total electricity consumption by Fuel Type (MMtCO2e)

Fuel Type	1990	1995	2000	2005	2008	2010	2015	2020	2025	2030	2035
Coal	2.80	3.37	2.73	0.70	0.90	0.93	0.93	0.93	0.93	0.93	0.93
Oil	2.08	0.55	0.76	0.58	0.05	0.03	0.03	0.03	0.03	0.03	0.03
Natural gas	15.46	17.62	24.18	12.31	17.51	14.65	16.26	18.08	18.08	18.08	18.08
Other gases	0.06	0.59	2.61	0.63	0.56	0.58	0.58	0.58	0.58	0.58	0.58
Nuclear	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Hydroelectric	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Biomass	0.00	0.00	0.01	0.01	0.02	0.02	0.05	0.07	0.07	0.08	0.08
Geothermal	0.00	0.00	0.00	0.29	0.29	0.28	0.32	0.40	0.42	0.45	0.47
MSW (fossil)	0.00	0.00	0.51	0.36	0.20	0.20	0.20	0.20	0.20	0.16	0.16
Landfill gas	0.00	0.05	1.29	1.25	1.34	1.33	0.56	0.81	0.85	0.90	0.95
Solar/PV	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Wind	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Specified imports (non-renewable)	25.39	23.24	23.54	27.23	19.80	19.44	19.79	11.28	12.28	13.31	14.41
Specified imports (renewable)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Unspecified imports (non-renewable)	10.55	11.70	7.62	15.92	17.31	17.55	14.51	16.68	18.52	20.41	22.42
Total (production-based)	20.39	22.19	32.09	16.13	20.87	18.03	18.94	21.10	21.18	21.21	21.29
Total (consumption-based)	56.33	57.14	63.25	59.28	57.98	55.03	53.24	49.06	51.98	54.94	58.13

Annex 1: Example of locations of electric power stations in the 6-county SCAG region (1997)

PLNTNAME	COUNTYNAME	PLANTSTATE	PLANTZIPCD
Venice	Los Angeles	CA	90230
Drop 5	Imperial	CA	92231
Alamitos	Los Angeles	CA	90815
Sepulveda Canyon	Los Angeles	CA	90025
Cool Water	San Bernardino	CA	92327
El Segundo	Los Angeles	CA	90245
Etiwanda	San Bernardino	CA	91739
Fontana	San Bernardino	CA	92336
Highgrove	Riverside	CA	92324
Huntington Beach	Orange	CA	92646
Long Beach	Los Angeles	CA	90813
Lytle Creek	San Bernardino	CA	93258
Mandalay	Ventura	CA	93030
Mill Creek 1	San Bernardino	CA	96061
Ontario 1	Los Angeles	CA	91786
Ontario 2	Los Angeles	CA	91786
Ormond Beach	Ventura	CA	93030
Redondo Beach	Los Angeles	CA	90277
San Bernardino	San Bernardino	CA	92408
San Gorgonio 2	Riverside	CA	92220
Santa Ana 1	San Bernardino	CA	92346
Santa Ana 2	San Bernardino	CA	92346
Santa Ana 3	San Bernardino	CA	92346
Sierra	Los Angeles	CA	92376
Magnolia	Los Angeles	CA	91502
Grayson	Los Angeles	CA	91201
Brawley	Imperial	CA	92227
Drop 2	Imperial	CA	92250
Drop 3	Imperial	CA	92250
Drop 4	Imperial	CA	92250
Pilot Knob	Imperial	CA	92283
El Centro	Imperial	CA	92243
Castaic	Los Angeles	CA	91384
Foothill	Los Angeles	CA	91342
Franklin	Los Angeles	CA	90210
Harbor	Los Angeles	CA	90744
Haynes	Los Angeles	CA	90803
San Fernando	Los Angeles	CA	91342
Scattergood	Los Angeles	CA	90291

PLNTNAME	COUNTYNAME	PLANTSTATE	PLANTZIPCD
Valley	Los Angeles	CA	91352
Broadway	Los Angeles	CA	91105
Glenarm	Los Angeles	CA	91105
Devil Canyon	San Bernardino	CA	92407
Parker	San Bernardino	CA	92267
Temescal	Riverside	CA	91720
Corona	Riverside	CA	91720
Perris	Riverside	CA	92370
Rio Hondo	Los Angeles	CA	90280
Coyote Creek	Orange	CA	90631
Valley View	Orange	CA	92686
Drop 1	Imperial	CA	92250
East Highline	Imperial	CA	92231
Etiwanda	San Bernardino	CA	91739
Alamo	Los Angeles	CA	91310
Catalina Micro Hydro	Los Angeles	CA	90704
Olive	Los Angeles	CA	91502
Coachella	Riverside	CA	92236
W E Warne	Los Angeles	CA	91310
Double Weir	Imperial	CA	92231
Turnip	Imperial	CA	92227
Azusa	Los Angeles	CA	91702
San Francisquito 1	Los Angeles	CA	91350
San Francisquito 2	Los Angeles	CA	91350
Greg Avenue	Los Angeles	CA	91352
Lake Mathews	Riverside	CA	92503
Foothill Feeder	Los Angeles	CA	91310
San Dimas	Los Angeles	CA	91773
Yorba Linda	Orange	CA	92686
Pebbly Beach	Los Angeles	CA	92704
Mojave Siphon	San Bernardino	CA	92345
Sawtelle	Los Angeles	CA	90077
Mill Creek 3	San Bernardino	CA	96061
San Gorgonio 1	Riverside	CA	92220
Vernon	Los Angeles	CA	90058
Anaheim GT	Orange	CA	0
Rockwood	Imperial	CA	92227
Mill Creek 2	San Bernardino	CA	96061

Annex 2: Example of unit-level annual fuel use and net generation data for electric power stations in the 6-county SCAG region (1997)

UTILNAME	PLTNAME	FUEL DESCRIPTION	PRIME MOVER	NET GENERATION (MWh/yr)	Total Fuel Use (MMbtu/yr
METROPOLITAN WATER DIST	VENICE	WATER	HYDRO	6,728	69,985
IMPERIAL IRRIGATION DIST	DROP NO 5	WATER	HYDRO	20,537	213,626
SOUTHERN CALIF EDISON CO	ALAMITOS	RESIDUAL OIL	STEAM	0	0
SOUTHERN CALIF EDISON CO	ALAMITOS	NATURAL GAS	STEAM	4,253,642	43,915,598
SOUTHERN CALIF EDISON CO	ALAMITOS	DIESEL OIL	COMBUSTION TURBINE	58	1,142
SOUTHERN CALIF EDISON CO	ALAMITOS	NATURAL GAS	COMBUSTION TURBINE	3,879	108,984
METROPOLITAN WATER DIST	SEPULV CYN	WATER	HYDRO	26,910	279,918
SOUTHERN CALIF EDISON CO	COOL WATER	RESIDUAL OIL	STEAM	0	0
SOUTHERN CALIF EDISON CO	COOL WATER	NATURAL GAS	STEAM	393,636	3,981,759
SOUTHERN CALIF EDISON CO	COOL WATER	NATURAL GAS	COMBINED CYCLE (TOTAL)	0	0
SOUTHERN CALIF EDISON CO	COOL WATER	DIESEL OIL	COMBINED CYCLE (TURBINE)	397	4,852
SOUTHERN CALIF EDISON CO	COOL WATER	NATURAL GAS	COMBINED CYCLE (TURBINE)	772,516	8,990,489
SOUTHERN CALIF EDISON CO	EL SEGUNDO	RESIDUAL OIL	STEAM	0	0
SOUTHERN CALIF EDISON CO	EL SEGUNDO	NATURAL GAS	STEAM	1,033,169	11,988,133
SOUTHERN CALIF EDISON CO	ETIWANDA	RESIDUAL OIL	STEAM	0	0
SOUTHERN CALIF EDISON CO	ETIWANDA	NATURAL GAS	STEAM	984,188	11,278,386
SOUTHERN CALIF EDISON CO	ETIWANDA	DIESEL OIL	COMBUSTION TURBINE	0	0
SOUTHERN CALIF EDISON CO	ETIWANDA	NATURAL GAS	COMBUSTION TURBINE	2,928	66,511
SOUTHERN CALIF EDISON CO	FONTANA	WATER	HYDRO	6,757	70,286
SOUTHERN CALIF EDISON CO	HIGHGROVE	RESIDUAL OIL	STEAM	0	0
SOUTHERN CALIF EDISON CO	HIGHGROVE	NATURAL GAS	STEAM	2,281	51,905
SOUTHERN CALIF EDISON CO	HUNTNGTON B	RESIDUAL OIL	STEAM	0	0
SOUTHERN CALIF EDISON CO	HUNTNGTON B	NATURAL GAS	STEAM	732,481	8,223,173
SOUTHERN CALIF EDISON CO	HUNTNGTON B	DIESEL OIL	COMBUSTION TURBINE	0	0
SOUTHERN CALIF EDISON CO	HUNTNGTON B	NATURAL GAS	COMBUSTION TURBINE	4,401	112,080

UTILNAME	PLTNAME	FUEL DESCRIPTION	PRIME MOVER	NET GENERATION (MWh/yr)	Total Fuel Use (MMbtu/yr
SOUTHERN CALIF EDISON CO	LONG BEACH	NATURAL GAS	COMBINED CYCLE (TOTAL)	0	0
SOUTHERN CALIF EDISON CO	LONG BEACH	DIESEL OIL	COMBINED CYCLE (TURBINE)	-1,303	1,223
SOUTHERN CALIF EDISON CO	LONG BEACH	NATURAL GAS	COMBINED CYCLE (TURBINE)	153,412	1,881,111
SOUTHERN CALIF EDISON CO	LYTLE CREEK	WATER	HYDRO	2,653	27,597
SOUTHERN CALIF EDISON CO	MANDALAY	RESIDUAL OIL	STEAM	0	0
SOUTHERN CALIF EDISON CO	MANDALAY	NATURAL GAS	STEAM	1,368,666	13,276,119
SOUTHERN CALIF EDISON CO	MANDALAY	DIESEL OIL	COMBUSTION TURBINE	2,362	32,585
SOUTHERN CALIF EDISON CO	MILL CRK 1	WATER	HYDRO	1,864	19,389
SOUTHERN CALIF EDISON CO	ONTARIO 1	WATER	HYDRO	3,902	40,589
SOUTHERN CALIF EDISON CO	ONTARIO 2	WATER	HYDRO	1,676	17,434
SOUTHERN CALIF EDISON CO	ORMOND BECH	RESIDUAL OIL	STEAM	0	0
SOUTHERN CALIF EDISON CO	ORMOND BECH	NATURAL GAS	STEAM	1,545,678	15,810,630
SOUTHERN CALIF EDISON CO	REDONDO B 1	RESIDUAL OIL	STEAM	0	0
SOUTHERN CALIF EDISON CO	REDONDO B 1	NATURAL GAS	STEAM	2,657,486	26,861,654
SOUTHERN CALIF EDISON CO	S BERNARDO	RESIDUAL OIL	STEAM	0	0
SOUTHERN CALIF EDISON CO	S BERNARDO	NATURAL GAS	STEAM	20,543	242,167
SOUTHERN CALIF EDISON CO	S GORGNIO	WATER	HYDRO	1,411	14,677
SOUTHERN CALIF EDISON CO	SANTA ANA 1	WATER	HYDRO	8,405	87,429
SOUTHERN CALIF EDISON CO	SANTA ANA 2	WATER	HYDRO	4,759	49,503
SOUTHERN CALIF EDISON CO	SANTA ANA 3	WATER	HYDRO	2,974	30,936
SOUTHERN CALIF EDISON CO	SIERRA	WATER	HYDRO	3,073	31,965
BURBANK (CITY OF)	MAGNOLIA	RESIDUAL OIL	STEAM	0	0
BURBANK (CITY OF)	MAGNOLIA	NATURAL GAS	STEAM	5,462	125,533
BURBANK (CITY OF)	MAGNOLIA	DIESEL OIL	COMBUSTION TURBINE	0	0
BURBANK (CITY OF)	MAGNOLIA	NATURAL GAS	COMBUSTION TURBINE	1,698	28,789
BURBANK (CITY OF)	MAGNOLIA	WASTE HEAT	COMBINED CYCLE (TOTAL)	-295	-3,069
GLENDALE (CITY OF)	GRAYSON	DIESEL OIL	STEAM	0	0

**This inventory and forecast has been prepared with the most up-to-date information and should not be compared to any previous analysis at this time.*

UTILNAME	PLTNAME	FUEL DESCRIPTION	PRIME MOVER	NET GENERATION (MWh/yr)	Total Fuel Use (MMbtu/yr
GLENDALE (CITY OF)	GRAYSON	RESIDUAL OIL	STEAM	0	0
GLENDALE (CITY OF)	GRAYSON	NATURAL GAS	STEAM	101,471	1,459,692
GLENDALE (CITY OF)	GRAYSON	DIESEL OIL	COMBUSTION TURBINE	0	0
GLENDALE (CITY OF)	GRAYSON	NATURAL GAS	COMBUSTION TURBINE	2,620	45,043
GLENDALE (CITY OF)	GRAYSON	DIESEL OIL	COMBINED CYCLE (TOTAL)	0	0
GLENDALE (CITY OF)	GRAYSON	RESIDUAL OIL	COMBINED CYCLE (TOTAL)	0	0
GLENDALE (CITY OF)	GRAYSON	NATURAL GAS	COMBINED CYCLE (TOTAL)	368	5,790
GLENDALE (CITY OF)	GRAYSON	DIESEL OIL	COMBINED CYCLE (TURBINE)	0	0
GLENDALE (CITY OF)	GRAYSON	NATURAL GAS	COMBINED CYCLE (TURBINE)	8,259	115,788
IMPERIAL IRRIGATION DIST	BRAWLEY	DIESEL OIL	COMBUSTION TURBINE	0	0
IMPERIAL IRRIGATION DIST	DROP NO 2	WATER	HYDRO	56,574	588,483
IMPERIAL IRRIGATION DIST	DROP NO 3	WATER	HYDRO	55,958	582,075
IMPERIAL IRRIGATION DIST	DROP NO 4	WATER	HYDRO	108,040	1,123,832
IMPERIAL IRRIGATION DIST	PILOT KNOB	WATER	HYDRO	68,028	707,627
IMPERIAL IRRIGATION DIST	EL CENTRO	RESIDUAL OIL	STEAM	0	0
IMPERIAL IRRIGATION DIST	EL CENTRO	NATURAL GAS	STEAM	119,081	1,350,015
IMPERIAL IRRIGATION DIST	EL CENTRO	WASTE HEAT	COMBINED CYCLE (TOTAL)	54,274	564,558
IMPERIAL IRRIGATION DIST	EL CENTRO	DIESEL OIL	COMBINED CYCLE (TURBINE)	0	0
IMPERIAL IRRIGATION DIST	EL CENTRO	NATURAL GAS	COMBINED CYCLE (TURBINE)	132,592	1,462,604
LOS ANGELES (CITY OF)	CASTAIC	WATER	HYDRO	-242,320	-2,520,613
LOS ANGELES (CITY OF)	FOOTHILL	WATER	HYDRO	69,664	724,645
LOS ANGELES (CITY OF)	FRANKLIN	WATER	HYDRO	11,848	123,243
LOS ANGELES (CITY OF)	HARBOR	RESIDUAL OIL	STEAM	0	0
LOS ANGELES (CITY OF)	HARBOR	NATURAL GAS	STEAM	397,065	3,747,841
LOS ANGELES (CITY OF)	HARBOR	DIESEL OIL	COMBUSTION TURBINE	-62	0
LOS ANGELES (CITY OF)	HARBOR	NATURAL GAS	COMBUSTION TURBINE	0	0
LOS ANGELES (CITY OF)	HAYNES	RESIDUAL OIL	STEAM	0	0

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UTILNAME	PLTNAME	FUEL DESCRIPTION	PRIME MOVER	NET GENERATION (MWh/yr)	Total Fuel Use (MMbtu/yr
LOS ANGELES (CITY OF)	HAYNES	NATURAL GAS	STEAM	652,708	8,164,822
LOS ANGELES (CITY OF)	S FERNANDO	WATER	HYDRO	43,649	454,037
LOS ANGELES (CITY OF)	SCATTERGOOD	WOOD	STEAM	121,533	1,264,186
LOS ANGELES (CITY OF)	SCATTERGOOD	RESIDUAL OIL	STEAM	0	0
LOS ANGELES (CITY OF)	SCATTERGOOD	NATURAL GAS	STEAM	663,484	8,311,864
LOS ANGELES (CITY OF)	VALLEY	RESIDUAL OIL	STEAM	0	0
LOS ANGELES (CITY OF)	VALLEY	NATURAL GAS	STEAM	-6,422	0
PASADENA (CITY OF)	BROADWAY	RESIDUAL OIL	STEAM	0	0
PASADENA (CITY OF)	BROADWAY	NATURAL GAS	STEAM	144,093	1,961,013
PASADENA (CITY OF)	GLENARM	RESIDUAL OIL	STEAM	0	0
PASADENA (CITY OF)	GLENARM	NATURAL GAS	STEAM	0	0
PASADENA (CITY OF)	GLENARM	DIESEL OIL	COMBUSTION TURBINE	0	0
PASADENA (CITY OF)	GLENARM	NATURAL GAS	COMBUSTION TURBINE	4,064	62,753
CALIFORNIA (STATE OF)	DEVIL CANYN	WATER	HYDRO	535,113	5,566,245
USBR-LOWER COLORADO REG	PARKER DAM	WATER	HYDRO	557,943	5,803,723
METROPOLITAN WATER DIST	TEMESCAL	WATER	HYDRO	18,678	194,289
METROPOLITAN WATER DIST	CORONA	WATER	HYDRO	19,584	203,713
METROPOLITAN WATER DIST	PERRIS	WATER	HYDRO	7,433	77,318
METROPOLITAN WATER DIST	RIO HONDO	WATER	HYDRO	5,789	60,217
METROPOLITAN WATER DIST	COYOTE CRK	WATER	HYDRO	13,014	135,372
METROPOLITAN WATER DIST	VALLEY VIEW	WATER	HYDRO	2,721	28,304
IMPERIAL IRRIGATION DIST	DROP NO 1	WATER	HYDRO	22,143	230,331
IMPERIAL IRRIGATION DIST	E HIGHLINE	WATER	HYDRO	2,428	25,256
METROPOLITAN WATER DIST	ETIWANDA	WATER	HYDRO	32,851	341,716
CALIFORNIA (STATE OF)	ALAMO	WATER	HYDRO	48,993	509,625
SOUTHERN CALIF EDISON CO	CATALINA MI	WATER	HYDRO	0	0
BURBANK (CITY OF)	OLIVE	RESIDUAL OIL	STEAM	0	0

UTILNAME	PLTNAME	FUEL DESCRIPTION	PRIME MOVER	NET GENERATION (MWh/yr)	Total Fuel Use (MMbtu/yr
BURBANK (CITY OF)	OLIVE	NATURAL GAS	STEAM	139,881	1,795,241
BURBANK (CITY OF)	OLIVE	DIESEL OIL	COMBINED CYCLE (TURBINE)	0	0
BURBANK (CITY OF)	OLIVE	NATURAL GAS	COMBINED CYCLE (TURBINE)	2,451	41,856
IMPERIAL IRRIGATION DIST	COACHELLA	DIESEL OIL	COMBUSTION TURBINE	70	2,575
IMPERIAL IRRIGATION DIST	COACHELLA	NATURAL GAS	COMBUSTION TURBINE	9,219	83,836
CALIFORNIA (STATE OF)	W E WARNE	WATER	HYDRO	235,927	2,454,113
IMPERIAL IRRIGATION DIST	DOUBLE WEIR	WATER	HYDRO	0	0
IMPERIAL IRRIGATION DIST	TURNIP	WATER	HYDRO	1,339	13,928
PASADENA (CITY OF)	AZUSA	WATER	HYDRO	9,881	102,782
LOS ANGELES (CITY OF)	SF PR PL 1	WATER	HYDRO	312,525	3,250,885
LOS ANGELES (CITY OF)	SF PR PL 2	WATER	HYDRO	122,188	1,271,000
METROPOLITAN WATER DIST	GREG AVE	WATER	HYDRO	2,064	21,470
METROPOLITAN WATER DIST	L MATHEWS	WATER	HYDRO	36,409	378,726
METROPOLITAN WATER DIST	FOOTHILL F	WATER	HYDRO	42,458	441,648
METROPOLITAN WATER DIST	SAN DIMAS	WATER	HYDRO	27,759	288,749
METROPOLITAN WATER DIST	YORBA LINDA	WATER	HYDRO	27,789	289,061
SOUTHERN CALIF EDISON CO	PEBBLY BECH	DIESEL OIL	ENGINE	27,283	311,300
CALIFORNIA (STATE OF)	MOJAVE SIPH	WATER	HYDRO	32,535	338,429
LOS ANGELES (CITY OF)	SAWTELLE	WATER	HYDRO	1,549	16,113
SOUTHERN CALIF EDISON CO	MILL CRK 3	WATER	HYDRO	10,830	112,654
SOUTHERN CALIF EDISON CO	S GORGONIO	WATER	HYDRO	0	0
IMPERIAL IRRIGATION DIST	ROCKWOOD	DIESEL OIL	COMBUSTION TURBINE	217	3,402
IMPERIAL IRRIGATION DIST	ROCKWOOD	NATURAL GAS	COMBUSTION TURBINE	3,230	41,353
SOUTHERN CALIF EDISON CO	MILL CRK 2	WATER	HYDRO	0	0

Annex 3: Example of Retail electricity sales by county in MWh (1990-1997)

County	Sector	1990	1,991	1,992	1993	1994	1995	1996	1997
IMPERIAL	Residential	136,984	77,573	67,636	67,467	310,439	303,892	328,855	332,884
	Non-Residential	640,938	644,297	700,850	772,968	806,886	823,601	834,853	858,054
	Total	777,923	721,870	768,485	840,435	1,117,324	1,127,493	1,163,707	1,190,938
LOS ANGELES	Residential	16,960,720	16,310,884	17,179,731	16,555,104	16,844,761	16,846,743	17,197,339	17,589,989
	Non-Residential	48,331,440	46,950,244	47,137,016	46,964,379	46,425,089	46,897,901	47,901,859	49,160,664
	Total	65,292,160	63,261,128	64,316,747	63,519,483	63,269,850	63,744,643	65,099,198	66,750,653
ORANGE	Residential	5,120,556	5,137,482	5,520,933	5,286,180	5,463,048	5,433,358	5,554,113	5,805,799
	Non-Residential	11,639,677	11,468,403	11,955,744	11,817,129	11,853,672	12,013,592	12,389,456	12,781,914
	Total	16,760,234	16,605,885	17,476,678	17,103,308	17,316,719	17,446,951	17,943,569	18,587,713
RIVERSIDE	Residential	3,381,207	3,387,376	3,633,307	3,496,673	4,029,239	4,056,946	4,235,349	4,294,920
	Non-Residential	3,429,272	3,563,902	3,685,650	3,735,958	4,821,427	4,798,740	5,116,889	5,350,277
	Total	6,810,478	6,951,278	7,318,957	7,232,631	8,850,666	8,855,686	9,352,238	9,645,197
SAN BERNARDINO	Residential	3,825,313	3,773,015	3,939,490	3,808,511	3,403,367	3,438,968	3,529,805	3,549,015
	Non-Residential	7,634,503	7,814,738	7,839,765	7,934,489	7,237,522	7,541,755	7,926,198	8,267,214
	Total	11,459,816	11,587,754	11,779,254	11,743,000	10,640,889	10,980,723	11,456,003	11,816,230
VENTURA	Residential	1,349,773	1,348,884	1,372,727	1,351,134	1,395,507	1,385,915	1,426,901	1,481,620
	Non-Residential	3,143,324	3,064,860	3,079,858	3,147,203	3,135,686	3,240,568	3,291,601	3,456,807
	Total	4,493,097	4,413,745	4,452,585	4,498,337	4,531,193	4,626,483	4,718,502	4,938,427
SCAG	**Residential**	**30,774,554**	**30,035,215**	**31,713,824**	**30,565,068**	**31,446,361**	**31,465,822**	**32,272,363**	**33,054,227**
	Non-Residential	**74,819,154**	**73,506,445**	**74,398,882**	**74,372,126**	**74,280,280**	**75,316,157**	**77,460,854**	**79,874,931**
	Total	**105,593,708**	**103,541,660**	**106,112,706**	**104,937,195**	**105,726,641**	**106,781,980**	**109,733,217**	**112,929,159**

Annex 4: Example of CO2 intensity of electricity imports into the SCAG region (2001)

All electricity data in MW and aMW, not in GWh.
All emission data in thousands of metric tons, not short tons.

	Year 2001	2002	2003	2004	2005	2006	2007	2008
2 LADWP Utility Name								
Estimate of Cumulative CEE	5	4	3	5	4	4	8	15
Demand (not adjusted for CEE)	2,775	2,878	2,972	3,070	3,036	3,155	3,159	3,231
Demand (adjusted for CEE)	2,770	2,874	2,969	3,066	3,032	3,150	3,151	3,216
Supply aMW, not GWh								
GHG-free - Not priced at market							[illegible]	[illegible]
Hydroelectricity-2001-2006 (actual or avg2001-20(	68	50	110	111	98	98		
Hydroelectricity > 30 MW (Line 14b of S-2)							45	6
State-Defined Eligible Renewable Energy, omitting QFs (S-2 lines 26a, 26c, 26d, 26f)							163	203
Hoover share	116	112	95	93	86	95	99	99
Nuclear Plant I Palo Verde								
Plant Capacity MW								
Capacity Factor (%)								
Ownership Share (%)	9.7%	9.7%	9.7%	9.7%	9.7%	9.7%	9.7%	9.7%
Generation aMW, not GWh	317	340	315	310	285	265	294	323
Nuclear Plant Name:								
Plant Capacity MW								
Capacity Factor (%)								
Ownership Share (%)								
Generation aMW, not GWh								
GHG-free - Not priced at market: Total aMV	476	524	510	501	491	488	602	631
Data in deep yellow cells was taken from 'LADWP 2000-2009 CO2 Emissions Reported to CCAR (updated 7-7-2010) just retail.xls' provided by Cath								
GHG-free - Priced at market								
QFs: Renewable	1	5	1	41	39	81	81	81
Incremental RPS post-2006, in aMW, not GWh	0	0	0	0	0	0	0	0
Other	0	0	0	0	0	0	0	0
GHG-free - Priced at market: Total aMW	1	5	1	41	39	81	81	81
Coal								
Coal Plants								
Interm Generation aMW, not MWh	975	973	998	1,032	976	1,017	957	938
Emissions thousands of metric tons	7,237	7,194	7,402	7,632	7,225	7,528	7,026	6,931
Navajo Generation aMW, not MWh	425	439	403	432	396	414	423	423
Emissions thousands of metric tons	3,316	3,448	3,142	3,334	3,027	3,196	3,274	3,254
Mohav Generation aMW, not MWh	222	116	124	129	127			
Emissions thousands of metric tons	1,750	916	974	1,013	1,009			
Data in deep yellow cells was taken from 'LADWP 2000-2009 CO2 Emissions Reported to CCAR (updated 7-7-2010) just retail.xls' provided by Cath								
ote: Slight differences between LADWP's adjusted CCAR (row 247 in yellow) and this model (row 248 in green)	1,633	1,536	1,539	1,655	1,548	1,475		
Coal: Total aMW	1,622	1,529	1,526	1,592	1,499	1,431	1,380	1,361
Coal: Total emissions - thousands of tonnes	12,303	11,558	11,518	11,979	11,262	10,724	10,300	10,185
Gas								
QFs: Non-Renewable	46	28	25	27	38	26	26	26
QF Gas: Total emissions - thousands of tonn	173	104	94	101	143	97	97	97
Residual Generation at Default Emission Rate	626	789	907	905	965	1,124	1,062	1,116
Gas: Total emissions - thousands of tonnes	2,388	3,008	3,459	3,452	3,681	4,287	4,051	4,258
Check: Does Supply equal Demand?	Yes	Yes	Yes	No	Yes	Yes	Yes	Yes
Emissions: Thousands of tonnes								
from Coal	12,303	11,558	11,518	11,979	11,262	10,724	10,300	10,185
from Gas	2,560	3,112	3,553	3,553	3,825	4,384	4,148	4,355
Total emissions - thousands of tonnes	14,864	14,670	15,071	15,532	15,086	15,107	14,448	14,540
GHG-free - Priced at market:								
Total equivalent CO2 burden - thousands of tonnes	4	17	4	155	150	311	311	311
Total equivalent emissions from CEE	18	15	13	18	15	17	30	58
Gross compliance burden omitting CEE	14,867	14,687	15,075	15,687	15,236	15,418	14,759	14,851
Gross compliance burden including CEE	14,886	14,702	15,088	15,705	15,251	15,435	14,789	14,909
Emissions Intensity (CO2 MT/MWH)	612	583	579	578	568	547	523	516

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Annex 5: Index of worksheets for the development of the SCAG ES GHG Inventory and forecast

	Woksheet name	Worksheet description
GHG EMISSION RESULTS	CO2	Carbon dioxide (CO2) emissions of plants in the SCAG region
	CH4	Methane (CH4) emissions of plants in the SCAG region
	N2O	Nitrous Oxide (N2O) emissions of plants in the SCAG region
	CO2e	Carbon dioxide equivalent (CO2e) emissions of plants in the SCAG region
GRAPHICAL SUMMARIES	INVENTORY SUMMARY CHARTS	Summary charts for the Inventory period (1990-2008)
	FORECAST SUMMARY CHARTS	Summary charts for the forecast period (2008-2035)
	OVERALL SUMMARY	Summary charts and tables for the overall period (1990-2035)
KEY SOURCES & ASSUMPTIONS	SOURCES	Sources of data and assumptions
	SCAG ZIP CODES	Zip codes in the 6 SCAG counties
	E-FACTORS	EIA and CARB fuel categories & emission factors
	SALES	Electricity Sales in the SCAG region
	T&D LOSSES	Electricity transmission & distribution losses
	MACRO	Macro structure to extract SCAG data from EIA forms
ELECTRIC SECTOR PLANNING CALCULATIONS	CARB BENCHMARKING-IMPORTS	CO2 intensity of imported power into California based on the CARB inventory, 1990-2004
	CARB BENCHMARKING-CHP	SCAG net generation, fuel use, and GHG emissions from CHP units based on the CARB inventory, 1990-1997
	SCAPPA	SCAPPA model synthesis - net generation, CO2e emissions, and CO2e intensity (adjusted to a 20% RPS)
	NET GENERATION	Net Generation to meet total electricity demand in SCAG region
	HEAT RATE	Heat Rates in SCAG region
	FUEL USE	Primary fuel use assocaited with net generation by plants in the SCAG region
INVENTORY RESULTS (1990-2010)	1990	Inventory summary of net generation and fuel use for 1990 (includes in-SCAG plants and specfiied imports)
	1991	Inventory summary of net generation and fuel use for 1991 (includes in-SCAG plants and specfiied imports)
	1992	Inventory summary of net generation and fuel use for 1992 (includes in-SCAG plants and specfiied imports)
	1993	Inventory summary of net generation and fuel use for 1993 (includes in-SCAG plants and specfiied imports)
	1994	Inventory summary of net generation and fuel use for 1994 (includes in-SCAG plants and specfiied imports)
	1995	Inventory summary of net generation and fuel use for 1995 (includes in-SCAG plants and specfiied imports)
	1996	Inventory summary of net generation and fuel use for 1996 (includes in-SCAG plants and specfiied imports)
	1997	Inventory summary of net generation and fuel use for 1997 (includes in-SCAG plants and specfiied imports)
	1998	Inventory summary of net generation and fuel use for 1998 (includes in-SCAG plants and specfiied imports)
	1999	Inventory summary of net generation and fuel use for 1999 (includes in-SCAG plants and specfiied imports)
	2000	Inventory summary of net generation and fuel use for 2000 (includes in-SCAG plants and specfiied imports)
	2001	Inventory summary of net generation and fuel use for 2001 (includes in-SCAG plants and specfiied imports)
	2002	Inventory summary of net generation and fuel use for 2002 (includes in-SCAG plants and specfiied imports)
	2003	Inventory summary of net generation and fuel use for 2003 (includes in-SCAG plants and specfiied imports)
	2004	Inventory summary of net generation and fuel use for 2004 (includes in-SCAG plants and specfiied imports)
	2005	Inventory summary of net generation and fuel use for 2005 (includes in-SCAG plants and specfiied imports)
	2006	Inventory summary of net generation and fuel use for 2006 (includes in-SCAG plants and specfiied imports)
	2007	Inventory summary of net generation and fuel use for 2007 (includes in-SCAG plants and specfiied imports)
	2008	Inventory summary of net generation and fuel use for 2008 (includes in-SCAG plants and specfiied imports)
	2009	Inventory summary of net generation and fuel use for 2010 (includes in-SCAG plants only)
	2010	Inventory summary of net generation and fuel use for 2008 (includes in-SCAG plants only)
OTHER	CHECK	Summary of checks for internal consistency
	CHP	Average share of CHP generation sold to utilities to meet retail load over the period 1998, 1999, and 2000 (information only)

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Appendix B. Residential, Commercial, and Industrial (RCI) Fuel Combustion

Overview

Activities in the RCI sectors produce carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O) emissions when fuels are combusted to provide space heating, water heating, process heating, cooking, and other energy end-uses. Carbon dioxide accounts for 99% of these emissions on a million metric tons of CO_2 equivalent ($MMtCO_2e$) basis in the SCAG region. Direct use of petroleum, natural gas, coal, and wood in the RCI sectors accounted for an estimated 37.5 $MMtCO_2e$ of gross greenhouse gas (GHG) emissions in 2008.[40]

In addition to direct fuel combustion, since these sectors consume electricity, one can also attribute emissions associated with electricity generation to these sectors in proportion to their electricity use.[41] It is important to note that emissions associated with electricity consumption have been allocated to the RCI sector and are compared to the RCI fuel-consumption-based emissions for information purposes only. For more details regarding the electricity supply sector, please refer to Appendix A. Emissions estimated for the RCI electricity consumption are not double-counted in the total emissions for the region.

Emissions and Reference Case Projections

Emissions from direct fuel use were estimated using the United States Environmental Protection Agency's (US EPA) State Greenhouse Gas Inventory Tool (SIT) software and the methods provided in the Emission Inventory Improvement Program (EIIP) guidance document for RCI fossil and wood fuel combustion.[42] The default data used in SIT for the SCAG region are from the United States Department of Energy (US DOE) Energy Information Administration's (EIA) *State Energy Data* (SED) for the State of California. However, in order to calculate accurately SCAG's GHG emissions, several default data were modified.

[40] Emissions estimates from wood combustion include only N_2O and CH_4. Carbon dioxide emissions from biomass combustion are assumed to be "net zero", consistent with US EPA and Intergovernmental Panel on Climate Change (IPCC) methodologies, and any net loss of carbon stocks due to biomass fuel use should be accounted for in the land use and forestry analysis.

[41] Emissions associated with the electricity supply sector (presented in Appendix A) have been allocated to the residential sector and to the non-residential sector for comparison of those emissions to the fuel-consumption-based emissions presented in Appendix B (when comparing emissions related to electricity usage and direct fuel use, commercial and industrial sectors are grouped into a single category. This is because electricity usage data were only available at this level). Note that this comparison is provided for information purposes and that emissions estimated for the electricity supply sector are not double-counted in the total emissions for the region. One could similarly allocate GHG emissions transport-related GHG sources to the RCI sectors based on their direct use of gas and other fuels, but we have not done so here due to the difficulty of ascribing these emissions to particular end-users. Estimates of emissions associated with the transportation sector are provided in Appendix C.

[42] GHG emissions were calculated using SIT, with reference to *EIIP*, *Volume VIII*: Chapter 1 "Methods for Estimating Carbon Dioxide Emissions from Combustion of Fossil Fuels", August 2004, and Chapter 2 "Methods for Estimating Methane and Nitrous Oxide Emissions from Stationary Combustion", August 2004.

First, the data sources for SIT's default emission factors are different from the ones used by California Air Resources Board (ARB) for their State inventory. Therefore, the default SIT emission factors for residential, commercial, and industrial sector fuel consumption for CO_2, N_2O, and CH_4 were replaced by those used by ARB for their State inventory (data sources for each fuel/GHG combination were verified in the Documentation of California's 2000-2008 GHG Inventory[43]). The sources of the ARB emission factor data include USEPA 2007[44], ARB 2010[45], and IPCC 2006[46]. Table B1 below summarizes the emission factors that were used for CO_2, N_2O, and CH_4 and compares them to SIT's default values.

Table B1. N_2O, CH_4, and CO_2 Emission Factors

N_2O Emission Factors (metric tons N_2O gas/BBtu) - Stationary Combustion

Fuel Type	Default SIT	ARB
Residential Sector		
Coal	0.00150	0.00158
Distillate Fuel	0.00060	0.00063
Kerosene	0.00060	0.00063
LPG	0.00060	0.00011
Natural Gas	0.00009	0.00011
Wood	0.00380	0.00422
Commercial Sector		
Coal	0.00150	0.00158
Distillate Fuel	0.00060	0.00063
Kerosene	0.00060	0.00063
LPG	0.00060	0.00011
Motor Gasoline	0.00060	0.00063
Residual Fuel	0.00060	0.00063
Natural Gas	0.00009	0.00011
Wood	0.00380	0.00422

Fuel Type	Default SIT	ARB
Industrial Sector		
Coking Coal	0.00150	0.00158
Independent Power Coal	0.00150	0.00158
Other Coal	0.00150	0.00158
Distillate Fuel	0.00060	0.00063
Kerosene	0.00060	0.00063
LPG	0.00060	0.00011
Motor Gasoline	0.00060	0.00063
Misc. Petro Products	0.00060	0.00063
Petroleum Coke	0.00060	0.00063
Residual Fuel	0.00060	0.00063
Natural Gas	0.00009	0.00011
Wood	0	0.00422

[43] Air Resources Board, *Documentation of California's Greenhouse Gas Inventory*, June 2010. Available at: http://www.arb.ca.gov/cc/inventory/doc/doc.htm
[44] USEPA (2007). Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2005. United States Environmental Protection Agency. EPA 430-R-07-002. Annex 2.1 (Tables A-31, A-32, A-35, and A-36). April 15, 2007. Washington DC. http://www.epa.gov/climatechange/emissions/usgginv_archive.html
[45] ARB (2010). Upcoming technical support document on GHG inventory methodologies. Version 3 (2000-2008 inventory). Specific questions may be directed to ARB staff, see: http://www.arb.ca.gov/cc/inventory/contacts.htm
[46] IPCC (2006). 2006 IPCC Guidelines for National Greenhouse Gas Inventories, Prepared by the National Greenhouse Gas Inventories Programme, Eggleston H.S., Buendia L., Miwa K., Ngara T., and Tanabe K. (eds). Volume 2, Chapter 2: Energy. Published: IGES, Japan. http://www.ipcc-ggip.iges.or.jp/public/2006gl/pdf/2_Volume2/V2_2_Ch2_Stationary_Combustion.pdf

CH_4 Emission Factors (metric tons CH_4 gas/BBtu) - Stationary Combustion

Fuel Type	Default SIT	ARB
Residential Sector		
Coal	0.30069	0.31652
Distillate Fuel	0.01002	0.01055
Kerosene	0.01002	0.01055
LPG	0.01002	0.00528
Natural Gas	0.00475	0.00528
Wood	0.28487	0.31652
Commercial Sector		
Coal	0.01002	0.01055
Distillate Fuel	0.01002	0.01055
Kerosene	0.01002	0.01055
LPG	0.01002	0.00528
Motor Gasoline	0.01002	0.01055
Residual Fuel	0.01002	0.01055
Natural Gas	0.00475	0.00528
Wood	0.28487	0.31652

Fuel Type	Default SIT	ARB
Industrial Sector		
Coking Coal	0.01002	0.01055
Independent Power Coal	0.01002	0.01055
Other Coal	0.01002	0.01055
Distillate Fuel	0.00301	0.00317
Kerosene	0.00301	0.00317
LPG	0.00301	0.00106
Motor Gasoline	0.00301	0.00317
Misc. Petro Products	0.00301	0.00317
Petroleum Coke	0.00301	0.00317
Residual Fuel	0.00301	0.00317
Natural Gas	0.00095	0.00106
Wood	0.02849	0.03165

CO_2 Emission Factors (lbs C/Million Btu) - Combustion of Fossil Fuels

Fuel Type	Default SIT	ARB
Residential Sector		
Coal*[47]	55.66	57.32
Distillate Fuel	43.94	43.98
Kerosene	43.44	43.48
LPG*	37.96	37.92
Natural Gas	31.87	31.90
Commercial Sector		
Coal *	55.66	57.32
Distillate Fuel	43.94	43.98
Kerosene	43.44	43.48
LPG*	37.96	37.92
Motor Gasoline*	42.80	42.64
Residual Fuel	47.33	47.38
Natural Gas	31.87	31.90

Fuel Type	Default SIT	ARB
Industrial Sector		
Coking Coal	-	68.34
Other Coal*	55.80	56.50
Distillate Fuel	43.94	43.98
Kerosene	43.44	43.48
LPG*	37.46	37.88
Motor Gasoline*	42.80	42.64
Petroleum Coke	61.34	61.40
Residual Fuel	47.33	47.38
Natural Gas	31.87	31.90

[47] Emission factors that have an asterisk vary by year (those used by ARB for their State inventory, which were also used in this SCAG inventory; default SIT emission factors do not vary). When they varied, CCS updated emission factors for every year from 1990 through 2007. The values listed in Table 1 are the values for 2007 (latest year available), after which emission factors were assumed to remain constant.

Then, default fuel consumption data were updated with SCAG region-specific data, when available:

- Natural gas: the California Energy Commission (CEC) was able to provide natural gas retail sales data by county from 1990 to 2008. These data were organized by Northern American Industry Classification System (NAICS) codes, rather than the IPCC categories required for this GHG inventory. Therefore, CCS matched IPCC categories and NAICS codes. It is important to note that there are differences between the IPCC-defined source categories and NAICS categories; those were matched based on the closest comparable description of industry/IPCC categories. In addition, emissions from natural gas consumption associated with useful thermal output at combined heat and power (CHP) facilities (i.e. fuel consumption at CHP facilities that is not associated with the production of electricity) was included in the commercial and industrial sectors. Emissions for years 2001-2008 were calculated based on form EIA-923 data[48]. Data included plant-level fuel consumption for CHP useful thermal output (only plants located in the SCAG region were selected for each inventory year; plant locations were obtained from the electricity supply sector; see Appendix A for details). For previous years, form EIA-923 data were not available. Therefore, for 1990-2000, emissions from CHP useful thermal output are based on statewide emissions[49], which were allocated to SCAG based on the 2001 to 2008 ratio of SCAG/State emissions[50] for that specific source category.

- Other fuels: natural gas is the only fuel for which county data were available. For other fuels, California data were allocated to the SCAG region. This allocation will not significantly affect the accuracy of the inventory as natural gas represents about 96% of the total fuel consumption in California for the residential sector, 92% for the commercial sector, and 62% for the industrial sector (based on the EIA State Energy Data from 1990 to 2008). For the residential sector inventory, data were allocated on a population pro-rata basis. For the commercial/industrial sectors inventory, data were allocated on a commercial and industrial employment pro-rata basis (“Service providing” or “Goods producing” jobs). The latest version of SIT includes data through 2007. Data from the EIA State Energy Data System were added for 2008, after which emissions were forecasted.

Note that the EIIP methods for the industrial sector exclude from CO_2 emission estimates the amount of carbon that is stored in products produced from fossil fuels for non-energy uses. This approach was also applied to the SCAG I&F. For example, the methods account for carbon

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[48] U.S. Department of Energy, The Energy Information Administration (EIA), EIA-923 Monthly Time Series File, Sources: EIA-906 and EIA-860. Available at: http://www.eia.gov/cneaf/electricity/page/eia906_920.html.
[49] Statewide emissions for 1990-2000 are based on ARB's Inventory Data Archive: Air Resources Board, Inventory Data Archive - 1990 to 2004 Inventory, November 2007. Available at: http://www.arb.ca.gov/cc/inventory/archive/archive.htm.
[50] The 2001-2008 ratio was calculated based on ARB's Greenhouse Gas Inventory Data - 2000 to 2008: Air Resources Board, Greenhouse Gas Emission Inventory Data – years 2000-2008, May 2010. Available at: http://www.arb.ca.gov/cc/inventory/data/data.htm.

stored in petrochemical feedstocks, liquefied petroleum gases (LPG), and natural gas used as feedstocks by chemical manufacturing plants (i.e., not used as fuel), as well as carbon stored in asphalt and road oil produced from petroleum. The carbon storage assumptions for these products are explained in detail in the EIIP guidance document.[51] The fossil fuel types for which the EIIP methods are applied in the SIT to account for carbon storage include the following: asphalt and road oil, coking coal, distillate fuel, feedstocks (naphtha with a boiling range of less than 401 degrees Fahrenheit), feedstocks (other oils with boiling ranges greater than 401 degrees Fahrenheit), LPG, lubricants, miscellaneous petroleum products, natural gas, pentanes plus, petroleum coke, residual fuel, still gas, and waxes. Data on annual consumption of the fuels in these categories as chemical industry feedstocks were obtained from the EIA SED.

Table B2 shows historical and projected growth rates for energy use by sector and fuel type. Reference case emissions from direct fuel combustion were estimated based on fuel consumption forecasts from EIA's *Annual Energy Outlook 2010* (AEO2010).[52] For the RCI sectors, annual growth rates for natural gas, oil, wood, and coal were calculated from the AEO2010 regional forecast that EIA prepared for the Pacific modeling region. For the residential sector, the AEO2010 annual growth rate in fuel consumption from 2008 through 2035 was normalized using the AEO2010 population forecast and then weighted using SCAG's population forecast over this period. Growth rates for the commercial and industrial sectors were based on the AEO2010 Pacific regional estimates of growth in fuel consumption. These estimates reflect expected responses of the economy – as simulated by the EIA's National Energy Modeling System – to changing fuel and electricity prices and changing technologies, as well as structural changes within each sector (such as shifts in subsectoral shares and energy use patterns).

Table B2. Historical and Projected Annual Growth in Energy Use in the SCAG region, by Sector and Fuel, 1990-2035

Sector/fuel	1990-2008[a]	2008-2010[b]	2010-2015[b]	2015-2020[b]	2020-2025[b]	2025-2030[b]	2030-2035[b]
Residential							
petroleum	0.8%	-2.2%	-3.2%	-2.4%	-2.3%	-2.2%	-2.0%
natural gas	-0.6%	0.0%	0.4%	0.8%	0.5%	0.0%	-0.1%
coal	-100%	0%	0%	0%	0%	0%	0%
wood	-5.7%	-5.0%	0.2%	0.7%	0.0%	0.2%	0.4%
Commercial							
petroleum	-3.0%	-7.4%	0.6%	-0.3%	0.0%	-0.1%	-0.1%
natural gas	1.5%	-0.2%	0.1%	0.2%	0.6%	0.3%	0.4%
coal	-100%	0%	0%	0.0%	0.0%	0.0%	0.0%
wood	-9.1%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%

[51] EIIP Volume VIII: Chapter 1 "Methods for Estimating Carbon Dioxide Emissions from Combustion of Fossil Fuels" August 2004.
[52] EIA AEO2010 projections to 2035 are available at http://www.eia.doe.gov/oiaf/aeo/aeoref_tab.html.

Sector/fuel	1990-2008[a]	2008-2010[b]	2010-2015[b]	2015-2020[b]	2020-2025[b]	2025-2030[b]	2030-2035[b]
Industrial							
petroleum	-2.2%	3.5%	1.9%	1.9%	0.2%	-0.3%	0.3%
natural gas	3.0%	-8.4%	0.3%	-1.5%	2.3%	0.1%	-0.2%
coal	-1.0%	-11.2%	3.3%	0.4%	0.0%	-0.2%	-0.5%
wood	-3.9%	-3.4%	3.3%	1.5%	0.8%	0.7%	0.7%

[a] Compound annual growth rates calculated from EIA SED historical consumption by sector and fuel type for California.[53] Petroleum includes distillate fuel, kerosene, and LPG for all sectors plus residual oil for the commercial and industrial sectors.
[b] Figures for growth periods starting after 2008 are calculated from AEO2010 projections for EIA's Pacific region. Regional growth rates for the residential sector are adjusted for SCAG's projected population.

Results - RCI Emissions from Direct Fuel Use Only (Petroleum, Natural Gas, Coal, and Wood)

Figures B1, B2, and B3 show historical and projected emissions for the RCI sectors in the SCAG region from 1990 through 2035. These figures show the emissions associated with the direct consumption of fossil fuels only (electricity is not included). For this section, the RCI sector is broken-down into residential, commercial and industrial sectors.

The residential sector's share of total RCI emissions from direct fuel use was 36.6% in 1990, decreased to 35.5% in 2008, and is projected to further decrease to 34.6% in 2035. The commercial sector's share of total RCI emissions from direct fuel use was 12.8% in 1990, 14.4% in 2008, and is projected to remain at 14.4% by 2035. The industrial sector's share of total RCI emissions from direct fuel use was 50.6% and 50.1% in 1990 and in 2008 respectively; it is projected to represent 51.0% of the total RCI emissions in 2035. From 1990 to 2035, natural gas consumption is the highest source of emissions for the residential and commercial sectors, accounting for an average of 93.9% and 82.9% of total emissions, respectively. For the industrial sector, emissions associated with the combustion of natural gas, petroleum, and coal account for 44.1%, 41.3%, and 14.4% respectively, on average, from 1990 to 2035.

Residential Sector

Figure B1 presents the emission inventory and reference case projections for the residential sector. Figure B1 was developed from the data in Table B3a. Table B3b shows the relative contributions of each fuel type to total residential sector emissions.

For the residential sector, emissions from direct fossil fuel use in 1990 were about 14.6 $MMtCO_2e$, and are estimated to decrease to 13.8 $MMtCO_2e$ by 2035. In 1990, natural gas consumption accounted for 93.1% of total residential emissions, and is projected to represent

[53] Energy Consumption by Sector in California is available at http://www.eia.doe.gov/emeu/states/state.html?q_state_a=ca&q_state=CALIFORNIA .

95.6% of total residential emissions by 2035. Residential sector emissions associated with the use of coal, petroleum, and wood in 1990 were about 1.0 $MMtCO_2e$ combined, and accounted for 6.9% of total residential emissions. By 2035, emissions associated with the consumption of these three fuels are estimated to slightly decrease to 0.6 $MMtCO_2e$, accounting for 4.4% of total residential sector emissions.

For the 30-year period 2005 to 2035, residential-sector GHG emissions associated with the use of natural gas and wood are expected to increase at average annual rates of 0.1% and 0.2%, respectively. Emissions related to the use of petroleum are expected to decrease annually by about -2.3 % and those due to the use of coal are projected to be nil by 2035. Over the 30-year period, total GHG emissions for this sector are stable (average rate of -0.003% annually).

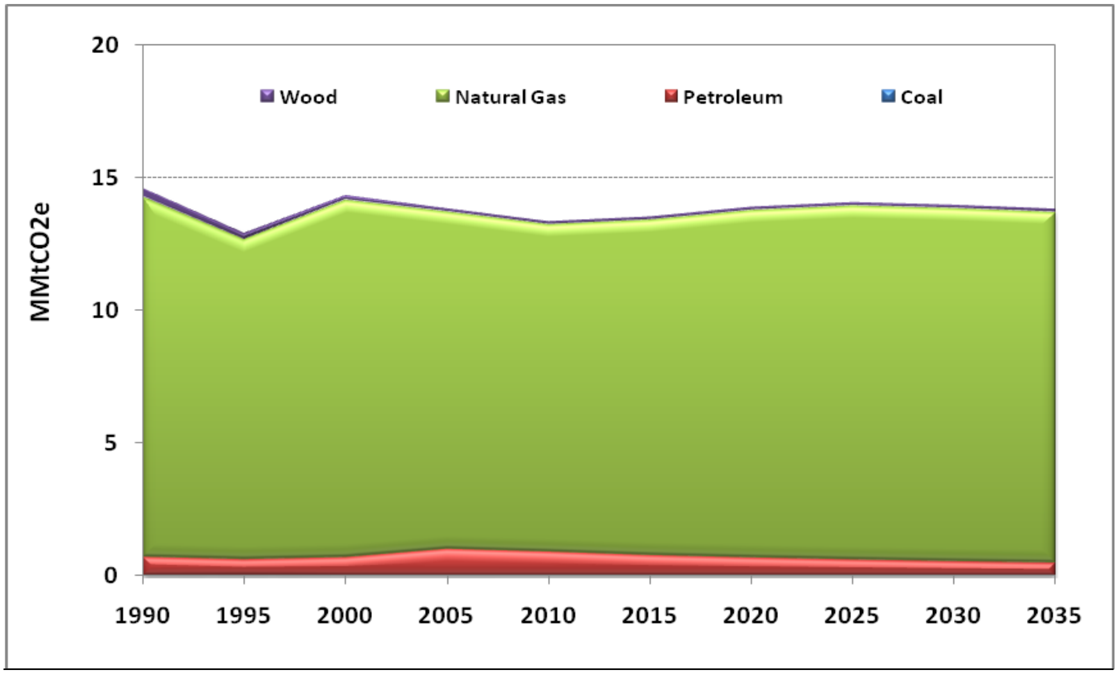
Commercial Sector

Figure B2 presents the emission inventory and reference case projections for the commercial sector. Figure B2 was developed from the data in Table B4a. Table B4b shows the relative contributions of each fuel type to total commercial sector emissions.

For the commercial sector, emissions from direct fossil fuel use were about 5.1 $MMtCO_2e$ in 1990 and are estimated to increase to about 5.7 $MMtCO_2e$ by 2035. In 1990, natural gas consumption accounted for 68.5% of total commercial emissions and is estimated to account for 86.1% of total commercial emissions by 2035. In 1990, commercial sector emissions associated with the use of coal, petroleum, and wood were about 1.6 $MMtCO_2e$, and accounted for 31.5% of total commercial emissions. By 2035, emissions associated with the consumption of these three fuels are estimated to be 0.8 $MMtCO_2e$ and to account for 13.9% of total commercial sector emissions.

For the 30-year period from 2005 to 2035, commercial sector GHG emissions associated with the use of natural gas are expected to remain stable. Emissions associated with the use of petroleum are estimated to increase at an average annual rate of 0.9%. Emissions related to the use of coal are projected to be nil in 2035 and those related to wood are expected to decrease at an average annual rate of -7.2%.. Over the 30-year period, total GHG emissions for this sector grow slightly by an average of 0.1% annually.

Figure B1. Residential Sector GHG Emissions from Fuel Consumption



Note: Emissions associated with coal and wood combustion are too small to be seen on this graph.

Table B3a - Residential Sector Emissions Inventory and Reference Case Projections ($MMtCO_2e$)

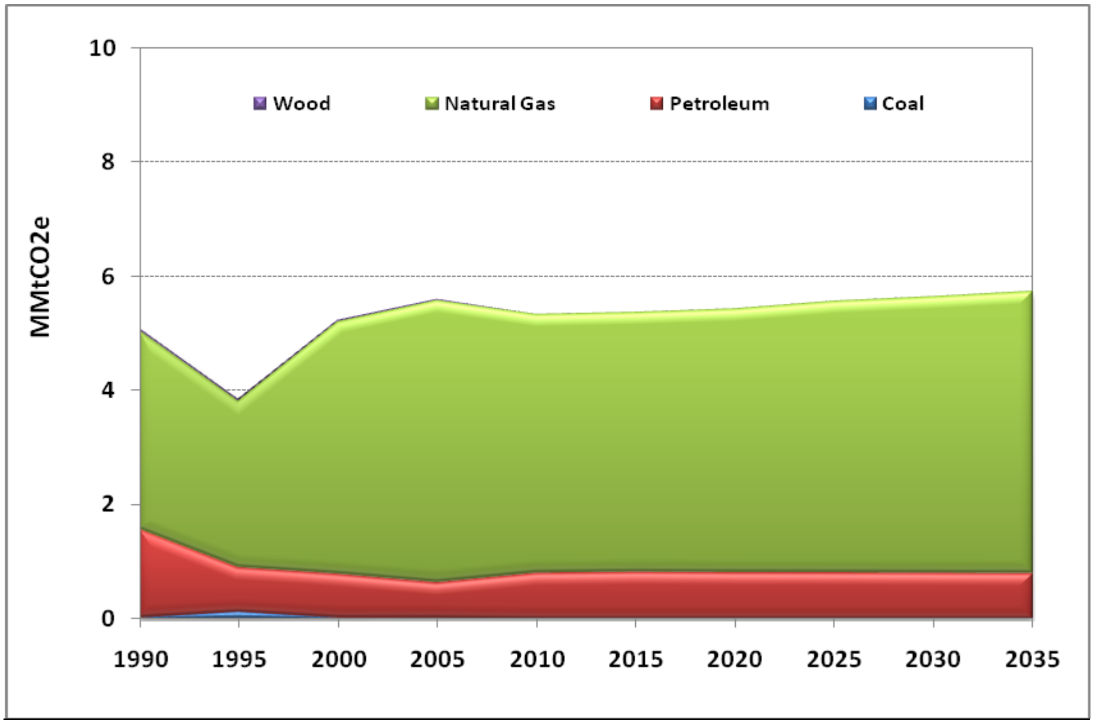
Fuel Type	1990	1995	2000	2005	2008	2010	2015	2020	2025	2030	2035
Coal	0.006	0.020	0.003	0.002	-	-	-	-	-	-	-
Petroleum	0.7	0.6	0.7	1.0	1.0	0.9	0.8	0.7	0.6	0.5	0.5
Natural Gas	13.6	12.0	13.4	12.7	12.3	12.3	12.6	13.1	13.3	13.3	13.2
Wood	0.3	0.2	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Total	14.6	12.9	14.3	13.8	13.3	13.3	13.5	13.9	14.0	13.9	13.8

Table B3b - Residential Sector Proportions of Total Emissions by Fuel Type (%)

Fuel Type	1990	1995	2000	2005	2008	2010	2015	2020	2025	2030	2035
Coal	0.04%	0.16%	0.02%	0.01%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Petroleum	4.9%	4.7%	4.9%	7.3%	7.2%	6.8%	5.8%	5.0%	4.4%	3.9%	3.6%
Natural Gas	93.1%	93.4%	94.1%	92.0%	92.0%	92.5%	93.5%	94.3%	94.9%	95.3%	95.6%
Wood	2.0%	1.7%	1.0%	0.7%	0.8%	0.7%	0.7%	0.7%	0.7%	0.8%	0.8%

Note: The percentages shown in this table reflect the emissions for each fuel type as a percentage of total emissions shown in Table B3a.

Figure B2. Commercial Sector GHG Emissions from Fuel Consumption



Note: Emissions associated with coal and wood combustion are too small to be seen on this graph.

Table B4a - Commercial Sector Emissions Inventory and Reference Case Projections ($MMtCO_2e$)

Fuel Type	1990	1995	2000	2005	2008	2010	2015	2020	2025	2030	2035
Coal	0.02	0.12	0.02	0.02	-	-	-	-	-	-	-
Petroleum	1.5	0.8	0.8	0.6	0.9	0.8	0.8	0.8	0.8	0.8	0.8
Natural Gas	3.5	2.9	4.4	4.9	4.5	4.5	4.5	4.6	4.8	4.8	4.9
Wood	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Total	5.1	3.9	5.2	5.6	5.4	5.3	5.4	5.4	5.6	5.6	5.7

Table B4b - Commercial Sector Proportions of Total Emissions by Fuel Type (%)

Fuel Type	1990	1995	2000	2005	2008	2010	2015	2020	2025	2030	2035
Coal	0.4%	3.2%	0.4%	0.3%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Petroleum	30.4%	20.2%	14.6%	11.0%	15.9%	15.0%	15.2%	14.9%	14.5%	14.2%	13.9%
Natural Gas	68.5%	75.9%	84.6%	88.3%	84.0%	84.9%	84.7%	85.1%	85.5%	85.8%	86.1%
Wood	0.6%	0.8%	0.5%	0.3%	0.03%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%

Note: The percentages shown in this table reflect the emissions for each fuel type as a percentage of total emissions shown in Table B4a.

**This inventory and forecast has been prepared with the most up-to-date information and should not be compared to any previous analysis at this time.*

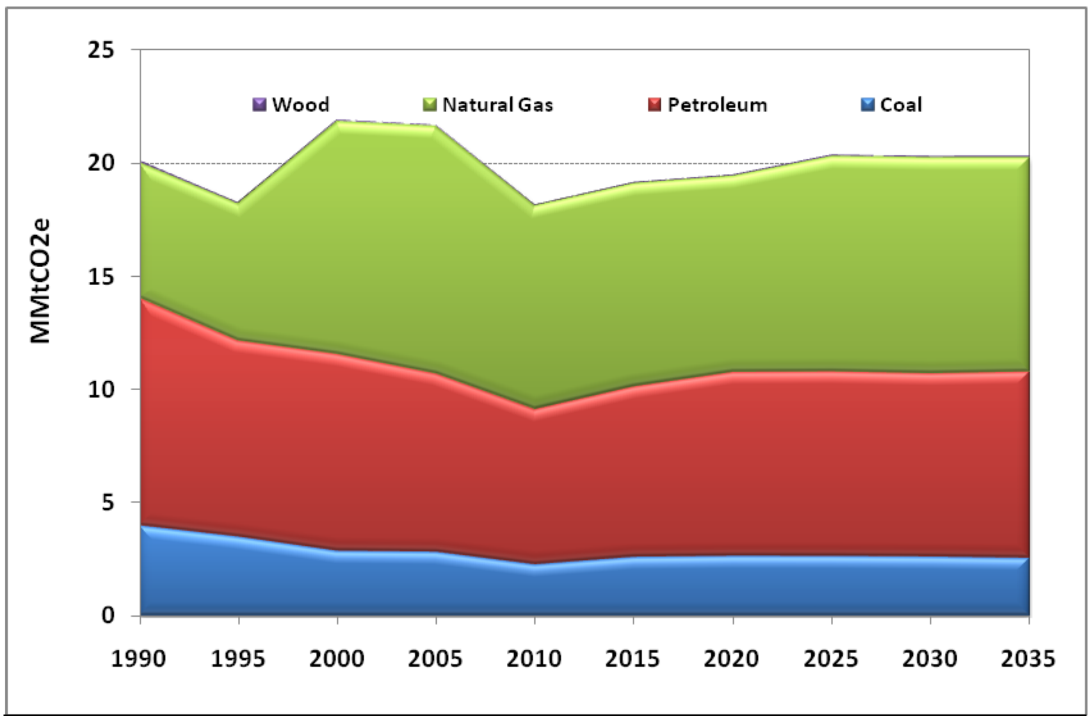
Industrial Sector

Figure B3 presents the emission inventory and reference case projections for the industrial sector. Figure B3 was developed from the emissions data in Table B5a. Table B5b shows the relative contributions of each fuel type to total industrial sector emissions.

For the industrial sector, emissions from direct fuel use in 1990 were about 20.1 $MMtCO_2e$ and are projected to stay relatively constant to reach about 20.3 $MMtCO_2e$ by 2035. In 1990, petroleum consumption accounted for 50.0% of total industrial emissions, and is estimated to decrease to 40.6% of total industrial emissions by 2035. Natural gas consumption accounted for 29.7% of total industrial emissions in 1990, and is expected to increase to 46.5% of total industrial emissions by 2035. Emissions related to the use of coal represented about 19.9% of total industrial emissions in 1990, and are estimated to drop to 12.7% by 2035. Finally, the proportion of industrial emissions associated with wood consumption decrease from 0.4% in 1990 to 0.3% in 2035.

For the 30-year period from 2005 to 2035, industrial sector GHG emissions associated with the use of wood and petroleum are expected to increase at an average annual rate of 1.3% and 0.1%, respectively. Emissions associated with the use of coal and natural gas are estimated to decrease annually by about -0.3% and -0.5%, respectively. Over the 30-year period, total GHG emissions for this sector decline by an average of -0.2% annually.

Figure B3. Industrial Sector GHG Emissions from Fuel Consumption



Note: Emissions associated with wood combustion are too small to be seen on this graph.

**This inventory and forecast has been prepared with the most up-to-date information and should not be compared to any previous analysis at this time.*

Table B5a - Industrial Sector Emissions Inventory and Reference Case Projections ($MMtCO_2e$)

Fuel Type	1990	1995	2000	2005	2008	2010	2015	2020	2025	2030	2035
Coal	4.0	3.5	2.9	2.8	2.5	2.3	2.6	2.7	2.7	2.6	2.6
Petroleum	10.1	8.7	8.7	7.9	6.5	6.9	7.5	8.1	8.2	8.1	8.2
Natural Gas	6.0	6.1	10.2	10.9	9.8	9.0	9.0	8.7	9.5	9.5	9.4
Wood	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1
Total	20.1	18.3	21.9	21.6	18.8	18.2	19.2	19.5	20.3	20.3	20.3

Table B5b - Industrial Sector Proportions of Total Emissions by Fuel Type (%)

Fuel Type	1990	1995	2000	2005	2008	2010	2015	2020	2025	2030	2035
Coal	19.9%	19.2%	13.2%	13.1%	13.3%	12.6%	13.7%	13.7%	13.1%	13.0%	12.7%
Petroleum	50.0%	47.4%	39.7%	36.4%	34.6%	37.8%	39.3%	41.7%	40.1%	39.9%	40.6%
Natural Gas	29.7%	33.2%	46.9%	50.3%	52.0%	49.4%	46.8%	44.4%	46.6%	46.9%	46.5%
Wood	0.4%	0.2%	0.2%	0.2%	0.2%	0.20%	0.2%	0.2%	0.2%	0.2%	0.3%

Note: The percentages shown in this table reflect the emissions for each fuel type as a percentage of total emissions shown in Table B5a.

Results - RCI Emissions from Direct Fuel Use (Scope 1) and Electricity Consumption (Scope 2)

Figures B4 and B5 show historical and projected emissions, from 1990 through 2035, for the RCI sector in the SCAG region. These figures show the emissions associated with the direct consumption of fossil fuels and, for comparison purposes, show the share of emissions associated with the generation of electricity consumed by each sector. For this first section, the RCI emissions are broken-down into the residential and non-residential sectors. Commercial and industrial sectors are grouped into a single category because electricity usage data were only available at this level. The next section of this appendix presents the RCI emissions from direct fuel use only, broken-down into three subsectors: residential, commercial, and industrial.

The residential sector's share of total RCI emissions from direct fuel use and electricity was 32.2% in 1990 and is projected to grow slightly to 32.3% in 2005 and to 40.7% 2035. The non-residential sector's share of total RCI emissions from direct fuel use and electricity use was 67.8% in 1990, and is projected to slightly decline to 67.7% of total RCI emissions in 2005 and to 59.3% in 2035. Emissions associated with the generation of electricity to meet RCI demand accounts for about 58.7% of the emissions for the residential sector and 58.6% of the emissions for the non-residential sector on average, over the 1990 to 2035 period. From 1990 to 2035, natural gas consumption is the next highest source of emissions for the residential sector, accounting for about 38.7% of total emissions, on average, from 1990 to 2035. Emissions associated with the combustion of natural gas, petroleum, and coal account for about 21.7%, 14.9%, and 4.7%, respectively, of the non-residential sector emission on average, from 1990 to 2035.

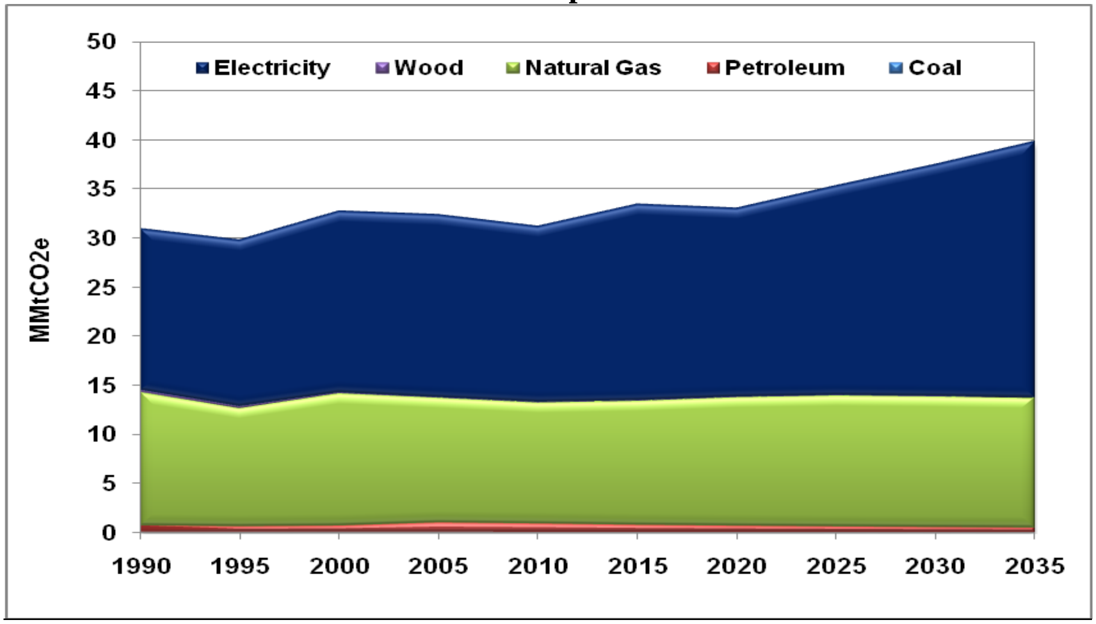
Residential Sector

Figure B4 presents the emission inventory and reference case projections for the residential sector. Figure B4 was developed from the data in Table B6a. Table B6b shows the relative contributions of each fuel type to total residential sector emissions.

For the residential sector, emissions from electricity and direct fossil fuel use in 1990 were about 31.0 $MMtCO_2e$, and are estimated to increase to about 39.8 $MMtCO_2e$ by 2035. Emissions associated with the generation of electricity to meet residential energy consumption demand accounted for about 53.0% of total residential emissions in 1990, and are projected to increase to 65.4% of total residential emissions by 2035. In 1990, natural gas consumption accounted for about 43.8% of total residential emissions, and is estimated to account for about 33.1% by 2035. Residential sector emissions associated with the use of coal, petroleum, and wood in 1990 were about 1.0 $MMtCO_2e$ combined, and accounted for about 3.2% of total residential emissions. By 2035, emissions associated with the consumption of these three fuels are estimated to decrease to 0.6 $MMtCO_2e$, accounting for 1.5% of total residential sector emissions.

For the 30-year period from 2005 to 2035, residential-sector GHG emissions associated with the use of electricity, wood, and natural gas are expected to increase at average annual rates of 1.1%, 0.2%, and 0.1% respectively. Emissions related to the use of petroleum are estimated to decrease annually by -2.3%. Finally, residential GHG emissions due to the use of coal are expected to be nil in 2035. Over the 30-year period, total GHG emissions for this sector increase by 0.7% annually.

Figure B4. Residential Sector GHG Emissions from Direct Fuel Use and Electricity Consumption



Note: Emissions associated with coal and wood combustion are too small to be seen on this graph.

**This inventory and forecast has been prepared with the most up-to-date information and should not be compared to any previous analysis at this time.*

Table B6a - Residential Sector Emissions Inventory and Reference Case Projections ($MMtCO_2e$)

Fuel Type	1990	1995	2000	2005	2008	2010	2015	2020	2025	2030	2035
Coal	0.006	0.020	0.003	0.002	-	-	-	-	-	-	-
Petroleum	0.7	0.6	0.7	1.0	1.0	0.9	0.8	0.7	0.6	0.5	0.5
Natural Gas	13.6	12.0	13.4	12.7	12.3	12.3	12.6	13.1	13.3	13.3	13.2
Wood	0.3	0.2	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Electricity	16.4	16.9	18.5	18.6	18.8	17.9	20.0	19.2	21.3	23.6	26.0
Total	**31.0**	**29.8**	**32.8**	**32.4**	**32.2**	**31.2**	**33.5**	**33.0**	**35.3**	**37.5**	**39.8**

Table B6b - Residential Sector Proportions of Total Emissions by Fuel Type (%)

Fuel Type	1990	1995	2000	2005	2008	2010	2015	2020	2025	2030	2035
Coal	0.02%	0.07%	0.01%	0.01%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Petroleum	2.3%	2.0%	2.1%	3.1%	3.0%	2.9%	2.3%	2.1%	1.7%	1.5%	1.2%
Natural Gas	43.8%	40.4%	41.0%	39.2%	38.1%	39.5%	37.7%	39.5%	37.7%	35.4%	33.1%
Wood	0.9%	0.7%	0.4%	0.3%	0.3%	0.3%	0.3%	0.3%	0.3%	0.3%	0.3%
Electricity	53.0%	56.8%	56.4%	57.4%	58.6%	57.3%	59.7%	58.1%	60.3%	62.8%	65.4%

Note: The percentages shown in this table reflect the emissions for each fuel type as a percentage of total emissions shown in Table B6a.

Non-residential (Commercial and Industrial) Sector

Figure B5 presents the emission inventory and reference case projections for the non-residential sector. Figure B5 was developed from the data in Table B7a. Table B7b shows the relative contributions of each fuel type to total non-residential sector emissions.

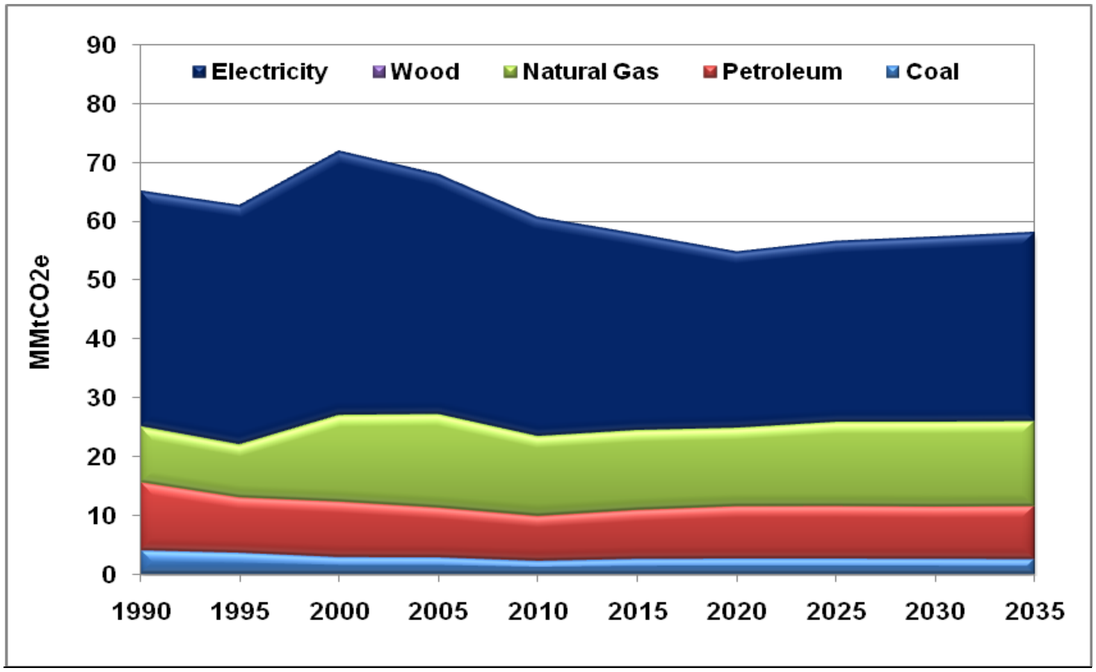
For the non-residential sector, emissions from electricity and direct fossil fuel use in 1990 were about 65.1 $MMtCO_2e$, and are estimated to decrease to about 58.1 $MMtCO_2e$ by 2035. Emissions associated with the generation of electricity to meet non-residential energy consumption demand accounted for about 61.3% of total emissions in 1990, and are projected to decrease to 55.2% by 2035. In 1990, natural gas consumption accounted for about 14.5% of total non-residential emissions and is expected to account for 24.7% by 2035. Petroleum consumption represented 17.8% of total non-residential emissions and is projected to decrease to 15.5% by 2035. Emissions related to the use of coal represented 6.2% of total non-residential emissions in 1990, and are estimated to decrease to 4.4% by 2035. Finally, the proportion of non-residential emissions associated with wood consumption decrease slightly from 0.2% in 1990 to 0.1% in 2035.

For the 30-year period from 2005 to 2035, non-residential sector GHG emissions associated with the use of petroleum are expected to increase at an average annual rate of 0.2%. Emissions associated with the use of electricity, coal, natural gas, and wood are projected to decline from

**This inventory and forecast has been prepared with the most up-to-date information and should not be compared to any previous analysis at this time.*

2005 levels at average annual rates of -0.8%, -0.4%, -0.3%, and -0.05%, respectively. Over the 30-year period, total GHG emissions for this sector decrease at an annual average rate of -0.5% annually.

Figure B5. Non-residential Sector GHG Emissions from Direct Fuel Use and Electricity Consumption



Note: Emissions associated with wood combustion are too small to be seen on this graph.

Table B7a - Non-residential Sector Emissions Inventory and Reference Case Projections ($MMtCO_2e$)

Fuel Type	1990	1995	2000	2005	2008	2010	2015	2020	2025	2030	2035
Coal	4.0	3.6	2.9	2.9	2.5	2.3	2.6	2.7	2.7	2.6	2.6
Petroleum	11.6	9.4	9.4	8.5	7.4	7.7	8.3	8.9	9.0	8.9	9.0
Natural Gas	9.5	9.0	14.7	15.8	14.3	13.5	13.5	13.3	14.2	14.3	14.4
Wood	0.1	0.1	0.1	0.1	0.0	0.0	0.0	0.0	0.0	0.1	0.1
Electricity	39.9	40.5	44.8	40.7	39.2	37.1	33.3	29.9	30.7	31.4	32.1
Total	**65.1**	**62.6**	**71.9**	**67.9**	**63.4**	**60.7**	**57.8**	**54.8**	**56.6**	**57.3**	**58.1**

Table B7b - Non-residential Sector Proportions of Total Emissions by Fuel Type (%)

Fuel Type	1990	1995	2000	2005	2008	2010	2015	2020	2025	2030	2035
Coal	6.2%	5.8%	4.0%	4.2%	3.9%	3.8%	4.5%	4.9%	4.7%	4.6%	4.4%
Petroleum	17.8%	15.1%	13.1%	12.5%	11.6%	12.6%	14.4%	16.3%	15.8%	15.5%	15.5%
Natural Gas	14.5%	14.3%	20.4%	23.3%	22.6%	22.3%	23.4%	24.2%	25.2%	25.0%	24.7%
Wood	0.2%	0.1%	0.1%	0.1%	0.1%	0.1%	0.1%	0.1%	0.1%	0.1%	0.1%
Electricity	61.3%	64.7%	62.3%	59.9%	61.8%	61.2%	57.6%	54.5%	54.2%	54.8%	55.2%

Note: The percentages shown in this table reflect the emissions for each fuel type as a percentage of total emissions shown in Table B7a.

Key Uncertainties

Key sources of uncertainty underlying the estimates above are:

- Population and economic growth are the principal drivers for electricity and fuel use. The reference case projections are based on regional fuel consumption projections for EIA's Pacific modeling region. Consequently, there are significant uncertainties associated with the projections. Future work should attempt to base projections of GHG emissions on fuel consumption estimates specific to the SCAG region to the extent that such data become available.
- Natural gas is the only fuel for which county data were available. For other fuels, default State data were allocated to the SCAG region. For the residential sector inventory, the allocation was done pro-rata to population. For the commercial and industrial sectors inventory, data were allocated pro-rata to commercial and industrial employment. This allocation assumes that fuel consumption per capita (or per job) is similar in the SCAG region and in California. Future work should attempt to base the inventory of GHG emissions on fuel consumption estimates specific to the SCAG region to the extent that such data become available (for all fuels rather than just natural gas).

**This inventory and forecast has been prepared with the most up-to-date information and should not be compared to any previous analysis at this time.*

Appendix C. Transportation Energy Use

Overview

The transportation sector is one of the largest sources of greenhouse gas (GHG) emissions in the SCAG Region. In 2008, carbon dioxide (CO_2) accounted for about 98% of transportation GHG emissions from fuel use.

Emissions and Reference Case Projections

Historical GHG emissions were estimated using methods similar to those used for the state GHG inventory developed by the California Air Resources Board (ARB). Emissions for gasoline and diesel onroad vehicles were estimated using ARB's EMFAC2007 model. Emissions for compressed natural gas (CNG), liquefied petroleum gas (LPG), marine gasoline, and aviation gasoline were estimated by allocating state consumption to the region. Commercial aviation emissions were estimated based on landing-takeoff operation data, and commercial marine emissions were taken from GHG inventories developed for the region's ports. Key assumptions used in this analysis are listed in Table C1.

Onroad Vehicles

Emissions for the onroad transportation subsector were estimated using the same method as the state inventory developed by ARB.[54] Emissions for gasoline and diesel onroad vehicles were estimated using ARB's EMFAC2007 model.[55] SCAG provided VMT data for two vehicle types (light/medium-duty vehicles and heavy-duty vehicles) for 2003, 2008, 2020, and 2035, shown in Table C2 and Figure C1. The VMT data from SCAG were allocated to the 13 vehicles types in EMFAC using the default vehicle distributions in the model. The SCAG VMT data were interpolated to estimate VMT for 2005, 2010, and 2015. Also, the 2003 VMT data were scaled to earlier years using EMFAC default VMT data. EMFAC was then run for the 6 SCAG counties for 1990, 1995, 2000, 2003, 2005, 2008, 2010, 2015, 2020, and 2035. Emissions were estimated based on EMFAC outputs for CO_2, total hydrocarbon (THC), CO, CH_4, and NO_x. EMFAC outputs emissions per weekday, so outputs were converted to emissions per average day by multiplying the emissions per weekday by the weekday to average day conversion factors used in the ARB inventory (0.95 for gasoline and 0.89 for diesel).

In the ARB inventory method, year-to-year differences between state-level fuel consumption estimated by EMFAC and fuel sales data were accounted for by applying the ratio of state-level gasoline or diesel to the EMFAC fuel consumption to the emissions results for each year. Since EMFAC is used by RPOs for conformity analysis, and because it is unclear how EMFAC output

[54] Air Resources Board, *California's 1990-2004 Greenhouse Gas Emissions Inventory and 1990 Emissions Level: Technical Support Document*, May 2009. Available at: http://www.arb.ca.gov/cc/inventory/doc/methods_v1/ghg_inventory_technical_support_document.pdf
[55] California Air Resources Board, EMFAC2007 model, http://www.arb.ca.gov/msei/onroad/latest_version.htm.

for the region relates to state-level fuel consumption data, SCAG decided that the EMFAC results should be used without any adjustments based on fuel sales data.

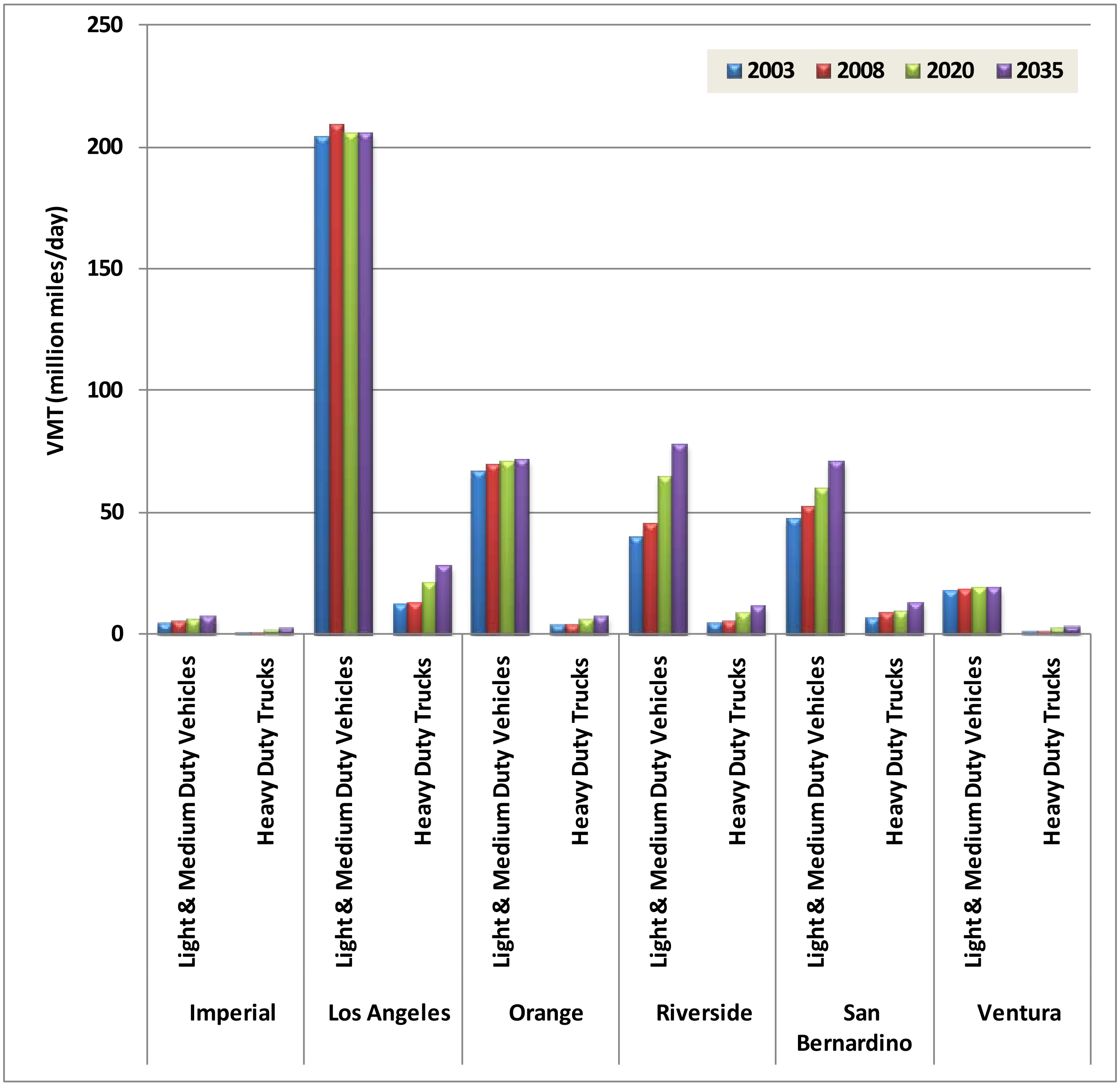
Table C1. Key Assumptions and Methods for the Transportation Inventory and Projections

Vehicle Type	Methods
Onroad Gasoline and Diesel Vehicles	**Inventory (1990 – 2008)** SCAG VMT data and ARB's EMFAC2007 model **Reference Case Projections (2009 – 2035)** SCAG VMT data and ARB's EMFAC2007 model adjusted based on Pavley I and Low Carbon Fuel Standard
Natural Gas and LPG Vehicles	**Inventory (1990 – 2008)** State-level vehicle CNG and LPG from EIA allocated based on ratio of regional to state VMT **Reference Case Projections (2009 – 2035)** AEO 2010 transportation CNG and LPG forecast for Pacific region
Commercial Aviation	**Inventory (1990 – 2008)** Operations data by aircraft type from BTS database, total operations from ATADS database **Reference Case Projections (2009 – 2035)** SCAG commercial aviation forecast
General Aviation (gasoline)	**Inventory (1990 – 2008)** State-level aviation gasoline from EIA allocated based on ATADS general aviation operations data **Reference Case Projections (2009 – 2035)** TAF general aviation operations forecast
Rail	**Inventory (1990 – 2008)** State-level rail diesel from EIA allocated based on rail length data from 2008 NEI **Reference Case Projections (2009 – 2035)** Rail line traffic density forecast provided by SCAG
Commercial Marine	**Inventory (1990 – 2008)** Emissions pulled from port GHG inventories scaled to other years based on port tonnage from Waterborne Commerce Statistics Center **Reference Case Projections (2009 – 2035)** Port cargo forecasts from SCAG 2008 RTP
Recreational Marine	**Inventory (1990 – 2008)** State-level marine gasoline from FHWA's Highway Statistics allocated based on data from ARB's OFFROAD Model **Reference Case Projections (2009 – 2035)** No growth assumed, based on trend over past 15 years

Table C2. Historical and Forecast VMT (miles/day) for the SCAG Region

County	Vehicle Type	2003	2008	2020	2035
Imperial	Light & Medium Duty Vehicles	4,334,861	5,336,048	6,200,402	7,291,614
	Heavy Duty Trucks	606,584	686,179	1,513,737	2,471,399
Los Angeles	Light & Medium Duty Vehicles	204,350,168	209,151,831	205,394,632	205,520,171
	Heavy Duty Trucks	12,024,554	12,710,449	20,975,546	28,074,867
Orange	Light & Medium Duty Vehicles	66,675,590	69,454,695	71,119,616	71,839,625
	Heavy Duty Trucks	3,782,601	3,894,506	5,911,548	7,241,065
Riverside	Light & Medium Duty Vehicles	39,485,358	45,039,651	64,815,117	77,622,156
	Heavy Duty Trucks	4,523,593	5,338,428	8,489,078	11,357,929
San Bernardino	Light & Medium Duty Vehicles	47,348,205	52,532,150	59,807,111	70,924,779
	Heavy Duty Trucks	6,892,165	8,618,413	9,273,069	12,897,246
Ventura	Light & Medium Duty Vehicles	17,397,543	18,316,002	18,917,051	18,906,121
	Heavy Duty Trucks	1,213,011	1,290,054	2,388,789	2,839,156
	Total	**408,634,233**	**432,368,406**	**474,805,696**	**516,986,128**

Figure C1. Historical and Forecast VMT (miles/day) for the SCAG Region



EMFAC outputs carbon emissions as CO_2, CO, and THC. IPCC guidelines assume 100 percent combustion, because all carbon-laden emissions will eventually form CO_2 in the atmosphere. Therefore, ARB converted CO and exhaust THC emissions to mass of CO_2 based on the relative molecular weights of the molecules and added to the CO_2 emissions. The same method was used in this inventory. While THC emissions are not treated discretely in other combustion sectors, this approach should still be consistent with the approaches used in other sectors in this SCAG inventory and forecast report, as well as with the ARB GHG emission inventory. For other combustion sectors, any THC emissions would be addressed by the selection of the oxidation factor for the fuel/technology being addressed. EMFAC provides THC emissions on a CH_2 basis. CO_2 emissions were estimated as[56]:

$$E_{CO2} = O_{CO2} + (O_{CO} * 44.01/28.01) + O_{THC}*(44.01/14.03)$$

Where:

E_{CO2} = CO_2 emissions for a category of vehicles

O_{CO2} = scaled EMFAC CO_2 output for that category of vehicles

O_{CO} = scaled EMFAC CO output for that category of vehicles

44.01 = molecular weight of CO_2 (grams/mole)

28.01 = molecular weight of CO (grams/mole)

O_{THC} = scaled EMFAC THC output for that category of vehicles

14.03 = molecular weight of CH_2 (grams/mole).

Emissions of N_2O were also estimated using ARB's method. Emissions from gasoline vehicles were estimated based on NO_x emissions. ARB has correlated N_2O emissions with NO_x based on ARB tailpipe test data. N_2O for gasoline vehicles was estimated as[57]:

$$E_{N2O} = 0.0167 + 0.0318 * O_{NOx}$$

Where:

E_{N2O} = N_2O emissions of a category of gasoline vehicles (grams)

0.0167 = intercept of the linear regression

0.0318 = slope of the linear regression

O_{NOX} = scaled EMFAC output for NO_x for the category of gasoline vehicles (grams)

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[56] This is method has since been updated by ARB. The updated version is documented here (page 42): http://www.arb.ca.gov/cc/inventory/doc/methods_00-09/ghg_inventory_00-09_technical_support_document.pdf ARB staff currently calculates CO_2 based on an EF and heat content thereby accounting for all carbon, rather than accounting separately for CO_2, CO, and hydrocarbons as had been done earlier.

[57] This is the N2O equation reported in ARB's previous Technical Support Document. ARB has indicated that this equation was incomplete, and thus, N2O emissions are underestimated here. The correct equation, as reported in ARB's December 2011 Technical Support Document is $E_{N2O} = D * (0.0318 * O_{NOx}/D + 0.0167)$ where D = Distance travelled by the vehicles (miles). Using this revised equation increases N2O emissions such that in 2008, the increase would be about 0.77 MMtCO2e, representing a 1.06% increase in onroad gasoline CO2e emissions or a 0.84% increase in total transportation CO2e emissions.

For diesel vehicles, N_2O emissions were estimated using the ARB emission factor (0.3316 grams N_2O/gallon) and the scaled EMFAC diesel consumption.

EMFAC2007 does not account for emission reductions due to Pavley I or the Low Carbon Fuel Standard (LCFS). Therefore, the reduction factors[58] shown in Tables C3 and C4 were applied to the estimated CO_2 emissions. First, Pavley I reduction factors are applied to emissions from light-duty vehicles for the specific model years, then LCFS reductions factors are applied to all vehicle types in each calendar year.

Table C3. Emission Reduction Factors for the Pavley I Standards

Model Year	LDA/LDT1	LDT2/MDV
2008 and older	0.00%	0.00%
2009	0.00%	0.90%
2010	3.50%	5.20%
2011	14.40%	12.00%
2012	25.30%	18.50%
2013	27.20%	19.90%
2014	28.80%	21.00%
2015	31.70%	23.00%
2016 +	34.30%	25.10%

Table C4. Emission Reduction Factors for the Low Carbon Fuel Standard

Calendar Year	Reduction Factor
2010	0.00%
2011	0.25%
2012	0.50%
2013	1.00%
2014	1.50%
2015	2.50%
2016	3.50%
2017	5.00%
2018	6.50%
2019	8.00%
2020 +	10.00%

[58] California Air Resources Board, *Pavley I + Low Carbon Fuel Standard Postprocessor, Version 1.0, User's Guide*, http://www.arb.ca.gov/cc/sb375/tools/pavleylcfs-userguide.pdf.

EMFAC2007 also does not account for ethanol consumption in vehicles. Therefore, emissions of CO_2 from gasoline vehicles were adjusted by applying the gasoline ratios shown in Table C5 (emissions of CO_2 are treated as biogenic and excluded from the GHG totals). The ethanol/gasoline proportions were held constant after 2010, because further increases in ethanol consumption are accounted for in the LCFS reductions.[59]

Table C5. Proportions of Gasoline and Ethanol Consumed

Fuel	1990	1995	2000	2003	2005	2008	2010
Gasoline	1.00	0.99	1.00	0.96	0.94	0.93	0.91
Ethanol	0.00	0.01	0.00	0.04	0.06	0.07	0.09

Emissions for CNG and LPG vehicles were estimated by allocating state-level fuel consumption data from SEDS to the region based on the ratio of regional to state total VMT. EPA emission factors for CO_2, CH_4, and N_2O were then applied to the estimated regional fuel consumption. As in ARB's state inventory, CH_4 and N_2O emissions from ethanol consumption were estimated using the EMFAC output. The EMFAC output values for CH_4 and NOx were allocated to ethanol based on the ratio of ethanol consumption to EMFAC gasoline consumption (shown in Table C5), and then N_2O was estimated from NO_x emissions as shown in the formula above for gasoline vehicles. CNG and LPG emissions were projected to 2035 based on forecasts of consumption of these transportation fuels in the Pacific region from EIA's Annual Energy Outlook 2010.[60]

Aviation

Emissions for commercial aviation were estimated based on aircraft operations data from the Bureau of Transportation Statistics (BTS) aviation database[61]. The BTS database provides data on number of flights by origin, destination, and aircraft type. This data was used with IPCC landing and take-off (LTO) emission factors by aircraft model to estimate emissions associated with the LTO cycle at airports in the SCAG region. The BTS database does not include all small commuter and air taxi flights. Therefore, total operations for each airport were obtained from the Federal Aviation Administration (FAA) Air Traffic Activity Data System (ATADS) database.[62] An average emission factor for commuter aircraft, based on the typical commuter aircraft models listed in the SCAG 2035 aviation projections, was applied to the difference between the ATADS data and the BTS data.

[59] Changes to the way in which ARB handles ethanol emissions are provided on page 41 of the TSD cited in a footnote above.
[60] Energy Information Administration, Annual Energy Outlook 2010, Table 9, http://www.eia.doe.gov/oiaf/aeo/aeoref_tab.html.
[61] Bureau of Transportation Statistics, Research and Innovative Technology Administration (RITA), TranStats, Air Carriers: T-100 Segment (All Carriers), http://www.transtats.bts.gov/homepage.asp.
[62] Federal Aviation Administration, Air Traffic Activity Data System, http://aspm.faa.gov/opsnet/sys/Main.asp?force=atads.

This method only estimates emissions associated with the landing and takeoff portions of flights or the emissions occurring at the airports within the region. This differs from the ARB method, which estimates emissions for the entire flight based on fuel purchased at airports within the state. However, since most flights are entering or leaving the region, most of the cruise emissions probably occur outside the region. It should also be noted that while ARB estimated emissions based on total fuel consumption, emissions were allocated to intrastate, interstate, and international flights, and only intrastate emissions were reported as part of the inventory. Intrastate flights are only a small portion of total flights in California, and as a result, the aviation emissions estimated for the SCAG region are greater than those reported in the ARB inventory.

While a small amount of aviation gasoline may be consumed by commercial aircraft, the majority of this fuel is used for general aviation. To estimate emissions from the consumption of this fuel, state-level aviation gasoline consumption data was allocated to the regional level based on itinerant general aviation and local civil aviation operations data from the ATADS database.

Aside from the cruise-related emissions from commercial flights, two other sources of aviation emissions are excluded from this inventory, jet fuel used by general aviation and military aviation. However, emissions from these sources are assumed to be relatively small.

Commercial aviation emissions were forecast based on a linear projection of total commercial operations from 2008 to 2035. Forecasted commercial aviation operations for 2035 were provided by SCAG. The operations forecasts were adjusted to account for increasing fuel efficiency of jet engines over the forecast period. Estimates of jet engine efficiency (in seat-miles/gallon) were taken from EIA's Annual Energy Outlook (AEO) 2010.[63] Aviation gasoline emissions were projected based on general aviation forecasts from the FAA's Terminal Area Forecast (TAF).[64] Growth rates for the aviation sector are summarized in Table C6.

Table C6. SCAG Aviation Compound Annual Growth Rates

Fuel	2008-2010	2010-2015	2015-2020	2020-2025	2025-2030	2030-3035
Commercial Aviation	2.51%	2.23%	1.79%	1.55%	1.25%	1.09%
Aviation Gasoline	-6.42%	1.01%	1.05%	1.07%	1.08%	0.98%

Rail and Marine Vehicles

Emissions for the rail subsector were estimated by allocating state-level rail diesel consumption to the region based on rail length. State-level diesel consumption by locomotives for 1990-2008

[63] Energy Information Administration, Annual Energy Outlook 2010, Table 66, http://www.eia.doe.gov/oiaf/aeo/aeoref_tab.html.
[64] Federal Aviation Administration, Terminal Area Forecast.

was obtained from EIA's Fuel Oil and Kerosene Sales publication.[65] Rail length for SCAG counties and California as a whole was obtained from the EPA's 2008 NEI documentation.[66]

Emissions for commercial marine vessels were taken from recent port GHG inventories. Emissions for the Ports of Los Angeles (POLA) and Long Beach (POLB) were taken from recent (2006-2008) bottom-up greenhouse gas inventories developed by the ports.[67,68] Emissions for the Port of Hueneme were taken from a commercial marine inventory for 2006 developed by ARB.[69] Only emissions within 24 nautical miles (nm) were included in this inventory. The POLB inventories do not break-out the within 24 nm and outside 24 nm emissions. Since, the POLB and POLA inventories use the same geographic ranges (from the Ventura-Los Angeles border to the Orange-San Diego border out to the western edge of California waters), the ratio of "within 24 nm mile" emissions to total emissions for the POLA inventory was applied to the POLB inventory to estimate the POLB emissions within 24 nm. There may be a small amount of emissions associated with vessels entering/leaving the POLA or POLB ports and travelling through Ventura County waters within 24 nm that are excluded. Emissions were scaled to other years based on port tonnage data from the Army Corp of Engineers' Waterborne Commerce Statistics Center.[70,71]

Emissions associated with recreational marine gasoline consumption were estimated by allocating state-level marine gasoline to the region based on allocation data from ARB's OFFROAD2007 model.[72] State-level marine consumption for 1990-2008 was obtained from the Federal Highway Administration's Highway Statistics publication.[73]

Commercial marine emissions were based on containerized cargo forecasts for POLA and POLB from SCAG's 2008 Regional Transportation Plan (RTP).[74] Recreational marine emissions have shown no significant trend over the past 15 years, remaining near 0.2 $MMtCO_2e$, so an assumption of no growth was used for projecting these emissions. Rail emissions 2008-2010 were forecast based on state-level rail diesel consumption from EIA. Emissions for 2010-2035

[65] Energy Information Administration, Fuel Oil and Kerosene Sales, http://www.eia.doe.gov/oil_gas/petroleum/data_publications/fuel_oil_and_kerosene_sales/foks.html.

[66] Environmental Protection Agency, 2008 National Emission Inventory, Rail Shapefiles, http://www.epa.gov/ttnchie1/net/2008inventory.html.

[67] Port of Los Angeles, Expanded Greenhouse Gas Inventories 2006-2008, http://www.portoflosangeles.org/environment/studies_reports.asp.

[68] Port of Long Beach, Air Emissions Inventories 2006-2008, http://www.polb.com/environment/air/emissions.asp.

[69] California Air Resources Board, Rulemaking to Consider the Adoption of a Proposed Regulation for Fuel Sulfur and Other Operational Requirements for Ocean-Going Vessels Within California Waters and 24 Nautical Miles of the California Baseline (July 24, 2008), http://www.arb.ca.gov/regact/2008/fuelogv08/appdfuel.pdf.

[70] US Army Corps of Engineers, Waterborne Commerce Statistics Center, Waterborne Tonnage 2004-2008 http://www.iwr.usace.army.mil/ndc/wcsc/wcsc.htm.

[71] Linda Briant, Waterborne Commerce Statistics Center, Waterborne Tonnage 1990-2003, personal communication with H. Lindquist, E.H. Pechan & Associates, July, 2010.

[72] California Air Resources Board, OFFROAD2007, http://www.arb.ca.gov/msei/offroad/offroad.htm.

[73] US Federal Highway Administration, Highway Statistics, http://www.fhwa.dot.gov/policyinformation/statistics/.

[74] Southern California Association of Governments, 2008 Regional Transportation Plan (2008 RTP), http://www.scag.ca.gov/rtp2008/.

were forecast based on train traffic volume forecasts provided by SCAG. The resulting growth rates for the rail and commercial marine sectors are shown in Table C7.

Table C7. SCAG Rail and Commercial Marine Compound Annual Growth Rates

Fuel	2008-2010	2010-2015	2015-2020	2020-2025	2025-2030	2030-3035
Rail	-4.66%	1.03%	1.03%	1.03%	1.03%	1.03%
Commercial Marine	23.9%	6.21%	6.21%	1.67%	1.67%	1.67%

Nonroad Engines

It should be noted that fuel consumption data from EIA includes nonroad gasoline and diesel fuel consumption in the commercial and industrial sectors. Emissions from these nonroad engines, including nonroad vehicles such as snowmobiles and dirt bikes, are included in the inventory and forecast for the residential, commercial, and industrial (RCI) sectors (see Appendix B). Table C8 shows how EIA divides gasoline and diesel fuel consumption between the transportation, commercial, and industrial sectors.

Table C8. EIA Classification of Gasoline and Diesel Consumption

Sector	Gasoline Consumption	Diesel Consumption
Transportation	Highway vehicles, marine	Vessel bunkering, military use, railroad, highway vehicles
Commercial	Public non-highway, miscellaneous use	Commercial use for space heating, water heating, and cooking
Industrial	Agricultural use, construction, industrial and commercial use	Industrial use, agricultural use, oil company use, off-highway vehicles

Results

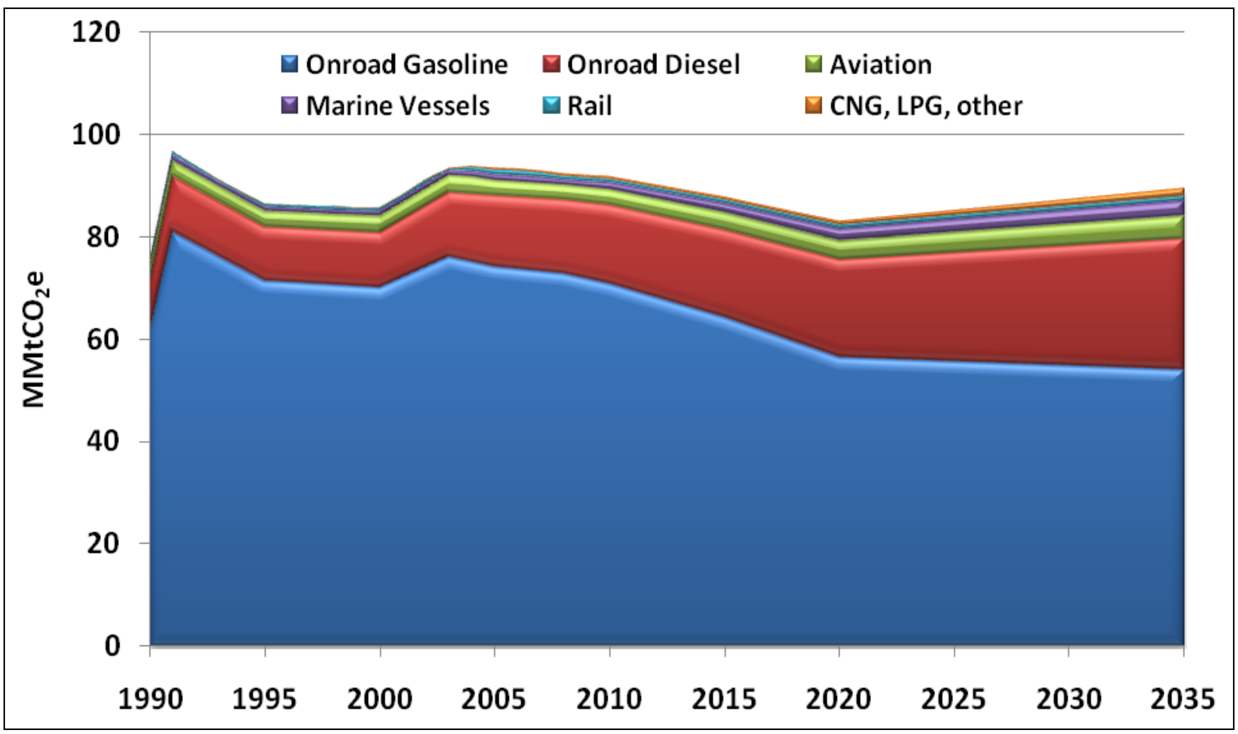
As shown in Figures C2 and C3 and Table C9, onroad gasoline accounts for the largest share of transportation GHG emissions. Emissions from onroad gasoline vehicles increased by about 18% from 1990 to 2008 to account for 79% of total transportation emissions in 2008. GHG emissions from onroad diesel fuel consumption increased by 58% from 1990 to 2008, and by 2008 accounted for 16% of GHG emissions from the transportation sector. Figure C3 shows the onroad gasoline and diesel emissions by vehicle type for 2008. The vast majority (89%) of gasoline vehicle emissions are from passenger cars and light-duty trucks and SUVs, while diesel emissions are almost entirely (98%) heavy-duty trucks, buses, and motorhomes. Aircraft emissions at SCAG region airports accounted for 3.1%, and emissions from commercial marine and recreational marine gasoline vehicles accounted for 1.0% of transportation emissions in 2008. Emissions from all other categories combined, including rail and alternative fueled vehicles contributed about 1.4% of total transportation emissions in 2008.

Total transportation GHG emissions are projected to decrease by 3% between 2008 and 2035. Due to increasing fuel efficiency, increased ethanol consumption, and additional standards such as Pavley I and the Low Carbon Fuel Standard, onroad gasoline emissions are forecast to decrease by 26% from 2008 to 2035 while onroad diesel emissions are expected to increase 77% from 2008 to 2035. During this same time period, VMT from onroad vehicles is expected to increase by 20%. Emissions from aviation are projected to increase by 55%, while marine and rail emissions are projected to increase by 201% and 17%, respectively.

Table C9. Transportation GHG Emissions by Source, 1990-2035 ($MMtCO_2e$)

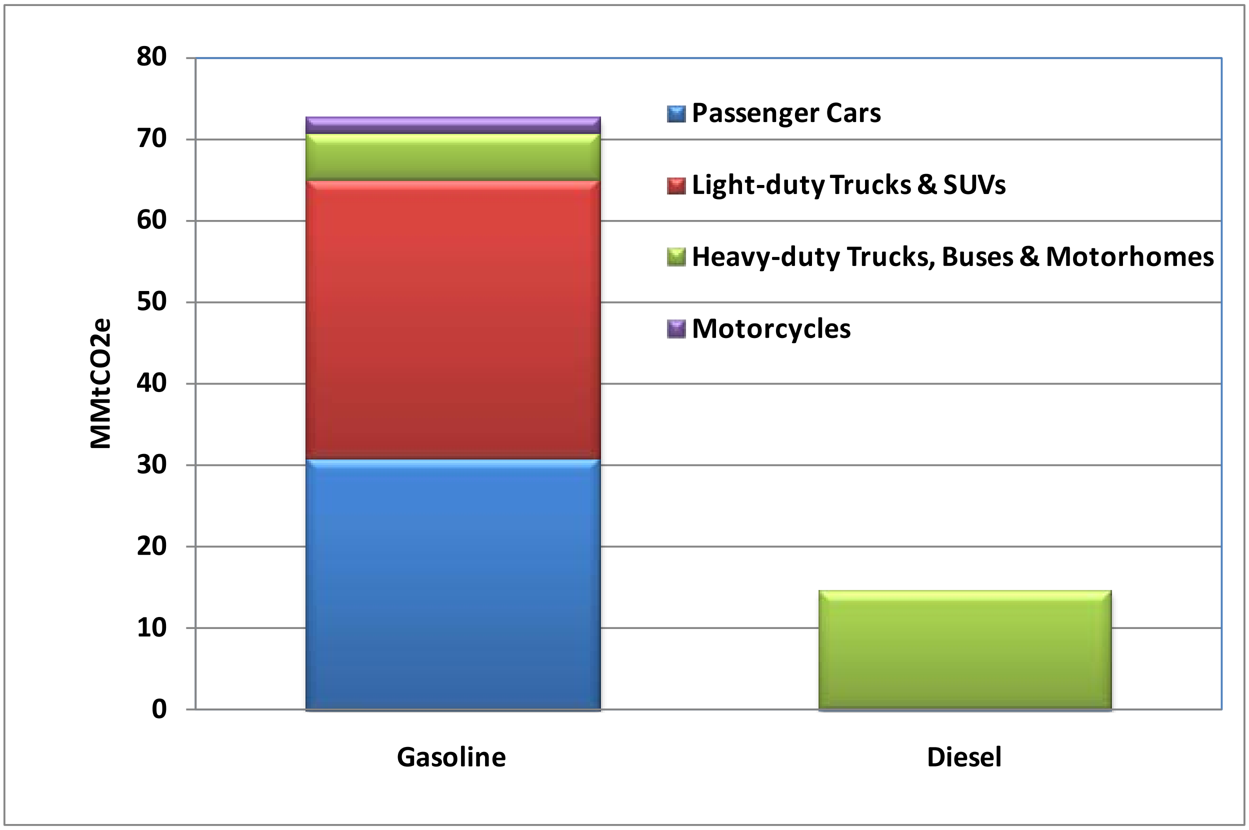
Source	*1990*	*1995*	*2000*	*2005*	*2008*	*2010*	*2015*	*2020*	*2025*	*2030*	*2035*
Onroad Gasoline	61.6	71.3	70.0	74.0	72.7	70.7	64.2	56.4	55.6	54.8	54.0
Onroad Diesel	9.2	10.7	10.8	14.0	14.5	15.5	17.2	19.2	21.3	23.5	25.7
Aviation	3.0	3.1	3.3	3.0	2.9	3.0	3.4	3.7	4.0	4.3	4.5
Marine Vessels	0.9	0.9	1.0	1.1	1.0	1.4	1.8	2.3	2.5	2.7	2.9
Rail	0.7	0.5	0.5	0.9	0.7	0.7	0.7	0.7	0.8	0.8	0.9
CNG, LPG, other	0.1	0.1	0.1	0.4	0.5	0.5	0.6	0.7	1.0	1.3	1.6
Total	**75.5**	**86.5**	**85.7**	**93.5**	**92.4**	**91.8**	**87.8**	**83.1**	**85.2**	**87.4**	**89.6**

Figure C2. Transportation GHG Emissions by Source under Reference Case Projection, 1990-2035



**This inventory and forecast has been prepared with the most up-to-date information and should not be compared to any previous analysis at this time.*

Figure C3. Onroad Gasoline and Diesel GHG Emissions by Vehicle Type, 2008



GHG Reductions from Recent Actions

Two recent actions were identified that have the potential to significantly reduce the forecast of the transportation sector GHG emissions and that could also be quantified within the scope of resources available for this project. These include the California Advanced Clean Car program and the Federal heavy-duty GHG emission standards. The potential emission reductions that could be achieved by these two programs and the quantification of these reductions are described below.

The Advanced Clean Cars program combines the control of smog-causing pollutants and greenhouse gas emissions into a single coordinated package of requirements for model years 2017 through 2025. The new rules will clean up gasoline and diesel-powered cars, and deliver increasing numbers of zero-emission technologies, such as full battery electric cars, newly emerging plug-in hybrid electric vehicles and hydrogen fuel cell cars. The package will also ensure adequate fueling infrastructure is available for the increasing numbers of hydrogen fuel cell vehicles planned for deployment in California.[75] ARB provided a table of the expected reduction in CO_2 emissions from light and medium-duty vehicles by model year as a result of this program. These reductions are shown in Table C10. These reductions were applied to the reference case emissions, which included the effects of the Pavley I and LCFS Standards.

Table C10. Emission Reduction Factors for the Advanced Clean Car Standards

Model Year	LDA/LDT1	LDT2/MDV
2016 and older	0.00%	0.00%
2017	5.75%	0.68%
2018	10.18%	4.11%
2019	15.04%	6.51%
2020	19.03%	9.59%
2021	23.45%	16.10%
2022	26.99%	20.21%
2023	30.09%	24.32%
2024	33.19%	28.08%
2025+	36.28%	31.51%

Notes: LDA = light-duty auto; LDT1 = light-duty truck 1 (up to 3,750 lbs); LDT2 = light-duty truck 2 (3,751-5,750 lbs); MDV = medium-duty truck (5,751-8,500 lbs).

In September 2011 the U.S. EPA and the Department of Transportation's National Highway Traffic Safety Administration (NHTSA) initiated a program to reduce GHG emissions and improve fuel efficiency of heavy-duty trucks and buses. This program will reduce fuel use and GHG emissions from medium- and heavy-duty vehicles, from semi trucks to the largest pickup trucks and vans, as well as all types and sizes of work trucks and buses in between. The standards are phased in from the 2014 through 2018 vehicle model years. To estimate GHG emission reductions from this program, the percentage reduction by model year and vehicle type, as identified in EPA's Regulatory Impact Assessment[76] were applied to the reference case emissions of the corresponding vehicle types by model year. Table C11 summarizes the GHG emission reductions by model year.

[75] "California Air Resources Board Approves Advanced Clean Car Rules," news release # 12-05 from California Air Resources Board, January 27, 2012.
[76] "Final Rulemaking to Establish Greenhouse Gas Emissions Standards and Fuel Efficiency Standards for Medium- and Heavy-Duty Engines and Vehicles," Regulatory Impact Analysis, EPA-420-11-901, USEPA and National Highway Traffic Safety Administration, August 2011.

Table C11. Emission Reduction Factors for the Federal Heavy-Duty GHG Emission Standards

Model Year	Diesel			Gasoline	
	Light Heavy-Duty	Medium Heavy-Duty	Heavy Heavy-Duty	Light Heavy-Duty	Medium Heavy-Duty
2014	2.3%	5.0%	3.0%	1.5%	0.0%
2015	3.0%	5.0%	3.0%	2.0%	0.0%
2016	6.0%	5.0%	3.0%	4.0%	5.0%
2017	9.0%	9.0%	6.0%	6.0%	5.0%
2018+	15.0%	9.0%	6.0%	10.0%	5.0%

Source: "Final Rulemaking to Establish Greenhouse Gas Emissions Standards and Fuel Efficiency Standards for Medium- and Heavy-Duty Engines and Vehicles," Regulatory Impact Analysis, EPA-420-11-901, USEPA and National Highway Traffic Safety Administration, August 2011.
Note: Buses and motorhomes were treated as Medium Heavy-Duty Vehicles.

Table C12 lists the expected GHG emission reductions from onroad vehicles within the SCAG region as a result of the implementation of these two recent actions. The combined effect of these two programs results in nearly a 23 percent reduction of GHG emissions from onroad gasoline vehicles, a 7 percent reduction in GHG emissions from onroad diesel vehicles, and a 16 percent reduction in total transportation GHG emissions, all in 2035 as compared to the reference case emissions. With the GHG reductions from these two programs, total transportation GHG emissions in the SCAG region are expected to be almost the same as the 1990 transportation GHG emissions in this region.

It should be noted that effect of the Federal program may increase emissions of fine particulate as a result of the use of auxiliary power units (APUs) in some heavy-duty trucks to comply with the Federal program. APUs are not required to be equipped with particulate filters or controls as is required for 2007 and later heavy-duty engines. EPA estimates an 8.4% increase in PM2.5 emissions from heavy-duty vehicles as a result of the APU emissions.[77] Assuming this applies only to the heavy heavy-duty diesel vehicle category, PM2.5 emissions could increase on the order of 116 tons per year in the SCAG region. However, this increase may be offset from a reduction in PM and other combustion emissions at upstream sources due to the lower volume of fuel being processed (although these reductions could occur outside of the region).

[77] EPA expects that other emissions of other criteria and toxic air pollutants would decrease as a result of this program.

Table C12. GHG Emission Reductions from Recent Actions ($MMtCO_2e$)

Program	***Source***	***2015***	***2020***	***2025***	***2030***	***2035***
CA Advanced Clean Cars	Onroad Gasoline	0.00	1.26	4.82	8.39	11.95
Federal HD GHG Standards	Onroad Gasoline	0.01	0.11	0.21	0.31	0.40
	Onroad Diesel	0.10	0.59	0.97	1.36	1.74
	Total	*0.11*	*0.70*	*1.18*	*1.66*	*2.14*
Total	Onroad Gasoline	0.01	1.37	5.03	8.70	12.36
	Onroad Diesel	0.10	0.59	0.97	1.36	1.74
	Total	***0.11***	***1.96***	***6.01***	***10.05***	***14.10***

Key Uncertainties

Uncertainties in Onroad Gasoline and Diesel

Fuel consumption values estimated by EMFAC differ from actual historical fuel consumption data. Also, the historical VMT provided by SCAG differs from EMFAC's default VMT data for SCAG counties. Therefore, there is some uncertainty associated with the fuel consumption and EMFAC emissions. In addition, EMFAC does not account for onroad vehicle consumption of ethanol, CNG, and LPG; although, the EMFAC emissions were adjusted to take ethanol into account. EMFAC does account for an increasing proportion of electric vehicles in forecasted values.

The primary development of this GHG I&F occurred in 2010, with some revisions in Spring 2012. However, during the interim time period, ARB has updated its GHG emissions inventory. The Technical Support Document accompanying the revised inventory was written in December 2011 and publicly released on the web in April 2012. Several changes made by ARB in this version of their GHG emissions inventory were not reflected in the SCAG GHG I&F due to timing and resource constraints. Thus, the resulting SCAG GHG I&F documented here will differ somewhat from an inventory estimated following the latest ARB methods. Key differences have been noted throughout this appendix and are summarized below:

- In converting EMFAC emissions output from weekday to average day, the SCAG emissions were multiplied by factors of 0.95 for gasoline and 0.89 for diesel, while ARB divides the weekday emissions by 1.05 for gasoline and 1.12 for diesel. Thus, differences due to rounding will result in the SCAG I&F.
- ARB has updated the method for estimating CO2 emissions. ARB staff currently calculates CO_2 based on an emission factor and heat content thereby accounting for all carbon, rather

than accounting separately for CO_2, CO, and hydrocarbons as had been done earlier, and as was done in this SCAG I&F.

- ARB has corrected the equation used to calculate N2O emissions in the December 2011 Technical Support Document. ARB had used this same N2O equation in calculating the previous version of the ARB GHG inventory, but the equation in the previous Technical Support Document was incomplete. Since the N2O equation from the previous Technical Support Document was used in developing the SCAG GHG I&F, N2O emissions from the onroad gasoline sector are underestimated in the SCAG I&F.
- ARB adjusts EMFAC emissions by scaling the EMFAC-estimated fuel consumption to actual state-level onroad fuel consumption. This adjustment was not made in the SCAG I&F because accurate regional fuel consumption data were not available.

Uncertainties in Aviation Emissions

Because the BTS operations data by aircraft type is incomplete, an average emissions factor was applied to the remaining commuter and air taxi operations. Since the specific aircraft types used for these flights is not available, there is some uncertainty associated with this average emission factor. Also, there is some portion of emissions associated with the cruise portion of flights occurring within the region that are not included in this inventory.

Appendix D. Industrial Processes

Overview

Emissions in the industrial processes category span a wide range of activities, and reflect non-combustion sources of greenhouse gas (GHG) emissions from several industries. The industrial processes that exist in the SCAG region, and for which emissions are estimated in this inventory, include the following:

- Carbon dioxide (CO_2) from:
    - Production of cement, lime, and ammonia;[78]
    - Consumption of limestone, dolomite, soda ash, and CO_2;
    - Fuel consumption as feedstock to hydrogen production.
- Sulfur hexafluoride (SF_6) from transformers used in electric power transmission and distribution (T&D) systems;
- Hydrofluorocarbons (HFCs) and perfluorocarbons (PFCs) from consumption of substitutes for ozone-depleting substances (ODS) used in cooling and refrigeration equipment; and
- HFCs, PFCs, and SF_6 from semiconductor manufacturing;

Other industrial processes that are sources of GHG emissions but are not found in the SCAG region include the following:

- CO_2 from taconite production;
- CO_2 from iron and steel production;
- Nitrous oxide (N_2O) from nitric and adipic acid production;
- SF_6 from magnesium production and processing;
- HFCs from HCFC-22 production; and
- PFCs from aluminum production.

Emissions and Reference Case Projections

This sector is composed of a diverse set of emission sources and for this reason requires the use of various approaches to estimating GHG emissions. These various approaches can be grouped into three categories: a) estimates using plant emissions data, b) estimates using industry segment throughput data, and c) estimates based on surrogate data.

[78] Note that CO_2 emissions from urea application are estimated as part of the same category as ammonia production. N_2O emissions from the application of nitrogen fertilizers, including urea, are included in the Agricultural sector inventory and forecast.

The California Air Resources Board (ARB)'s GHG mandatory reporting program provides plant information specific to non-combustion emissions for various segments of the industrial processes sector, including cement manufacturing, SF_6 fugitive emissions from electrical equipment operated by electricity generators and providers, and process emissions from hydrogen plants. This information is to be considered highly reliable since the program requires third party verification of emissions assertions. However, a complete data set was only available for year 2008 except when noted. Emissions for the corresponding industry segment of the California Greenhouse Gas Inventory were used as surrogate data to back-cast emissions to year 1990.[79]

Originally, emissions from lime and nitric acid production were expected to be calculated with the methodology relying on industry throughput and standard emission factors (IPCC or US EPA). Due to a lack of information about industry throughput, this approach was replaced with one relying on surrogate economic data to scale emissions for the SCAG region from the state-level emissions in ARB's GHG inventory to the SCAG region for this source category. It is likely that lime production occurs in the SCAG region in conjunction with or in support of the cement industry. On the other hand, emissions from nitric acid production were not estimated because there is no evidence that nitric acid production occurs in the SCAG region.

For the remaining emissions source categories, state emissions were apportioned to the SCAG region using economic data that most closely related to the industrial process in question. Economic data were retrieved from the Bureau of Economic Analysis (BEA), U.S. Department of Commerce. The BEA tracks economic activity at the sub-state level by Metropolitan Statistical Area (MSA). "The MSAs used by BEA for its entire series of gross domestic product (GDP) statistics are the county-based definitions developed by the Office of Management and Budget (OMB) for federal statistical purposes and last updated in November 2008. OMB's general concept of a metropolitan area is that of a geographic area consisting of a large population nucleus together with adjacent communities having a high degree of economic and social integration with the nucleus."[80] The MSAs that best cover the 6-county SCAG region are:

- El Centro, CA (MSA);
- Los Angeles-Long Beach-Santa Ana, CA (MSA);
- Oxnard-Thousand Oaks-Ventura, CA (MSA); and
- Riverside-San Bernardino-Ontario, CA (MSA).

Table D1summarizes the approach to quantifying historical emissions, including methods and data sources. Table D2 lists the data and methods that were used to estimate future activity levels related to industrial process emissions and the annual compound growth rates computed from the

[79] Air Resources Board, *Inventory Data Archive - 1990 to 2004 Inventory*, November 2007. Available at: http://www.arb.ca.gov/cc/inventory/archive/archive.htm
and
Air Resources Board, *Greenhouse Gas Inventory Data - 2000 to 2008*, September 2010. Available at: http://www.arb.ca.gov/cc/inventory/data/data.htm .
[80] http://www.bea.gov/newsreleases/regional/gdp_metro/gdp_metro_newsrelease.htm

data/methods for the reference case projections. Because available forecast information is generally provided for economic sectors that are too broad to reflect trends in the specific emissions producing processes, the majority of projections are based on historical activity trends. In particular, state historical trends were analyzed for three periods: 1990-2008, 1995-2008 and 2000-2008 (or the closest available approximation of these periods). A no growth assumption was assumed when the historical periods indicated divergent activity trends (i.e., growth in certain periods and decline in other periods). In cases where the historical periods indicated either continual growth or decline, the smallest annual rate of growth/decline was selected from the values computed for each period. This conservative assumption was adopted because of the uncertainty associated with utilizing historical trends to estimate future emission activity levels.

Additional details on the inventory and forecast approach for several key industrial process subsectors are provided following the summary of results below.

Table D1. Approach to Estimating Historical Emissions

Source Category	Time Period	Data Description	Data Source
Cement Manufacture	2008	Metric tons (Mt) of emissions from cement plants[81]	ARB, GHG Tool. http://www.arb.ca.gov/cc/reporting/ghg-rep/ghg-tool.htm. Surrogate data for missing inventory years: California Greenhouse Gas Inventory, versions 1 and 3. Retrieved August 2010 versions 1 and 3. Retrieved August 2010 from http://www.arb.ca.gov/cc/inventory/inventory.htm
Lime Manufacture	1990-2008	Mt of emissions from statewide lime production	California Greenhouse Gas Inventory, versions 1 and 3. Retrieved August 2010 from http://www.arb.ca.gov/cc/inventory/inventory.htm. Apportioned to the SCAG region using related industry segment economic data. Source: Bureau of Economic Analysis, U.S. Department of Commerce.
Semiconductor manufacturing	1990-2008	Mt of emissions from statewide semiconductor manufacturing	California Greenhouse Gas Inventory, versions 1 and 3. Retrieved August 2010 from http://www.arb.ca.gov/cc/inventory/inventory.htm. Apportioned to the SCAG region using related industry segment economic data. Source: Bureau of Economic Analysis, U.S. Department of Commerce.
ODS Substitutes	1990 - 2006	Mt of emissions from statewide use of ODS substitutes	California Greenhouse Gas Inventory, versions 1 and 3. Retrieved August 2010 from http://www.arb.ca.gov/cc/inventory/inventory.htm. Apportioned to the SCAG region using population statistics. Source: Population Division, U.S. Census Bureau

[81] Note that the emission values from CARB were not used directly because these reflect both energy emissions (i.e., fuel combustion in kiln ovens) and non-energy emissions (i.e., process emissions). Instead, the CARB information was used to determine the share of state emissions attributable to cement production sources within the SCAG region, since these emissions are based on actual California clinker production data. For 2008, SCAG region combined process and stationary combustion emissions were 4.8 $MMtCO_2e$ (in agreement with ARB estimate); for the entire state, these emissions were on the order of 8.6 $MMtCO_2e$. The ratio of these two values is 0.55. For 2009, the same analysis produced a ratio of 0.58 and the two year average (2008-2009) produced a ratio of 0.56. The estimate reported here is the product of the latter ratio times the state-wide emission estimate (i.e., Category 2A1) found in the Third Edition of the California GHG Inventory 2000 to 2008. For 2008, this approach results in the following computation: 0.56 x 5.3 MMtCO2e = 2.995 $MMtCO_2e$.

Source Category	Time Period	Data Description	Data Source
Electric Power T&D Systems	2008	Mt of emissions from activity	ARB, GHG Tool. http://www.arb.ca.gov/cc/reporting/ghg-rep/ghg-tool.htm. Surrogate data for missing inventory years: California Greenhouse Gas Inventory, versions 1 and 3. Retrieved August 2010 from http://www.arb.ca.gov/cc/inventory/inventory.htm
Carbon Dioxide Consumption	1990-2008	Mt of emissions from statewide carbon dioxide consumption	California Greenhouse Gas Inventory, versions 1 and 3. Retrieved August 2010 from http://www.arb.ca.gov/cc/inventory/inventory.htm. Apportioned to the SCAG region using related industry segment economic data. Source: Bureau of Economic Analysis, U.S. Department of Commerce.
Limestone and Dolomite Consumption	1990-2008	Mt of emissions from statewide limestone and dolomite consumption	California Greenhouse Gas Inventory, versions 1 and 3. Retrieved August 2010 from http://www.arb.ca.gov/cc/inventory/inventory.htm. Apportioned to the SCAG region using related industry segment economic data. Source: Bureau of Economic Analysis, U.S. Department of Commerce.
Soda Ash Consumption	1990 - 2006	Mt of emissions from statewide soda ash consumption	California Greenhouse Gas Inventory, versions 1 and 3. Retrieved August 2010 from http://www.arb.ca.gov/cc/inventory/inventory.htm. Apportioned to the SCAG region using related industry segment economic data. Source: Bureau of Economic Analysis, U.S. Department of Commerce.
Fuel Consumption as Feedstock for Hydrogen Production	2008	Metric tons (Mt) of emissions from hydrogen plants	ARB, GHG Tool. http://www.arb.ca.gov/cc/reporting/ghg-rep/ghg-tool.htm. Surrogate data for missing inventory years: California Greenhouse Gas Inventory, versions 1 and 3. Retrieved August 2010 from http://www.arb.ca.gov/cc/inventory/inventory.htm

Table D2. Approach to Forecasting Emissions through 2035

			Annual Growth Rates (%)					
Source Category	**Projection Assumptions**	**Data Source**	**2008 to 2010**	**2010 to 2015**	**2015 to 2020**	**2020 to 2025**	**2025 to 2030**	**2030 to 2035**
Cement Manufacture	Growth rates computed from Portland Cement Association's Cement Outlook 2008	Portland Cement Association.[82]	-3.26%	2.39%	2.10%	1.82%	1.51%	1.51%
Lime Manufacture	Smallest historical annual decline in state production from each of three periods analyzed	Annual change in SCAG region lime production:1990-2008 = -8.8%; 1995-2008 = -9.8%; and 2000-2008 = -5.8%	-5.85%	-5.85%	-5.85%	-5.85%	-5.85%	-5.85%

[82] Portland Cement Association *Forecast Report: Long-Term Cement Consumption Outlook.* January 31, 2008.

			Annual Growth Rates (%)					
Source Category	Projection Assumptions	Data Source	2008 to 2010	2010 to 2015	2015 to 2020	2020 to 2025	2025 to 2030	2030 to 2035
Semiconductor manufacturing	No growth assumption based on conflicting state historical consumption trends; forecast information too broad	Annual change in t SCAG region:1990-2008 = 1.6%; 1995-2008 = -1.9%; and 2000-2008 = -5.6%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
ODS Substitutes	Used SCAG population annual growth rates	California, Department of Finance. http://www.dof.ca.gov/research/demographic/reports/projections/p-1/	1.45%	1.10%	1.10%	0.90%	0.90%	0.74%
Electric Power T&D Systems	Used annual rate of decline calculated from US national emissions for 2005-2020 for "Technology-Adoption" scenario for Electric Power T&D Systems from	Appendix D, Table D-8 in Global Anthropogenic Emissions of Non-CO2 Greenhouse Gases 1990-2020 (EPA Report 430-R-06)	-1.05%	-0.86%	-0.79%	-0.79%	-0.79%	-0.79%
Carbon Dioxide Consumption	Used demand of refined oil products, because it is generated as a by-product of that process.	AEO 2010, Regional outlook, table 9.	-0.33%	0.82%	0.55%	0.16%	0.31%	0.17%
Limestone and Dolomite Consumption	No growth assumption based on conflicting state historical consumption trends; forecast information too broad	Annual change in SCAG region: 1990-2008 = 1.6% 1995-2008 = -0.7%; and 2000-2008 = 2.3%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Soda Ash Consumption	Smallest historical annual decline in state production from each of three periods analyzed	Annual change in SCAG region lime production:1990-2008 = -0.6%; 1995-2008 = -0.5%; and 2000-2008 = -0.6%	-0.45%	-0.45%	-0.45%	-0.45%	-0.45%	-0.45%

			Annual Growth Rates (%)					
Source Category	**Projection Assumptions**	**Data Source**	**2008 to 2010**	**2010 to 2015**	**2015 to 2020**	**2020 to 2025**	**2025 to 2030**	**2030 to 2035**
Fuel Consumption as Feedstock for Hydrogen Production	Used demand of refined oil products, because it is generated as a by-product of that process.	AEO 2010, Regional outlook, table 9.	-0.33%	0.82%	0.55%	0.16%	0.31%	0.17%

Results

Figures D1 and D2 show historical and projected emissions for the industrial processes sector from 1990 to 2035. Table D3 shows the historical and projected emission values upon which Figures D1 and D2 are based. Total gross GHG emissions were about 3.8 $MMtCO_2e$ in 1990, 11.0 $MMtCO_2e$ in 2008, and are projected to increase to about 15.1 $MMtCO_2e$ in 2035. Emissions from the overall industrial processes category are expected to grow by about 1.2% annually from 2008 through 2035, as shown in Figures D1 and D2, with emissions growth primarily associated with the increasing use of HFCs and PFCs in refrigeration and air conditioning equipment.

Figure D1. GHG Emissions from Industrial Processes, 1990-2035

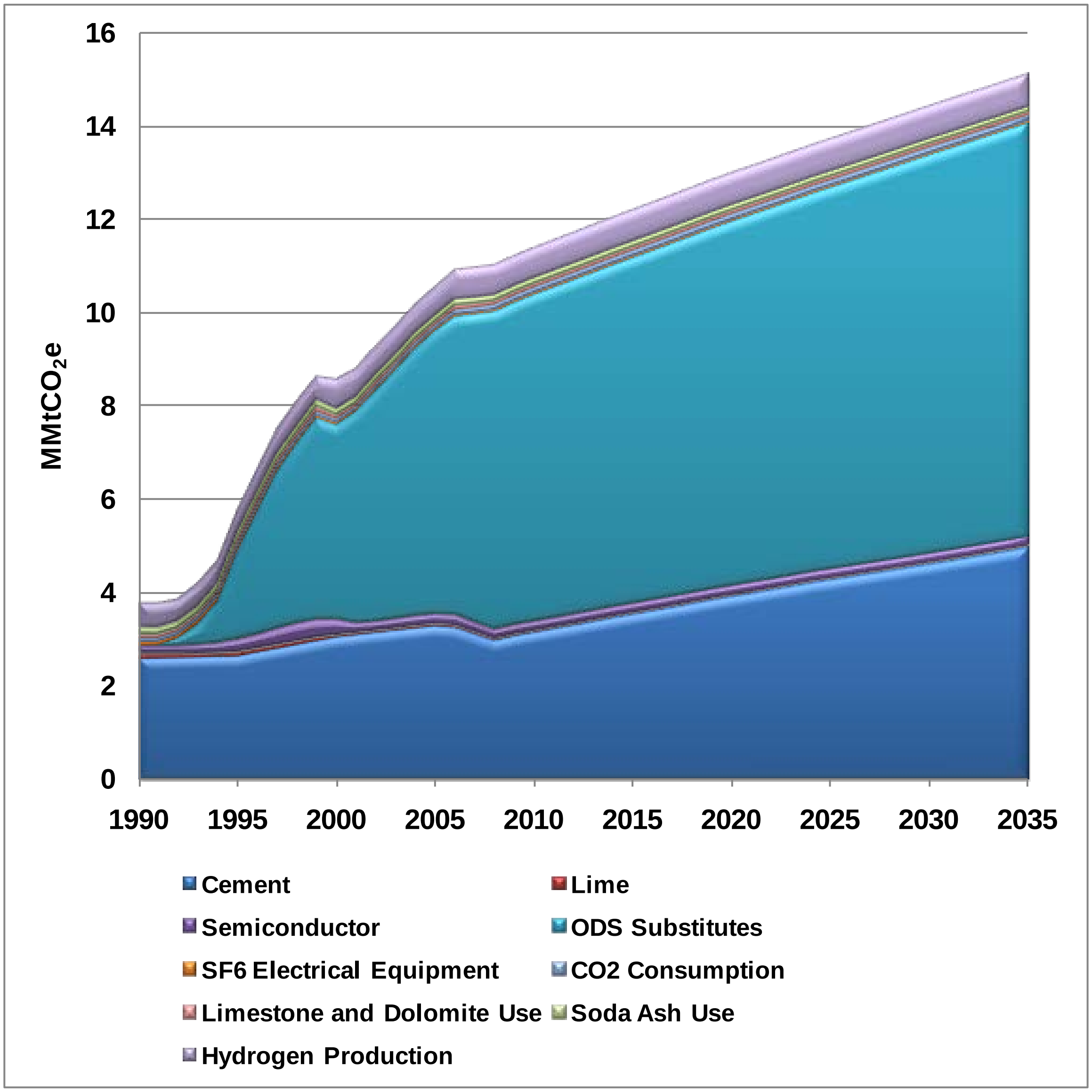
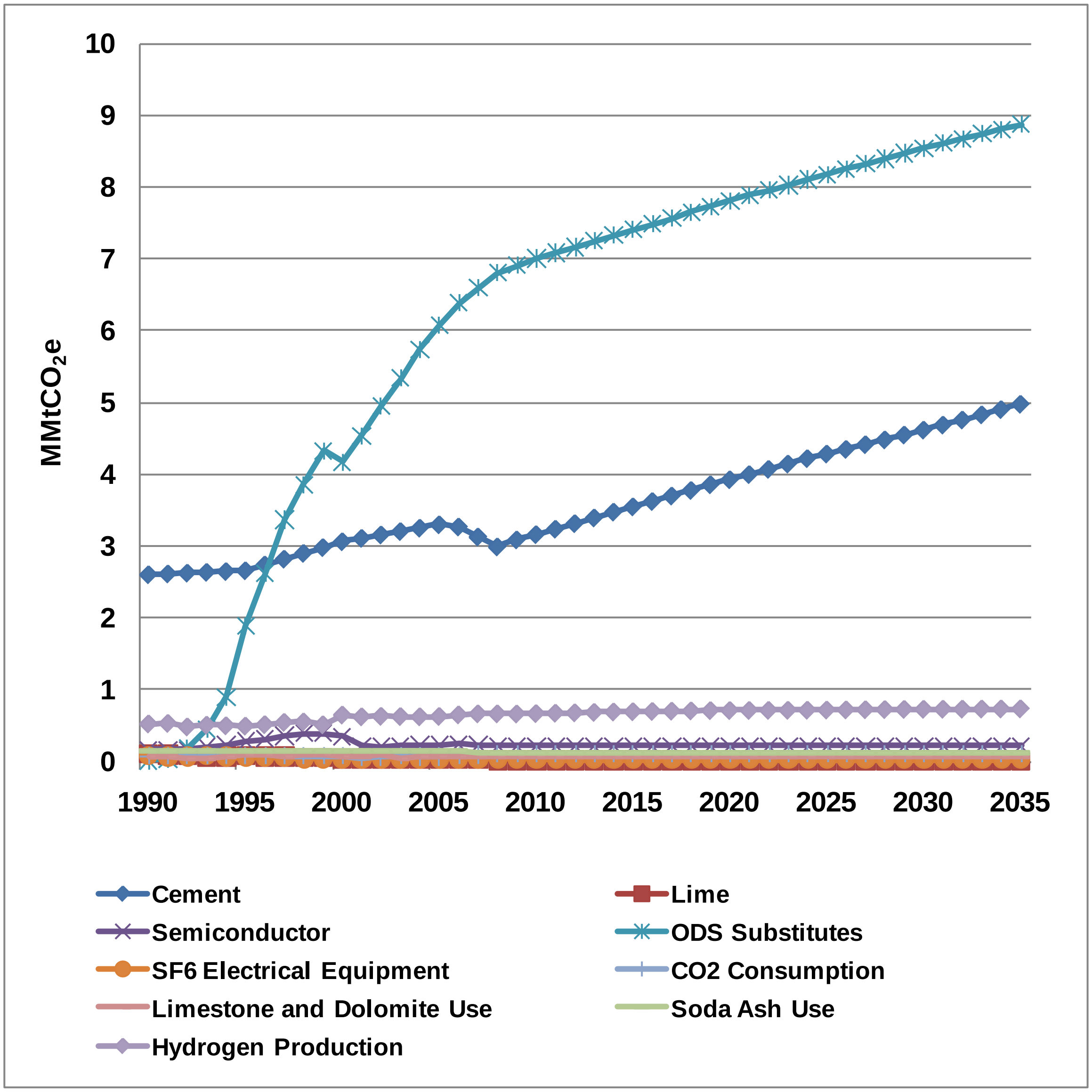


Figure D2. GHG Emissions from Industrial Processes, 1990-2035, by Source



**This inventory and forecast has been prepared with the most up-to-date information and should not be compared to any previous analysis at this time.*

Table D3. Historical and Projected Emissions for the Industrial Processes Sector ($MMtCO_2e$)

Source	1990	1995	2000	2005	2008	2010	2015	2020	2025	2030	2035
Cement	2.61	2.66	3.07	3.30	3.00	3.17	3.55	3.93	4.29	4.62	4.98
Lime	0.11	0.08	0.03	0.03	0.02	0.02	0.01	0.01	0.01	0.01	0.004
Semiconductor	0.16	0.28	0.35	0.22	0.22	0.22	0.22	0.22	0.22	0.22	0.22
ODS Substitutes	0.02	1.88	4.17	6.07	6.81	7.00	7.41	7.81	8.17	8.54	8.87
SF_6 Electrical Equipment	0.08	0.05	0.04	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.02
CO_2 Consumption	0.08	0.08	0.07	0.06	0.1	0.1	0.11	0.11	0.11	0.11	0.11
Limestone and Dolomite Use	0.07	0.09	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06
Soda Ash Use	0.15	0.14	0.14	0.14	0.13	0.13	0.13	0.13	0.12	0.12	0.12
Hydrogen Production	0.53	0.50	0.65	0.63	0.67	0.67	0.70	0.71	0.72	0.73	0.74
Total	**3.79**	**5.77**	**8.58**	**10.56**	**11.03**	**11.40**	**12.21**	**13.00**	**13.73**	**14.43**	**15.12**

Additional Inventory & Forecast Details for Key Subsectors

Cement Manufacture

Clinker is an intermediate product from which finished Portland and masonry cement are made. Clinker production releases CO_2 when calcium carbonate ($CaCO_3$) is heated in a cement kiln to form lime (calcium oxide) and CO_2 (see Chapter 6 of EIIP guidance document). Emissions are calculated by multiplying annual clinker production by emission factors to estimate emissions associated with the clinker production process.

Masonry cement requires additional lime, over and above the lime used in the clinker. During the production of masonry cement, non-plasticizer additives such as lime, slag, and shale are added to the cement, increasing its weight by 5%. Lime accounts for approximately 60% of the added substances.

Plant-level GHG emissions for years 2008 and 2009 were obtained from ARB's GHG Mandatory Reporting Program. Cement plants report to ARB a combined value of process and combustion emissions. Because the methods in this appendix focus on estimating process emissions only, the combined process-combustion emissions values could not be used to report process emissions in the SCAG region.[83] Nonetheless, the combined process-combustion emissions values were used to determine the share of emissions from state total emissions associated with plants located in the SCAG region. The share was determined as the ratio of SCAG/California cement plant emissions and the 2008-2009 average ratio was 0.56. This ratio was applied to California Greenhouse Gas Inventory GHG emissions from cement

[83] Emissions associated with the combustion of cement plants are included in the industrial fuel use emissions, described in Appendix B.

manufacturing for the period 1990-2008 in order to scale down state emissions to those of the SCAG region. Emissions were projected through 2035 using rates specific to each projection period that were computed from the Portland Cement Association.[84]. Note that the source of projected growth rates were derived from cement consumption in California since the outlook for California cement production was not available.

Lime Manufacture

Lime is a manufactured product that is used in many chemical, industrial, and environmental applications including steel making, construction, pulp and paper manufacturing, and water and sewage treatment. Lime is manufactured by heating limestone (mostly $CaCO_3$) in a kiln, creating calcium oxide and CO_2. The CO_2 is driven off and normally emitted to the atmosphere, leaving behind a product known as quicklime. Some of this quicklime undergoes slaking (combining with water), which produces hydrated lime. The consumption of lime for certain uses, specifically the production of precipitated $CaCO_3$ and refined sugar, results in the reabsorption of some airborne CO_2 (see Chapter 6 of EIIP guidance document.).

Emissions associated with lime manufacture were estimated for 1990 through 2008 by scaling down statewide emissions on the basis of economic data for the nonmetallic mineral product manufacturing sector (BEA industry code 15)[85] measured in GDP by MSA (millions of current dollars). The annual growth rate was developed from an analysis of historical growth, selecting the smallest historical annual decline in state production (5.58% from 2000 to 2008) from each of three periods analyzed (see Table D2).

Semiconductor Manufacturing

Manufacturers of semiconductors use fluorinated GHGs in plasma etching and plasma enhanced chemical vapor deposition processes. Plasma etching of dielectric films creates the pattern of pathways connecting individual circuit components in semiconductors. Vapor deposition chambers are used for depositing the dielectric films, and are cleaned periodically using fluorinated gases. Fluorinated gases are converted to fluorine atoms in plasma, which etches away dielectric material or cleans the chamber walls and hardware. Undissociated fluorinated gases and other products end up in the waste streams and, unless captured by abatement systems, into the atmosphere. Some fluorinated compounds can also be transformed in the plasma processes into other compounds (e.g., CF_4 generated from C_2F_6). If they are not captured by emission control systems, the process-generated gases will also be released into the atmosphere.[86]

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[84] Portland Cement Association *Forecast Report: Long-Term Cement Consumption Outlook.* January 31, 2008.
[85] Source: Bureau of Economic Analysis, U.S. Department of Commerce
[86] Air Resources Board, *California's 1990-2004 Greenhouse Gas Emissions Inventory and 1990 Emissions Level: Technical Support Document,* May 2009. Available at: http://www.arb.ca.gov/cc/inventory/doc/methods_v1/ghg_inventory_technical_support_document.pdf

Emissions associated with semiconductor manufacturing were estimated for 1990 through 2008 by scaling down statewide emissions on the basis of economic data for the computer and electronic product manufacturing sector (BEA industry code 19)[87] measured in GDP by MSA (millions of current dollars). No growth assumption was made due to conflicting historical emissions trends (e.g., emissions were held constant at 2008 levels through 2035—see Table D2). It should be noted that GHG emissions from semiconductor manufacturing reached a peak in the late 1990s in California, but the industry has since experienced a decline attributable to outsourcing. It is reasonable to expect that a similar trend would follow in the SCAG region.

Substitutes for Ozone-Depleting Substances (ODS)

HFCs and PFCs are used as substitutes for ODS, most notably CFCs (CFCs are also potent warming gases, with global warming potentials on the order of thousands of times that of CO_2 per unit of emissions) in compliance with the *Montreal Protocol* and the *Clean Air Act Amendments of 1990*.[88] Even low amounts of HFC and PFC emissions, for example, from leaks and other releases associated with normal use of the products, can lead to high GHG emissions on a CO_2e basis. Emissions in the SCAG region from this sector are estimated to have increased rapidly through 2008 as their use has become more widespread. It was assumed that emissions increased through 2035 at the same rate as the population growth in the SCAG region (up to 1.5% mean annual growth rate). This last assumption may need revision in the future because the projected rate of increase by the US EPA for the national inventory is substantially greater (up to 6.7% mean annual growth rate). See Table D2 for details on emission forecast rates.

Electric Power Transmission and Distribution (T&D)

Emissions of SF_6 from electrical equipment have experienced declines since the mid nineties, mostly due to voluntary action by industry. Sulfur hexafluoride is used as an electrical insulator and interrupter in the electric power T&D system. The largest use for SF_6 is as an electrical insulator in electricity T&D equipment, such as gas-insulated high-voltage circuit breakers, substations, transformers, and transmission lines, because of its high dielectric strength and arc-quenching abilities. Not all of the electric utilities in the US use SF_6; use of the gas is more common in urban areas where the space occupied by electric power T&D facilities is more valuable.[89]

Emissions associated with electric power T&D were estimated for 1990 through 2008 by scaling down statewide emissions on the basis of power plant disclosure of SF_6 emissions to ARB under

[87] Source: Bureau of Economic Analysis, U.S. Department of Commerce

[88] As noted in EIIP Chapter 6, ODS substitutes are primarily associated with refrigeration and air conditioning, but also many other uses including as fire control agents, cleaning solvents, aerosols, foam blowing agents, and in sterilization applications. The applications, stocks, and emissions of ODS substitutes depend on technology characteristics in a range of equipment types. For the US national inventory, a detailed stock vintaging model was used to track ODS substitutes uses and emissions, but this modeling approach has not been completed at the state level.

[89] US EPA, Draft User's Guide for Estimating Carbon Dioxide, Nitrous Oxide, HFC, PFC, and SF_6 Emissions from Industrial Processes Using the State Inventory Tool, prepared by ICF International, March 2007.

the GHG Mandatory Reporting program. Note that the GHG Mandatory Reporting program tracks SF_6 emissions from power plants and entities that have a stake in the maintenance and operation of T&D lines. Whereas SF_6 emissions from power plants can be pinned down to a locality from public records, emission from entities that act as electricity retailers and marketers cannot, because they are not physically tied to a specific location. Their responsibility for the emissions is determined from contractual arrangements. For this reason, the scale-down factor is based on power generation plants only and set equal to the ratio of SCAG/California SF_6 emissions for reporting year 2008 (ratio was 0.03).

The national trend in US emissions estimated for 2008-2035 for the US EPA's technology-adoption scenario shows expected decreases in these emissions at the national level (see Table D2), and the same rate of decline is assumed for emissions in the SCAG region. The decline in SF_6 emissions in the future reflects expectations of future actions by the electric power industry to reduce these emissions.

Carbon Dioxide Consumption

Carbon dioxide is used in chemical production, food processing, carbonated beverages, refrigeration, and for enhanced oil recovery (EOR) in petroleum production. Except in the case of EOR (where CO_2 is injected in underground reservoirs), the CO_2 used in these applications is eventually released to the atmosphere. The CO_2 used for these applications is either produced as a by-product from energy production (fossil fuel combustion) and industrial processes (e.g., ethanol production), as a by-product from the extraction of crude oil and natural gas, or from naturally occurring CO_2 reservoirs. However, CO_2 originating from biogenic sources (e.g., ethanol production plants) is not included in the inventory, so it is not considered here. Carbon dioxide captured from crude oil and gas production is used in EOR applications and is accounted for in the Fossil Fuel Industries sector (see Appendix E). Carbon dioxide from fuel combustion or other industrial process is already accounted for in the appropriate fossil fuel combustion or industry section of the inventory where it is assumed to have been emitted to the atmosphere. This leaves only the CO_2 extracted from naturally occurring CO_2 reservoirs to be accounted for in this section.[90]

Emissions associated with the consumption of CO_2 were estimated for 1990 through 2008 by scaling down statewide emissions on the basis of economic data for petroleum and coal products manufacturing and chemical manufacturing sectors (BEA industry codes 31 and 32, respectively)[91] measured in GDP by MSA (millions of current dollars). Forecast emissions relied on information from the *Annual Energy Outlook 2010* (AEO 2010)[92] for the demand of petroleum derived products in the Pacific region. Annual growth rates are shown in Table D2.

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[90] Air Resources Board, *California's 1990-2004 Greenhouse Gas Emissions Inventory and 1990 Emissions Level: Technical Support Document,* May 2009. Available at: http://www.arb.ca.gov/cc/inventory/doc/methods_v1/ghg_inventory_technical_support_document.pdf
[91] Source: Bureau of Economic Analysis, U.S. Department of Commerce
[92] http://www.eia.doe.gov/oiaf/aeo/.

Limestone and Dolomite Consumption

Limestone and dolomite are basic raw materials used by a wide variety of industries, including the construction, agriculture, chemical, glass manufacturing, and environmental pollution control industries, as well as in metallurgical industries such as magnesium production. Emissions associated with the use of limestone and dolomite to manufacture steel and glass and for use in flue-gas desulfurization scrubbers to control sulfur dioxide emissions from the combustion of coal in boilers are included in the industrial processes sector.[93]

Emissions associated with the consumption of limestone and dolomite were estimated for 1990 through 2008 by scaling down statewide emissions on the basis of economic data for the manufacturing sector (BEA industry code 12)[94] measured in GDP by MSA (millions of current dollars). Emissions were assumed to remain at 2008 levels through 2035 due to conflicting historical emissions trends (see Table D2).

Soda Ash Consumption

Commercial soda ash (sodium carbonate) is used in many consumer products such as glass, soap and detergents, paper, textiles, and food. Carbon dioxide is released when soda ash is consumed (see Chapter 6 of EIIP guidance document).

Emissions associated with the consumption of soda ash were estimated for 1990 through 2008 by scaling down statewide emissions on the basis of economic data for food product manufacturing, textile and textile product mills, and paper manufacturing sectors (BEA industry codes 26, 27, 29, respectively)[95] measured in GDP by MSA (millions of current dollars). The smallest historical decline was used to forecast emissions (see Table D2 for details).

Fuel Consumption as Feedstock for Hydrogen Consumption

In California, hydrogen production by and for refineries generates substantial amounts of CO_2 because the most common processes use carbon-based feedstock inputs (e.g., CH_4 from natural gas) as a source of hydrogen and emit the carbon as CO_2. Hydrogen production is not a direct part of the petroleum refining process, but it provides the hydrogen gas needed to upgrade heavier fractions into lighter, more valuable products.[96]

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[93] In accordance with EIIP Chapter 6 methods, emissions associated with the following uses of limestone and dolomite are not included in this category: (1) crushed limestone consumed for road construction or similar uses (because these uses do not result in CO_2 emissions), (2) limestone used for agricultural purposes (which is counted under the methods for the agricultural sector), and (3) limestone used in cement production (which is counted in the methods for cement production).

[94] Source: Bureau of Economic Analysis, U.S. Department of Commerce

[95] Source: Bureau of Economic Analysis, U.S. Department of Commerce

[96] Air Resources Board, *California's 1990-2004 Greenhouse Gas Emissions Inventory and 1990 Emissions Level: Technical Support Document,* May 2009. Available at: http://www.arb.ca.gov/cc/inventory/doc/methods_v1/ghg_inventory_technical_support_document.pdf

Plant-level GHG emission for years 2008 were obtained from ARB's GHG Mandatory Reporting Program. Statewide emissions for this industry segment were used as surrogate data to back-cast emissions to year 1990. Forecast emissions relied on information from the *Annual Energy Outlook 2010* (AEO 2010)[97] for the demand of petroleum derived products in the Pacific region. Detail of growth rates is provided in Table D2.

Key Uncertainties

Key sources of uncertainty underlying the estimates above are as follows:

- Emissions from a number of industrial processes are determined by the level of production. The level of production of some industries is sometimes determined by a few key plants. Hence, there is a relatively high level of uncertainty regarding future emissions from the industrial processes category as a whole. Future emissions depend on the competitiveness of the SCAG region manufacturers in these industries, and the specific nature of the production processes used in the SCAG region. These estimates should be reviewed and modified as necessary based on actual data reported by facilities within the SCAG region, particularly in the case of cement emissions and hydrogen plant emissions. Also, for other industrial processes, the emission levels are determined based on estimated levels of consumption. In many of these cases, SCAG-specific data were not available, so state-level emissions were allocated to the SCAG region. Future work to refine the emission estimates should focus on gathering regionally-specific data on consumption.
- For the cement manufacture category, an alternative approach to estimating historical emissions in the SCAG region is to use the Mandatory Reporting Rule values of Clinker production rather than total emissions. For 2008, the 6 SCAG counties account for 54.7% 54.7% of the statewide clinker production. This is similar to the 56% share of the state's emissions for 2008 determined using the approach documented above.
- Growth rates for cement process emissions reflect the projected demand of Portland cement in the entire state of California. Better estimates could be developed if an outlook of cement production were available from the Portland Cement Association rather than a cement consumption forecast. Ultimately, the best estimate would come from production projections by cement plants located within the SCAG inventory boundary.
- The projected largest source of future industrial emissions, HFCs and PFCs used in cooling applications, is subject to several uncertainties as well. Emissions through 2035 and beyond will be driven by future choices in mobile and stationary air conditioning technologies and the use of refrigerants in commercial applications, for which several non-GHG options currently exist.
- The current approach to scaling historical state-level CO_2 emissions from the CO_2 consumption category to the SCAG region on the basis of production surrogates may not be

[97] http://www.eia.doe.gov/oiaf/aeo/.

appropriately capturing SCAG's share of emissions. The appropriateness of instead using a consumption-based surrogate for allocating these emissions should be investigated.

- The current approach to scaling historical state-level CO_2 emissions from the Fuel Consumption as Feedstock for Hydrogen Consumption category based on plant-level refinery emissions may not be appropriately capturing SCAG's share of emissions for this category. An alternative approach would include using ARB state-level data which has broken out emissions from hydrogen production and scale it to SCAG by using the 2008 GHG Mandatory Reporting Rule data on H2 produced as a surrogate. This approach could cause the 2008 GHG emissions to increase to 3 MMtCO2e (up from 0.6 MMtCO2e estimated in this report for 2008).
- Due to the lack of reasonably specific projection surrogates, historical trend data were used to project emission activity level changes for multiple industrial process categories. There is significant uncertainty associated with any projection, including a projection that assumes that past historical trends will continue in future periods. Reflecting this uncertainty, the lowest historical annual rate of increase/decrease was selected as a conservative assumption for use in projecting future activity level changes. These assumptions on growth should be reviewed by industry experts and revised to reflect their expertise on future trends especially for the lime manufacture industry, limestone and dolomite consumption, and soda ash consumption. If possible, economic-based growth factors should be considered to replace the growth factors used here based on historical trends. Where applied in the future, the economic growth factors should be consistent with those used for forecasting emissions in other related sectors (e.g., industrial fuel combustion).
- For the electricity T&D and semiconductor industries, future efforts should include a survey of companies within these industries to determine the extent to which they are implementing techniques to minimize emissions to improve the emission estimates and forecasts for these industries. Lacking these data, additional work is needed to improve the allocation of state-level emissions to the SCAG region, in particular for SF_6 emissions, which could be significantly underestimated in these initial estimates. It has also been noted that the mandatory reporting of SF_6 emissions for this category is not complete due to the methods permitted. To better align with ARB methods, using a surrogate of electricity consumption rather than the Mandatory Reporting Rule emissions should be considered.

Appendix E. Fossil Fuel Industries

Overview

The inventory for this subsector of the Energy Supply sector includes methane (CH_4), nitrous oxide (N_2O), and carbon dioxide (CO_2) emissions associated with the production, processing, transmission, and distribution of fossil fuels in the SCAG region.[98] In 2008, emissions from the subsector accounted for an estimated 20 million metric tons (MMt) of CO_2 equivalent (CO_2e) of gross greenhouse gas (GHG) emissions in the SCAG region, and are estimated to increase slightly to 23 $MMtCO_2e$ by 2035.

Emissions and Reference Case Projections

Table E1 summarizes the data and approach used to estimate historical emissions for the fossil fuel industries. The emission sources and emission estimation approach for each subsector is discussed in more detail below.

Oil and Gas Production

According to the Bureau of Ocean Energy Management, in the Pacific Outer Continental Shelf (OCS) Region, twenty-three oil and gas production facilities have been installed in Federal waters. All of these facilities are located off the coast of California. Twenty-two of these facilities produce oil and gas--the other is a processing facility. As of February 2007, these facilities have produced a total of over 1.1 billion barrels of oil and 1.5 trillion cubic feet of gas. Six companies are operating offshore oil and gas facilities in the Pacific Region.[99] Emissions from these facilities were not included in this inventory because they fall outside the inventory boundary of SCAG due to their location in Federal waters.

Some on-shore oil and gas production occurs in the region; however, no specific operations data were found in ARB's Mandatory GHG Reporting Program database.[100] Note that this program applies to crude petroleum and natural gas [Northern American Industry Classification System (NAICS) code 211111] facilities that emit greater than 25,000 metric tons of CO_2 in a year. There are extraction and production operations with GHG emissions under the reporting threshold present in the SCAG region; however, emissions data are not readily-available.

Oil Industry Emissions

Mandatory reporting of GHG emissions became effective in California January 1, 2008 for large emitting sources including oil refineries. The ARB Mandatory GHG Reporting Program database identified eleven oil refineries present in the SCAG region. Emissions data for 2008 from this database were used to determine the baseline emissions level for this segment of the industry.

[98] Note that emissions from natural gas consumed as lease fuel (used in well, field, and lease operations) and plant fuel (used in natural gas processing plants) are included in Appendix B in the industrial fuel combustion category.
[99] http://www.mms.gov/omm/pacific/offshore/offshore.htm.
[100] Public record request to the California Air Resources Board's Mandatory Greenhouse Gas Reporting database queried on July 13, 2010

State emissions data from 1990 to 2008 were used as surrogates to backcast SCAG regional emissions to 1990.

Gas Industry Emissions
Emissions can occur at several stages of production, processing, transmission, and distribution of oil and gas. Based on the information provided in the Emission Inventory Improvement Program (EIIP) guidance[101] for estimating emissions for this sector, transmission pipelines are large diameter, high-pressure lines that transport gas from production fields, processing plants, storage facilities, and other sources of supply over long distances to local distribution companies or to large volume customers. Sources of CH_4 emissions from transmission pipelines include leaks, compressor fugitives, vents, and pneumatic devices. Distribution pipelines are extensive networks of generally small diameter, low-pressure pipelines that distribute gas within cities or towns. Sources of CH_4 emissions from distribution pipelines are leaks, meters, regulators, and mishaps. Carbon dioxide, CH_4, and N_2O emissions occur as the result of the combustion of natural gas by internal combustion engines used to operate compressor stations.

With nearly 4,300 miles of gas pipelines, there are significant uncertainties associated with estimates of the SCAG region's GHG emissions from this sector. This is compounded by the fact that there are no regulatory requirements to track GHG emissions. Therefore, estimates based on emissions measurements in the SCAG region are not possible at this time.

The EPA's State Greenhouse Gas Inventory Tool (SIT) facilitates the development of a rough estimate of state-level GHG emissions. GHG emission estimates are calculated by multiplying emissions-related activity levels (e.g., miles of pipeline, number of compressor stations) by aggregate industry-average emission factors. The information source for the activity data is the US Department of Transportation's Office of Pipeline Safety (OPS).[102] OPS collects information from natural gas operators that conduct business in the state of California. The OPS database includes the county of the field office associated with the transmission and distribution activity data. For this analysis, the transmission and distribution activity (e.g., pipeline mileage, number of compressor stations, and number of services) in the OPS database associated with any field office located within any of the six SCAG counties was assumed to be physically located within the SCAG region. Regional emissions for SCAG were estimated using the SIT, using activity data for the SCAG region and with reference to methods/data sources outlined in the EIIP guidance document for natural gas and oil systems.[103]

Unfortunately, OPS has not collected data from pipeline operators using a consistent set of reporting requirements over the 1990-2007 analysis period. In particular, OPS has only required operators to report state-level data for their transmission/gathering pipelines since 2001 and

[101] Emission Inventory Improvement Program, Volume VIII: Chapter 5. "Methods for Estimating Methane Emissions from Natural Gas and Oil Systems," August 2004.
[102] US Department of Transportation, Office of Pipeline Safety, "Distribution, Transmission and Liquid Annual Data," accessed from http://ops.dot.gov/stats/DT98.htm, December 2009.
[103] Emission Inventory Improvement Program, Volume VIII: Chapter. 5. "Methods for Estimating Methane Emissions from Natural Gas and Oil Systems", August 2004.

state-level data for their distribution pipelines since 2004. Emissions for the years 1990 through 2007 were backcast from 2008 proportionally to state-level emissions for the corresponding activity as reported in the California GHG inventory.[104]

Coal Mining Emissions

No coal mining occurs in California;[105] therefore, no further assessment was conducted for the SCAG region.

Emission Forecasts

Table E1 provides an overview of data sources and approaches used to develop projected fossil fuel industries sector emission estimates for the SCAG region. The approach to forecasting sector emissions and activity consisted of compiling and comparing two alternative sets of annualized growth rates for each emissions category – one using Annual Energy Outlook (AEO) 2010 forecast data for each 5-year time-frame over the 2008-2035 analysis period, and the other using the historical 1990-2008 GHG emissions data for each of 3 periods (i.e., 1990 to 2008, 1995 to 2008, and 2000 to 2008). The AEO-based growth rates were calculated from the Pacific Region delivered energy consumption forecast data for liquid fuels for the oil refining categories and delivered energy consumption for natural gas for the gas transmission and distribution categories. Because available AEO forecast information is for a broad region that may not reflect the SCAG region-specific trends (AEO forecasts of natural gas production are for the Pacific Region, and include 4 states: Arizona, California, Hawaii, Nevada), the AEO forecast growth rates were only used when they were consistent with the SCAG historical emission growth rates for the corresponding categories. In cases where the growth rates estimated from the historical emissions for each of the three historical periods listed above indicated continual growth or decline, the period with the smallest annual rate of growth/decline was used in the projection. This conservative assumption was adopted because of the uncertainty associated with utilizing historical trends to estimate future emission activity levels. As a result of this analysis, emissions from the oil refining categories were projected based on the AEO Pacific Region growth in delivered energy consumption for liquid fuels while the emissions from natural gas transmission and distribution were projected based on the historical SCAG GHG emissions from these subcategories.

It is important to note that potential improvements to production, processing, and pipeline technologies or inspections and maintenance programs that could result in GHG emissions reductions are generally not accounted for in the projections analysis.

[104] California Greenhouse Gas Inventory, versions 1 and 3. Retrieved August 2010 from http://www.arb.ca.gov/cc/inventory/inventory.htm

[105] California Greenhouse Gas Inventory, versions 1 and 3. Retrieved August 2010 from http://www.arb.ca.gov/cc/inventory/inventory.htm

Table E1. Approach to Estimating Historical and Projected Emissions from Fossil Fuel Systems

Activity	Approach to Estimating Historical Emissions: Required Data	Approach to Estimating Historical Emissions: Data Source	Surrogate Data Used to Backcast Activity to 1990	Forecasting Approach: Projection Assumption
Natural Gas Production	Number of gas/ associated wells	No facilities identified		
Natural Gas Processing	Number of gas processing plants	Not estimated due to lack of information		
Natural Gas Transmission	Miles of gathering pipeline	Office of Pipeline Safety[106]	Emissions data for corresponding activity from California GHG Inventory[107]	Used historical growth rate (0.6%) since there was poor correspondence with AEO 2010[108] natural gas flows projections.
	Miles of transmission pipeline			
	Number of gas transmission compressor stations	Default SIT	Apportioned by SIT according to length of transmission pipeline miles	
	Number of gas storage compressor stations	Default SIT		
Natural Gas Distribution	Miles of distribution pipeline by pipeline material type	Office of Pipeline Safety[109]	Emissions data for corresponding activity from California GHG Inventory[110]	Used historical growth rate (0.6%) since there was poor correspondence with AEO 2010[111] natural gas flows projections.
	Total number of services			
	Number of unprotected steel services			
	Number of protected steel services			

[106] US Department of Transportation, Office of Pipeline Safety, "Distribution, Transmission and Liquid Annual Data," accessed from http://ops.dot.gov/stats/DT98.htm, December 2009.
[107] California Greenhouse Gas Inventory, versions 1 and 3. Retrieved August 2010 from http://www.arb.ca.gov/cc/inventory/inventory.htm
[108] US DOE, Energy Information Administration, "Annual Energy Outlook 2010 with Projections to 2035," accessed from http://www.eia.doe.gov/oiaf/archive/aeo09/index.html, December 2009.
[109] US Department of Transportation, Office of Pipeline Safety, "Distribution, Transmission and Liquid Annual Data," accessed from http://ops.dot.gov/stats/DT98.htm, December 2009.
[110] California Greenhouse Gas Inventory, versions 1 and 3. Retrieved August 2010 from http://www.arb.ca.gov/cc/inventory/inventory.htm
[111] US DOE, Energy Information Administration, "Annual Energy Outlook 2010 with Projections to 2035," accessed from http://www.eia.doe.gov/oiaf/archive/aeo09/index.html, December 2009.

Table E1. Approach to Estimating Historical and Projected Emissions from Fossil Fuel Systems (continued)

Activity	Approach to Estimating Historical Emissions		Surrogate Data Used to Backcast Activity to 1990	Forecasting Approach
	Required Data	Data Source		Projection Assumption
Natural Gas Pipeline Fuel Use (CO_2, CH_4, N_2O)	Volume of natural gas consumed by pipelines	Not estimated due to lack of information		
Oil Production	Emissions	No large emitters identified		
Oil Refining	Emissions	ARB, GHG Mandatory Reporting Program	Emissions data for corresponding activity from California GHG Inventory[112]	Used AEO 2010 growth rate since it was consistent with historical annualized growth rate (0.44%).
Oil Transport	Annual volume transported	Not estimated due to lack of information		
Coal Mining	Methane emissions in million cubic feet	Does not occur in the SCAG region		

Results

Table E2 displays the estimated emissions from the fossil fuel industry in the SCAG region for select years over the period from 1990 to 2035. Emissions from this sector increase by 17% from 1990 to 2008 and are projected to increase by an additional 13% between 2008 and 2035. Process and stationary combustion emissions from refineries are the major contributors to both recent historic and future year emissions. Figure E1 displays emission trends from the fossil fuel industry, on an $MMtCO_2e$ basis. The trend for historical emissions in this figure appears jagged because it is driven by annual changes in regional oil refining activity. Forecast emissions are smoother because the approach to forecasting makes the assumption that mean annual growth rate is constant over the projection period. As discussed above, the mean annual growth rate for the forecast is selected after considering the consistency between historical trends in the SCAG region and future trends in the Pacific Region (i.e., Arizona, California, Hawaii, Nevada) as projected in the 2010 Annual Energy Outlook.

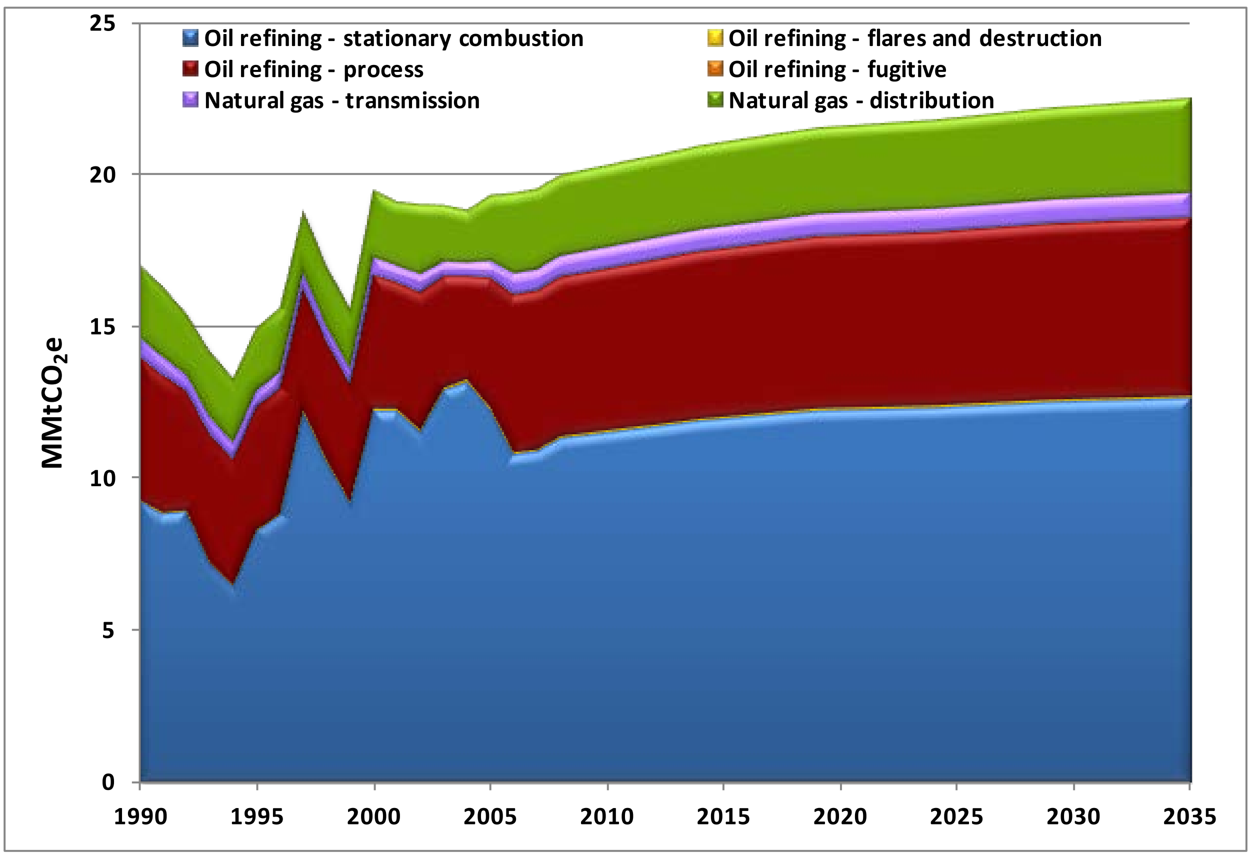
[112] California Greenhouse Gas Inventory, versions 1 and 3. Retrieved August 2010 from http://www.arb.ca.gov/cc/inventory/inventory.htm

Table E2. Historical and Projected Emissions for the Fossil Fuel Industry

(Million Metric Tons CO_2e)	1990	1995	2000	2005	2008	2010	2015	2020	2025	2030	2035
Total Fossil Fuel Industries	**17.05**	**14.99**	**19.51**	**19.34**	**20.00**	**20.31**	**21.07**	**21.60**	**21.87**	**22.24**	**22.52**
Oil and gas production	9.31	8.33	12.29	12.31	11.39	11.57	12.02	12.31	12.42	12.60	12.71
Oil refining - stationary combustion	*9.26*	*8.28*	*12.22*	*12.24*	*11.32*	*11.51*	*11.96*	*12.24*	*12.35*	*12.53*	*12.64*
Oil refining - flares and destruction	*0.05*	*0.05*	*0.07*	*0.07*	*0.06*	*0.06*	*0.07*	*0.07*	*0.07*	*0.07*	*0.07*
Fugitive emissions from oil and natural gas	7.74	6.66	7.22	7.03	8.61	8.74	9.05	9.29	9.45	9.64	9.81
Oil refining - process	*4.69*	*4.04*	*4.38*	*4.27*	*5.22*	*5.31*	*5.52*	*5.65*	*5.70*	*5.78*	*5.83*
Oil refining - fugitive	*0.01*	*0.01*	*0.01*	*0.01*	*0.01*	*0.01*	*0.01*	*0.01*	*0.01*	*0.01*	*0.01*
Natural gas - transmission	*0.65*	*0.56*	*0.60*	*0.59*	*0.72*	*0.73*	*0.75*	*0.77*	*0.80*	*0.82*	*0.85*
Natural gas - distribution	*2.39*	*2.06*	*2.23*	*2.17*	*2.66*	*2.69*	*2.77*	*2.85*	*2.94*	*3.03*	*3.12*

Note: CCS calculations based on approach described in text.

Figure E1. Fossil Fuel Industry Emission Trends ($MMtCO_2e$)



Source: CCS calculations based on approach described in text.

**This inventory and forecast has been prepared with the most up-to-date information and should not be compared to any previous analysis at this time.*

Key Uncertainties

Key sources of uncertainty underlying the estimates above are as follows:

- On-shore oil and gas extraction occurs within the SCAG region; however, information for installations emitting less than 25,000 metric tons a year is not currently collected by the authorities and therefore not publicly available.
- Fugitive emissions methods for natural gas systems rely on infrastructure data that are not available at the county level. Significant uncertainties will remain in the emission estimates for this sector until there is a comprehensive tally of county level infrastructure data.
- Due to data limitations associated with OPS reporting, natural gas distribution, gathering, and transmission pipeline emissions in years prior to 2008 were backcast based on state-level emission trends and the ratio of 2008 SCAG emissions to California emissions for these emission categories. It is possible that the California emission trends over this time period were not representative of the trends within the SCAG region, in which case, the SCAG historical emission estimates would be inaccurate. It is also important to note that the amount of infrastructure assessed at the county level was based on an assumed association between the geographical location of a field office and the geographical location of infrastructure reported to the OPS from that field office. It is plausible that a field office may serve two counties, one of which is not within the SCAG region.
- The assumptions used in projecting the future production, transmission, and distribution of fossil fuels do not reflect all potential future changes that could affect GHG emissions, including potential changes in regulations and emissions-reducing improvements in oil and gas production, processing, and pipeline technologies.

Appendix F. Agriculture

Overview of Emissions Sources

The emissions discussed in this appendix refer to non-energy methane (CH_4) and nitrous oxide (N_2O) emissions from both livestock and crop production. These include emissions and sinks of carbon dioxide (CO_2) in agricultural (Ag) soils. The primary greenhouse gas (GHG) sources and sinks - livestock production and crop production are further subdivided as follows:

- *Fossil Fuel Consumption:* Agricultural equipment and agricultural processes can cause emissions from fossil fuel consumption. This includes fuel consumption from processes such as heavy machinery operation and water pumping during crop cultivation.
- *Livestock production – enteric fermentation:* CH_4 emissions from enteric fermentation are the result of normal digestive processes in ruminant and non-ruminant livestock. Microbes in the animal digestive system break down food and emit CH_4 as a by-product. More CH_4 is produced in ruminant livestock because of digestive activity in the large fore-stomach.
- *Livestock production – manure management:* CH_4 and N_2O emissions from the storage and treatment of livestock manure (e.g., in compost piles or anaerobic treatment lagoons) occur as a result of manure decomposition. The environmental conditions of decomposition drive the relative magnitude of emissions. In general, the more anaerobic the conditions are, the more CH_4 is produced because decomposition is aided by CH_4-producing bacteria that thrive in oxygen-limited conditions. In contrast, N_2O emissions are increased under aerobic conditions. Emission estimates from manure management are based on manure that is stored and treated on livestock operations (e.g. dairies, feedlots, swine operations). Emissions from manure deposited directly on land by grazing animals and emissions from manure that is applied to agricultural soils as an amendment are accounted for in the next sector.
- *Livestock production, agricultural soils – livestock:* This source sector accounts for N_2O emissions resulting from animal excretions directly on agricultural soils (e.g. pasture, paddock or range) or manure spreading on agricultural soils.
- *Crop production, agricultural soils – fertilizers:* The management of agricultural soils can result in N_2O emissions and net fluxes of CO_2 (causing emissions or sinks). In general, soil amendments that add nitrogen to soils can also result in N_2O emissions. Nitrogen additions drive the underlying soil nitrification and de-nitrification cycle, which produces N_2O as a by-product. The emissions estimation methodologies used in this inventory account for several sources of N_2O emissions from agricultural soils, including decomposition of crop residues, synthetic and organic fertilizer application, manure application, nitrogen fixation, and cultivation of histosols (high organic soils, such as wetlands or peatlands) cultivation (see additional agricultural soils subsectors below). Both direct and indirect emissions of N_2O occur from the application of manure and fertilizer to agricultural soils. Direct emissions occur at the site of application. Nitrous oxide is an intermediary compound in soil nitrification/denitrification cycles and some of N_2O generated is emitted to the atmosphere. Indirect emissions occur when nitrogen leaches to groundwater or into surface runoff and

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enters the nitrification/denitrification cycle, potentially in an area distant from where the nitrogen was applied.

- *Crop production, agricultural soils – crops:* This source sector accounts for N_2O emissions from the decomposition of crop residues, production of nitrogen-fixing crops, and the cultivation of histosols.
- *Crop production, agricultural soils – liming:* the practice of adding limestone and dolomite to agricultural soils (for neutralizing acidic soil conditions) results in CO_2 emissions.
- *Crop production, agricultural soils – rice cultivation:* CH_4 emissions occur during rice cultivation; however, rice is not grown in the SCAG region.
- *Crop production, agricultural soils – soil carbon:* The net flux of CO_2 in agricultural soils depends on the balance of carbon losses from management practices and gains from organic matter inputs to the soil. Carbon dioxide is absorbed by plants through photosynthesis and ultimately becomes the carbon source for organic matter inputs to agricultural soils. When inputs are greater than losses, the soil accumulates carbon and there is a net sink of CO_2 into agricultural soils. In addition, soil disturbance from the cultivation of histosols releases large stores of carbon from the soil to the atmosphere in the form of CO_2 (Note: N_2O emissions from cultivation of histosols are covered under the *Agricultural soils - crops* sector above).
- *Crop production, residue burning:* CH_4 and N_2O emissions are produced when crop residues are burned (CO_2 is also emitted, however, since the source of carbon is biogenic, these emissions are not included in the inventory).

Emissions and Reference Case Projections

Livestock population and crop production estimates were obtained from the County Agricultural Reports of the six SCAG counties.[113] The following years of data reports were used in this analysis:

- Imperial – 1990, 1996, 2002, 2005, 2008;
- Los Angeles – 1990, 1996, 2002, 2005, 2007;
- Orange – 1997, 2002, 2005, 2009;
- Riverside – 1990, 2000, 2002, 2005, 2008;
- San Bernardino - 1990, 1998, 2002, 2005, 2008; and
- Ventura - 1990, 1996, 2002, 2005, 2008.

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[113] Riverside Agricultural Commissioner's Office, "Agricultural Production Reports." http://www.rivcoag.org/opencms/index.html
Imperial County Agricultural Commissioner. "Imperial County Agricultural Livestock Reports." http://www.co.imperial.ca.us/ag/default.htm
Orange County Agricultural Commissioner. "Orange County Yearly Crop Reports." http://ocgov.com/ocgov/Agricultural%20Commissioner/Agricultural%20Services/Orange%20County%20Yearly%20Crop%20Report
San Bernardino County Agricultural Commissioner. "San Bernardino County Crop and Livestock Reports." http://www.co.san-bernardino.ca.us/awm/questionsandforms/statistics.htm
Ventura County Agricultural Commissioner. "Ventura County Crop Reports." http://portal.countyofventura.org/portal/page/portal/AgCommissioner/Public_Data_Requests
Los Angeles County Agricultural Commissioner. "Los Angeles County Crop Reports." http://acwm.co.la.ca.us/scripts/publications.htm

Data for intervening years for all six counties were interpolated, and then the estimates were summed to get the SCAG total. From this information, estimates of crop production and livestock population in the state were developed for the SCAG region for 1990 to 2006.
For some agricultural categories, GHG emissions for 1990 through 2006 were estimated using EPA's State Inventory Tool (SIT) module for agriculture and the methods provided in the Emission Inventory Improvement Program (EIIP) guidance document for the sector, replacing California activity data with the corresponding SCAG activity data.[114] In general, the SIT methodology applies emission factors developed for the US to activity data for livestock and crop production. The SIT methodology is only used when it matches the procedures outlined by the California Air Resources Board (ARB), as is the case for enteric fermentation and crop residues.

For other emissions sources, such as manure management and agricultural burning, emissions were estimated using the ARB methodology directly, and substituting SCAG crop/livestock numbers for California totals.

Fossil Fuel Consumption: Direct emissions from fossil fuel consumption in agriculture were estimated based on the percentage of California agricultural acreage in cultivation in the SCAG region multiplied by the California total emissions. This assumes that agriculture in the SCAG region is just as energy intensive as agriculture statewide. Limestone and dolomite emissions were calculated using the same formula - California total limestone/dolomite emissions times the percentage of California agricultural land in the SCAG region.

Livestock Production – Enteric Fermentation: Historical emission for these categories were estimated by multiplying the livestock populations in the SCAG region by the corresponding ARB emission factors[115].

Livestock Production – Manure Management: Emissions from manure management categories came from the estimate of manure emissions in California, multiplied by the percentage of each animal type in the SCAG region. For example, information from the county livestock inventories indicates that 18% of California's dairy cows were located in SCAG in 1990, which is then multiplied by manure management emissions for California in 1990 to get the estimate of 0.74 $MMtCO_2e$ of methane emissions in California manure management.

[114] GHG emissions were calculated using SIT, with reference to Emission Inventory Improvement Program, Volume VIII: Chapter 8. "Methods for Estimating Greenhouse Gas Emissions from Livestock Manure Management", August 2004; Chapter 10. "Methods for Estimating Greenhouse Gas Emissions from Agricultural Soil Management", August 2004; and Chapter 11. "Methods for Estimating Greenhouse Gas Emissions from Field Burning of Agricultural Residues", August 2004.
[115] Air Resources Board, *California's 1990-2004 Greenhouse Gas Emissions Inventory and 1990 Emissions Level: Technical Support Document,* May 2009. Available at: http://www.arb.ca.gov/cc/inventory/doc/methods_v1/ghg_inventory_technical_support_document.pdf

Crop Production - Agricultural Soils (Livestock, Liming, Fertilizers, Crops and Histosols): For the agricultural soils categories, emissions from fertilizer usage, including from manure application, came from the estimate of fertilizer emissions in California, multiplied by the percentage of agricultural acreage in the SCAG region (7.7% of the state total).[116] Data on crop production in the SCAG region from 1990 to 2006 from the county agricultural reports were used to calculate N_2O emissions from crop residues and crops that use nitrogen (i.e., nitrogen fixation).

Emissions from the cultivation of histosols are estimated to be relatively small in California (0.15 $MMtCO_2e$ statewide in 2006). The majority of these emissions are likely to occur in central or northern California, and given the lack of data on high organic soil cultivation, it was assumed that these emissions in the SCAG region are zero.

Crop Production – Residue Burning: Agricultural residue burning occurs in California barley, corn, rice, wheat, walnut, and almond crops. Of these, only corn and barley are grown in the SCAG region. A portion of statewide burning emissions from these crops were assumed to occur in SCAG. The ARB methodology calculates emissions by multiplying the amount (e.g., bushels or tons) of each crop produced by a series of emission factors to calculate the amount of crop residue burned, the resultant dry matter, and the carbon/nitrogen content of the dry matter. Agricultural burning emissions factors from ARB were multiplied by estimated SCAG production levels to estimate SCAG emissions from residue burning.

Crop Production – Soil Carbon: Soil carbon flux was estimated at the county level in a California Energy Commission (CEC) report.[117] The study indicated that agricultural lands in the six-county area are responsible for 107,000 tons of CO_2 released every year.

Growth Rates

The reference case emission forecasts were made based on trends in historical emissions estimates, with the exception of certain animal populations. Emission projections from dairy cows, swine, and pullets were estimated based on population forecasts. These annual livestock growth rates were applied to the most recent year for which historical emissions were estimated, which varies based on the subsector. Future reference case emissions from enteric fermentation and manure management were estimated based on the annual growth rate in emissions associated with historical livestock populations in SCAG for 1990 to 2006. No change in livestock

[116] USDA NASS. "Number of Farms, Land Area and Average Size of Farms by County, 2002." www.nass.usda.gov/Statistics_by_State/.../200407farminfo.pdf

[117] This estimate is based on data from Table 2-10 of the CEC report, "Carbon Stock in Agricultural Land by County in 1987, 1992 and 1997". The flux between 1987 and 1997 for the six counties was then divided by ten to get annual flux and converted to CO2 by multiplying by 44/12. This results in estimated annual emissions (carbon loss) of 107,000 tons of CO_2e in the SCAG region.
California Energy Commission. "Baseline Greenhouse Gas Emissions for Forest, Range and Agricultural Lands in California." 2004. http://www.energy.ca.gov/reports/CEC-500-2004-069/CEC-500-2004-069F.PDF

management practices is assumed during the forecast period. The annual growth factors for fertilizers, agricultural crop residues, and nitrogen-fixing crops were developed based on the annual growth rate in historical emissions, on a CO_2 equivalent basis, for these categories in the SCAG region. Table F1 summarizes the annual growth rates resulting from emissions projections in the agricultural subsector.

Table F1. Resultant Annual Growth Rates for the Agricultural Sector

Subsector	2005-2015	2015-2025	2025-2035	Basis For Emissions Forecast
Fuel Combustion	1.0%	0.9%	0.8%	Historical emissions from 1990-2006
Enteric Fermentation	-2.8%	-2.4%	-2.6%	Historical emissions from 1990-2007
Manure Management	-2.6%	-2.3%	-2.3%	Historical emissions from 1990-2005
Ag Burning	-0.8%	-2.9%	-2.1%	Historical emissions from 1990-2007
Ag Soils - Livestock	2.0%	1.8%	1.6%	Historical emissions from 1990-2006
Ag Soils - Liming	5.0%	2.8%	2.2%	Historical emissions from 1990-2006
Ag Soils - Fertilizer	3.2%	2.3%	1.9%	Historical emissions from 1990-2006
Ag Soils - Crops	-0.6%	-1.2%	-1.3%	Historical emissions from 1990-2007
Soil Carbon Flux	0.0%	0.0%	0.0%	N/A

The growth factors shown in Table F1 were calculated based on the sum of emissions for each emissions category in a given year. These growth rates are therefore an average of the overall growth seen in each agricultural subsector. There was no growth rate used for soil carbon flux, as this was a single data point, and no estimate of growth could be made. Fuel combustion and Agricultural Soils are the only two subsectors that are predicted to show emissions growth in the forecast period.

Results

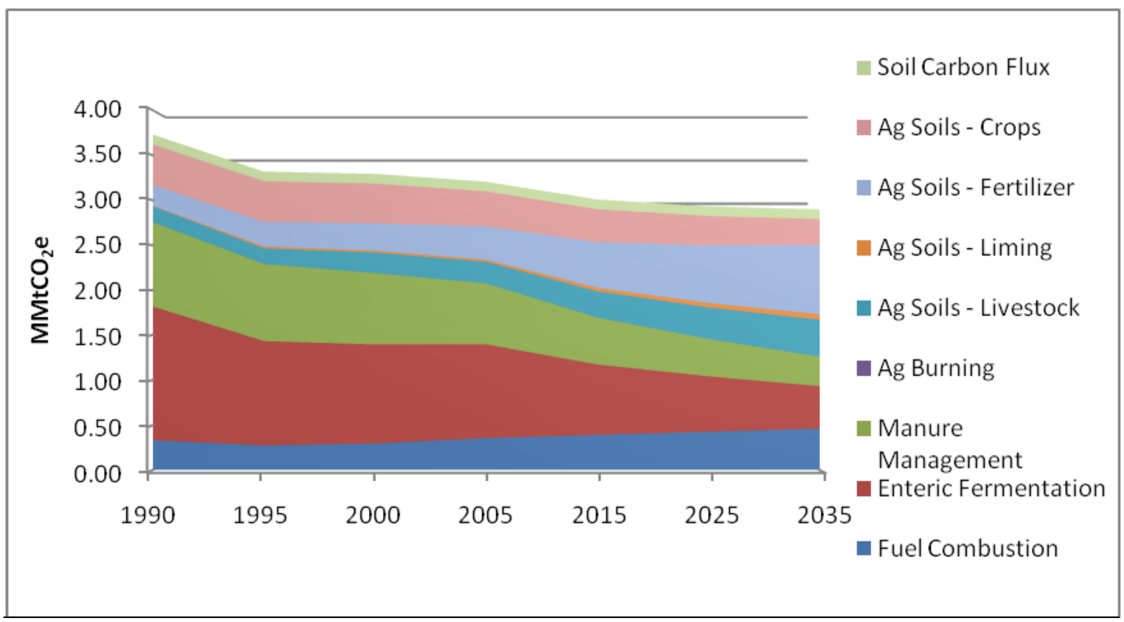
As shown in Figure F1 and Table F2, gross GHG emissions from agricultural sources range between about 3.7 and 2.9 $MMtCO_2e$ from 1990 through 2035, respectively. In 1990, enteric fermentation accounted for about 40% (1.49 $MMtCO_2e$) of total agricultural emissions and is estimated to account for about 16% (0.47 $MMtCO_2e$) of total agricultural emissions in 2035. The manure management category accounted for 25% (0.94 $MMtCO_2e$) of total agricultural emissions in 1990 and is estimated to account for about 11% (0.33 $MMtCO_2e$) of total agricultural emissions in 2035. The agricultural soils categories show 1990 emissions accounting for 23% (0.88 $MMtCO_2e$) of total agricultural emissions and 2035 emissions estimated to be about 53% (1.54 $MMtCO_2e$) of total agricultural emissions. Within the Ag Soils category, emissions from crops decrease over the forecast period, whereas all other categories show an emissions increase, particularly fertilizer emissions, which are estimated to increase 108% between 2005 and 2035. Fuel combustion accounted for only 9% of total emissions in 1990 (0.33 $MMtCO_2e$), but this is estimated to increase to 16% (0.46 $MMtCO_2e$) of the total by 2035.

For the entire inventory and forecast period, agricultural burning emissions account for less than 1% of SCAG's total gross GHG emissions from the agricultural sector. Due to a lack of historical information or other forecast data, soil carbon flux is held constant throughout the period, although emissions account for between 3% and 4% of the agricultural sector total.

Table F2. Gross GHG Emissions from Agriculture (MMtCO$_2$e)

Subsector	1990	1995	2000	2005	2008	2010	2020	2035
Fuel Combustion	0.33	0.27	0.29	0.35	0.36	0.37	0.41	0.46
Enteric Fermentation	1.49	1.16	1.10	1.04	0.92	0.88	0.70	0.47
Manure Management	0.94	0.86	0.80	0.68	0.61	0.58	0.47	0.33
Ag Burning	0.0004	0.0004	0.0003	0.0001	0.0001	0.0001	0.0001	0.0001
Ag Soils - Livestock	0.18	0.17	0.23	0.24	0.25	0.26	0.32	0.41
Ag Soils - Liming	0.01	0.02	0.02	0.02	0.03	0.03	0.04	0.06
Ag Soils - Fertilizer	0.23	0.27	0.30	0.37	0.42	0.44	0.57	0.77
Ag Soils - Crops	0.45	0.45	0.44	0.39	0.40	0.39	0.35	0.29
Soil Carbon Flux	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11
Total	**3.74**	**3.33**	**3.30**	**3.21**	**3.09**	**3.07**	**2.96**	**2.90**

Figure F1. Gross GHG Emissions from Agriculture



Source: CCS calculations based on approach described in text.
Notes: Emissions for agricultural residue burning are too small to be seen in this chart.

**This inventory and forecast has been prepared with the most up-to-date information and should not be compared to any previous analysis at this time.*

For enteric fermentation and manure management, historical emissions were driven primarily by the negative growth (about -2.2% annually) in the dairy cattle population from 1990 through 2006. The beef cattle population showed a similar decline (-1.8% annually for 1990 through 2006). Swine populations declined by about 5.6% annually during the 1990 through 2006 period. Overall enteric fermentation emissions declined by 2.3% annually between 1990 and 2006, whereas manure management emissions declined by 2.2%.

The growth in fuel combustion comes primarily from steady growth in emissions from natural gas and diesel use. Ag soils emissions growth are primarily the result of increases seen in fertilizer application.

Key Uncertainties

Emissions from enteric fermentation and manure management are dependent on the estimates of animal populations and the various factors used to estimate emissions for each animal type and manure management system (i.e., emission factors that are dependent on several variables, including manure production levels, volatile solids content of manures, and CH_4 formation potential). Each of these factors has some level of uncertainty. Also, animal populations fluctuate throughout the year, and thus using point estimates introduces uncertainty into the average annual estimates of these populations.

In addition, there is uncertainty associated with the original population survey methods, because only select years were obtained from each county. The largest contributors to uncertainty in emissions from manure management are the emission factors, which are derived from limited data sets. It should also be noted that the current estimates do not account for manure methane reduction projects (e.g., anaerobic digesters) in place or to be constructed within the SCAG region during the forecast period. Future refinements for manure management emissions should be based on bottom-up methods rather than apportioning the state-level totals based on animal populations. These refinements should include the effects of manure digestion projects currently in place and expected during the forecast period.

For fuel combustion emissions in agriculture, the key uncertainty is whether state-level crop production fuel intensity is representative of the SCAG region. As with manure management, future work should assess emissions from the bottom-up using studies and data on SCAG region specific crops and the associated fuel use intensity.

Another contributor to uncertainty in the emission estimates is the projection assumptions. For the fertilizers, agricultural crop residues, and nitrogen-fixing crops categories, this inventory assumes that the average annual rate of change in future year emissions will follow the historical average annual rate of change from 1990 through the most recent year of data.

For the fuel combustion, agricultural burning and fertilizer use subsectors, the emissions in this analysis were estimated based on SCAG's portion of overall California emissions. This was used as a surrogate method since no further specific information was available on the emissions in the SCAG region. Because a stand-in value was used to allocate SCAG's portion of state emissions, there is an additional level of uncertainty for estimates using this method.

Appendix G. Waste Management

Overview

Greenhouse gas (GHG) emissions from waste management include:

- Solid waste management –
- Methane (CH_4) emissions from solid waste landfills, accounting for CH_4 that is flared or captured for energy production (this includes both open and closed landfills),
- Nitrous oxide (N_2O) emissions from the combustion of biogas generated at landfills that capture and combust landfill gas (LFG),
- CH_4 and N_2O emissions from composting operations – due to limited data availability at the time of this report, this source has not been included in this inventory and forecast report,
- Carbon dioxide (CO_2) flux at landfills and composting operations – due to limited data availability at the time of this report, this source has not been included in this inventory and forecast report,
- Solid waste combustion – CH_4, CO_2, and N_2O emissions from the combustion of solid waste in incinerators or waste to energy plants[118]; and
- Wastewater management –
- CH_4 and N_2O from municipal wastewater (WW), and
- CH_4 and N_2O from industrial WW – due to limited data availability at the time of this report, this source has not been included in this inventory and forecast report.

Inventory and Reference Case Projections

Solid Waste Management

For solid waste management, the data source was the California Air Resources Board (ARB) 1990-2008 GHG Inventory and 2020 Forecast.[119] The ARB Inventory and Forecast utilized a bottom-up approach to the solid waste landfill inventory. Representatives of ARB provided the Center for Climate Strategies (CCS) with the annual CH_4 and N_2O emissions estimates for all landfills in the SCAG region for the years 1990 through 2020. ARB utilized the first-order decay equation to estimate potential CH_4 emissions due to waste emplacement at landfills. The default collection efficiency at landfills that collect and combust LFG, which is either flared or utilized for energy, is 75% and the default oxidation rate is 10%. Emissions that took place prior to placement of the LFG controls at controlled landfills are classified as uncontrolled emissions.

[118] According to W. Tasat and L. Hunsaker at California ARB, waste combustion emissions without energy recovery do not exist in the SCAG region. While there may be a very small amount of illegal open burning, this practice is not common enough to produce significant GHG emissions.
[119] ARB. "California Greenhouse Gas Emission Inventory". Results and supporting documents available at: http://www.arb.ca.gov/cc/inventory/inventory.htm

ARB also provided N_2O emissions that result from the combustion of LFG. These emissions are minor and not typically included in GHG inventories of landfills, but there is sufficient LFG collection in California to produce enough N_2O to warrant inclusion in this inventory.

ARB extended the emissions forecast for landfills (and all other sources) to 2020. CalRecycle provided ARB with forecasts of waste deposition rates for 2008-2020, which ARB used to forecast emissions for this period. However, CalRecycle did not have estimates of waste deposition forecasts for the 2020-2035 period[120]. Therefore, for the SCAG forecast of landfill CH_4 and N_2O emissions from 2021 through 2035, CCS estimated emissions by applying the calculated 2008-2020 average annual emissions growth rate (3.24% for controlled landfills, 1.04% for uncontrolled landfills) to estimate the 2020 through 2035 emissions. These emission growth rates do not necessarily reflect growth in waste disposal, as there is a lag of up to a few years between when waste is disposed in landfills and the peak of CH_4 emissions from that waste. This occurs because CH_4 emissions at a landfill begin as soon as oxygen within the waste disposal mass is depleted; and these emissions increase as anaerobic decomposition increases. Given the steady increase in population in the SCAG region between 1990 and 2010, waste emissions could increase through 2035, to the extent that waste generated within the SCAG region is landfilled within the region.

Emissions from industrial landfills are not quantified as a separate emissions category because all landfills in the SCAG region are captured in the ARB data set, and it is assumed that there are no additional landfills that manage only industrial waste. Composting is a growing practice in California and the United States, as the practice reduces the volume of waste disposed in landfills, manages organic residuals in an aerobic manner that reduces CH_4 emissions, and provides a carbon sink as carbon from the organic waste is formed into humic compounds that can be applied to soils to reduce or eliminate the use of fossil-based nitrogen fertilizers. Composting does produce CH_4 and N_2O emissions. However, neither CalRecycle nor ARB was able to provide CCS with composting throughput data at the time of this study.

Solid waste management can represent a potential carbon sink, as carbon that would have been emitted as CO_2 if organic residuals were left above ground to decompose naturally is stored over a long period of time(e.g., >50 years). The composting carbon sink, and the reasons for its omission from this inventory, is described in the previous paragraph. Landfills can be a carbon sink, as less than 100% of the carbon contained in wood, paper, food, and yard waste is eventually released as LFG, which contains CH_4 and CO_2. The EPA State Inventory Tool (SIT) does provide a module (Land Use, Land Use Change, and Forestry) that estimates carbon sinks at the state level. However, this is a top-down estimate based on population and is not compatible with the bottom-up approach used in this inventory. Therefore, the carbon sink from landfill disposal of waste is not estimated in this inventory and forecast report.

[120] Personal communication: C. Williams (CalRecycle) to Jackson Schreiber (CCS). February 14, 2012.

Solid Waste Combustion

According to ARB, waste combustion emissions without energy recovery do not exist in the SCAG region. While there may be a very small amount of illegal open burning, this practice is not common enough to produce significant GHG emissions. Therefore, this source is not included in this inventory and forecast report. However, any waste combustion source in which the resulting heat is used to generate electricity or thermal energy would be included in the Electricity Use and Supply sector or Residential, Commercial, and Industrial sector inventories, respectively.

Wastewater Management

Greenhouse gas emissions from municipal wastewater treatment were also estimated using a bottom-up procedure. Every four years, most recently in 2008,[121] the US EPA releases a Clean Watersheds Needs Survey (CWNS) database that includes the location and total existing flow for each municipal wastewater treatment facility.[122] Emission factors were developed from default parameters provided by the EPA SIT Wastewater Module. This includes direct CH_4 emissions from wastewater treatment and direct N_2O emissions from wastewater treatment. Indirect N_2O emissions were not included in this estimate because they are not included in the ARB statewide waste GHG emissions estimate.

The amount of wastewater treated in each year throughout the historic inventory and reference case forecast period (1990-2035) is based on the 2008 existing municipal wastewater flow at wastewater treatment plants (WWTPs) in the SCAG region, as provided by the CWNS database, and the population data and projections for the SCAG region, as provided to CCS by SCAG. The existing flow in 2008 is divided by the 2008 population to yield flow per capita in units of million gallons per day per capita (MGD/person). This value is multiplied by the population and appropriate number of days in the year (366, as 2008 was a leap year) to yield the total flow for each year.

The total flow for each year is multiplied by the appropriate emission factor to yield the estimated GHG emissions in that year. The emission factors were developed from SIT methods and default parameters. As the flow data are bottom-up, each county ended up with different emission factors. The development of these factors is shown in the equations below:

[121] 2004 CWNS data were collected and assessed, but not used for this study due to significant variability between the 2004 and 2008 datasets. As 2008 is the most recent dataset, it was chosen for this study.
[122] US EPA. 2010. "Clean Watersheds Need Survey Report 2008 Report to Congress and 2008 Data." Available at: http://www.epa.gov/cwns/2008reportdata.htm.

Direct CH_4:

$$EF_{CH_4} = \frac{P_{2008} \times BOD \times n \times BOD_{AD} \times EF_{BOD}}{1000 \times WWF_E}$$

where:

EF_{CH_4}: Direct CH_4 Municipal Wastewater Emission Factor (tCH_4/MG)[123]

P_{2008} : Population in a given county, 2008

BOD : SIT default for Biological Oxygen Demand (BOD) per capita (0.09 kg per capita per day)

n : number of days per year

BOD_{AD} : SIT default fraction of BOD anaerobically digested (16.25%) at WWTPs

EF_{BOD} : SIT default CH_4 emission factor for BOD (0.6 tCH_4/tBOD)

1000 : Conversion factor to convert kg BOD into tBOD

WWF_E : Existing flow for 2008 in county (MG). From EPA CWNS data.

Direct N_2O:

$$EF_{N_2O} = \frac{P_{2008} \times \%P_{NS} \times EF_{CAP} \times 1{,}000{,}000}{WWF_E}$$

where:

EF_{N_2O}: Direct N_2O Municipal Wastewater Emission Factor (tN_2O/MG)[124]

WWF_E : Existing flow for 2008 in county (MG). From EPA CWNS data.

P_{2008} : Population in a given county, 2008

$\%P_{NS}$: Percent of county population not on septic (see Table G1)

EF_{CAP} : SIT default N_2O emission factor for N_2O per person per year (4.0 gN_2O/person/year)

$1{,}000{,}000$: Conversion factor to convert gN_2O into tN_2O

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[123] tCH_4: metric tons CH4; MG: million gallons influent flow
[124] tCH_4: metric tons CH4; MG: million gallons influent flow

Table G1. Fraction of Population Utilizing Centralized Wastewater Treatment, 2008[125]

County	2008 Fraction not on Septic
Imperial	89.94%
Los Angeles	99.77%
Orange	99.24%
Riverside	96.41%
San Bernardino	91.50%
Ventura	99.29%

Figure G1. Fraction of Population Utilizing Centralized Wastewater Treatment, 2008

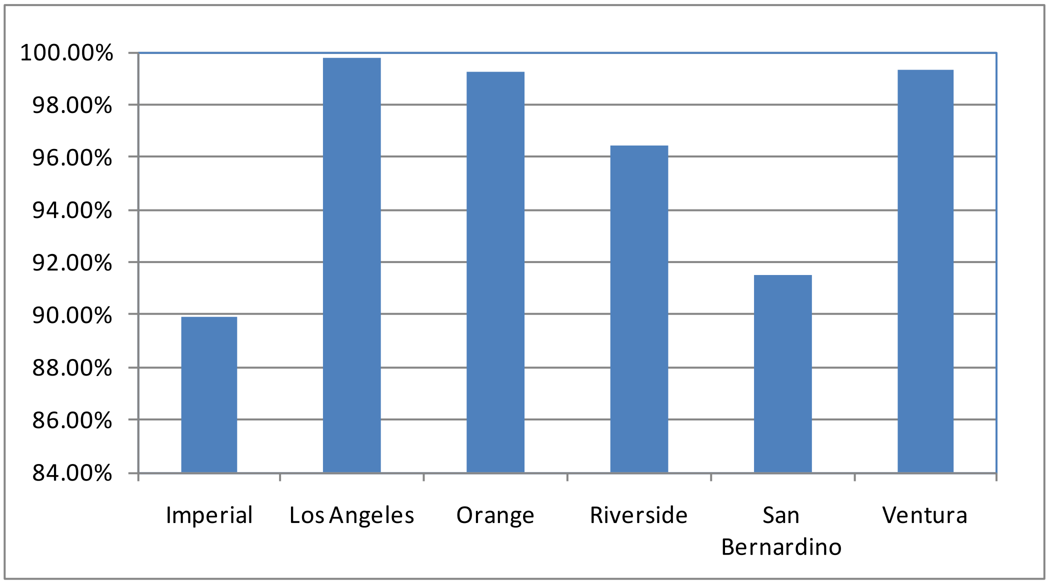


Table G2 summarizes the emission factors for each county in the SCAG region. These factors are multiplied by the estimated flow for each year throughout the inventory and forecast period, as well as the global warming potential for CH_4 or N_2O, as appropriate.

Table G2. Municipal Wastewater Emission Factors, by SCAG County

County	CH_4 Emission Factor (tCH_4/MG)	Direct N_2O Emission Factor (tN_2O/MG)
Imperial	0.077	8.59 E-05
Los Angeles	0.031	3.89 E-05
Orange	0.016	1.95 E-05
Riverside	0.086	1.03 E-04
San Bernardino	0.038	4.32 E-05
Ventura	0.093	1.15 E-04

[125] US EPA. 2010. "Clean Watersheds Need Survey Report 2008 Report to Congress and 2008 Data." Available at: http://www.epa.gov/cwns/2008reportdata.htm.

For industrial wastewater emissions, SIT provides default assumptions and emission factors for three industrial sectors: Fruits & Vegetables, Red Meat & Poultry, and Pulp & Paper. However, default data are only available for the Red Meat sector from the SIT module. Upon checking the source data for these default numbers, none of these red meat facilities are in the SCAG region. Therefore, lacking sufficient industrial wastewater data, this source was not included in this inventory and forecast report.[126] It has been reported that there are industrial wastewater emissions sources from the petroleum refinery industry. There are not enough throughput data or methods available to estimate emissions from this source at the time of this report.

Results

Figure G2 and Table G3 show the gross emission estimates for the waste management sector. Overall, the sector accounts for about 5.1 $MMtCO_2e$ in 2008. By 2035, gross emissions are expected to grow to about 9.0 $MMtCO_2e$. The growth in emissions is driven by the solid waste management sector, primarily due to emissions from the decomposition of waste that is already in place or soon to be emplaced in SCAG landfills.

Table G3. SCAG GHG Emissions from Waste Management ($MMtCO_2e$)

	1990	2000	2005	2008	2010	2015	2020	2030	2035
Solid Waste Landfill CH_4	3.77	3.38	3.72	3.84	3.99	4.45	4.99	6.48	7.40
Solid Waste Landfill N_2O	0.00043	0.00068	0.00087	0.00090	0.00093	0.0010	0.0012	0.0016	0.0019
Total Landfill	**3.77**	**3.38**	**3.72**	**3.84**	**3.99**	**4.45**	**4.99**	**6.48**	**7.40**
Municipal WW CH_4	0.99	1.14	1.21	1.26	1.27	1.33	1.39	1.49	1.55
Municipal WW Direct N_2O	0.018	0.021	0.022	0.023	0.023	0.024	0.025	0.027	0.028
Total Municipal WW	**1.01**	**1.16**	**1.23**	**1.28**	**1.30**	**1.35**	**1.41**	**1.52**	**1.58**
Total Waste Sector	**4.78**	**4.54**	**4.96**	**5.12**	**5.29**	**5.80**	**6.41**	**8.00**	**8.98**

Key Uncertainties

Emissions from landfills were based on annual disposal data, which is more uncertain than landfill-specific LFG monitoring data. Landfill-specific monitoring data would provide exact emissions estimates, but are usually only available at controlled landfills, and then only track the amount of LFG actually collected. As a result, the amount of LFG released is typically estimated based on the first-order decay equation.

The landfill CH_4 emission forecast for 2021 through 2035 is based on the growth rate from the results of the ARB model. The application of the first order decay equation in these years may yield a curve that flattens out over time. However, ARB does not model past 2020. Better forecasts for the SCAG region beyond 2020 could be developed with forecasted waste emplacement data at SCAG landfills and the first-order decay model.

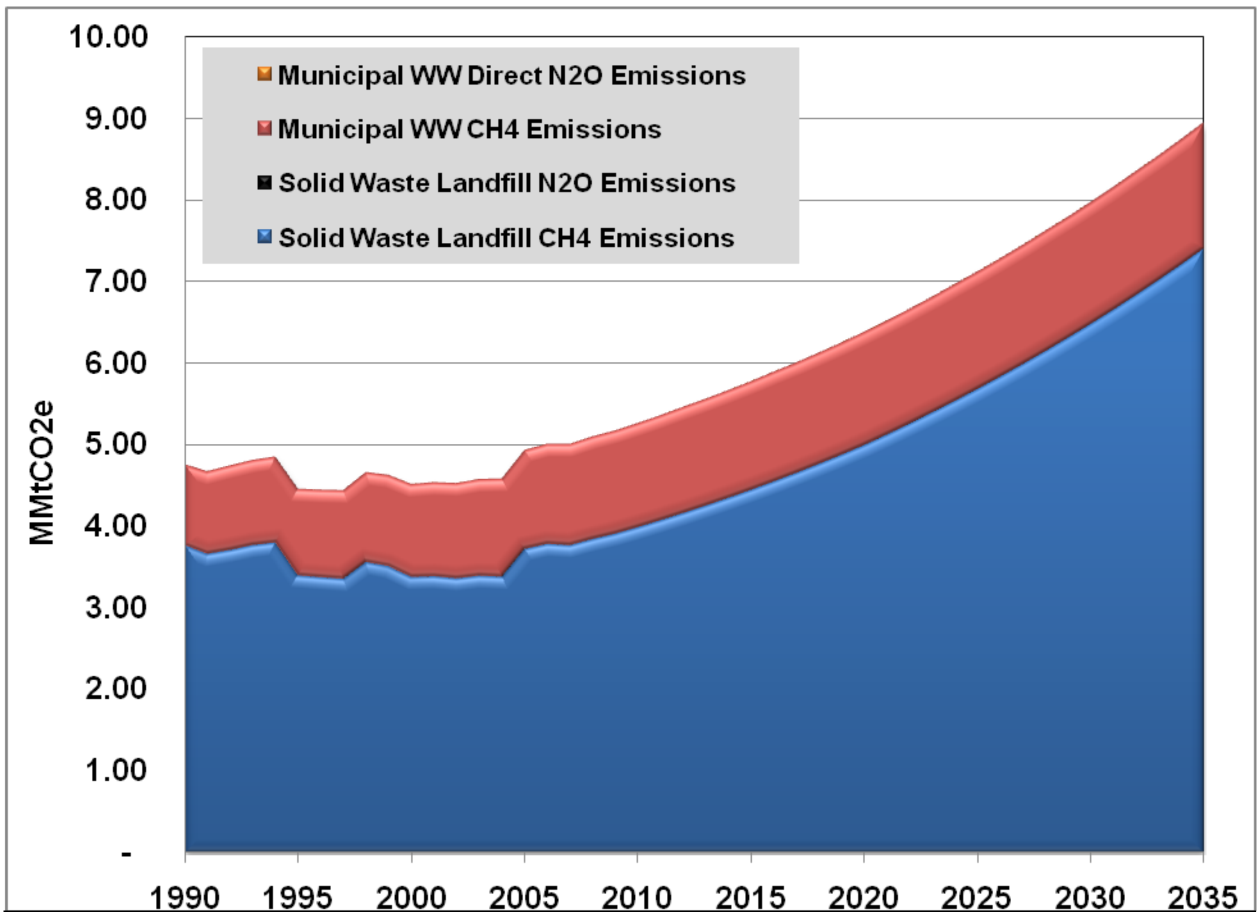
[126] It is understood by CCS that emissions likely exist from this industrial wastewater. However, CCS could not locate a data source on which to base the calculations. Further investigation is recommended.

It is not known how much of the wastewater treatment biosolids generated in the SCAG region are applied to soils within the region. Additional work is needed to gain a better understanding of biosolids management within the region and the associated GHG emissions.

Industrial wastewater emissions were not included in this Inventory and Forecast. While it is likely that these emissions do occur within the SCAG jurisdiction, insufficient data were available at the time of this study to compute GHG emissions estimates from this source (including refinery wastewater treatment).

Composting emissions, solid waste management carbon sinks, and industrial wastewater treatment have not been included in this inventory due to insufficient data. Including these sources would decrease the uncertainty of the total waste sector emissions.

Figure G2. SCAG GHG Emissions from Waste Management (MMtCO$_2$e)



Notes: LF – landfill; WW – wastewater; emissions for solid waste combustion were estimated to be negligible.

This inventory and forecast has been prepared with the most up-to-date information and should not be compared to any previous analysis at this time.

Appendix H. Forestry & Land Use

Overview

The forestry sector includes net carbon dioxide (CO_2) flux from both forested lands and urban forests. The sector covers a number of GHG sources and sinks, but is primarily devoted to accounting for CO_2 sequestration or removals (emissions) in forested landscapes and urban forests. Carbon dioxide flux in any given area could represent a net source or a net sink. Wildfires and prescribed burns also produce methane (CH_4) and nitrous oxide (N_2O) emissions.

Other emission sources include non-farm fertilizer application, such as from residential landscaping, parks, or golf courses (this category of emissions is sometimes referred to as settlement soils). Any fuel combustion occurring in this sector (e.g., forest industry) is captured within the industrial fuel combustion sector.

Inventory and Reference Case Projections

Forested Landscape

Estimates of net CO_2 sequestration/emissions were developed using two primary sources of input data:

1. County-level estimates of carbon stocks in forests and carbon sequestration rates from the US Forest Service (USFS) and National Council for Air and Stream Improvement (NCASI) Carbon On-Line Estimator (COLElite);[127]
2. County-level estimates of forest acreage for 1992, 2001, and 2005 provided by the Southern California Association of Governments [(SCAG) in conjunction with the United States Geological Survey].

Carbon sequestration by forestland for each county was estimated using three steps:

- First, by multiplying the forest area in a given year by the forest carbon sequestration rate for that county (estimated from 2001-2008 forest carbon values from COLElite), an estimate of carbon stocks was obtained for each year. For historic and forecast years where a COLElite carbon stock estimate was not available, the 2001-2008 average county-level value was used;
- Second, carbon flux (sequestration or emission) was estimated by subtracting carbon stocks for a previous year by the stocks for the current year; a negative value indicates a net growth in carbon stocks (sequestration), while a positive value indicates a loss of carbon stocks (emission);
- Third, this net loss or gain was then multiplied by 44/12 to convert carbon to CO_2.

[127] COLElite homepage: http://www.ncasi2.org/cgi-bin/RCOLE/coleLite.pl; accessed August 2010.

The steps above are represented by the equations below:

County-level carbon stocks (tC) = carbon density (tC/ha) x area (ha)

Carbon dioxide flux (tCO_2) = [Carbon stocks Year 1 (tC) – Carbon stocks Year 2] x 44/12

Note that this carbon stock accounting approach is commonly used to estimate regional, state and national carbon fluxes in forested areas. In using this type of approach, any loss of forest carbon due to disease, fire, pest, or other factor is accounted for in the estimation of annual carbon densities. In this case, the COLE modeling data stem from the US Forest Service's Forest Inventory & Analysis (FIA) surveys. It is assumed that these carbon densities are representative of the areas under study and would thus have captured the average annual carbon losses occurring in between survey years. Table H1 and Figure H1 provide the carbon density values output by the COLElite tool in metric tons of carbon per hectare (tC/ha). Table H2 provides a summary of the historic forest area estimates for the SCAG counties in hectares (ha)[128]. It's important to note that some of the year to year differences at the county level could be the result of differing data sources or classification systems; however at the regional level, a clear trend toward loss of forested area is apparent.

Table H1. Forest Carbon Density Values from COLElite, tC/ha

County	2001	2002	2003	2004	2005	2006	2007	2008	AVG
Imperial	62.2	62.2	62.2	63.6	65.0	69.5	66.8	64.1	64.4
Los Angeles	63.4	138.5	114.2	90.2	92.2	113.7	93.6	93.6	99.9
Orange	131.2	102.1	98.4	98.4	94.7	111.8	111.8	111.8	107.6
Riverside	100.7	116.8	265.6	56.5	110.1	85.3	153.0	69.9	119.7
San Bernardino	93.9	118.2	58.2	122.0	123.5	123.8	82.9	82.9	100.7
Ventura	79.7	74.5	69.5	112.7	78.8	77.2	90.2	90.2	84.1

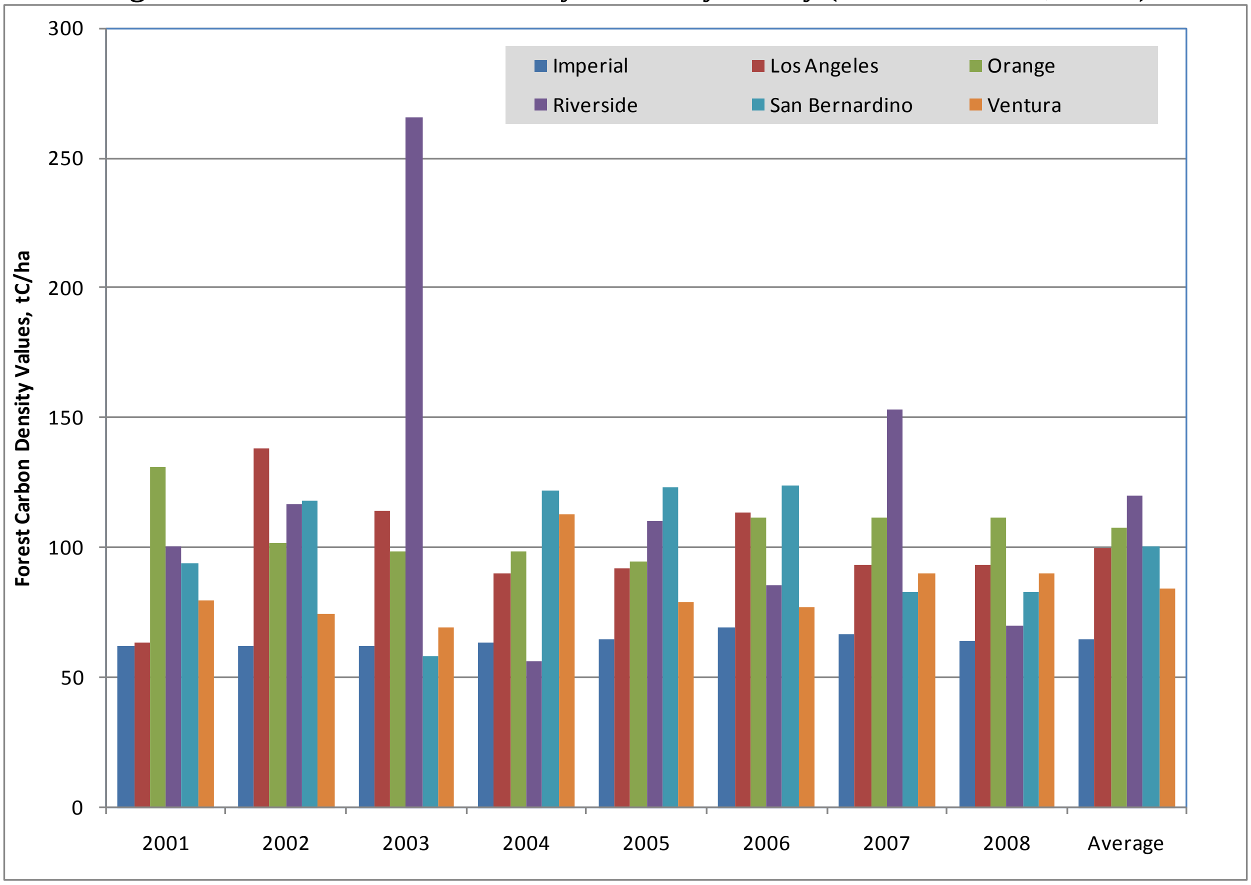
Table H2. SCAG Region Historic Forest Area, ha

County	1992	2001	2005
Imperial	4,551	513	15
Los Angeles	118,471	74,204	44,990
Orange	16,928	3,269	3,300
Riverside	75,007	41,509	32,784
San Bernardino	135,309	106,961	83,495
Ventura	71,081	101,409	50,264
Total SCAG Region	**421,347**	**327,864**	**214,847**

Notes: includes deciduous forest, evergreen forest, and mixed forest classifications; excludes woods wetlands.

[128] 1 hectare = 2.47 acres

Figure H1. Forest Carbon Density Values by county (from COLElite, tC/ha)



For more precise subregional estimates, a different and more bottom-up approach would be needed to pinpoint the locations and timing of immediate losses of carbon due to large disturbances, such as wildfires. Such an approach would require consistent sub-county level data on forest area, wildfire acreage, forest type, carbon density, fraction of biomass/carbon burned, and, for forecasting purposes, information on the expected successional change of the burned area (e.g., grassland to hardwood to conifer).

Urban Forestry & Land Use

Historic urban acreage was obtained from SCAG geographic information systems data. Urban forest sequestration was estimated by multiplying urban acreage by canopy cover percentage[129] and a state-specific urban forest carbon sequestration rate.[130] The estimated carbon sequestration rate is then multiplied by 44/12 to convert to CO_2.

Emissions of N_2O from non-farm fertilizer application were also estimated. The US Environmental Protection Agency (EPA) State Inventory Tool (SIT) Land Use, Land Use

[129] For California, 11%; from EPA's State Inventory Tool Forest and Land Use Module.
[130] For California, 2.23 metric tons C/hectare/year; from EPA's State Inventory Tool Forest and Land Use Module.

Change and Forestry module was used to develop a state-level estimate. The state-level estimate was allocated to the SCAG region based on urban acreage (developed land).[131]

Wildfire and Prescribed Burning Emissions

Forest fires, whether wildfires or prescribed burns, emit CH_4 and N_2O as well as CO_2. Carbon dioxide emissions from forest fires are not included here, because they are accounted for under the carbon stock modeling approaches described under the forested landscape subsector above (carbon losses as a result of forest fires are assumed to be captured within the carbon density estimates provided by the COLE model).

For prescribed burns, emissions of CH_4 and N_2O were estimated by multiplying burned acreage by the amount of dry matter, the combustion efficiency, the CH_4 or N_2O emission factor, and the global warming potential of CH_4 or N_2O.[132] Due to a lack of readily-available wildfire and prescribed burn acreage estimates for much of the historical period and the low contribution of the non-CO_2 gases to sector-level totals, bounding estimates were developed using 2003 prescribed burn acreage data and 2009 wildfire acreage data. Both of these selected years are thought to be of fairly high activity compared to other years, so the estimated emissions should also be considered conservatively high. For example, 2003 prescribed burn activity was 15,800 acres compared to about 900 acres in 2002.[133] For wildfires, in 2009 there were approximately 200,000 acres burned in the SCAG region based on California Department of Forestry data.[134]

The equation for estimating emissions for non-CO_2 gases is as follows:

$$\text{Emissions } (MMtCO_2e/yr) = A \times F \times CE \times EF \times 1/2.47 \times GWP \times 1/10^{12}$$

where: A = area; acres

F = fuel loading; 150 kg dry matter/ha

CE = combustion efficiency; 34%

EF = emission factor; 8.1 g CH_4/kg dry matter burned; 11 g N_2O/kg dry matter burned;

2.47 = conversion from ha to acres;

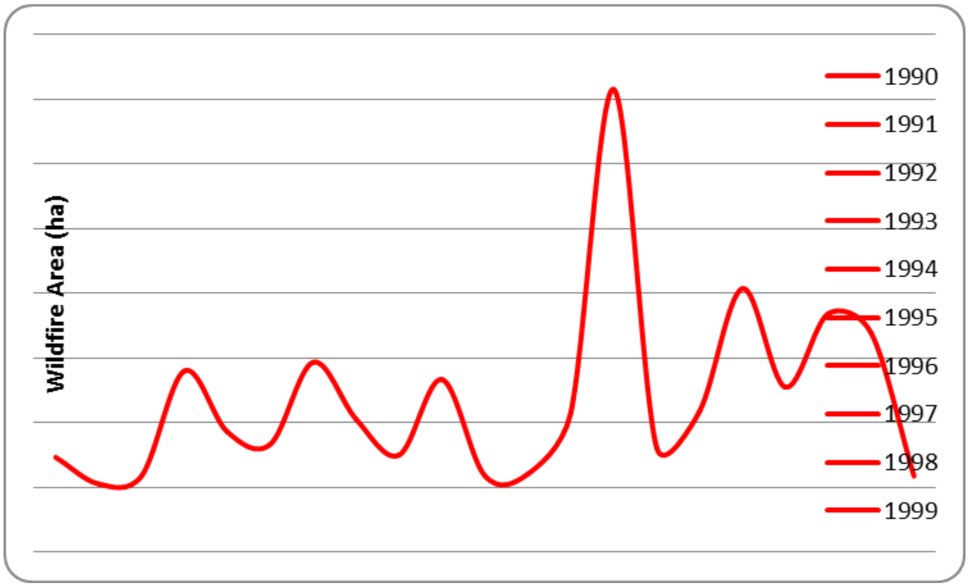
GWP = global warming potential; 21 for CH_4, 310 for N_2O;

1/12 = conversion from grams to million metric tons

[131] Urban acreage for California found in Table 1 of the "Summary Report - 2007 National Resources Inventory" published by the US Department of Agriculture Natural Resources Conservation Service; report available at http://www.nrcs.usda.gov/technical/NRI/. SCAG urban acreage: in 2005, the developed areas in the SCAG region represented 23% of the developed acres in the state. This value was used for all years in the inventory and forecast.
[132] Factors and values from EPA's State Inventory Tool Forest and Land Use Module.
[133] Data received from South Coast Air Quality Management District.
[134] http://cdfdata.fire.ca.gov/pub/cdf/images/incidentstatsevents_178.pdf.

For wildfires, screening-level estimates of CH_4 and N_2O were developed based on a study conducted on wildfire emissions in southern California during a period of significant activity (October 2003)[135] and area data on wildfires that burned greater than 100 acres from the CA Department of Forestry and Fire Protection.[136] Estimates of the annual wildfire activity in the SCAG region are provided in Figure H2.

Figure H2. SCAG Region Wildfire Activity



Bounding estimates were developed for CH_4 and N_2O emissions based on the estimated emissions and wildfire area from the Clinton et al study (235,627 ha) and the SCAG wildfire areas in each year. The high end of the range includes emissions from the burning of all areas including shrub cover, while the low end of the range excludes these areas (likely a closer estimate of just the emissions associated with forest cover). The bounding estimates for 1990-2010 annual average emissions were 70,308 tCO_2e to 184,707 tCO_2e. The low end of the range estimated for each year is reported in the results for wildfire emissions.

Forecast Method

Forested landscape and urban forestry carbon sequestration/emission estimates were forecasted based on estimated changes in future land use. The estimated changes in future land use were derived from regional population growth projections from SCAG. Assuming that urban growth occurs at the same density as current household density in the region, then urban areas will grow at approximately 13,000 acres annually from 2008-2035. Assuming that future land use change

[135] Clinton, N.E., Gong, P., Scott, K., "Quantification of pollutants emitted from very large wildland fires in Southern California, USA", *Atmospheric Environment*, vol. 40, pp. 3686-3695, 2006.
[136] CA Dept. of Forestry and Fire Protection, Fire and Resource Assessment Program; http://frap.cdf.ca.gov/data/frapgisdata/download.asp?spatialdist=1&rec=fire.

will mirror that of the past 20 years, about two-thirds of this new urban area will come from current forested areas and the other third from agricultural areas.

For the forecast years, forest and urban acreage was estimated for each year from 2008-2035. Forested area was estimated to decrease at a rate of 2.7%/yr. This rate is about half that observed from 1992-2005 (5.0%/yr). Carbon densities in both forested landscapes and urban forests were held constant at base year levels.

Future emissions from wildfires and prescribed burns were held at the bounding level estimates described above. It is possible that forest fire activity will grow during the forecast period due to the near-term effects of climate change; however, the contribution of non-CO_2 gases should remain fairly small. See the Key Uncertainties section below for more discussion of future forested landscape carbon flux.

For non-farm fertilizer application, emissions were assumed to grow at the same rate as urban development (0.91% annually) from 2008-2035.

Results

Table H3 provides a summary of the historic and forecast estimates of GHG emissions for the forestry and land use sector in the SCAG region. Negative values in this table are shown for subsectors that are net sinks of carbon, while those with positive values are a source of GHG emissions.

Table H3. SCAG Forestry & Land Use Sector GHG Emissions

Sector	($MMtCO_2e$)											
	1990	**1995**	**2000**	**2005**	**2007**	**2008**	**2010**	**2015**	**2020**	**2025**	**2030**	**2035**
Forest Land	4.47	4.00	3.48	15.36	16.28	3.33	1.32	1.32	1.32	1.27	1.27	1.27
Forest Fires & Prescribed Burns (CH_4 & N_2O)	0.03	0.04	0.01	0.06	0.08	0.14	0.01	0.07	0.07	0.07	0.07	0.07
Urban Forests	-0.43	-0.45	-0.48	-0.51	-0.52	-0.53	-0.53	-0.56	-0.58	-0.61	-0.64	-0.67
Non-farm Fertilizer (Settlement Soils)	0.05	0.06	0.06	0.08	0.08	0.08	0.08	0.09	0.09	0.09	0.10	0.10
Total	**4.12**	**3.64**	**3.07**	**15.00**	**15.93**	**3.03**	**0.87**	**0.91**	**0.89**	**0.82**	**0.80**	**0.77**

The forestry sector represents a net source of emissions during the period of analysis; however, the strength of the source is expected to diminish over time as less forest land is lost to development than has occurred since 1990. Historic data on land use for the region show that forested area was over 1 million acres in 1992 and had shrunk to 530,000 acres by 2005. While the carbon sequestration potential of forested lands is expected to continue to shrink during the planning period due to some continued losses of forested area, the urban forest sink will grow slightly, simply driven by a growing urban land base.

The net emissions from forest fires represent CH_4 and N_2O emissions from acres burned in wildfires and prescribed fires. Since only limited data were available for prescribed burns (2002 and 2003); the higher 2003 estimates were selected as a conservatively high estimate as an average to apply over the entire inventory and forecast. Non-farm fertilizer application is a source of N_2O emissions and also grows over the projection period due to an increase in population and expected growth in urbanized area.

Key Uncertainties

Consideration of forest carbon flux did not include the soil carbon pool due to high levels of uncertainty expressed by the US Forest Service on these values during previous communications with CCS. When conducting a forest carbon inventory using a stock change based approach, such as that used here, year to year variations are much less certain than longer term trends (e.g., 5 to 10 years or more). This is due to at least two factors:

- First, there was a change in FIA forest survey methods used by the US Forest Service beginning around the year 2000. Historical surveys were aimed at gathering data important to the forest products industry, while the current survey methods are designed to gather data to support overall forest biomass estimates. As an example of the differences, all tree species and forms are surveyed in addition to more completed coverage of each forest carbon pool (i.e., standing live tree, standing dead, dead/down, undergrowth, forest floor, soil carbon).
- Second, the FIA surveys are now conducted on a rolling 5 or 10 year schedule whereby 10% or 20% of plots are surveyed each year; so, the overall coverage of any given FIA data set could be limited to a relatively small number of plots, which could affect representativeness for that data set.

Significant impacts to the forecasted carbon flux from the forested landscape are possible during the policy period due to the near-term effects of climate change, including warmer temperatures and reduced precipitation. These could lead to increases in mortality and disease, as well as wildfire activity. The current forecast does not address these potentially significant impacts.

Projections in forest land change, urban forestry change, and settlement soils are all based on expected growth in developed area driven by population predictions. Therefore, uncertainties in the population predictions and the type of future growth (population density of future development) will have a great impact on each of these sub-sectors. The large apparent loss of forested acreage between 1992 and 2005 should be further investigated. It is possible that some of this decline is due to differences in land cover classifications by USGS during these two years. For example, it is possible that some types of shrubland could have previously been defined as forests.

Appendix I. Greenhouse Gases and Global Warming Potential Values: Excerpts from the Inventory of US Greenhouse Emissions and Sinks: 1990-2000

Original Reference: Material for this Appendix is taken from the *Inventory of US Greenhouse Gas Emissions and Sinks: 1990 - 2000*, US Environmental Protection Agency, Office of Atmospheric Programs, EPA 430-R-02-003, April 2002 www.epa.gov/globalwarming//emissions. Michael Gillenwater directed the preparation of this appendix.

Introduction

The *Inventory of US Greenhouse Gas Emissions and Sinks* presents estimates by the United States government of US anthropogenic greenhouse gas emissions and removals for the years 1990 through 2000. The estimates are presented on both a full molecular mass basis and on a Global Warming Potential (GWP) weighted basis in order to show the relative contribution of each gas to global average radiative forcing.

The Intergovernmental Panel on Climate Change (IPCC) has recently updated the specific global warming potentials for most greenhouse gases in their Third Assessment Report (TAR, IPCC 2001). Although the GWPs have been updated, estimates of emissions presented in the US *Inventory* continue to use the GWPs from the Second Assessment Report (SAR). The guidelines under which the *Inventory* is developed, the *Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories* (IPCC/UNEP/OECD/IEA 1997) and the United Nations Framework Convention on Climate Change (UNFCCC) reporting guidelines for national inventories[137] were developed prior to the publication of the TAR. Therefore, to comply with international reporting standards under the UNFCCC, official emission estimates are reported by the United States using SAR GWP values. This excerpt of the US *Inventory* addresses in detail the differences between emission estimates using these two sets of GWPs. Overall, these revisions to GWP values do not have a significant effect on US emission trends.

Additional discussion on emission trends for the United States can be found in the complete *Inventory of US Greenhouse Gas Emissions and Sinks: 1990-2000*.

What is Climate Change?

Climate change refers to long-term fluctuations in temperature, precipitation, wind, and other elements of the Earth's climate system. Natural processes such as solar-irradiance variations, variations in the Earth's orbital parameters, and volcanic activity can produce variations in climate. The climate system can also be influenced by changes in the concentration of various gases in the atmosphere, which affect the Earth's absorption of radiation.

The Earth naturally absorbs and reflects incoming solar radiation and emits longer wavelength terrestrial (thermal) radiation back into space. On average, the absorbed solar radiation is balanced by the outgoing terrestrial radiation emitted to space. A portion of this terrestrial

[137] See FCCC/CP/1999/7 at www.unfccc.de.

radiation, though, is itself absorbed by gases in the atmosphere. The energy from this absorbed terrestrial radiation warms the Earth's surface and atmosphere, creating what is known as the "natural greenhouse effect." Without the natural heat-trapping properties of these atmospheric gases, the average surface temperature of the Earth would be about 33°C lower (IPCC 2001).

Under the UNFCCC, the definition of climate change is "a change of climate which is attributed directly or indirectly to human activity that alters the composition of the global atmosphere and which is in addition to natural climate variability observed over comparable time periods." Given that definition, in its Second Assessment Report of the science of climate change, the IPCC concluded that:

> *Human activities are changing the atmospheric concentrations and distributions of greenhouse gases and aerosols. These changes can produce a radiative forcing by changing either the reflection or absorption of solar radiation, or the emission and absorption of terrestrial radiation (IPCC 1996).*

Building on that conclusion, the more recent IPCC Third Assessment Report asserts that "[c]oncentrations of atmospheric greenhouse gases and their radiative forcing have continued to increase as a result of human activities" (IPCC 2001).

The IPCC went on to report that the global average surface temperature of the Earth has increased by between 0.6 ± 0.2°C over the 20th century (IPCC 2001). This value is about 0.15°C larger than that estimated by the Second Assessment Report, which reported for the period up to 1994, "owing to the relatively high temperatures of the additional years (1995 to 2000) and improved methods of processing the data" (IPCC 2001).

While the Second Assessment Report concluded, "the balance of evidence suggests that there is a discernible human influence on global climate," the Third Assessment Report states the influence of human activities on climate in even starker terms. It concludes that, "[I]n light of new evidence and taking into account the remaining uncertainties, most of the observed warming over the last 50 years is likely to have been due to the increase in greenhouse gas concentrations" (IPCC 2001).

Greenhouse Gases

Although the Earth's atmosphere consists mainly of oxygen and nitrogen, neither plays a significant role in enhancing the greenhouse effect because both are essentially transparent to terrestrial radiation. The greenhouse effect is primarily a function of the concentration of water vapor, carbon dioxide, and other trace gases in the atmosphere that absorb the terrestrial radiation leaving the surface of the Earth (IPCC 1996). Changes in the atmospheric concentrations of these greenhouse gases can alter the balance of energy transfers between the atmosphere, space, land, and the oceans. A gauge of these changes is called radiative forcing, which is a simple measure of changes in the energy available to the Earth-atmosphere system (IPCC 1996). Holding everything else constant, increases in greenhouse gas concentrations in the atmosphere will produce positive radiative forcing (i.e., a net increase in the absorption of energy by the Earth).

Climate change can be driven by changes in the atmospheric concentrations of a number of radiatively active gases and aerosols. We have clear evidence that human activities have affected concentrations, distributions and life cycles of these gases (IPCC 1996).

Naturally occurring greenhouse gases include water vapor, carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), and ozone (O_3). Several classes of halogenated substances that contain fluorine, chlorine, or bromine are also greenhouse gases, but they are, for the most part, solely a product of industrial activities. Chlorofluorocarbons (CFCs) and hydrochlorofluorocarbons (HCFCs) are halocarbons that contain chlorine, while halocarbons that contain bromine are referred to as bromofluorocarbons (i.e., halons). Because CFCs, HCFCs, and halons are stratospheric ozone depleting substances, they are covered under the Montreal Protocol on Substances that Deplete the Ozone Layer. The UNFCCC defers to this earlier international treaty; consequently these gases are not included in national greenhouse gas inventories. Some other fluorine containing halogenated substances—hydrofluorocarbons (HFCs), perfluorocarbons (PFCs), and sulfur hexafluoride (SF_6)—do not deplete stratospheric ozone but are potent greenhouse gases. These latter substances are addressed by the UNFCCC and accounted for in national greenhouse gas inventories.

There are also several gases that, although they do not have a commonly agreed upon direct radiative forcing effect, do influence the global radiation budget. These tropospheric gases—referred to as ambient air pollutants—include carbon monoxide (CO), nitrogen dioxide (NO_2), sulfur dioxide (SO_2), and tropospheric (ground level) ozone (O_3). Tropospheric ozone is formed by two precursor pollutants, volatile organic compounds (VOCs) and nitrogen oxides (NO_x) in the presence of ultraviolet light (sunlight). Aerosols—extremely small particles or liquid droplets—often composed of sulfur compounds, carbonaceous combustion products, crustal materials and other human induced pollutants—can affect the absorptive characteristics of the atmosphere. However, the level of scientific understanding of aerosols is still very low (IPCC 2001).

Carbon dioxide, methane, and nitrous oxide are continuously emitted to and removed from the atmosphere by natural processes on Earth. Anthropogenic activities, however, can cause additional quantities of these and other greenhouse gases to be emitted or sequestered, thereby changing their global average atmospheric concentrations. Natural activities such as respiration by plants or animals and seasonal cycles of plant growth and decay are examples of processes that only cycle carbon or nitrogen between the atmosphere and organic biomass. Such processes—except when directly or indirectly perturbed out of equilibrium by anthropogenic activities—generally do not alter average atmospheric greenhouse gas concentrations over decadal timeframes. Climatic changes resulting from anthropogenic activities, however, could have positive or negative feedback effects on these natural systems. Atmospheric concentrations of these gases, along with their rates of growth and atmospheric lifetimes, are presented in Table I1.

Table I1. Global Atmospheric Concentration (ppm Unless Otherwise Specified), Rate of Concentration Change (ppb/year) and Atmospheric Lifetime (Years) of Selected Greenhouse Gases

Atmospheric Variable	CO_2	CH_4	N_2O	SF_6[a]	CF_4[a]
Pre-industrial atmospheric concentration	278	0.700	0.270	0	40
Atmospheric concentration (1998)	365	1.745	0.314	4.2	80
Rate of concentration change[b]	1.5[c]	0.007[c]	0.0008	0.24	1.0
Atmospheric Lifetime	50-200[d]	12[e]	114[e]	3,200	>50,000

Source: IPCC (2001)

[a] Concentrations in parts per trillion (ppt) and rate of concentration change in ppt/year.

[b] Rate is calculated over the period 1990 to 1999.

[c] Rate has fluctuated between 0.9 and 2.8 ppm per year for CO_2 and between 0 and 0.013 ppm per year for CH_4 over the period 1990 to 1999.

[d] No single lifetime can be defined for CO_2 because of the different rates of uptake by different removal processes.

[e] This lifetime has been defined as an "adjustment time" that takes into account the indirect effect of the gas on its own residence time.

A brief description of each greenhouse gas, its sources, and its role in the atmosphere is given below. The following section then explains the concept of Global Warming Potentials (GWPs), which are assigned to individual gases as a measure of their relative average global radiative forcing effect.

Water Vapor (H_2O). Overall, the most abundant and dominant greenhouse gas in the atmosphere is water vapor. Water vapor is neither long-lived nor well mixed in the atmosphere, varying spatially from 0 to 2 percent (IPCC 1996). In addition, atmospheric water can exist in several physical states including gaseous, liquid, and solid. Human activities are not believed to directly affect the average global concentration of water vapor; however, the radiative forcing produced by the increased concentrations of other greenhouse gases may indirectly affect the hydrologic cycle. A warmer atmosphere has an increased water holding capacity; yet, increased concentrations of water vapor affects the formation of clouds, which can both absorb and reflect solar and terrestrial radiation. Aircraft contrails, which consist of water vapor and other aircraft emittants, are similar to clouds in their radiative forcing effects (IPCC 1999).

Carbon Dioxide (CO_2). In nature, carbon is cycled between various atmospheric, oceanic, land biotic, marine biotic, and mineral reservoirs. The largest fluxes occur between the atmosphere and terrestrial biota, and between the atmosphere and surface water of the oceans. In the atmosphere, carbon predominantly exists in its oxidized form as CO_2. Atmospheric carbon dioxide is part of this global carbon cycle, and therefore its fate is a complex function of geochemical and biological processes. Carbon dioxide concentrations in the atmosphere increased from approximately 280 parts per million by volume (ppmv) in pre-industrial times to 367 ppmv in 1999, a 31 percent increase (IPCC 2001). The IPCC notes that "[t]his concentration has not been exceeded during the past 420,000 years, and likely not during the past 20 million years. The rate of increase over the past century is unprecedented, at least during the past 20,000 years." The IPCC definitively states that "the present atmospheric CO_2 increase is caused by anthropogenic emissions of CO_2" (IPCC 2001). Forest clearing, other biomass burning, and some non-energy production processes (e.g., cement production) also emit notable quantities of carbon dioxide.

In its second assessment, the IPCC also stated that "[t]he increased amount of carbon dioxide [in the atmosphere] is leading to climate change and will produce, on average, a global warming of the Earth's surface because of its enhanced greenhouse effect—although the magnitude and significance of the effects are not fully resolved" (IPCC 1996).

Methane (CH_4). Methane is primarily produced through anaerobic decomposition of organic matter in biological systems. Agricultural processes such as wetland rice cultivation, enteric fermentation in animals, and the decomposition of animal wastes emit CH_4, as does the decomposition of municipal solid wastes. Methane is also emitted during the production and distribution of natural gas and petroleum, and is released as a by-product of coal mining and incomplete fossil fuel combustion. Atmospheric concentrations of methane have increased by about 150 percent since pre-industrial times, although the rate of increase has been declining. The IPCC has estimated that slightly more than half of the current CH_4 flux to the atmosphere is anthropogenic, from human activities such as agriculture, fossil fuel use and waste disposal (IPCC 2001).

Methane is removed from the atmosphere by reacting with the hydroxyl radical (OH) and is ultimately converted to CO_2. Minor removal processes also include reaction with Cl in the marine boundary layer, a soil sink, and stratospheric reactions. Increasing emissions of methane reduce the concentration of OH, a feedback which may increase methane's atmospheric lifetime (IPCC 2001).

Nitrous Oxide (N_2O). Anthropogenic sources of N_2O emissions include agricultural soils, especially the use of synthetic and manure fertilizers; fossil fuel combustion, especially from mobile combustion; adipic (nylon) and nitric acid production; wastewater treatment and waste combustion; and biomass burning. The atmospheric concentration of nitrous oxide (N_2O) has increased by 16 percent since 1750, from a pre industrial value of about 270 ppb to 314 ppb in 1998, a concentration that has not been exceeded during the last thousand years. Nitrous oxide is primarily removed from the atmosphere by the photolytic action of sunlight in the stratosphere.

Ozone (O_3). Ozone is present in both the upper stratosphere, where it shields the Earth from harmful levels of ultraviolet radiation, and at lower concentrations in the troposphere, where it is the main component of anthropogenic photochemical "smog." During the last two decades, emissions of anthropogenic chlorine and bromine-containing halocarbons, such as chlorofluorocarbons (CFCs), have depleted stratospheric ozone concentrations. This loss of ozone in the stratosphere has resulted in negative radiative forcing, representing an indirect effect of anthropogenic emissions of chlorine and bromine compounds (IPCC 1996). The depletion of stratospheric ozone and its radiative forcing was expected to reach a maximum in about 2000 before starting to recover, with detection of such recovery not expected to occur much before 2010 (IPCC 2001).

The past increase in tropospheric ozone, which is also a greenhouse gas, is estimated to provide the third largest increase in direct radiative forcing since the pre-industrial era, behind CO_2 and CH_4. Tropospheric ozone is produced from complex chemical reactions of volatile organic compounds mixing with nitrogen oxides (NO_x) in the presence of sunlight. Ozone, carbon monoxide (CO), sulfur dioxide (SO_2), nitrogen dioxide (NO_2) and particulate matter are included in the category referred to as "criteria pollutants" in the United States under the Clean Air Act and its subsequent amendments. The tropospheric concentrations of ozone and these other pollutants are short-lived and, therefore, spatially variable.

Halocarbons, Perfluorocarbons, and Sulfur Hexafluoride (SF_6). Halocarbons are, for the most part, man-made chemicals that have both direct and indirect radiative forcing effects. Halocarbons that contain chlorine—chlorofluorocarbons (CFCs), hydrochlorofluorocarbons (HCFCs), methyl chloroform, and carbon tetrachloride—and bromine—halons, methyl bromide, and hydrobromofluorocarbons (HBFCs)—result in stratospheric ozone depletion and are therefore controlled under the Montreal Protocol on Substances that Deplete the Ozone Layer. Although CFCs and HCFCs include potent global warming gases, their net radiative forcing effect on the atmosphere is reduced because they cause stratospheric ozone depletion, which is itself an important greenhouse gas in addition to shielding the Earth from harmful levels of ultraviolet radiation. Under the Montreal Protocol, the United States phased out the production and importation of halons by 1994 and of CFCs by 1996. Under the Copenhagen Amendments to the Protocol, a cap was placed on the production and importation of HCFCs by non-Article 5 countries beginning in 1996, and then followed by a complete phase-out by the year 2030. The ozone depleting gases covered under the Montreal Protocol and its Amendments are not covered by the UNFCCC.

Hydrofluorocarbons (HFCs), perfluorocarbons (PFCs), and sulfur hexafluoride (SF_6) are not ozone depleting substances, and therefore are not covered under the Montreal Protocol. They are, however, powerful greenhouse gases. HFCs—primarily used as replacements for ozone depleting substances but also emitted as a by-product of the HCFC-22 manufacturing process—currently have a small aggregate radiative forcing impact; however, it is anticipated that their contribution to overall radiative forcing will increase (IPCC 2001). PFCs and SF_6 are predominantly emitted from various industrial processes including aluminum smelting, semiconductor manufacturing, electric power transmission and distribution, and magnesium casting. Currently, the radiative forcing impact of PFCs and SF_6 is also small; however, they have a significant growth rate, extremely long atmospheric lifetimes, and are strong absorbers of infrared radiation, and therefore have the potential to influence climate far into the future (IPCC 2001).

Carbon Monoxide (CO). Carbon monoxide has an indirect radiative forcing effect by elevating concentrations of CH_4 and tropospheric ozone through chemical reactions with other atmospheric constituents (e.g., the hydroxyl radical, OH) that would otherwise assist in destroying CH_4 and tropospheric ozone. Carbon monoxide is created when carbon-containing fuels are burned incompletely. Through natural processes in the atmosphere, it is eventually oxidized to CO_2. Carbon monoxide concentrations are both short-lived in the atmosphere and spatially variable.

Nitrogen Oxides (NO_x). The primary climate change effects of nitrogen oxides (i.e., NO and NO_2) are indirect and result from their role in promoting the formation of ozone in the troposphere and, to a lesser degree, lower stratosphere, where it has positive radiative forcing effects. Additionally, NO_x emissions from aircraft are also likely to decrease methane concentrations, thus having a negative radiative forcing effect (IPCC 1999). Nitrogen oxides are created from lightning, soil microbial activity, biomass burning – both natural and anthropogenic fires – fuel combustion, and, in the stratosphere, from the photo-degradation of nitrous oxide (N_2O). Concentrations of NO_x are both relatively short-lived in the atmosphere and spatially variable.

Nonmethane Volatile Organic Compounds (NMVOCs). Nonmethane volatile organic compounds include compounds such as propane, butane, and ethane. These compounds participate, along with NO_x, in the formation of tropospheric ozone and other photochemical oxidants. NMVOCs are emitted primarily from transportation and industrial processes, as well as biomass burning and non-industrial consumption of organic solvents. Concentrations of NMVOCs tend to be both short-lived in the atmosphere and spatially variable.

Aerosols. Aerosols are extremely small particles or liquid droplets found in the atmosphere. They can be produced by natural events such as dust storms and volcanic activity, or by anthropogenic processes such as fuel combustion and biomass burning. They affect radiative forcing in both direct and indirect ways: directly by scattering and absorbing solar and thermal infrared radiation; and indirectly by increasing droplet counts that modify the formation, precipitation efficiency, and radiative properties of clouds. Aerosols are removed from the atmosphere relatively rapidly by precipitation. Because aerosols generally have short atmospheric lifetimes, and have concentrations and compositions that vary regionally, spatially, and temporally, their contributions to radiative forcing are difficult to quantify (IPCC 2001).

The indirect radiative forcing from aerosols is typically divided into two effects. The first effect involves decreased droplet size and increased droplet concentration resulting from an increase in airborne aerosols. The second effect involves an increase in the water content and lifetime of clouds due to the effect of reduced droplet size on precipitation efficiency (IPCC 2001). Recent research has placed a greater focus on the second indirect radiative forcing effect of aerosols.

Various categories of aerosols exist, including naturally produced aerosols such as soil dust, sea salt, biogenic aerosols, sulphates, and volcanic aerosols, and anthropogenically manufactured aerosols such as industrial dust and carbonaceous aerosols (e.g., black carbon, organic carbon) from transportation, coal combustion, cement manufacturing, waste incineration, and biomass burning.

The net effect of aerosols is believed to produce a negative radiative forcing effect (i.e., net cooling effect on the climate), although because they are short-lived in the atmosphere—lasting days to weeks—their concentrations respond rapidly to changes in emissions. Locally, the negative radiative forcing effects of aerosols can offset the positive forcing of greenhouse gases (IPCC 1996). “However, the aerosol effects do not cancel the global-scale effects of the much longer-lived greenhouse gases, and significant climate changes can still result” (IPCC 1996).

The IPCC’s Third Assessment Report notes that “the indirect radiative effect of aerosols is now understood to also encompass effects on ice and mixed-phase clouds, but the magnitude of any such indirect effect is not known, although it is likely to be positive” (IPCC 2001). Additionally, current research suggests that another constituent of aerosols, elemental carbon, may have a positive radiative forcing (Jacobson 2001). The primary anthropogenic emission sources of elemental carbon include diesel exhaust, coal combustion, and biomass burning.

Global Warming Potentials

Global Warming Potentials (GWPs) are intended as a quantified measure of the globally averaged relative radiative forcing impacts of a particular greenhouse gas. It is defined as the cumulative radiative forcing—both direct and indirect effects—integrated over a period of time from the emission of a unit mass of gas relative to some reference gas (IPCC 1996). Carbon dioxide (CO_2) was chosen as this reference gas. Direct effects occur when the gas itself is a greenhouse gas. Indirect radiative forcing occurs when chemical transformations involving the original gas produce a gas or gases that are greenhouse gases, or when a gas influences other radiatively important processes such as the atmospheric lifetimes of other gases. The relationship between gigagrams (Gg) of a gas and Tg CO_2 Eq. can be expressed as follows:

$$\text{Tg CO}_2\text{ Eq} = (\text{Gg of gas}) \times (\text{GWP}) \times \left(\frac{\text{Tg}}{1{,}000\text{ Gg}}\right) \text{where,}$$

Tg CO_2 Eq. = Teragrams of Carbon Dioxide Equivalents
Gg = Gigagrams (equivalent to a thousand metric tons)
GWP = Global Warming Potential
Tg = Teragrams

GWP values allow policy makers to compare the impacts of emissions and reductions of different gases. According to the IPCC, GWPs typically have an uncertainty of roughly ±35 percent, though some GWPs have larger uncertainty than others, especially those in which lifetimes have not yet been ascertained. In the following decision, the parties to the UNFCCC have agreed to use consistent GWPs from the IPCC Second Assessment Report (SAR), based upon a 100 year time horizon, although other time horizon values are available (see Table I2).

> *In addition to communicating emissions in units of mass, Parties may choose also to use global warming potentials (GWPs) to reflect their inventories and projections in carbon dioxide-equivalent terms, using information provided by the Intergovernmental Panel on Climate Change (IPCC) in its Second Assessment Report. Any use of GWPs should be based on the effects of the greenhouse gases over a 100-year time horizon. In addition, Parties may also use other time horizons. (FCCC/CP/1996/15/Add.1)*

Greenhouse gases with relatively long atmospheric lifetimes (e.g., CO_2, CH_4, N_2O, HFCs, PFCs, and SF_6) tend to be evenly distributed throughout the atmosphere, and consequently global average concentrations can be determined. The short-lived gases such as water vapor, carbon monoxide, tropospheric ozone, other ambient air pollutants (e.g., NO_x, and NMVOCs), and tropospheric aerosols (e.g., SO_2 products and black carbon), however, vary spatially, and consequently it is difficult to quantify their global radiative forcing impacts. GWP values are generally not attributed to these gases that are short-lived and spatially inhomogeneous in the atmosphere.

Table I2. Global Warming Potentials (GWP) and Atmospheric Lifetimes (Years) Used in the Inventory

Gas	Atmospheric Lifetime	100-year GWP[a]	20-year GWP	500-year GWP
Carbon dioxide (CO_2)	50-200	1	1	1
Methane (CH_4)[b]	12±3	21	56	6.5
Nitrous oxide (N_2O)	120	310	280	170
HFC-23	264	11,700	9,100	9,800
HFC-125	32.6	2,800	4,600	920
HFC-134a	14.6	1,300	3,400	420
HFC-143a	48.3	3,800	5,000	1,400
HFC-152a	1.5	140	460	42
HFC-227ea	36.5	2,900	4,300	950
HFC-236fa	209	6,300	5,100	4,700
HFC-4310mee	17.1	1,300	3,000	400
CF_4	50,000	6,500	4,400	10,000
C_2F_6	10,000	9,200	6,200	14,000
C_4F_{10}	2,600	7,000	4,800	10,100
C_6F_{14}	3,200	7,400	5,000	10,700
SF_6	3,200	23,900	16,300	34,900

Source: IPCC (1996)
[a] GWPs used here are calculated over 100 year time horizon
[b] The methane GWP includes the direct effects and those indirect effects due to the production of tropospheric ozone and stratospheric water vapor. The indirect effect due to the production of CO_2 is not included.

Table I3 presents direct and net (i.e., direct and indirect) GWPs for ozone-depleting substances (ODSs). Ozone-depleting substances directly absorb infrared radiation and contribute to positive radiative forcing; however, their effect as ozone-depleters also leads to a negative radiative forcing because ozone itself is a potent greenhouse gas. There is considerable uncertainty regarding this indirect effect; therefore, a range of net GWPs is provided for ozone depleting substances.

Table I3. Net 100-year Global Warming Potentials for Select Ozone Depleting Substances*

Gas	Direct	Net_{min}	Net_{max}
CFC-11	4,600	(600)	3,600
CFC-12	10,600	7,300	9,900
CFC-113	6,000	2,200	5,200
HCFC-22	1,700	1,400	1,700
HCFC-123	120	20	100
HCFC-124	620	480	590
HCFC-141b	700	(5)	570
HCFC-142b	2,400	1,900	2,300
$CHCl_3$	140	(560)	0
CCl_4	1,800	(3,900)	660
CH_3Br	5	(2,600)	(500)
Halon-1211	1,300	(24,000)	(3,600)
Halon-1301	6,900	(76,000)	(9,300)

Source: IPCC (2001)
* Because these compounds have been shown to deplete stratospheric ozone, they are typically referred to as ozone depleting substances (ODSs). However, they are also potent greenhouse gases. Recognizing the harmful effects of these compounds on the ozone layer, in 1987 many governments signed the *Montreal Protocol on Substances that Deplete the Ozone Layer* to limit the production and importation of a number of CFCs and other halogenated compounds. The United States furthered its commitment to phase-out ODSs by signing and ratifying the Copenhagen Amendments to the *Montreal Protocol* in 1992. Under these amendments, the United States committed to ending the production and importation of halons by 1994, and CFCs by 1996. The IPCC Guidelines and the UNFCCC do not include reporting instructions for estimating emissions of ODSs because their use is being phased-out under the *Montreal Protocol*. The effects of these compounds on radiative forcing are not addressed here.

The IPCC recently published its Third Assessment Report (TAR), providing the most current and comprehensive scientific assessment of climate change (IPCC 2001). Within that report, the GWPs of several gases were revised relative to the IPCC's Second Assessment Report (SAR) (IPCC 1996), and new GWPs have been calculated for an expanded set of gases. Since the SAR, the IPCC has applied an improved calculation of CO_2 radiative forcing and an improved CO_2 response function (presented in WMO 1999). The GWPs are drawn from WMO (1999) and the SAR, with updates for those cases where new laboratory or radiative transfer results have been published. Additionally, the atmospheric lifetimes of some gases have been recalculated. Because the revised radiative forcing of CO_2 is about 12 percent lower than that in the SAR, the GWPs of the other gases relative to CO_2 tend to be larger, taking into account revisions in lifetimes. However, there were some instances in which other variables, such as the radiative efficiency or the chemical lifetime, were altered that resulted in further increases or decreases in particular GWP values. In addition, the values for radiative forcing and lifetimes have been calculated for a variety of halocarbons, which were not presented in the SAR. The changes are described in the TAR as follows:

New categories of gases include fluorinated organic molecules, many of which are ethers that are proposed as halocarbon substitutes. Some of the GWPs have larger uncertainties than that of others, particularly for those gases where detailed laboratory data on lifetimes are not yet *available. The direct GWPs have been calculated relative to CO_2 using an improved calculation of the CO_2 radiative forcing, the SAR response function for a CO_2 pulse, and new values for the radiative forcing and lifetimes for a number of halocarbons.*

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