California Greenhouse Gas Emissions from 2000 to 2021: Trends of Emissions and Other Indicators

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Executive Summary

Each year the California Air Resources Board (CARB) produces the statewide Greenhouse Gas (GHG) Emissions Inventory (AB 32 GHG Inventory), which is one tool to track progress of California's climate programs toward achieving statewide GHG targets. This document summarizes the trends in emissions and indicators in the AB 32 GHG Inventory. The emissions included in the AB 32 GHG Inventory represent actual emissions released into the atmosphere from the AB 32 sectors.[1] The 2023 edition of the AB 32 GHG Inventory includes GHG emissions released during the 2000–2021 calendar years and includes several technical updates. For some sectors, these changes are substantial and impact the entire time series. Details on these updates are described in the technical documentation.[2]

In 2021, emissions from GHG emitting activities statewide[3] were 381.3 million metric tons of carbon dioxide equivalent (MMTCO_2e). This is 12.6 MMTCO_2e (3.4%) higher than 2020 (368.7 MMTCO_2e), but 23.1 MMTCO_2e (5.7%) lower than 2019 levels (404.4 MMTCO_2e). Both the 2019 to 2020 decrease and the 2020 to 2021 increase in emissions are likely due in large part to the impacts of the COVID-19 pandemic that were felt globally. Emissions levels in 2020 are anomalous to the long-term trend, and the one-year increase from 2020 to 2021 should be considered in the broader context of the pandemic and subsequent economic recovery that took place over 2021. The most notable highlights in the 2023 edition of the AB 32 GHG Inventory include:

- The transportation sector showed the largest increase in emissions of 10.0 MMTCO_2e (7.4%) compared to 2020. This increase was most likely from passenger vehicles whose activity and emissions rebounded after COVID-19 shelter-in-place orders were lifted. Overall, transportation sector emissions in 2021 remained 16.6 MMTCO_2e (10.2%) below pre-pandemic (2019) levels.
- Electricity sector emissions increased by 2.8 MMTCO_2e (4.8%) from 2020 to 2021. Total electricity generation increased by 4.7 TWh (1.5%) while the carbon intensity of generation increased by 3.2%. Hydropower generation decreased by 13.5 TWh

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[1] To categorize emissions to assist in policy development, CARB's "2022 Scoping Plan for Achieving Carbon Neutrality" (https://ww2.arb.ca.gov/sites/default/files/2023-04/2022-sp.pdf) presents statewide emissions in seven sectors: transportation, electric power, industrial, commercial & residential, agriculture, high GWP, and recycling & waste.

[2] Inventory Updates Since the 2022 Edition of the AB 32 GHG Inventory - Supplement to the Technical Support Document.

[3] Pursuant to Assembly Bill (AB) 32 (Nuñez and Pavley, Chapter 488, Statutes of 2006), the AB 32 GHG Inventory includes emissions from in-state sources and imported electricity, emissions of which were released from electricity generation facilities located outside of California.

(24.3%) given ongoing drought conditions.[4] This was largely compensated for by a 11.4 TWh (15.3%) increase in solar and wind generation incentivized by California's clean energy policies. Fossil gas-powered electricity generation increased by 7.4 TWh (7.3%) to meet demand even as overall renewable generation increased.

- Industrial sector emissions increased by 0.6 MMTCO_2e (0.9%) compared to 2020. The increase is driven by higher emissions from the refining sector, which is likely related to increased demand for transportation fuels in 2021 relative to the lower transportation fuel demand levels occurring during 2020 at the height of COVID-19 pandemic. Industrial sector emissions in 2021 remained 6.9 MMTCO_2e (8.6%) below 2019 levels.
- Between 2020 and 2021, California's Gross Domestic Product (GDP) increased 7.8% while the GHG intensity of California's economy (GHG emissions per unit GDP) decreased 4.1%.

[4] This metric includes data from asset-controlling suppliers (ACS) which imported low GHG intensity electricity consisting primarily of hydropower. Imports from ACS dropped 11.0 TWh (56.5%) and in-state plus imported hydropower decreased 2.5 TWh (6.8%).

Figure 1. Annual Statewide GHG Emissions and the 2020 GHG Limit.

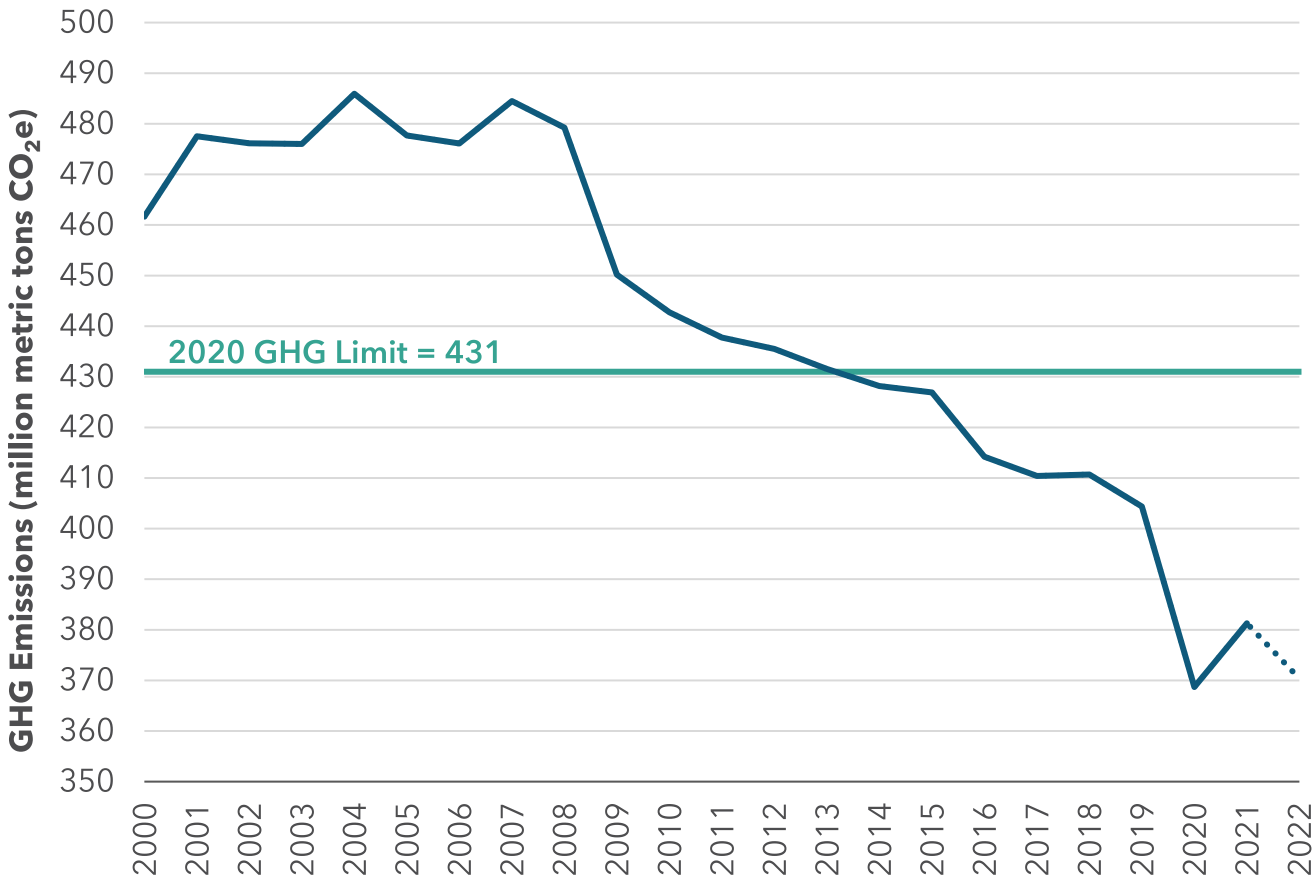


Figure 1 shows California's annual GHG emissions from 2000 to 2021 in relation to the 2020 GHG Limit established by AB 32 [1]. The dotted blue line shows an estimate of AB 32 GHG Inventory emissions for 2022 based solely on data reported and third-party verified to CARB pursuant to the Regulation for the Mandatory Reporting of GHG Emissions (MRR). The 2022 estimate is provided for informational purposes only and should not be used for any policy making decisions or regulatory compliance. The 2022 estimate of AB 32 GHG Inventory emissions is calculated as 2022 MRR non-biogenic emissions, divided by the ratio of 2019-2021 MRR non-biogenic emissions to 2019-2021 AB 32 GHG Inventory emissions. California's GHG emissions dropped below the 2020 GHG Limit in 2014 (428.2 $MMTCO_2e$) and have remained below this level since that time.

Introduction

The AB 32 GHG Inventory is one tool to track California's progress toward achieving the statewide GHG targets established by Assembly Bill (AB) 32 (Nuñez and Pavley, Chapter 488, Statutes of 2006) [1] to reduce emissions to 1990 levels by 2020; Senate Bill 32 (Pavley, Chapter 249, Statutes of 2016) to reduce emissions to at least 40% below 1990 levels by 2030; and AB 1279 (Muratsuchi, Chapter 337, Statutes of 2022) to reduce anthropogenic emissions at least 85% below 1990 levels no later than 2045. The AB 32 GHG Inventory includes emissions from the following types of sources: fossil fuel combustion, including combustion for imported electricity consumed in state, by-products of chemical reactions in industrial processes, use of GHG-containing consumer products and human-made chemicals, agricultural operations, and recycling and waste sector operations. The exchange of ecosystem carbon between the atmosphere and plants and soils (including through wildfires) is separately quantified in the Natural and Working Lands Ecosystem Carbon Inventory [2]. The methods used to quantify emissions included in the AB 32 GHG Inventory are consistent with international and national practices [3] and meet the requirements of AB 32.

The 2023 edition of the AB 32 GHG Inventory includes the emissions of the seven GHGs identified in AB 32 for the years 2000 to 2021. There are additional climate pollutants that are not included in AB 32 that are tracked separately from the AB 32 GHG Inventory. These include black carbon and sulfuryl fluoride (SO_2F_2), which are discussed in the Short-Lived Climate Pollutant (SLCP) Strategy [4], and ozone depleting substances (ODS), which are being phased out under a 1987 international treaty[5] [5].

In this report, emissions trends and indicators are presented in the categories outlined in the Initial AB 32 Climate Change Scoping Plan [6]. There are alternative ways of organizing emissions sources into categories, and the resulting percentages will differ depending on the categorization used.[6] All emissions in this report are expressed in units of carbon dioxide equivalent (CO_2e) calculated using 100-year Global Warming Potential (GWP) values from the Intergovernmental Panel on Climate Change (IPCC) 4th Assessment Report (AR4) [7].

Statewide Trends of Emissions and Indicators

In 2021, emissions from statewide emitting activities were 381.3 $MMTCO_2e$, 12.6 $MMTCO_2e$ higher than 2020 levels and 49.7 $MMTCO_2e$ below the 2020 GHG Limit of 431 $MMTCO_2e$.

[5] Many ODS substitutes are GHGs whose emissions are included in the AB 32 GHG Inventory, consistent with IPCC Guidelines.

[6] The *Additional Information* section of this report provides further information on alternative categorization schemes.

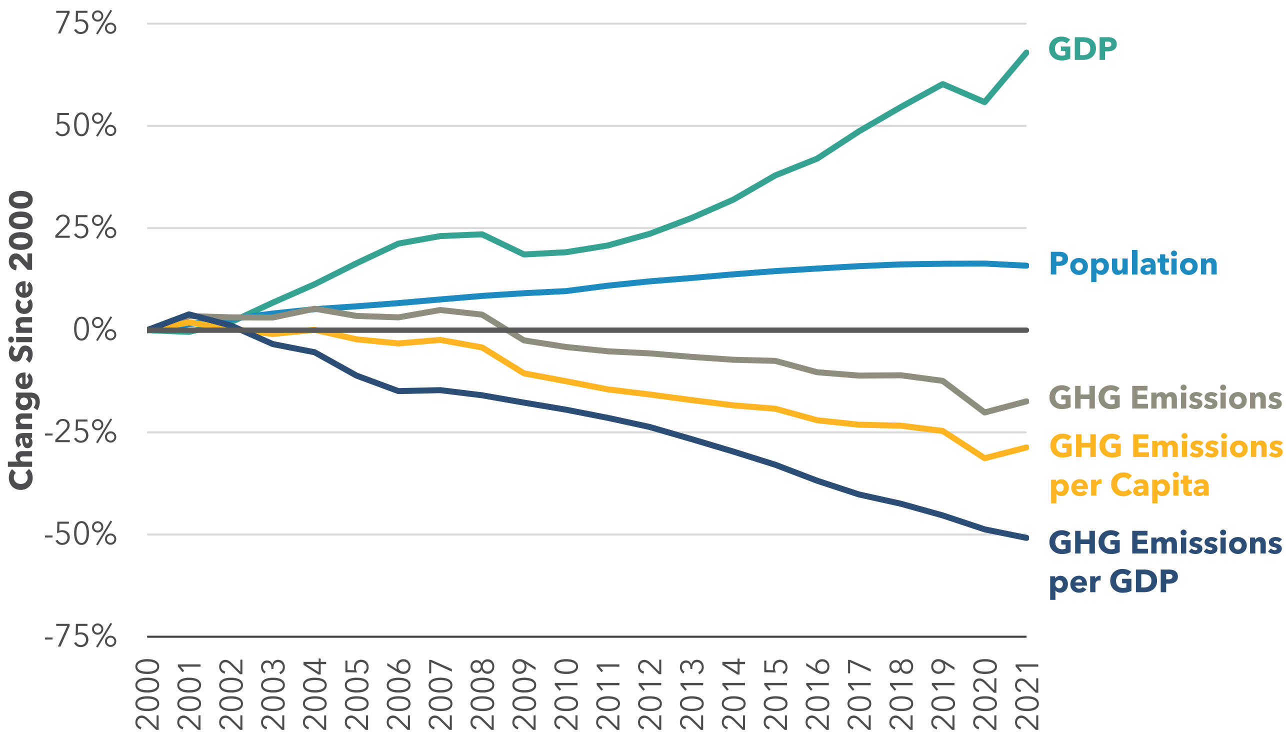
Since the peak level in 2004, California's GHG emissions have generally followed a decreasing trend. In 2014, statewide GHG emissions dropped below the 2020 GHG Limit and have remained below the Limit since that time.

Per capita GHG emissions in California have dropped from a 2001 peak of 13.8 metric tons per person to 9.7 metric tons per person in 2021, a 30.0% decrease [8][9]. Overall trends in the AB 32 GHG Inventory also continue to demonstrate that the carbon intensity of California's economy (the amount of carbon pollution per million dollars of gross domestic product (GDP)) is declining. From 2000 to 2021, the carbon intensity of California's economy decreased by 50.8% while the GDP increased by 67.9%. Likely in part due to the COVID -19 pandemic and rebound, GDP fell 2.8% in 2020 and then increased 7.8% in 2021 [10]. Emissions per GDP declined by 6.2% from 2019 to 2020 and declined by 4.1% from 2020 to 2021 [8][10]. Figures 2-4 show these economic indicators alongside GHG emissions.

Data reported to CARB through the Regulation for the Mandatory Reporting of GHG Emissions (MRR) is the primary data source for the AB 32 GHG Inventory. This data shows a decline in MRR emissions of 11.1 MMTCO_2e (3.2%) from 2021 to 2022, with 2022 emissions dropping nearly to 2020 levels [11].[7] The 2022 estimate of total AB 32 GHG Inventory emissions shown in Figure 1 is based on MRR emissions for 2019-2022 and AB 32 GHG Inventory emissions for 2019-2021. The continuation of the downward GHG emissions trend from 2021 to 2022 indicates that the increase in emissions from 2020 to 2021 is likely an anomaly caused by broader economic trends related to the COVID-19 pandemic and associated recovery. The remainder of this report focuses on 2021 data because that is the most recent year for which complete AB 32 GHG Inventory data is available.

[7] This metric excludes CO_2 emissions from combustion of biofuels, which are classified as "biogenic CO_2." Biogenic CO_2 is tracked separately from the rest of the emissions in the AB 32 GHG Inventory and is not included in the total emissions when comparing to California's GHG reduction goals.

Figure 2. Change in California GDP, Population, and GHG Emissions Since 2000.



Metric	Associated 2021 Value
GDP	2.9 Trillion (2012 $)
Population	39.4 Million
GHG Emissions	381.3 $MMTCO_2e$
GHG Emissions per Capita	9.7 Metric Tons CO_2e per person
GHG Emissions per GDP	133 Metric Tons CO_2e per Million $

Figure 3. California Total and Per Capita GHG Emissions.

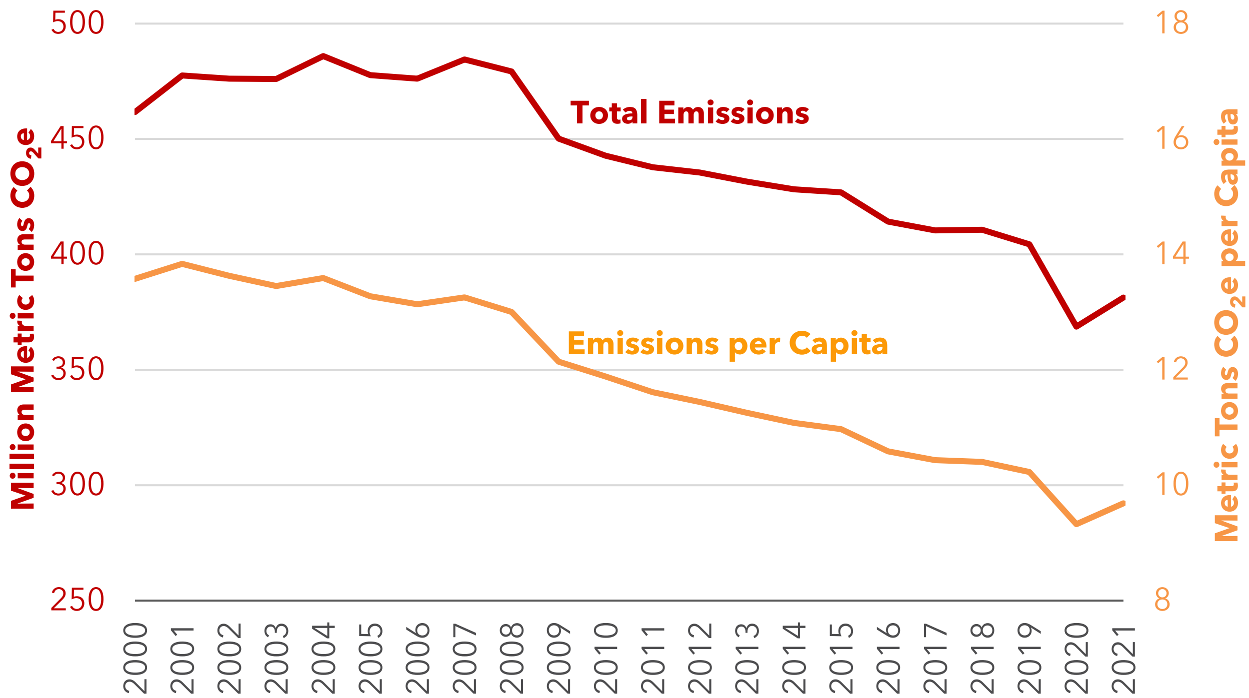
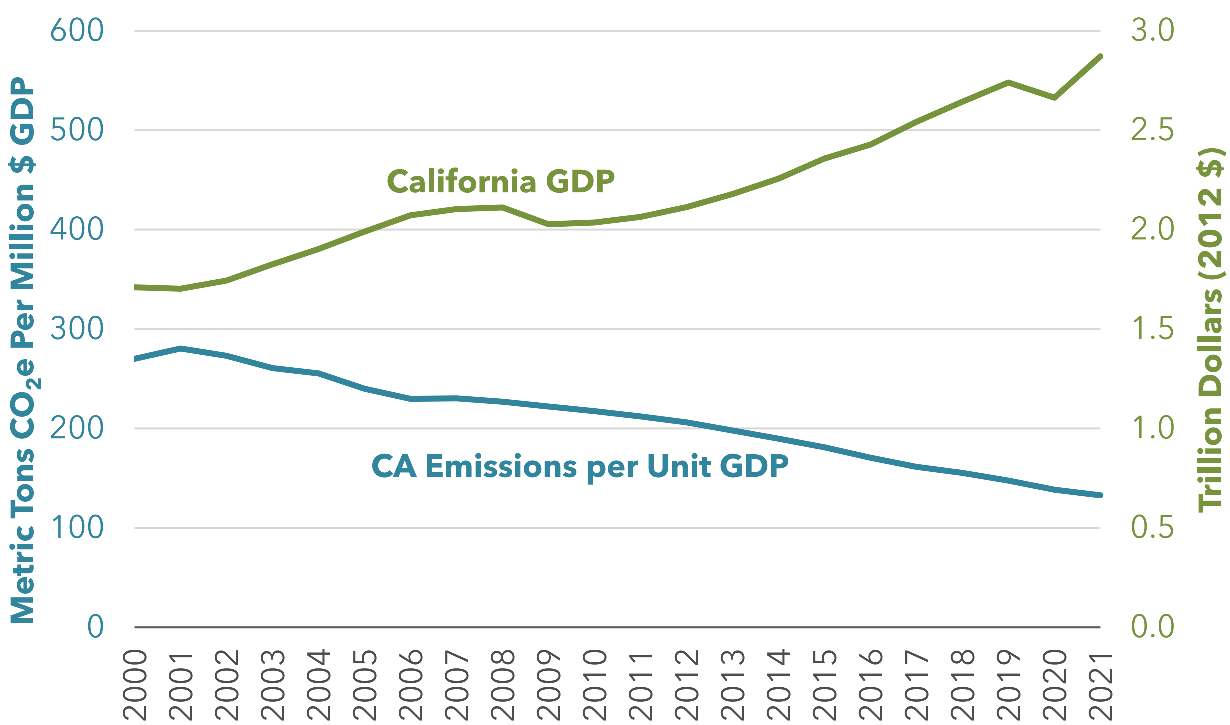


Figure 4. Carbon Intensity of California's Economy.



Overview of Emissions Trends by Sector

The growth in statewide emissions from 2020 to 2021 was likely due in large part to the increase of transportation and other economic activity that occurred in 2021 relative to 2020 as the California emerged from the COVID-19 pandemic. Similar trends were seen globally [12]. Additional drivers of emissions changes are noted for each sector below.

The transportation sector remains the largest source of GHG emissions in the state. Direct emissions from vehicle tailpipes, off-road transportation sources, intrastate aviation, and other transportation sources account for 38.2%[8] of statewide emissions in 2021. Emissions from this sector increased by 10.0 MMTCO_2e (7.4%) compared to 2020. This increase was likely from passenger vehicles whose emissions rebounded after COVID-19 shelter-in-place orders were lifted. When upstream emissions from oil extraction, petroleum refining, and oil pipelines in California are included, transportation is responsible for 48.4% of statewide emissions in 2021.

Emissions from the electricity sector account for 16.4% of the inventory in 2021. Emissions from this sector increased by 2.8 MMTCO_2e (4.8%) compared to 2020. Continued growth of in-state solar generation and increases in imported renewable electricity nearly compensated for the significant drop in in-state and imported hydropower generation due to below average precipitation levels. Fossil gas-powered generation increased by 7.4 TWh (7.3%) to meet the remaining demand.

The industrial sector accounted for 19.4% of California's 2021 GHG emissions. This sector saw an increase of 0.6 MMTCO_2e (0.9%) from 2020 to 2021, most notably in the refining sector. Commercial and residential emissions, which accounted for 10.2% of the state's total, saw a decrease of 0.1 MMTCO_2e (0.2%) from 2020 to 2021.

The high-GWP gases sector accounted for 5.6% of California's 2021 GHG emissions. These emissions have continued to increase as high-GWP gases replace ODS that are being phased out under the 1987 Montreal Protocol [5]. However, in 2021, the emissions growth was the lowest of any year covered by the AB 32 GHG Inventory at only 0.01 MMTCO_2e (0.1%). Agriculture sector emissions accounted for 8.1% of the state's total and decreased by 0.7 MMTCO_2e (2.1%) from 2020 to 2021, mostly due to reductions in livestock methane emissions. Emissions from the recycling and waste sector account for the remaining 2.2% of statewide emissions, and have remained relatively constant in recent years, decreasing 0.1 MMTCO_2e (1.7%) from 2020 to 2021.

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[8] The transportation sector represents tailpipe emissions from on-road vehicles and direct emissions from other off-road mobile sources. It does not include upstream well-to-tank emissions from oil extraction, petroleum refining, and oil pipelines. These upstream emissions are included in the industrial sector category.

Figure 5 shows emissions trends by Scoping Plan sector for 2000 to 2021. Figure 6 shows 2021 emissions by Scoping Plan sector and sub-sector.

Figure 5. Trends in California GHG Emissions.

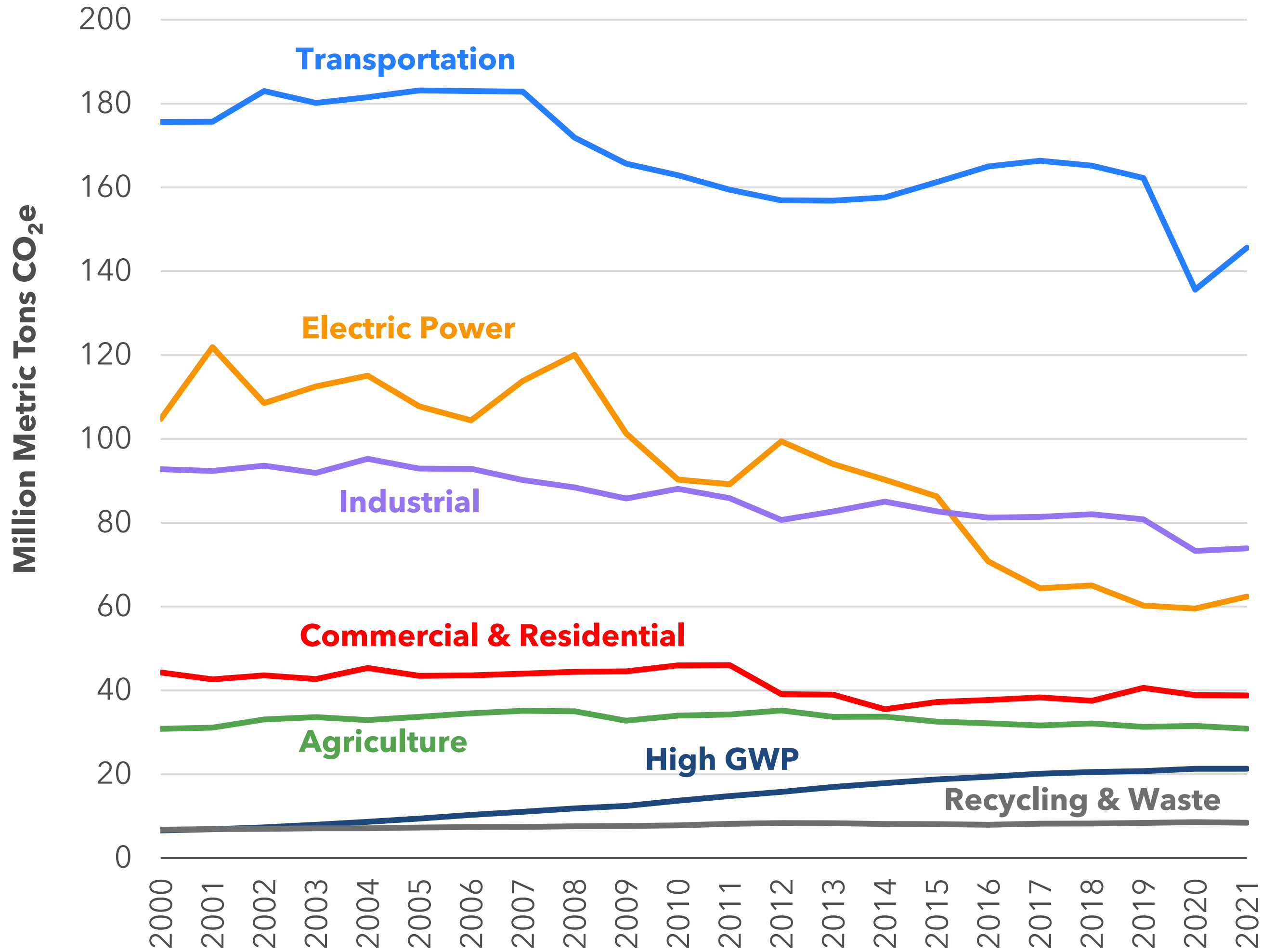

Figure 5 shows changes in emissions by Scoping Plan sector between 2000 and 2021.

Figure 6. 2021 GHG Emissions by Scoping Plan Sector and Sub-Sector.

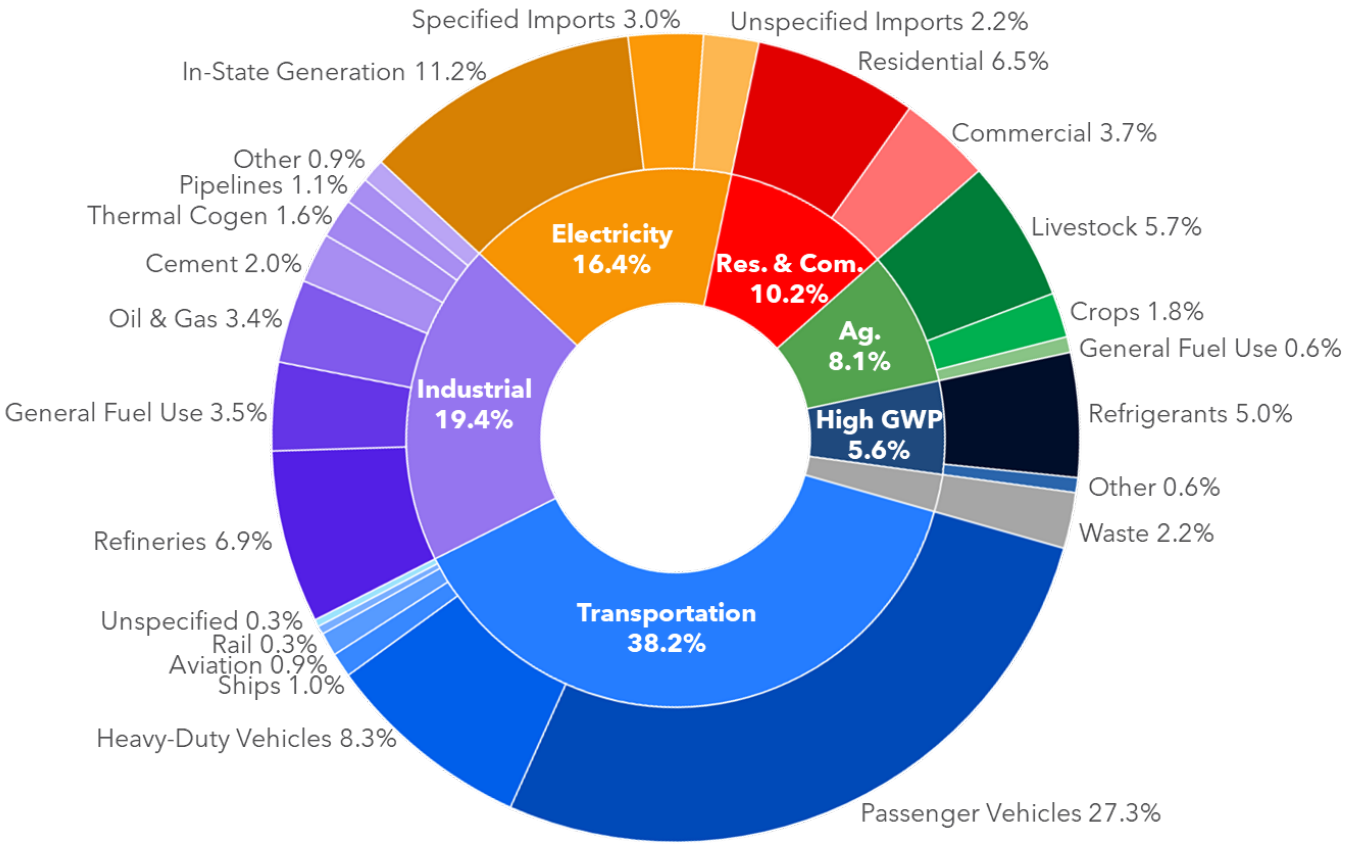

Figure 6 shows 2021 GHG emissions by Scoping Plan category. The inner ring shows the Scoping Plan sectors, while the outer shows the sub-sectors. Values do not sum to 100% due to independent rounding.

Transportation

The transportation sector remains the largest source of GHG emissions in 2021 at 38.2% of total emissions. Transportation sector emissions increased 7.4% from 2020 levels, likely due in large part to the increase of transportation activity that occurred in 2021 relative to 2020 as the state emerged from the COVID-19 pandemic. The transportation sector includes emissions from in-state fuel combustion by on- and off-road vehicles, intrastate flights, trains, water-borne vessels, and a few other smaller sources. [9], [10], [11] Several factors can influence transportation sector emissions. These include vehicle miles traveled (VMT), fuel efficiency, the number of zero-emission vehicles on the road, and the amount of fuel derived from biogenic sources. Year-to-year changes in economic conditions can also impact the amount of transportation fuel used across the state.

In 2020, the COVID-19 pandemic had wide-ranging impacts on people and economies around the world. In California, the measures implemented to slow the spread of COVID-19 resulted in substantial changes in human and vehicle activity. Most notably, VMT decreased from 2019 to 2020, then increased from 2020 to 2021 [13]. A similar trend in emissions from on-road vehicles is shown in Figure 7. Since the majority of emissions from the transportation sector are from on-road vehicles, the sector total also follows a similar trend.

Emissions from transportation sources peaked between 2002 and 2007, steadily decreased from 2008–2013, rose again from 2014–2017, declined in 2018 and 2019, then underwent the significant drop and rebound in 2020 and 2021. The drop in 2020 was the largest year-to-year change in the time-series, a decrease of 26.6 MMTCO_2e. The rebound in 2021 (10.0 MMTCO_2e) was less than half of the decrease in 2020. Figure 7 shows an overview of GHG emissions from the transportation sector.

[9] Emissions from the following sources are not included in the AB 32 GHG Inventory for the purpose of comparing to statewide GHG reduction goals. These emissions are, however, tracked separately as informational items and are published as excluded emissions within the AB 32 GHG Inventory data: Interstate and international aviation, diesel and jet fuel use at military bases, and a portion of bunker fuel purchased in California that is combusted by ships beyond 24 nautical miles from California's shores.

[10] The following emissions are not included or tracked in the AB 32 GHG Inventory: emissions from the combustion of fuels purchased outside of California that are used in-state by passenger vehicles and trains crossing into California, and out-of-state upstream emissions accounted for in the Low Carbon Fuel Standard (LCFS) program.

[11] Emissions from refrigerants and air conditioners used in vehicles, airplanes, trains, and water-borne vessels are shown in the high-GWP gases section of this report.

Figure 7. Overview of GHG Emissions from the Transportation Sector.

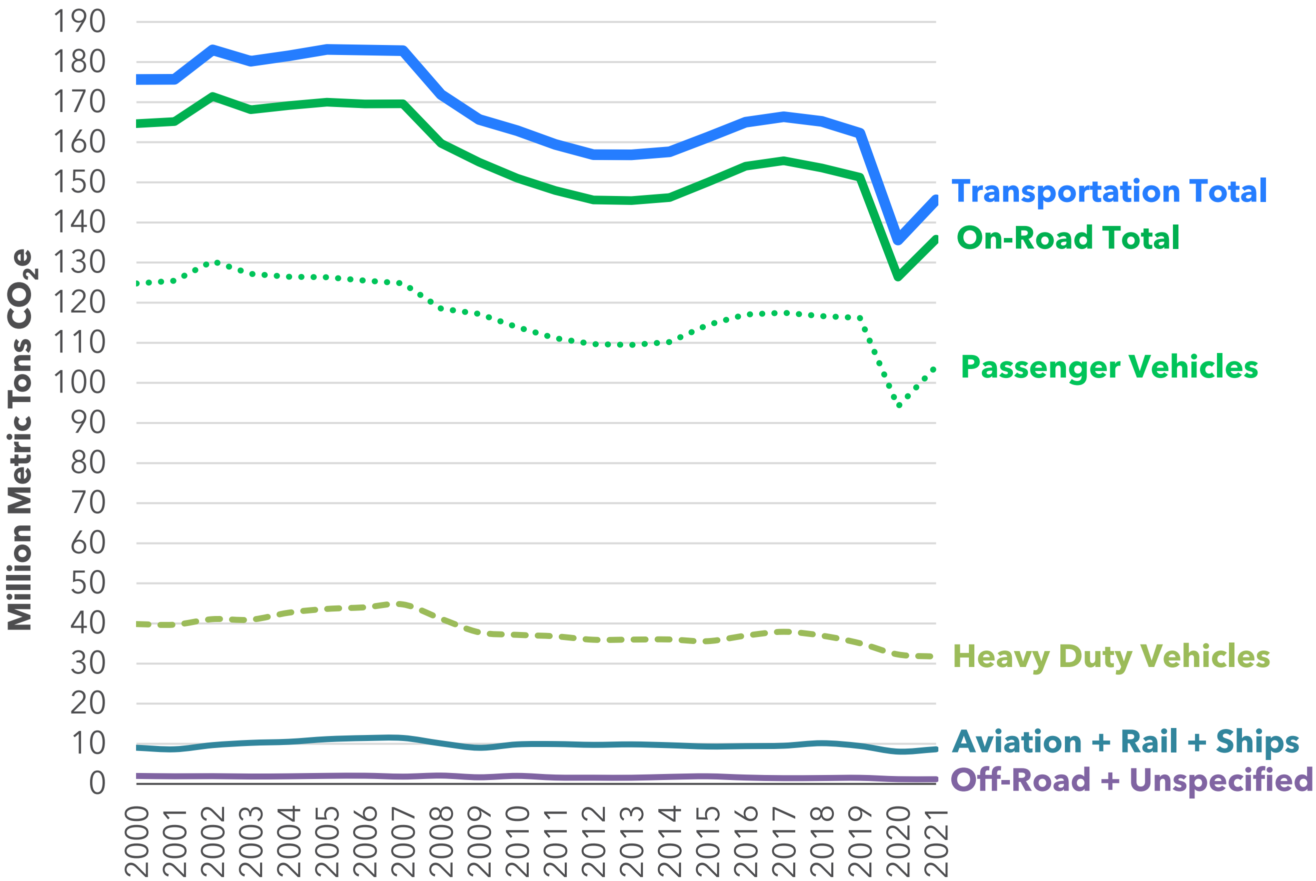

Figure 7: "Transportation Total" is the sum of "On-Road Total," "Aviation + Rail + Ships," and "Off-Road + Unspecified." "On-Road Total" is the sum of "Passenger Vehicles" and "Heavy Duty Vehicles."

The fuel efficiency of the passenger vehicle fleet in California has generally been rising since 2009, when it was 20.3 miles per gallon (mpg), to 24.0 mpg in 2021. New 2021 model year passenger vehicles are 12.2% more fuel efficient than 2012 model year vehicles [14]. In addition, there were 450,000 battery electric vehicles (BEV) in the state in 2021, representing 34.1% growth from 2020 [15]. Figure 8 shows the transformation of California's light-duty fleet, with significant strides being made in fuel efficiency improvements and zero-emission vehicle adoption.

Figure 8. Light Duty Vehicle Fleet Transformation.

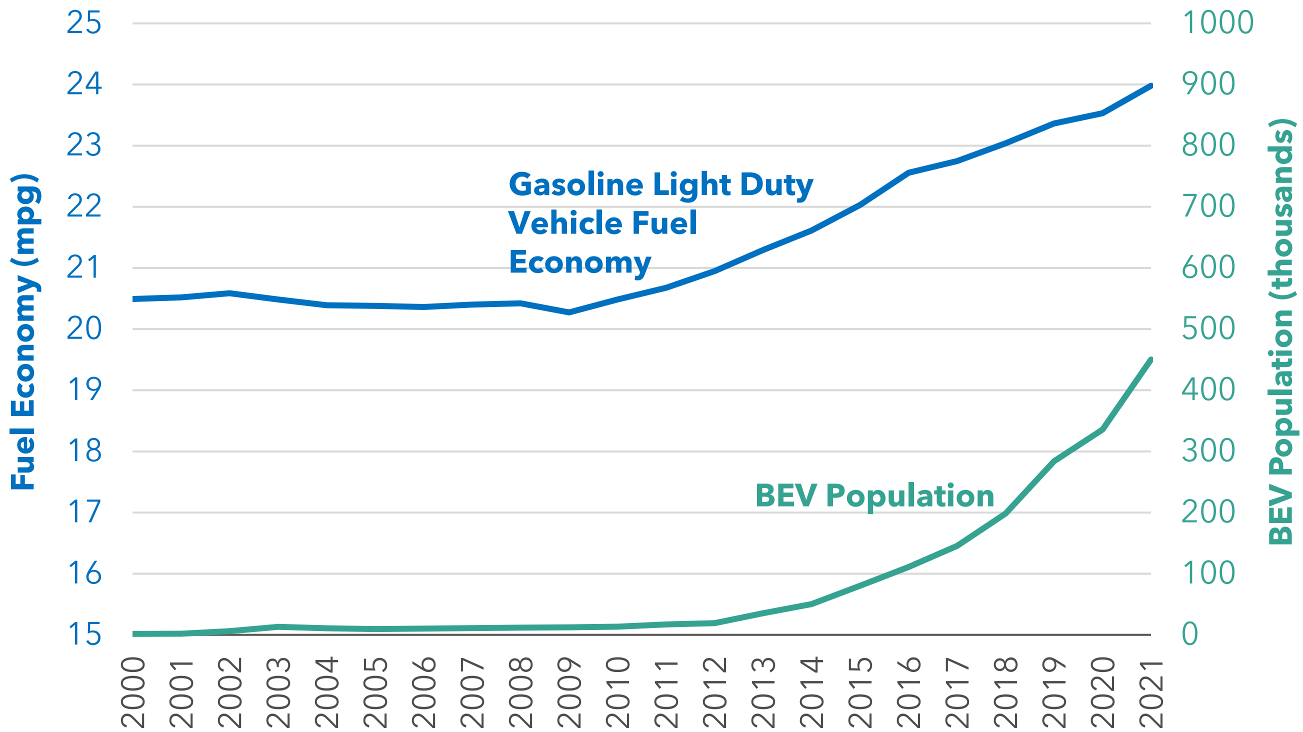

Figure 8 shows the fuel economy of California's light-duty fleet and the growth in BEVs. "Gasoline Light Duty Vehicle Fuel Economy" is the average mpg for all gasoline passenger cars, trucks, and SUVs in California. "BEV Population" includes vehicles that do not carry any fuel (e.g., gasoline and hydrogen) or any other energy source onboard [15].

Biofuels, such as ethanol, biodiesel, renewable diesel, and biomethane displace fossil fuels and reduce the amount of fossil-based CO_2 emissions released into the atmosphere. The percentages of biodiesel and renewable diesel in the total diesel blend[12] have shown significant growth in recent years, growing from 0.4% in 2011 to 29.0% in 2021, due mostly to the implementation of the Low Carbon Fuel Standard. The same is true of the percentage of biomethane in natural gas used for transportation, which has increased from 1.0% in 2019 to 5.5% in 2021. Without biofuels, California tailpipe fossil CO_2 would be 18.3 MMT higher in 2021.

Figure 9 and Figure 10 show the trends in emissions and fuel used in light-duty gasoline and heavy-duty diesel vehicles, respectively. Total fuel combustion emissions, inclusive of

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[12] For the purpose of this report, the term "fuel blend" refers to combined, aggregated volume of fossil fuels and biofuels that have been distributed across the state, some may be distributed as a blend of fossil fuel and biofuel while some may be sold as biofuel. "Gasoline blend" refers to E85 and typical gasoline-ethanol fuel. "Diesel blend" refers to aggregation of R99, B5, pure fossil diesel, and others.

both the fossil component (orange line) and bio-component (yellow shaded region) of the fuel blend, track trends in fuel sales. Consistent with the IPCC Guidelines for National GHG Inventories (IPCC Guidelines) [3], CO_2 emissions from biofuels (the biofuel components of fuel blends) are classified as "biogenic CO_2." They are tracked separately from the rest of the emissions in the AB 32 GHG Inventory and are not included in the total emissions when comparing to California's GHG reduction goals. Biogenic CO_2 emissions data are available on CARB's AB 32 GHG Emissions Inventory webpage [8]. Emissions of methane (CH_4) and nitrous oxide (N_2O) from biofuel combustion are included in the inventory along with CO_2, CH_4, and N_2O from fossil fuel combustion, consistent with IPCC guidance.

Figure 9. Trends in On-Road Light Duty Gasoline Emissions.

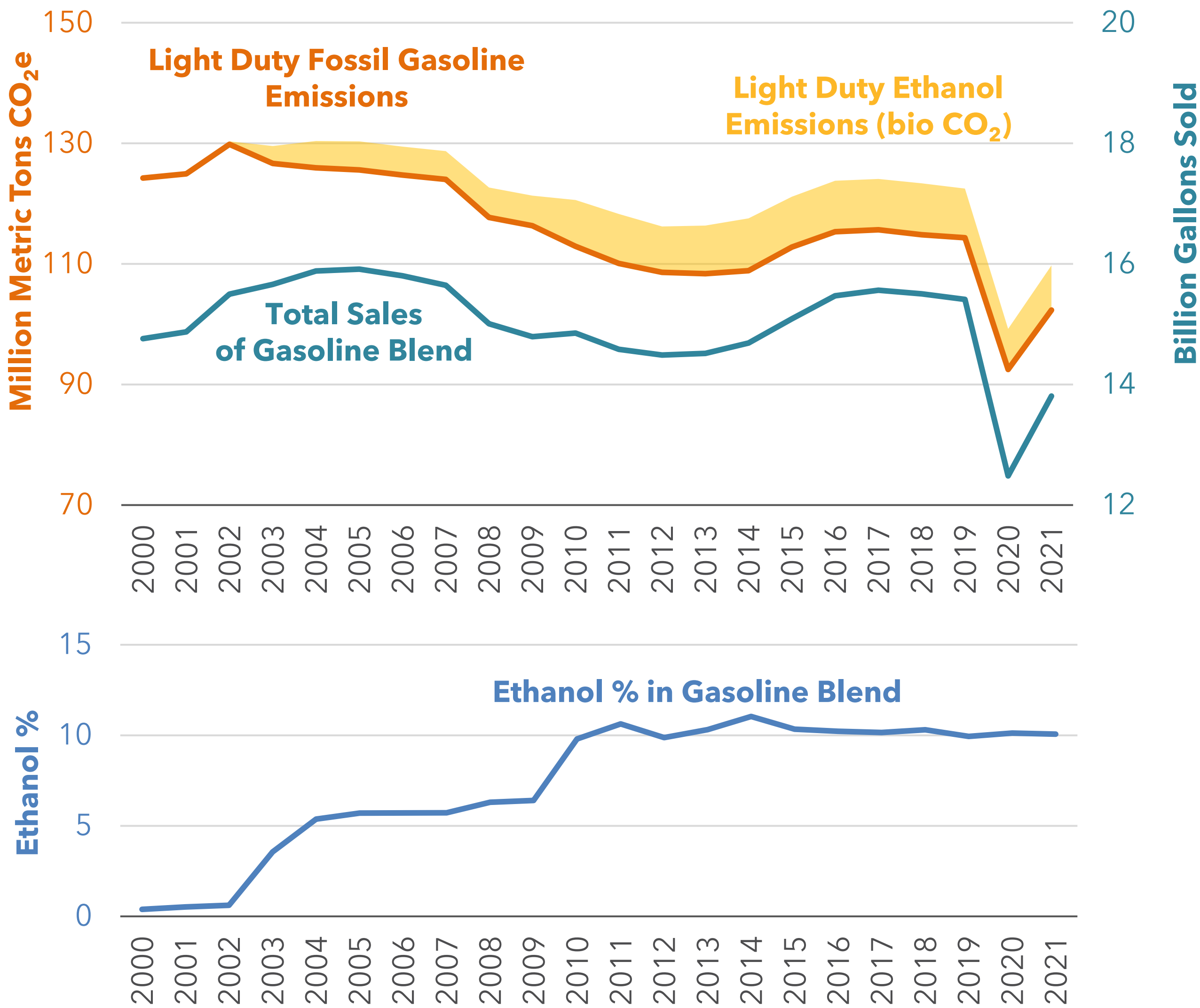

Figure 9: In the top panel, the yellow shaded region represents CO_2 emissions from the ethanol component of the gasoline fuel blend. The orange line includes all GHG emissions from the fossil gasoline component of the fuel blend, as well as the CH_4 and N_2O emissions from the ethanol component. "Total Sales of Gasoline Blend" includes gasoline used in any type of vehicle, 93% of which is used in light duty vehicles. The color of a trend line matches the color of its corresponding vertical axis label. The bottom panel shows the percent of gasoline blend that is ethanol.

Figure 10. Trends in On-Road Diesel Vehicle Emissions.

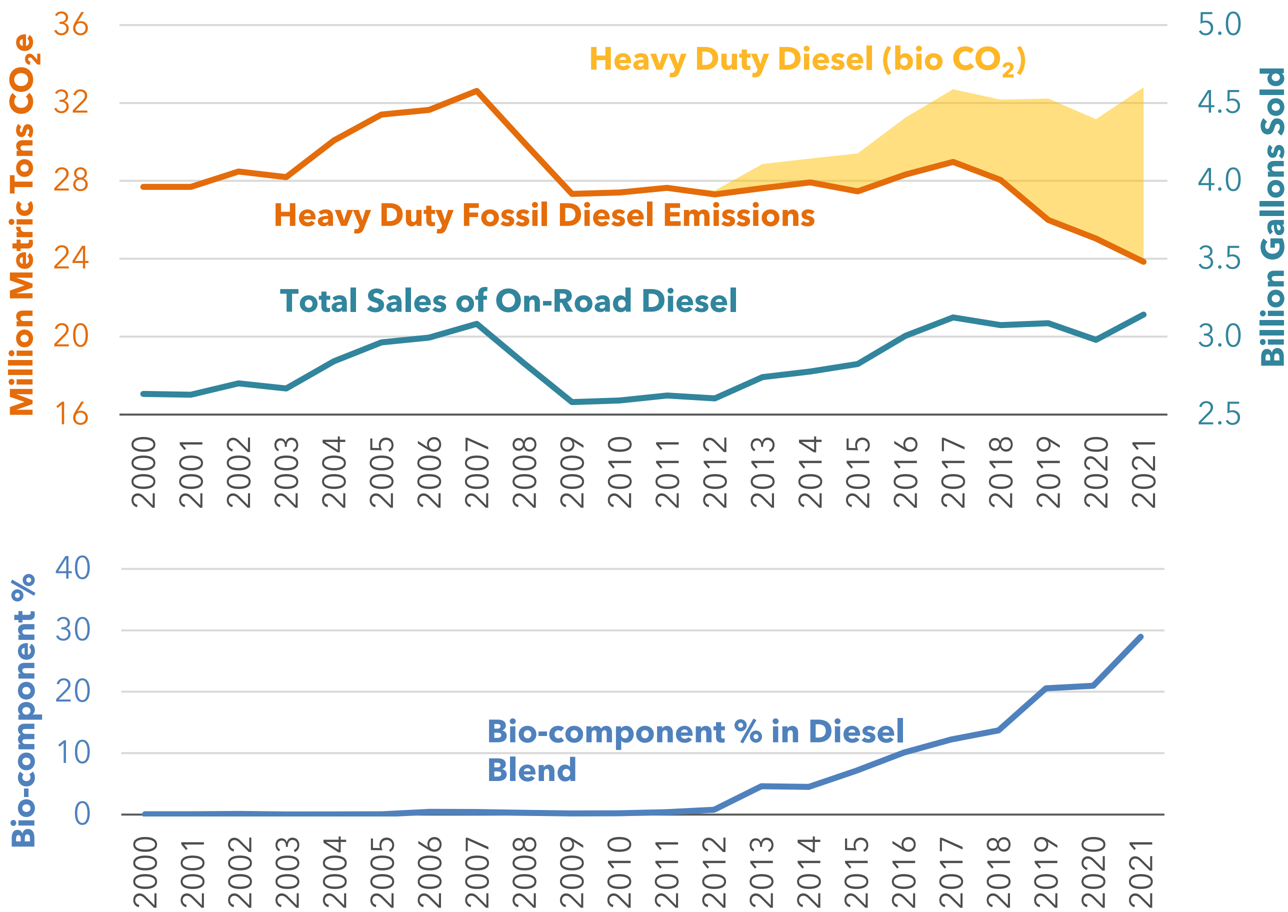

Figure 10: In the top panel, the yellow shaded region represents CO_2 emissions from the biogenic component (biodiesel and renewable diesel) of the diesel fuel blend. The orange line includes all GHG emissions from the fossil diesel component of the fuel blend, as well as the CH_4 and N_2O emissions from the biogenic component. "Total Sales of On-Road Diesel" includes diesel blends used in any type of vehicle, 98% of which are used in heavy duty vehicles. The color of a trend line matches the color of its corresponding vertical axis label. The bottom panel shows the percent of diesel blend that is biodiesel or renewable diesel.

Electricity

Emissions from the electricity sector comprise 16.4% of 2021 statewide GHG emissions. The AB 32 GHG Inventory divides electricity sector emissions into two broad categories: in-state generation (including the portion of industrial and commercial cogeneration emissions attributed to electricity generation) and imported electricity. Electricity sector emissions are primarily driven by fossil gas combustion such that years with low hydropower availability typically lead to increased emissions, as more fossil gas is required to fulfill the remaining demand. Increased production of zero-GHG resources such as solar and wind in California and imports from other western states also reduces demands for in-state fossil gas generation over time.

Since the early 2000's, the deployment of renewable and less carbon-intensive resources have facilitated the continuing decline in fossil fuel electricity generation.

The Renewable Portfolio Standard (RPS) Program and the Cap-and-Trade Program continue to incentivize the dispatch of renewables over fossil fuel generation to serve California's load. Higher energy efficiency standards also counter the growth in electricity consumption that is driven by a growing population and economy. While year-to-year fluctuations in hydropower availability result in small changes to GHG intensity, the overall downward trend prevails for GHG intensity from electricity generation. According to the California Energy Commission, the COVID-19 pandemic did not have a significant impact on total electricity consumption [16].

Figure 11 shows California's electricity sector emissions broken out between in-state and imported sources. Figure 12 shows the overall GHG intensity of electricity generation for California and for in-state and imported sources separately.

Figure 11. GHG Emissions from the Electricity Sector.

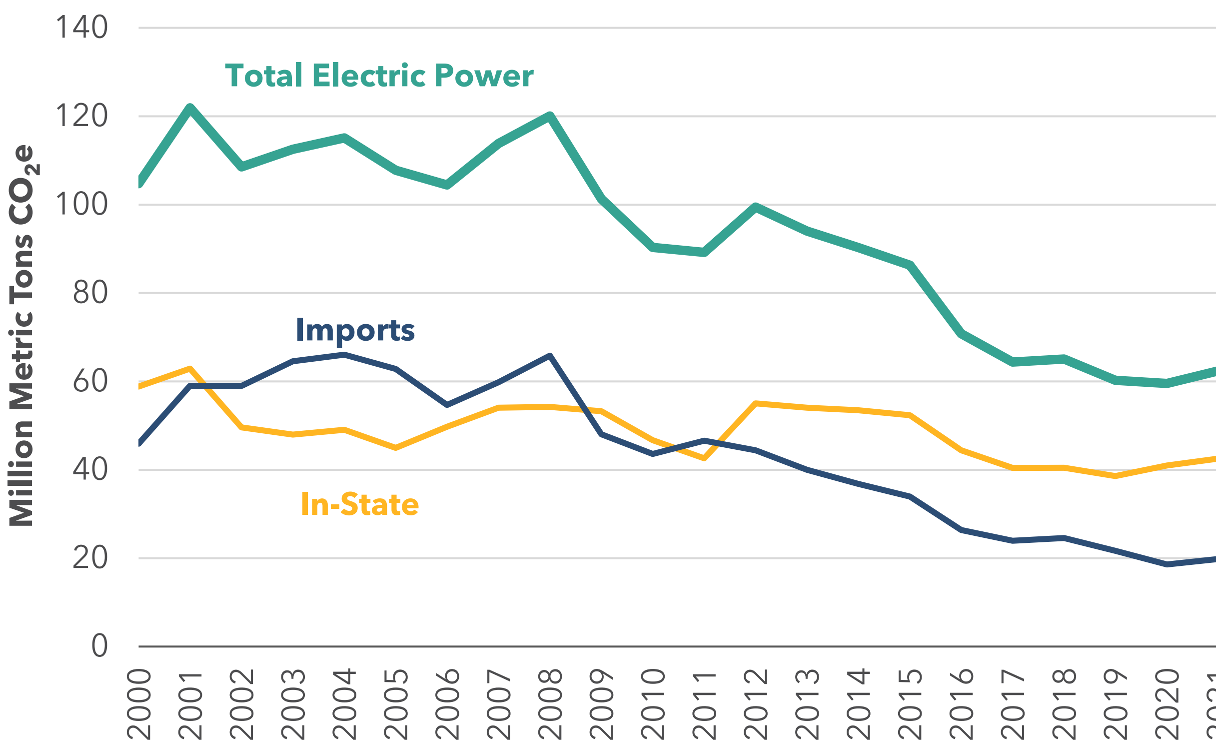

Figure 11 shows trends in emissions of in-state electricity generation, emissions associated with electricity imported from outside of California, and the total electricity sector emissions, which is the sum of in-state generation and imports.

Figure 12. GHG Intensity of Electricity.

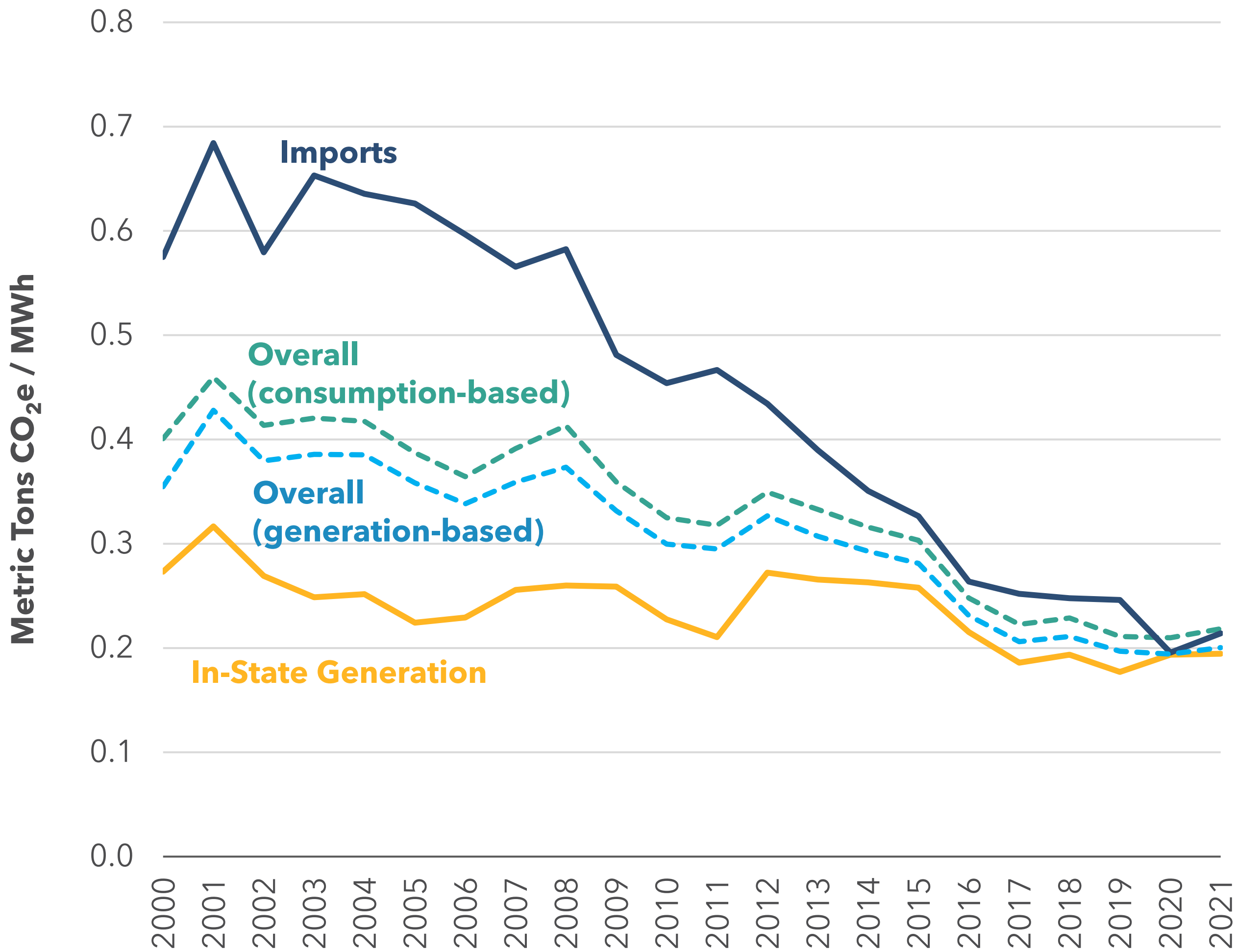

Figure 12 shows trends in GHG intensities of in-state electricity generation, electricity imported from outside of California, and the overall GHG intensities aggregating both in-state generation and electricity imports.[13]

Total electricity sector emissions increased in from 2020 to 2021 due to another year of low hydropower availability and a slight increase in total electricity generation. California

[13] All four GHG intensities account for renewables and exclude biogenic CO_2 emissions. For calculating in-state and overall intensities, in-state electricity emissions and generation (MWh) include on-site generation for on-site use, cogeneration emissions attributed to electricity generation, in-state generated electricity exported out-of-state, and rooftop solar. The denominator of the "overall (consumption-based)" intensity is the total electricity (MWh) consumed in and exported from California and excludes electricity (MWh) lost during transmission and distribution. The denominator of the "overall (generation-based)" intensity is the total electricity generated in and exported from California; however, in this case, it includes line losses. The numerator of both the consumption- and generation-based intensities is the total emissions from the electricity sector.

continued the trend of increasing in-state renewable generation and increasing imports of solar and wind power. In 2021, 47.5% of total electricity generation (in-state generation plus imported electricity) came from solar, wind, hydropower, and nuclear power; another 2.7% came from asset controlling suppliers (ACS),[14] which imported low GHG intensity electricity consisting primarily of hydropower.

In-state solar generation grew 15.4% in 2021 compared to 2020. Between 2011 and 2021, in-state solar generation saw significant growth as rooftop photovoltaic solar generation increased by a factor of 12 [17] and total solar generation (commercial-scale plus rooftop solar) increased by a factor of 22 during that period [17][18]. In-state wind energy generation ramped up through 2013 and then remained relatively constant through 2020. In 2021, wind energy generation increased by 11.7% compared to 2020, exceeding 15 TWh for the first time [18]. Figure 13 shows trends in in-state hydro, solar, and wind electricity generation.

[14] The term "asset controlling suppliers" refers to an electric power entity that owns or operates inter-connected electricity generating facilities or serves as an exclusive marketer for these facilities even though it does not own them (as defined by the Mandatory GHG Reporting Regulation (MRR)). Imports from ACS are primarily hydropower; however, they include some non-zero GHG power sources such as fossil gas.

Figure 13. In-State Hydro, Solar, and Wind Electricity Generation.

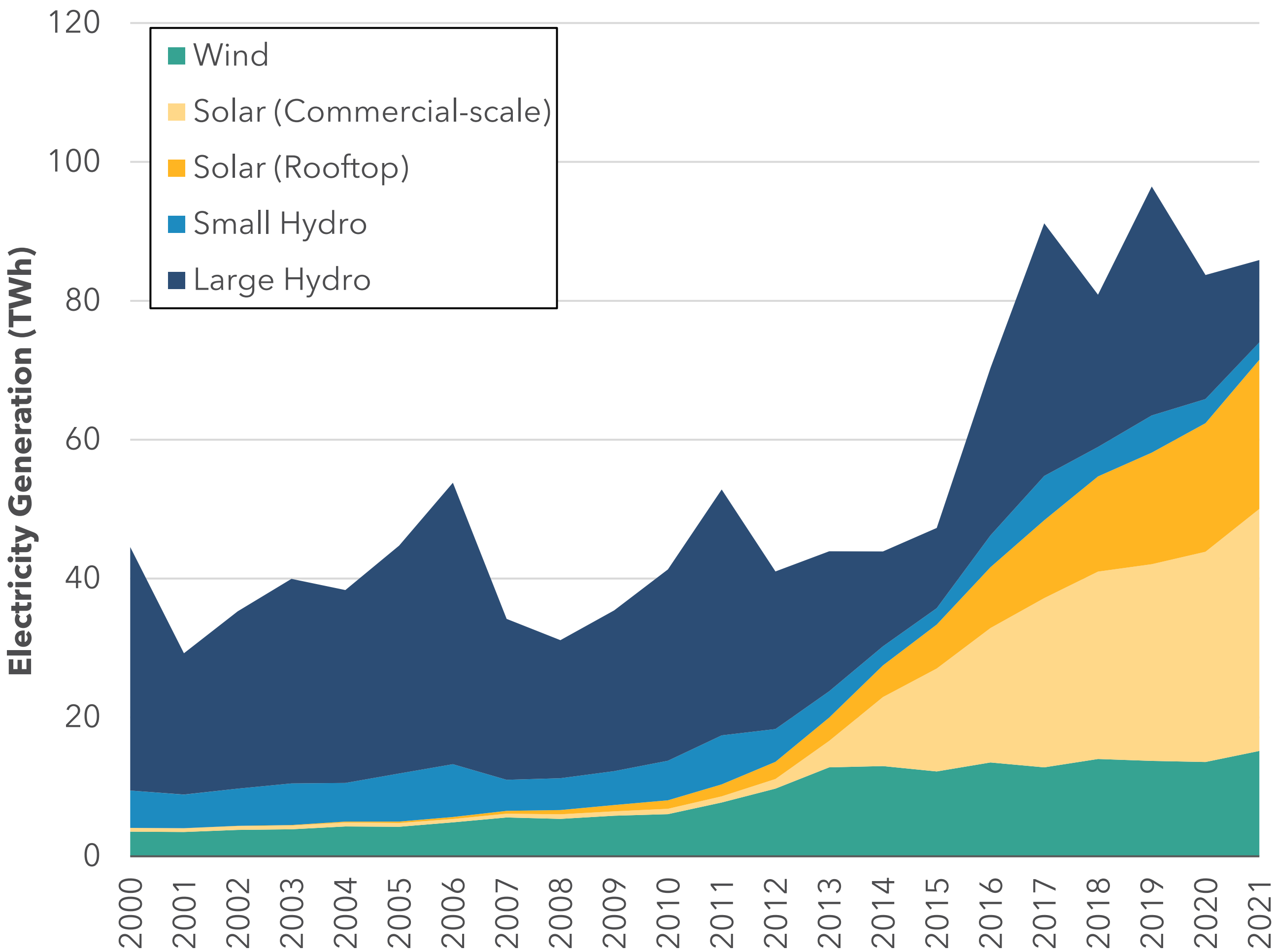

Figure 13 shows the amounts of electricity generated by California's in-state wind power projects, large commercial-scale solar power projects, rooftop solar panels, and hydropower generation stations in TWh (1 TWh = 10^9 kWh).

Trends in in-state generation by source are presented in Figure 14. In-state fossil gas generation varies annually in part based on year-to-year fluctuations in hydro, solar, wind, nuclear power generation, and demand. Generation from other fuel types has gradually declined over time.

Figure 14. In-State Electricity Generation by Source.

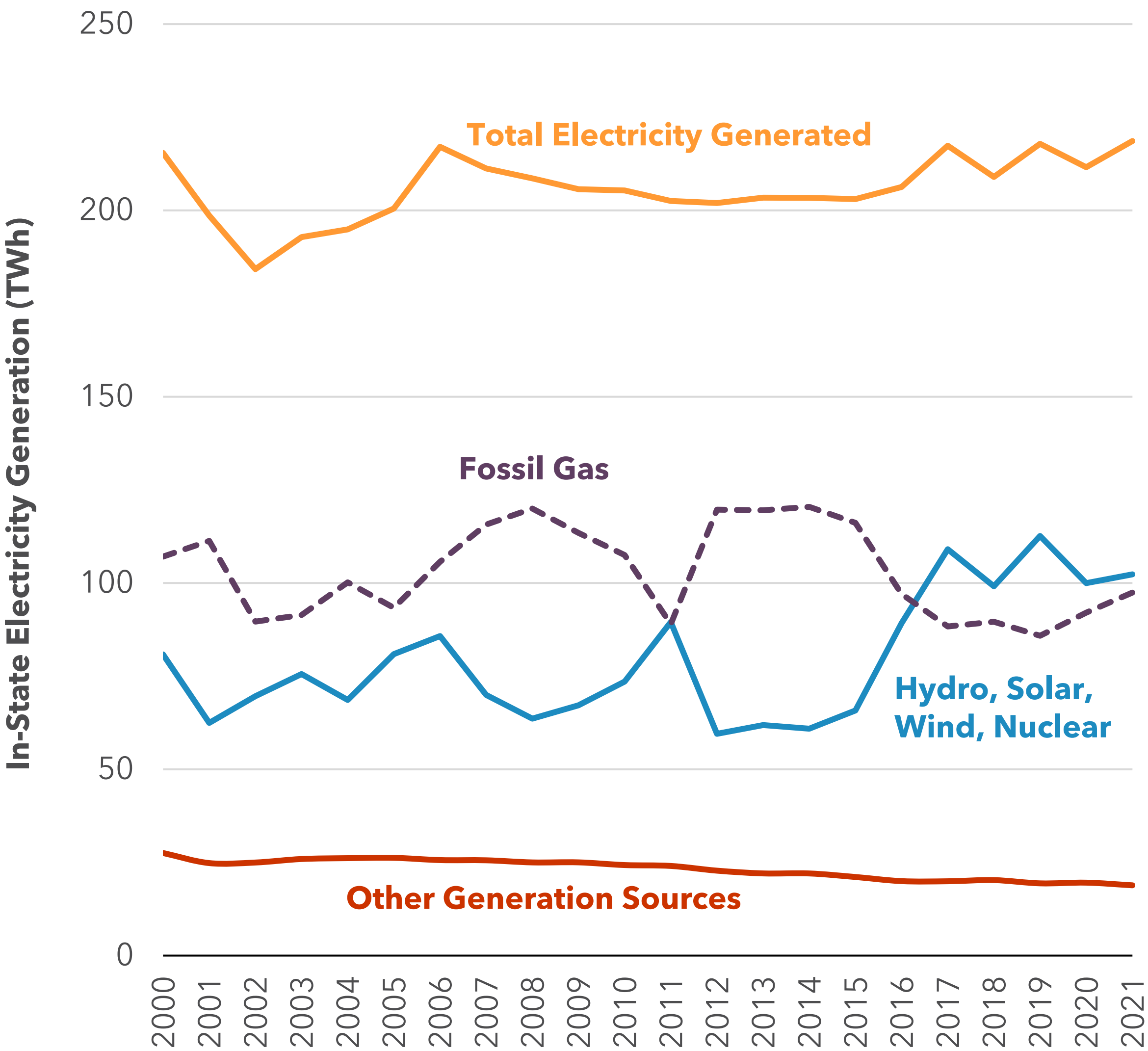

Figure 14 shows the amounts of electricity generated in-state from fossil gas; from hydro, solar, wind, and nuclear resources (combined); and from other generation sources.[15]

[15] "Other Generation Sources" include electricity generation from associated gas, biomass, coal, crude oil, digester gas, distillate, geothermal, jet fuel, kerosene, landfill gas, lignite coal, municipal solid waste, petroleum coke, propane, purchased steam, refinery gas, residual fuel oil, sub-bituminous coal, synthetic coal, tires, waste coal, waste heat, and waste oil. CO_2 and CH_4 emissions from geothermal power and CH_4 and N_2O emissions from biomass combustion are included in the total emissions used for comparison to statewide GHG reduction goals. Most of these fuels are combusted in industrial cogeneration facilities.

Industrial

Emissions from the industrial sector contributed 19.4% of California's total GHG emissions in 2021. Emissions in this sector are primarily driven by fuel combustion from sources that include refineries, oil and gas production, cement plants, and the portion of cogeneration emissions attributed to thermal energy output.[16] Process emissions, such as from clinker production in cement plants and hydrogen production for refinery use, also contribute significantly to the total emissions for this sector. Refineries and hydrogen production represent the largest individual source in the industrial sector, contributing 35.5% of the sector's total emissions.

From 2020 to 2021, refining and hydrogen production sector emissions increased by 0.4 $MMTCO_2e$ (1.7%), which may be related to increased demand for transportation fuels in 2021 relative to the lower transportation fuel demand levels occurring during 2020 at the height of COVID-19 pandemic. Overall, industrial sector emissions increased 0.6 $MMTCO_2e$ (0.9%) from 2020 to 2021, which is shown in Figure 5. Figure 15 shows trends by sub-sector within the industrial sector over time.

[16] The portion of cogeneration emissions attributed to electricity generation is included in the electricity sector.

Figure 15. Industrial Sector Emissions by Sub-Sector.

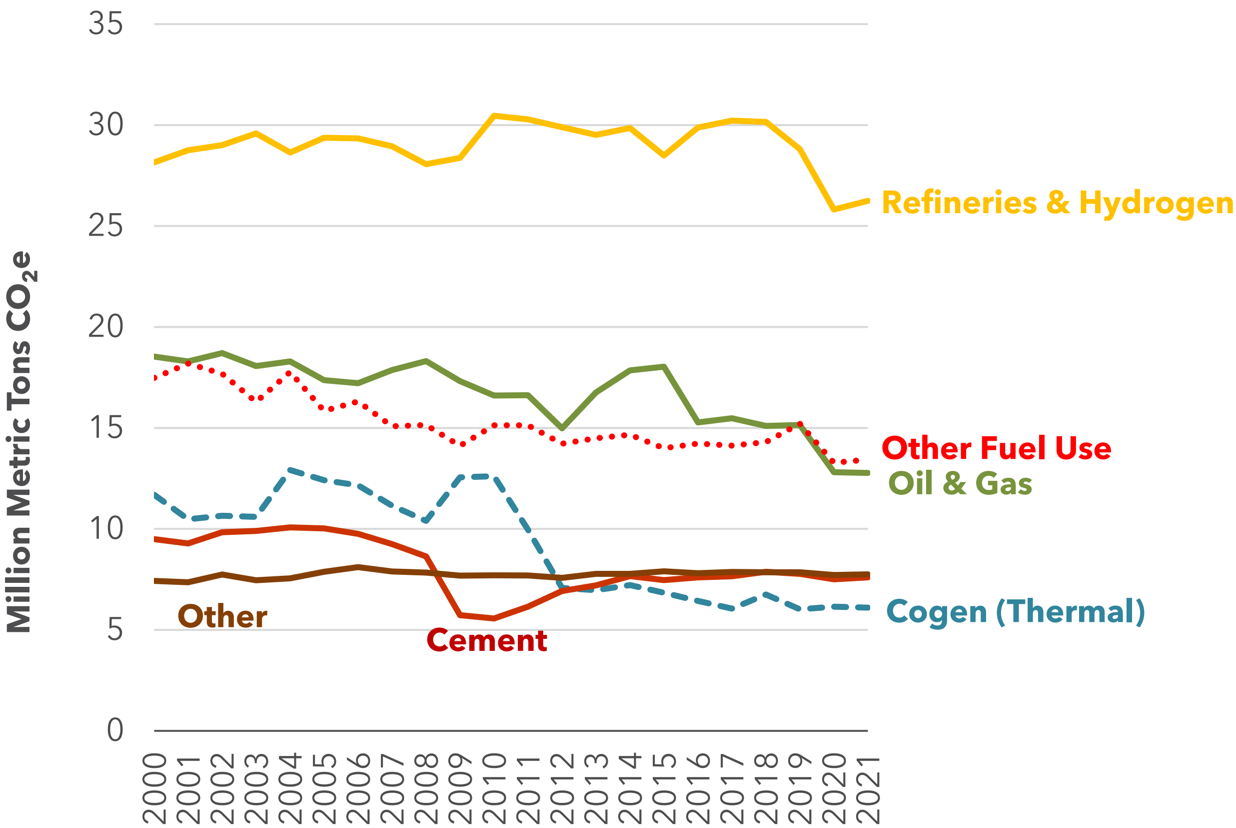

Figure 15 shows emissions by industrial sub-sector. The "Other Fuel Use" category includes emissions from combustion of fuels used by sub-sectors not specificied elsewhere in this figure. The "Other" category includes fugitive and process emissions from sub-sectors not already shown in the figure. The "Cogen (thermal)" category includes only the portion of cogeneration emissions attributed to thermal output. The portion of cogeneration emissions attributed to electricity generation is assigned to the electricity sector.

Commercial and Residential

Greenhouse gas emissions from the commercial and residential sectors come predominantly from the combustion of fossil gas and other fuels for uses such as space heating, cooking, water heating, and steam generation. Emissions from this sector also include commercial and residential fertilizer application and behind-the-meter gas leaks.[17] Emissions from electricity used in these sectors are accounted for in the electricity sector, and emissions of high-GWP gases used for purposes including refrigeration and air

[17] "Behind-the-meter" emissions include natural gas leaks after the gas passes through building-level gas meter. Potential leak points include valves and joints of gas pipes and gas appliances. Leaks from natural gas transmission and distribution infrastructure are accounted for in the industrial sector.

conditioning are included in the high global warming potential gases sector. Changes in annual fuel combustion emissions are primarily driven by variability in weather conditions which impacts demand for fuels used to heat buildings, as well as growth in commercial floor space and the number of residential housing units.

In 2021, residential and commercial sector emissions decreased by 0.1 $MMTCO_2e$ (0.2%) compared to 2020. While commercial fossil gas use and emissions increased during this time, likely due in part to the economic rebound coming out of the COVID-19 pandemic, this emissions increase was more than compensated for by decreased fossil gas use and emissions from residential space heating, resulting in the overall decrease in sector emissions. Figure 5 presents the sector-wide emissions trend while Figure 16 presents emissions trends from the commercial and residential sectors individually, along with heating degree days (a proxy for the amount of energy needed for space heating).

Figure 16. Emissions from Residential and Commercial Sectors.

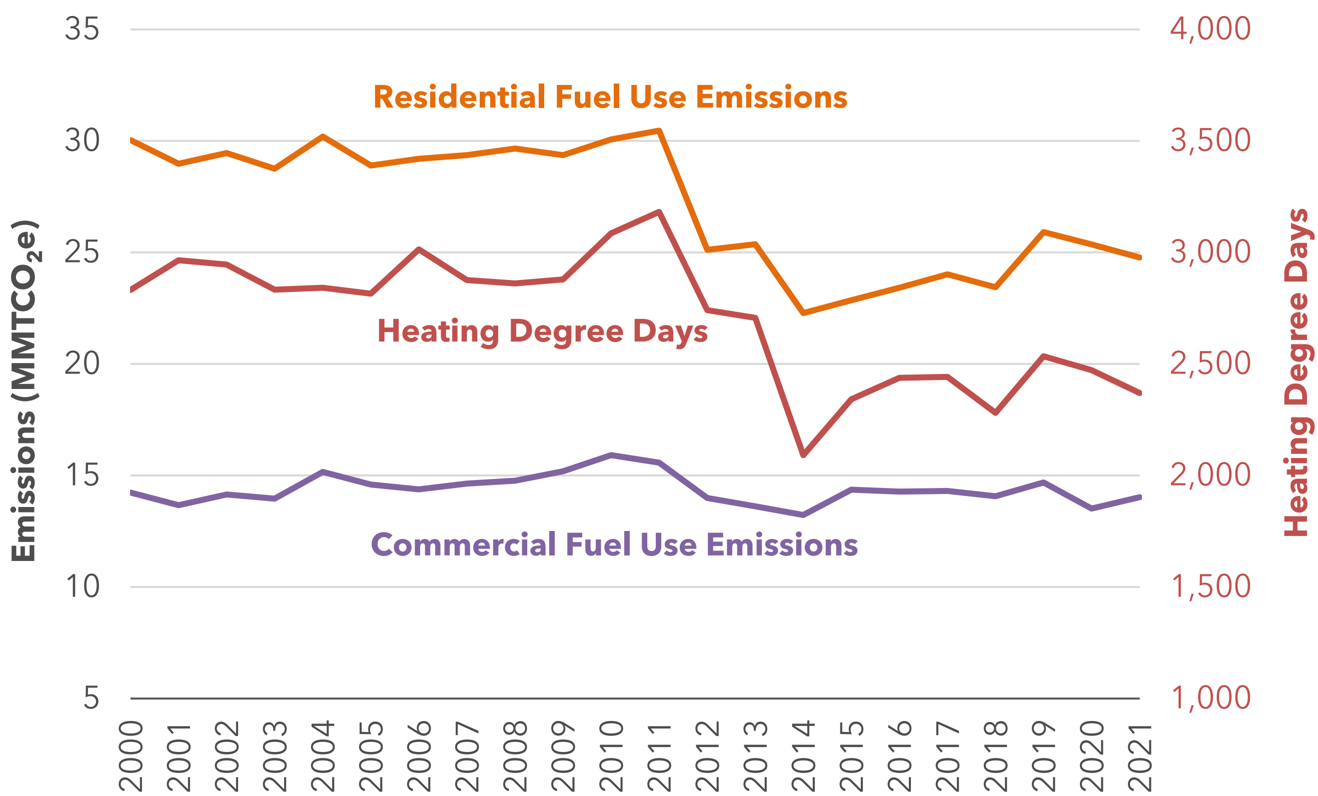

Figure 16 shows emissions from the residential and commercial sectors and heating degree days, a proxy for the amount of energy needed for space heating.

Commercial sector floor space has grown by 32.7% since 2000, yet emissions from fuel use, much of which is used to heat this space, have seen relatively small changes [19]. Figure 17 shows commercial sector floor space, which has grown, and emissions from fuel use per unit area, which have declined. This reduction in emissions per unit area is due to improvements in building efficiency. The number of occupied residential housing units has grown steadily from 11.9 million units in 2000 to 13.5 million units in 2021 [20]. Emissions per housing unit generally fluctuate with the need for heating depending on the temperatures of the given year, which is illustrated by the heating degree days index in Figure 16 [21]. Figure 18 shows residential sector emissions from fuel use and the number of housing units.

Figure 17. Commercial Sector Fuel Use Emissions per Unit Floor Space.

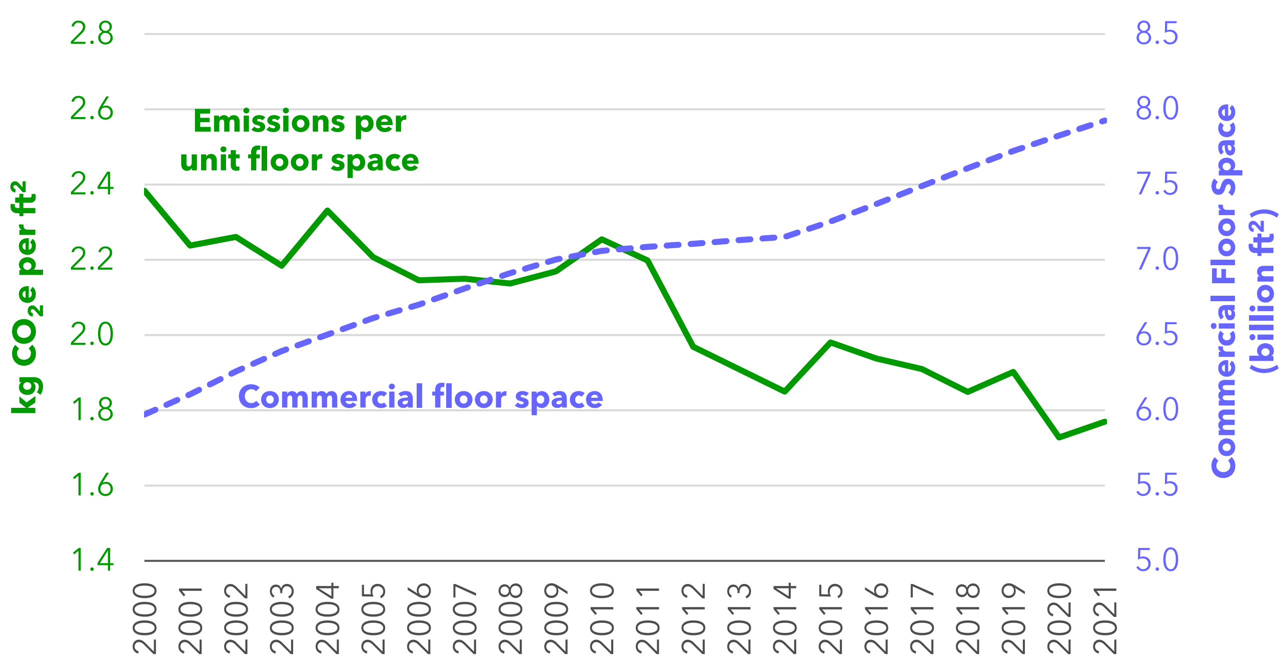

Figure 17 shows total square feet of commercial floor space and the emissions per square foot. Only commercial sector emissions from fuel use are included in the figure.

Figure 18. Residential Sector Fuel Use Emissions per Residential Housing Unit.

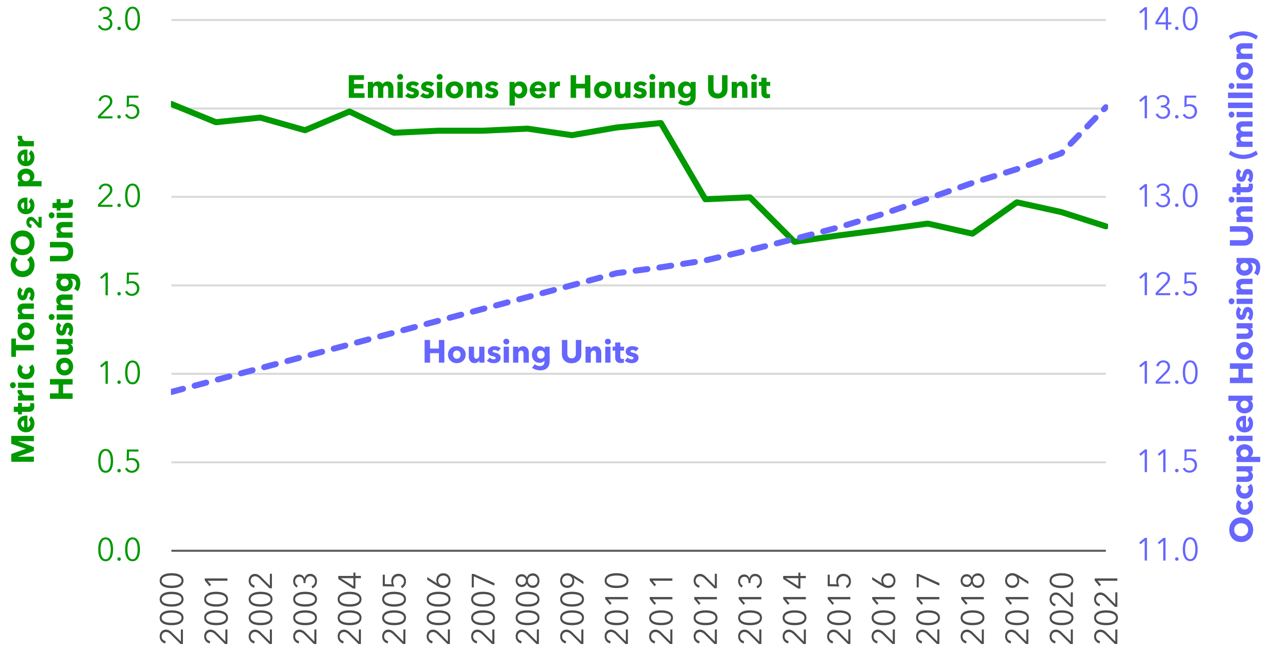

Figure 18 shows the number of occupied residential housing units and emissions per housing unit. Only residential sector emissions from fuel use are included in the figure.

Agriculture

California's agricultural sector contributed 8.1% of statewide GHG emissions in 2021, mainly from CH_4 and N_2O sources. Major emissions sources in the agricultural sector include enteric fermentation and manure management from livestock, crop production (fertilizer use, soil preparation and disturbance, and crop residue burning), and fuel combustion (water pumping, heating buildings, processing commodities, and tractors).

Approximately 70% of agricultural sector GHGs are emitted from livestock. Livestock emissions peaked in 2012 at 23.9 $MMTCO_2e$ and have decreased by 2.2 $MMTCO_2e$ (9.4%) to 21.7 $MMTCO_2e$ as of 2021. Livestock emissions are almost entirely CH_4 generated from enteric fermentation and manure management, and most of the livestock emissions are from dairy operations. Dairy population followed a generally increasing trend between 2000 and 2012, and GHG emissions from dairy manure management and enteric fermentation followed a similar trend as dairy herd sizes grew over this time. After 2012, methane emissions from dairy operations in California began to decline in proportion to population decreases. Beginning in 2015, California dairy operations increasingly began implementing anaerobic digesters as part of their manure management strategy in response to increased State incentives. Anaerobic digesters process manure in a closed environment, capturing CH_4 that would otherwise be emitted to the atmosphere from manure treatment and storage in open lagoons. As of 2021, over 60 anaerobic digesters were operational and managed at least 8.9% of the statewide dairy population's manure.

Crop production accounted for 22.0% of agriculture sector emissions in 2021. Emissions from the growing and harvesting of crops have generally declined since 2000. The long-term trend of emissions reduction from 2000 to 2021 corresponds to a reduction in crop acreage [22] (which leads to an associated decrease in synthetic fertilizer use) and a shift away from flood irrigation to sprinkler and drip irrigation. Figure 19 presents emissions from the agriculture sector, broken out by sub-sector. The trend in total agriculture sector emissions is displayed in Figure 5.

Figure 19. Agriculture Sector Emissions.

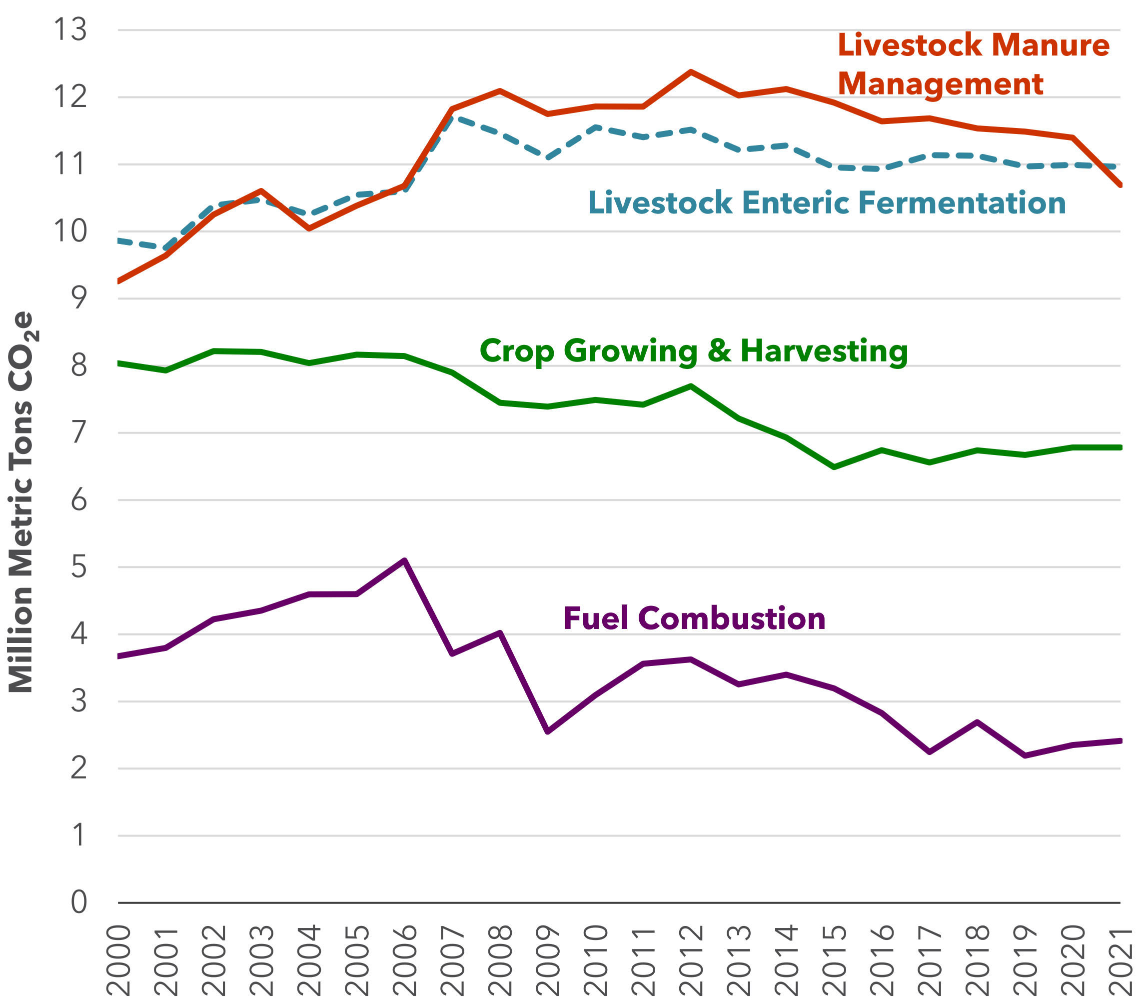

Figure 19 presents the trends in emissions from livestock manure management, livestock enteric fermentation, crop growing and harvesting (fertilizer use, soil preparation and disturbance, and crop residue burning), and fuel combustion (water pumping, heating buildings, processing commodities, and tractors).

High Global Warming Potential Gases

In 2021, high-GWP gases comprised 5.6% of California's emissions. This sector includes releases of ozone-depleting substances (ODS)[18] substitutes, sulfur hexafluoride emissions from the electricity transmission and distribution system, and emissions from semiconductor manufacturing. Emissions of ODS substitutes account for 97.5% of emissions from this sector and consist primarily of hydrofluorocarbons (HFC). ODS substitutes are used in refrigeration and air conditioning equipment, solvent cleaning, foam production, fire retardants, and aerosols. In 2021, refrigeration and air conditioning equipment contributed 91.6% of ODS substitutes emissions.

As shown in Figure 20, emissions of ODS substitutes grew from 2000–2020. The steady growth occurred as these gases replaced ODS being phased out under the Montreal Protocol [5]. Emissions of ODS have decreased significantly since they began to be phased out in the 1990s. The combined emissions of ODS and ODS substitutes have been steadily decreasing over time as ODS are phased out, even as emissions from ODS substitutes increased from 2000–2020.

After growing steadily from 2000–2020, the trend in emissions of ODS substitutes began to flatten for the first time beginning in 2021, with very little change compared to 2020. There are four main sub-sectors within the ODS substitutes category: transportation, commercial, industrial, and residential. From 2020 to 2021, emissions from the transportation sub-sector declined, continuing a long-term trend that exists for two main reasons. First, the transportation refrigeration units (TRU) Airborne Toxic Control Measure (ATCM), adopted in 2004 and implemented in January 2010, reduces emissions by limiting the charge size of TRUs, thus reducing leakage rates [23]. Second, the Low-Emission Vehicle (LEV) III regulations (as part of the Advanced Clean Cars rulemaking package) were adopted in 2012 and include increasingly stringent emissions standards for new passenger vehicles through the 2025 model year. LEV III prescribes measures that lower refrigerant emissions, including reducing end-of-life losses for passenger vehicle air conditioning systems.

Figure 20 shows emissions from ODS and ODS substitutes from 2000–2021 while total emissions from the high-GWP sector are shown in Figure 5. Figure 21 shows emissions of ODS substitutes by sub-category for 2021.

[18] ODS are also high-GWP gases, however they are outside the scope of the IPCC accounting framework and AB 32.

Figure 20. Trends in ODS and ODS Substitutes Emissions.

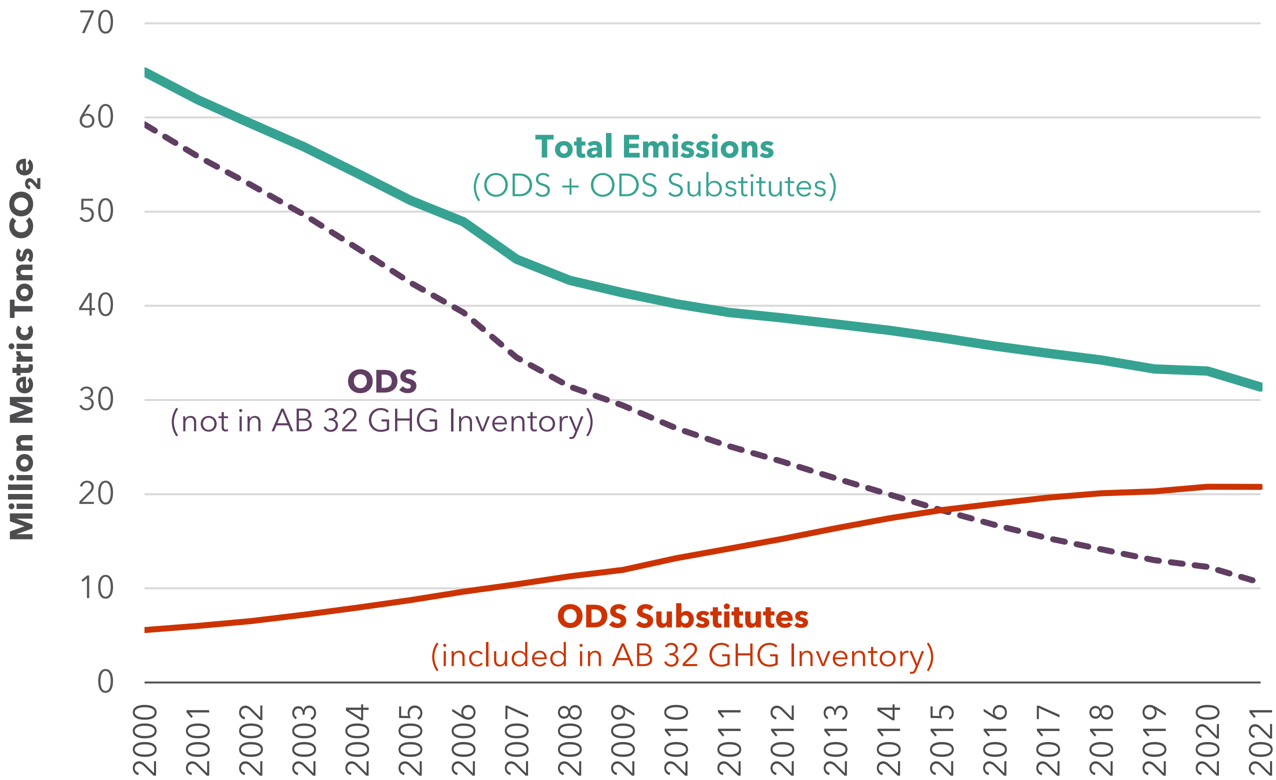

Figure 20 presents the trends in emissions from ODS substitutes, ODS, and their sum ("Total Emissions"). ODS are GHGs; however, they are not included in the AB 32 GHG Inventory.

Figure 21. ODS Substitutes Emissions by Category.

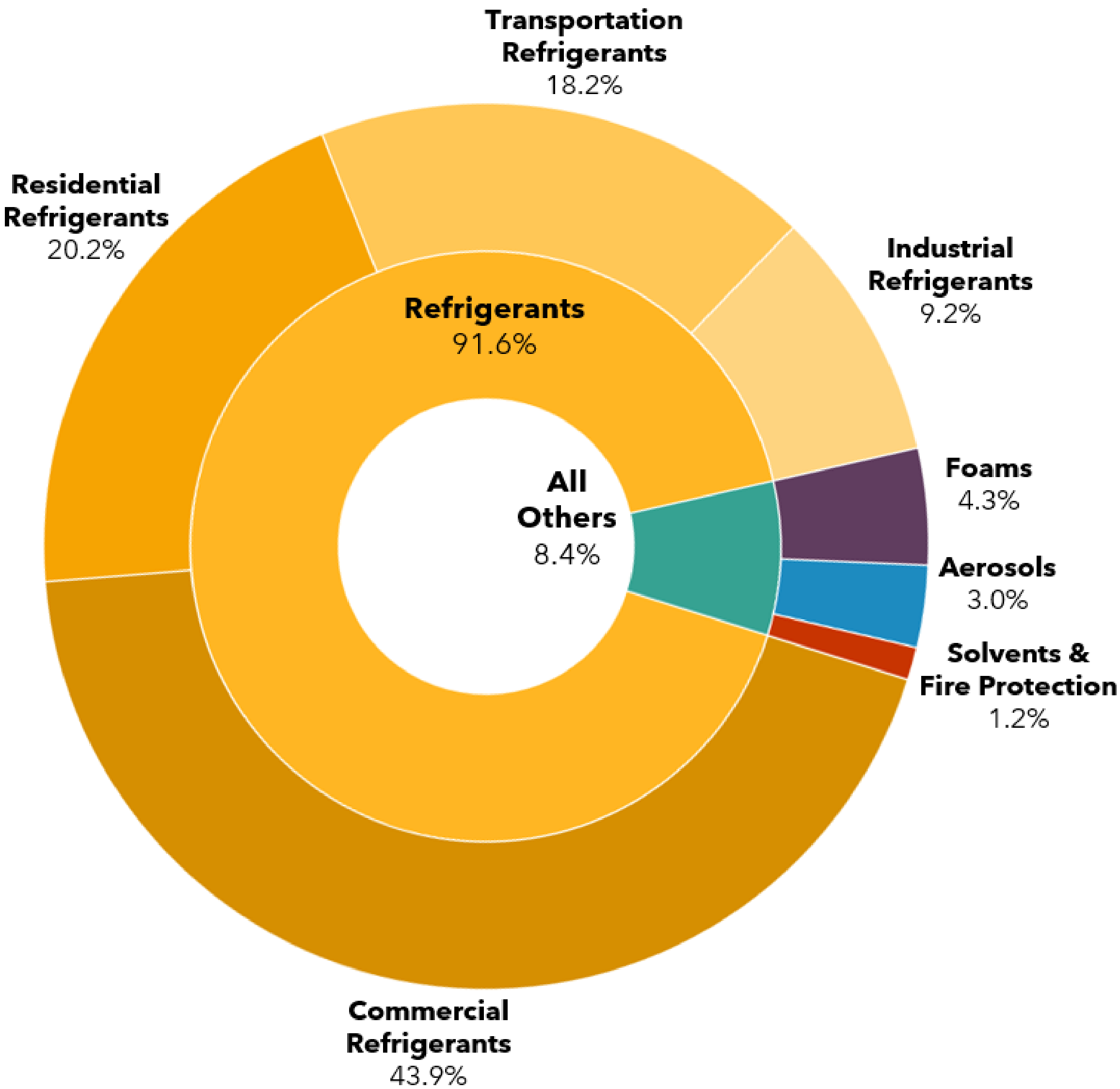

Figure 21 presents the breakdown of ODS substitutes emissions in 2021 by product type and sector in which they are used. Refrigerants used in various sectors make up the majority of ODS substitutes emissions.

Recycling and Waste

Emissions from the recycling and waste sector include CH_4 and N_2O emissions from landfills and commercial-scale composting. Emissions from this sector have grown by 24.4% since 2000 and comprised 2.2% of California's GHG emissions in 2021. Landfill emissions are primarily CH_4 and account for 95.2% of the emissions from this sector in 2021. Compost production facilities produce the remaining fraction of emissions.

Landfill emissions are the difference between the methane generated from waste decomposition and the methane captured by landfill gas collection and control systems. The annual amount of solid waste deposited in California's landfills grew from 39 million short tons in 2000 to its peak of 46 million short tons in 2005, then declined until 2012. After 2012, deposited waste amounts have increased every year, with the exception of a drop in 2020 likely due in part to the COVID-19 pandemic and the resulting decline in commercial and industrial waste generation [24]. Landfill methane generation is driven by the total amount of degradable carbon remaining in California landfills rather than year-to-year fluctuations in deposition of solid waste [25]. Figure 5 shows the trend in total emissions from the recycling and waste sector. Figure 22 and Figure 23 show trends in landfill emissions and activities that drive emissions.

Figure 22. Landfill Methane Emissions.

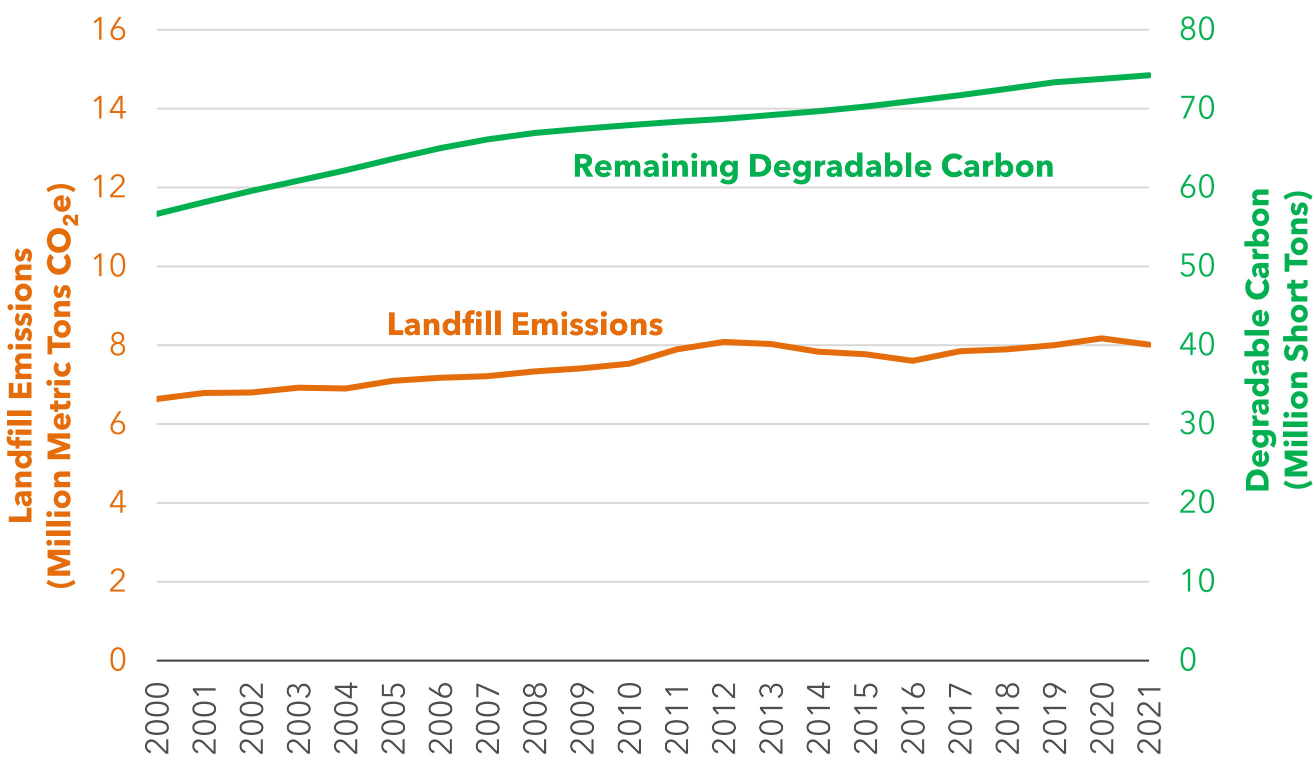

Figure 22 presents trends in landfill emissions and the amount of degradable carbon remaining in California landfills. The latter drives the emissions generated by landfills. The color of a trend line matches the color of its corresponding vertical axis label.

Figure 23. Landfill Waste.

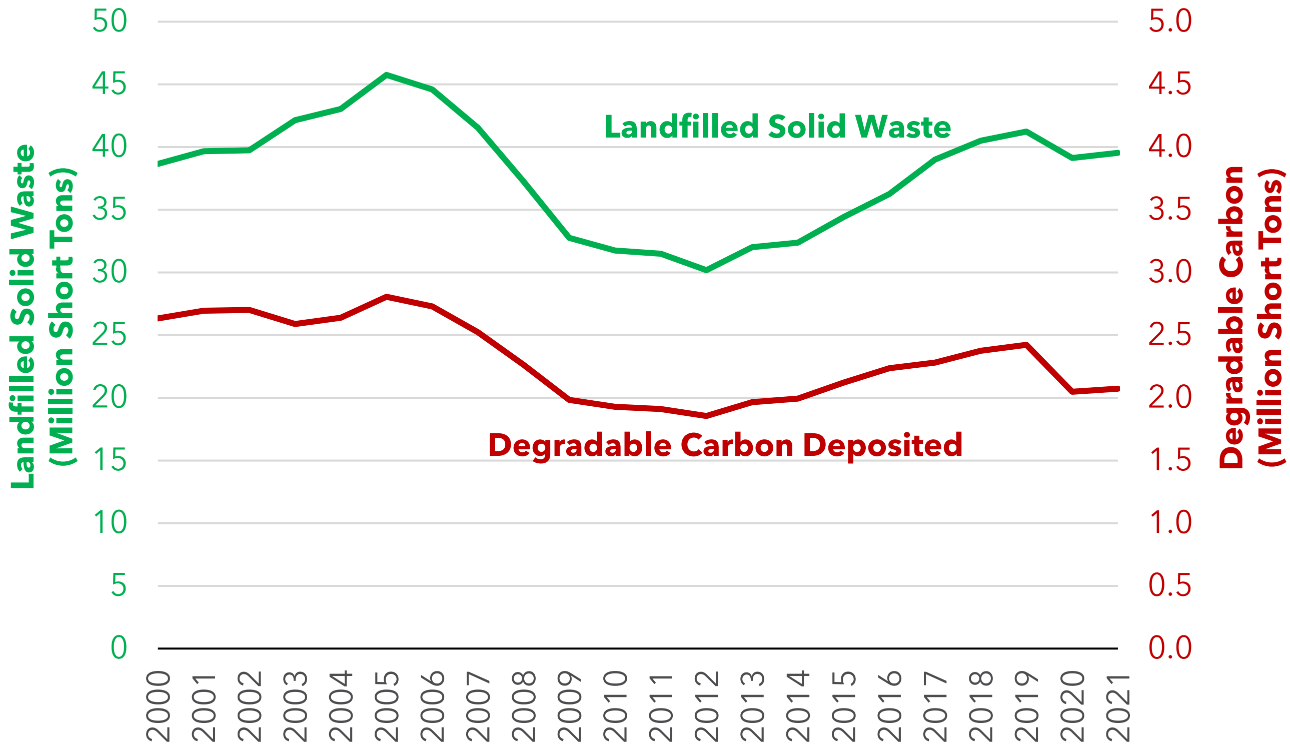

Figure 23 presents the annual amount of solid waste deposited into California landfills and the amount of degradable carbon contained in the solid waste. The vertical axes are color coded to match each trend line.

Additional Information

International GHG Inventory Practice of Recalculating Emissions for Previous Years

Consistent with the IPCC Guidelines, recalculations are made to incorporate new methods or reflect updated data for all years from 2000 to 2020 to maintain a consistent inventory time series. Therefore, emissions estimates for a given calendar year may be different between editions as methods and supplemental data are updated. For example, in the 2022 edition, total 2020 emissions were estimated to be 369.2 $MMTCO_2e$. In the 2023 edition, recalculation revised the 2020 emissions to 368.7 $MMTCO_2e$, reflecting refinements and updates to methodology and information gained since 2022. Analyses of emissions trends, including the emissions increase of 12.6 $MMTCO_2e$ between 2020 and 2021, are based on the recalculated numbers in the 2023 edition of the AB 32 GHG Inventory. A description of the method updates is available in the Inventory Updates Since the 2022 Edition of the AB 32 GHG Inventory - Supplement to the Technical Support Document.

Global Warming Potential Values

In accordance with the IPCC Guidelines, California's AB 32 GHG Inventory uses the 100-year GWPs from the IPCC 4th Assessment Report. However, other CARB programs may use different GWP values.

Sources of Data Used in California's AB 32 GHG Inventory

Statewide GHG emissions are calculated using several data sources. The primary data source is from reports submitted to CARB through the Regulation for the Mandatory Reporting of GHG Emissions (MRR). MRR requires facilities and entities with more than 10,000 metric tons CO_2e per year of combustion and process emissions, all facilities belonging to certain industries, and all electricity importers to submit an annual GHG emissions data report directly to CARB. Reports from facilities and entities that emit more than 25,000 metric tons of CO_2e per year are verified by a CARB-accredited third-party verification body. For additional information see: emissions data reported to MRR.

CARB also relies on data from other California State and federal agencies to develop the AB 32 GHG Inventory. These agencies include, but are not limited to the California Energy Commission, California Department of Tax and Fee Administration, California Department of Conservation, California Department of Food and Agriculture, California Department of Resources Recycling and Recovery, U.S. Energy Information Administration, and U.S. Environmental Protection Agency (U.S. EPA). The timing for when these data sources are available drives the publication date for the AB 32 GHG Inventory each year. All data sources used to develop the AB 32 GHG Inventory are listed in supporting documentation on the following webpage: California AB 32 GHG Emission Inventory Data.

Other Ways of Categorizing Emissions in the AB 32 GHG Inventory

There are multiple ways to organize emissions by category in an emissions inventory. Each year, CARB makes the AB 32 GHG Inventory available in three categorization schemes:

- The Scoping Plan Categorization organizes emissions by CARB program structure. (This is the categorization scheme used in this report.)
- The Economic Sector/Activity Categorization generally aligns with how sectors are defined in the North America Industry Classification System (NAICS).
- The IPCC Categorization groups emissions into four broad categories of emission processes. This format conforms to international GHG inventory practice and is consistent with the national GHG inventory that U.S. EPA annually submits to the United Nations.

Although this report uses the Scoping Plan Categorization, the Economic Sector/Activity Categorization is also often used by the public. The differences between the Scoping Plan Categorization and the Economic Sector/Activity Categorization are as follows:

- High-GWP gas emissions are grouped into a single sector under the Scoping Plan Categorization; they are included in the economic sectors where they are used in the Economic Sector/Activity Categorization.
- Emissions from recycling and waste are shown in their own sector under the Scoping Plan Categorization; they are included in the industrial sector under the Economic Sector/Activity Categorization.

The figures below show emissions from each sector using the Scoping Plan Categorization and the Economic Sector/Activity Categorization side-by-side. Detailed data for these categorization schemes can be accessed from CARB's Current California AB 32 GHG Emission Inventory Program webpage.

Figure 24. 2021 GHG Emissions by Economic Sector.

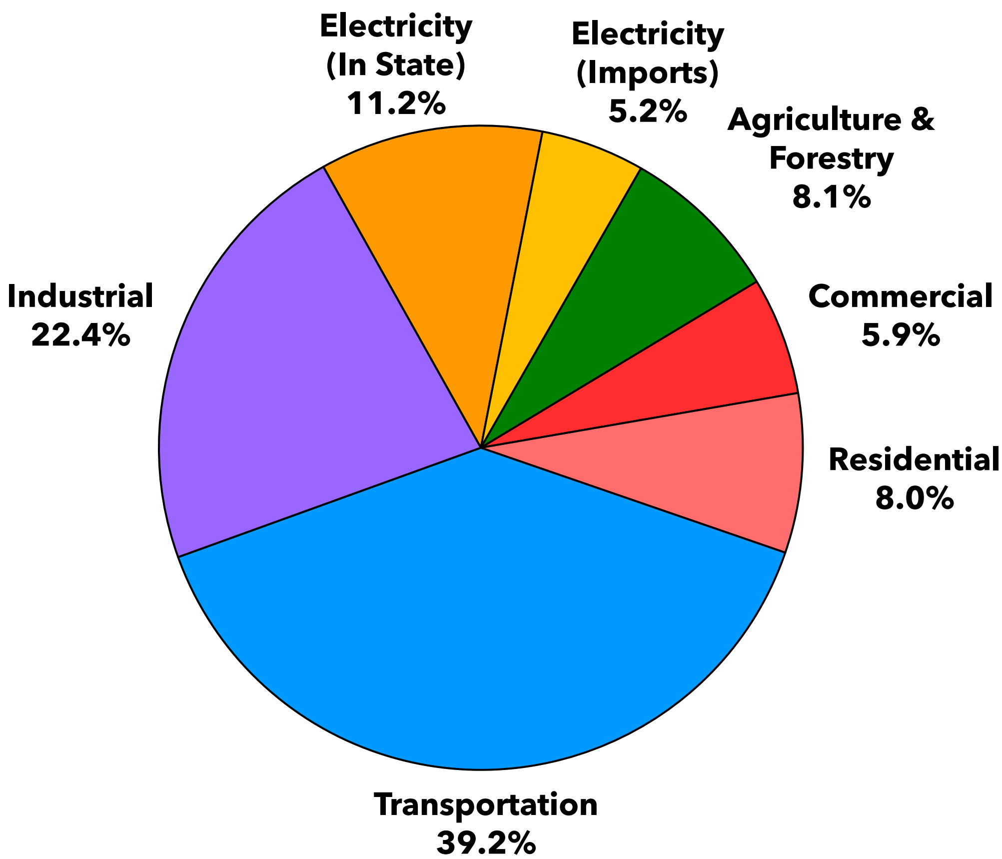

Figure 24 shows the relative size of 2021 emissions by sector using the Economic Sector/Activity Categorization scheme.

Figure 25. 2021 GHG Emissions by Scoping Plan Sector.

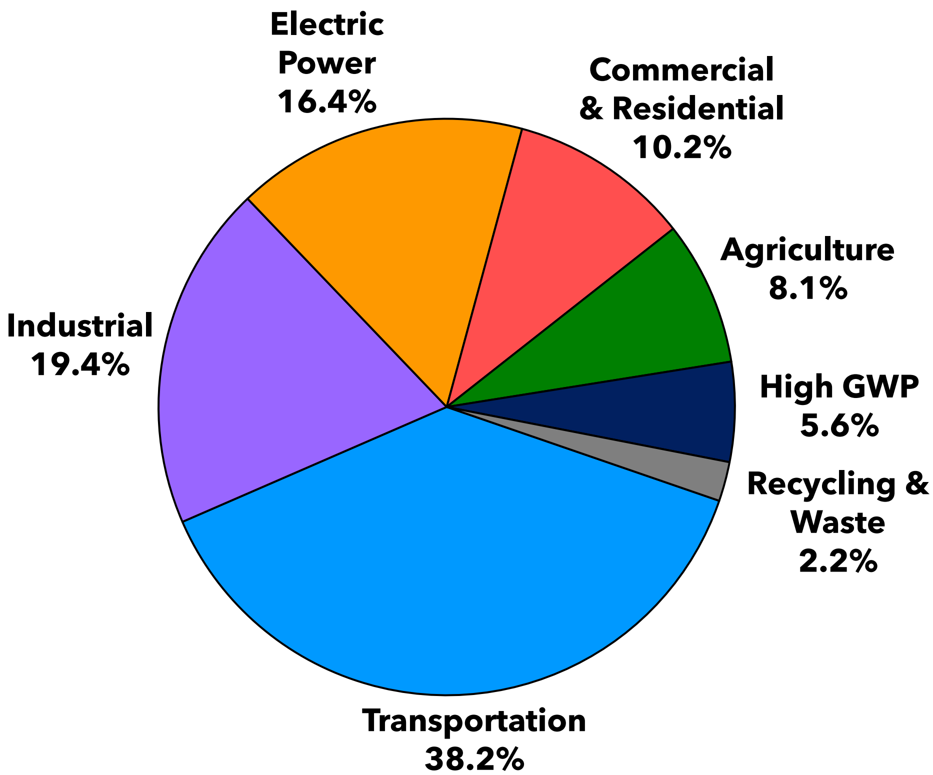

Figure 25 shows the relative size of 2021 emissions, organized by the categories in the AB 32 Scoping Plan.

Uncertainties in the AB 32 GHG Inventory

CARB is committed to continually working to reduce the uncertainty in the AB 32 GHG Inventory estimates. The uncertainty of emissions estimates varies by sector. The emissions data reported under MRR is subject to third-party verification, ensuring a high level of accuracy. Other non-MRR sources, mainly non-combustion, biochemical processes, have varying uncertainty depending on the input data and the emission processes.

Natural and Working Lands Inventory and Wildfire Emissions

CARB has also developed an Inventory of Ecosystem Carbon in California's Natural and Working Lands [2] (NWL Inventory) separate from the AB 32 GHG Inventory. The NWL Inventory quantifies ecosystem carbon stored in plants and soils in California's Natural and Working Lands (including forest, woodland, shrubland, grassland, wetland, orchard crop, urban forest, and soils) and tracks changes in carbon stocks over time. More information can be found on the NWL Inventory webpage.

Fire has served a natural beneficial function in California's diverse ecosystems for millennia, such as facilitating germination of seeds for certain tree species, replenishing soil nutrients, clearing dead biomass to make room for living trees to grow, and reducing accumulation of fuels that lead to high-intensity wildfires. However, emissions from fire also negatively impact human health and safety because fire emits GHGs, black carbon, and other harmful air pollutants. GHG emissions from wildfires are estimated separately when compared to anthropogenic sources due to differences in their carbon cycling.

Anthropogenic (human-caused) GHG emissions from fossil fuels come from geological carbon sources, which are part of the earth's slow carbon cycle, where carbon pools change over the course of many millennia (e.g., fossil fuel formation). In contrast, the fast carbon cycle, in which carbon moves between pools over months to centuries, includes natural emissions sources, such as wildfires, plant decomposition and respiration. The acceleration of fossil fuel burning has led to an increase in ambient CO_2 concentrations globally; however, wildfire emissions are part of a fast carbon cycle that is balanced by vegetation growth. In recent years the intensity and size of wildfires have increased across California. In an effort to contextualize the GHG emissions from wildfires, CARB annually publishes wildfire emissions estimates. More information can be found in CARB's document, Frequently Asked Questions: Wildfire Emissions.

Pesticides

The gases included in this AB 32 GHG Inventory were informed by AB 32 and IPCC Guidelines. Pesticides that act as GHGs but are not listed in AB 32, nor the IPCC Guidelines, are not included in the AB 32 GHG Inventory. Two examples include methyl bromide, a fumigant used to control pests in agriculture and shipping, and sulfuryl fluoride, a pesticide used for building fumigation and post-harvest storage of commodities. CARB has provided estimates of sulfuryl fluoride emissions as an informational item in the Short-Lived Climate Pollutant Inventory. CARB will continue to track emissions from pesticide use.

Figure References

Figure Number	Reference
Figure 1	[8]
Figure 2	[8] [9] [10]
Figure 3	[8] [9]
Figure 4	[8] [10]
Figure 5	[8]
Figure 6	[8]
Figure 7	[8]
Figure 8	[13] [14] [15]
Figure 9 & 10	[8]
Figure 11	[8]
Figure 12	[8] [11] [17] [18]
Figure 13	[17] [18]
Figure 14	[17] [18]
Figure 15	[8]
Figure 16	[8] [21]
Figure 17	[8] [19]
Figure 18	[8] [20]
Figure 19	[8]
Figure 20 & 21	[8] [23]
Figure 22	[8]
Figure 23	[8] [24]
Figure 24 & 25	[8]

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