California Greenhouse Gas Emissions from 2000 to 2022: Trends of Emissions and Other Indicators

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CALIFORNIA
AIR RESOURCES BOARD

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Contents

List of Figures

Executive Summary

Each year the California Air Resources Board (CARB) produces the Assembly Bill (AB) 32 Greenhouse Gas Emissions Inventory (Inventory) which estimates anthropogenic emissions within California, as well as emissions associated with imported electricity. The Inventory is one tool to track progress of California's climate programs toward achieving statewide greenhouse gas (GHG) targets. This document summarizes the trends in emissions and indicators in the Inventory. The emissions included in the Inventory represent actual emissions released into the atmosphere from the AB 32 sectors.[1] The 2024 edition of the Inventory includes GHG emissions released during the 2000–2022 calendar years and includes several technical updates. Details on these updates are described in the technical documentation.

In 2022, emissions from GHG emitting activities statewide[2] were 371.1 million metric tons of carbon dioxide equivalent (MMTCO_2e). This is 9.3 MMTCO_2e (2.4%) lower than in 2021 (380.4 MMTCO_2e). The 2022 emissions data shows that the State of California is continuing its established long-term trend of GHG emissions declines, despite the anomalous emissions trends from 2019 through 2021, due in large part to the impacts of the COVID-19 pandemic. The most notable highlights in the 2024 edition of the Inventory include:

- The transportation sector showed the largest decrease in emissions of 5.2 MMTCO_2e (3.6%) compared to 2021. On-road transportation emissions decreased 5.7 MMTCO_2e (4.2%). The decrease in on-road transportation was due in large part to reduced use of fossil distillate (17.6%) and fossil gasoline (1.7%).
- Electricity sector emissions decreased by 2.6 MMTCO_2e (4.1%) compared to 2021. Total electricity generation increased by 8.5 TWh (2.7%) while the carbon intensity of generation decreased by 6.7%. Solar power generation increased by 8.8 TWh (14.5%) and wind power generation increased by 1.4 TWh (5.5%), incentivized by California's clean energy policies. Hydropower generation had a modest increase of 1.8 TWh (4.2%) as drought continued to impact hydropower generation.[3] As a result, fossil gas-powered electricity generation decreased by 2.7 TWh (2.5%).
- Industrial sector emissions decreased by 1.5 MMTCO_2e (2.0%) compared to 2021. The oil and gas production and processing sub-sector accounted for most of the

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

[3] The hydropower generation metric includes data from asset-controlling suppliers which imported low GHG intensity electricity consisting primarily of hydropower.

decrease, with emissions decreasing by 0.9 $MMTCO_2e$ (7.0%). Overall, the industrial sector's 2022 emissions were 72.7 $MMTCO_2e$, which is the lowest of any point during the inventory time series and 21.7% below the 2000 level.

Figure 1. Annual Statewide GHG Emissions and GHG Limits.

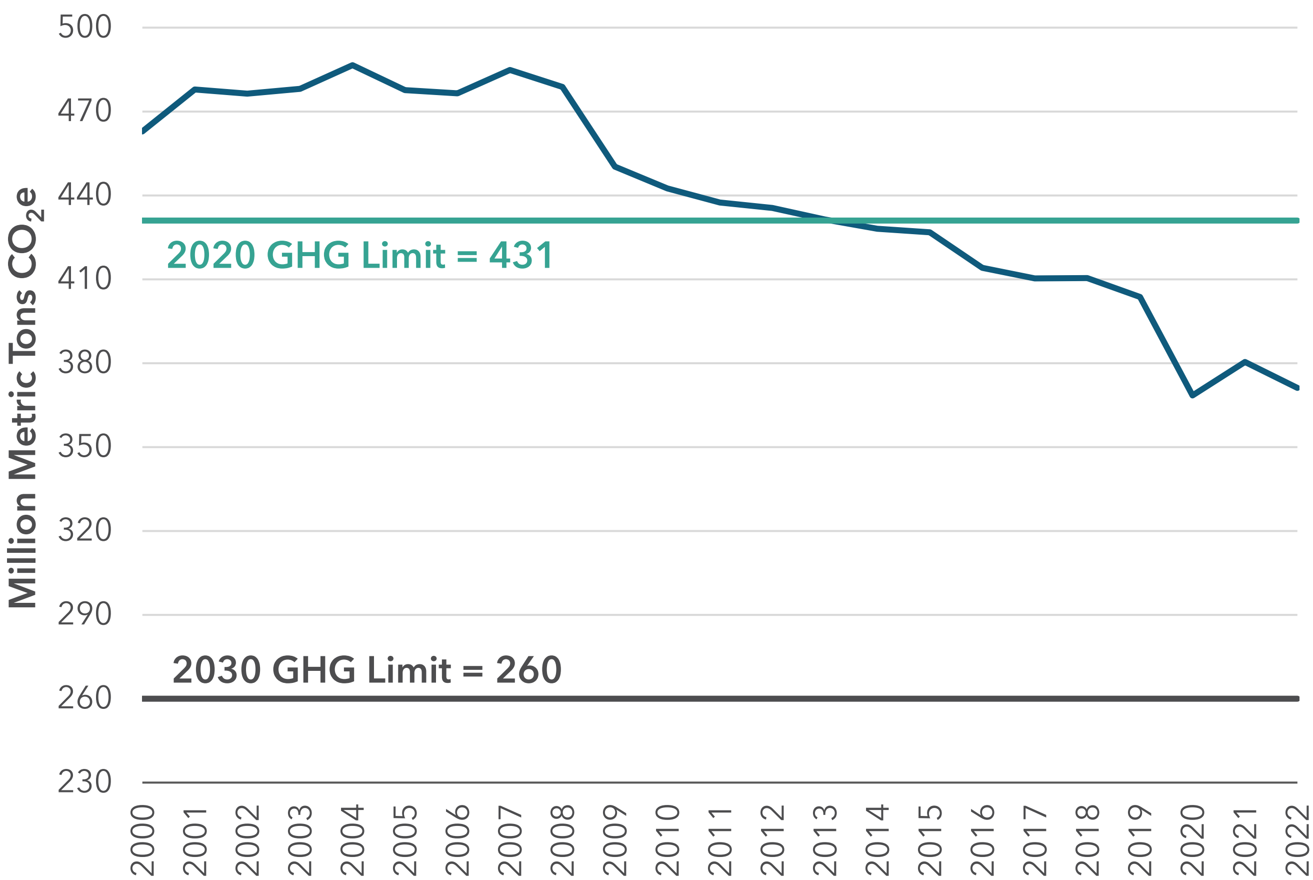

Figure 1 shows California's annual GHG emissions from 2000 to 2022 in relation to the 2020 GHG Limit established by AB 32 and the 2030 GHG Limit established by SB 32. California's GHG emissions dropped below the 2020 GHG Limit in 2014 (428.1 $MMTCO_2e$) and have remained below this level since that time.

Introduction

The AB 32 GHG Inventory is one tool to track California's progress toward achieving the statewide GHG targets established by 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) [2] to reduce emissions to at least 40% below 1990 levels by 2030; and AB 1279 (Muratsuchi, Chapter 337, Statutes of 2022) [3] to reduce anthropogenic emissions at least 85% below 1990 levels no later than 2045. The 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 [4]. The methods used to quantify emissions included in the AB 32 GHG Inventory are consistent with international and national practices [5] and meet the requirements of AB 32.

The 2024 edition of the AB 32 GHG Inventory includes the emissions of the seven GHGs identified in AB 32 for the years 2000 to 2022. There are additional climate pollutants that are not included in AB 32 that are tracked separately from the Inventory. These include black carbon and sulfuryl fluoride (SO_2F_2), which are discussed in the Short-Lived Climate Pollutant (SLCP) Strategy [6], and ozone depleting substances (ODS), which are being phased out under a 1987 international treaty[4] [7].

In this report, emissions trends and indicators are presented in the categories outlined in the Initial AB 32 Climate Change Scoping Plan [8]. There are alternative ways of organizing emissions sources into categories, and the resulting percentages will differ depending on the categorization used.[5] 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) [9].

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[4] Many ODS substitutes are GHGs whose emissions are included in the Inventory, consistent with IPCC Guidelines.

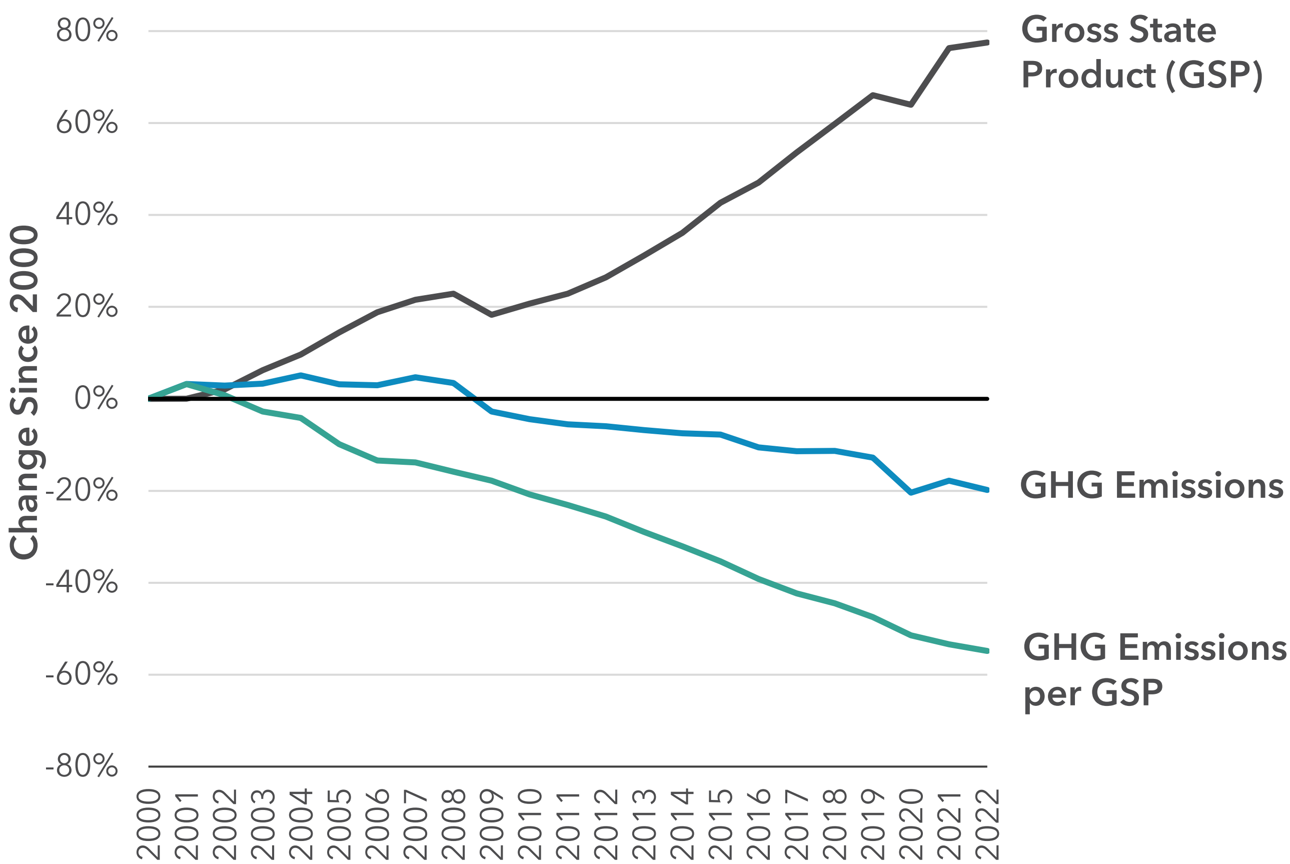
[5] The *Additional Information* section of this report provides further information on alternative categorization schemes.

Statewide Trends of Emissions and Indicators

In 2022, emissions from statewide emitting activities were 371.1 $MMTCO_2e$, 9.3 $MMTCO_2e$ (2.4%) lower than 2021 levels. 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.

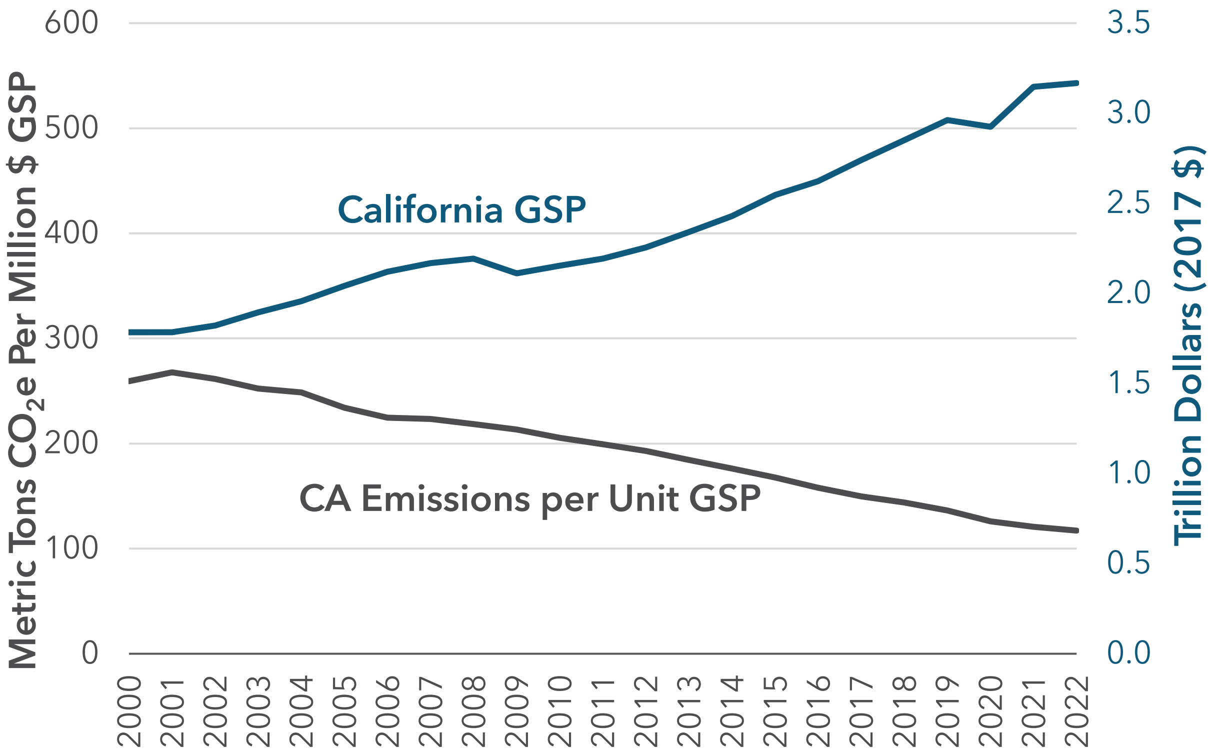
Overall trends in the Inventory continue to demonstrate that the carbon intensity of California's economy (the amount of carbon pollution per million dollars of gross state product (GSP)) is declining. From 2000 to 2022, the carbon intensity of California's economy decreased by 54.8% while the GSP increased by 77.5%. California's GSP increased 0.7% in 2022 [10]. Emissions per GSP declined by 3.1% from 2021 to 2022 [10][11]. Figures 2-3 show these economic indicators alongside GHG emissions.

Figure 2. Change in California GSP and GHG Emissions Since 2000.



Metric	Associated 2022 Value
GSP	3.2 Trillion (2017 $)
GHG Emissions	371.1 $MMTCO_2e$
GHG Emissions per GSP	117.2 Metric Tons CO_2e per Million $

Figure 3. Carbon Intensity of California's Economy.



Overview of Emissions Trends by Sector

The transportation sector remains the largest source of GHG emissions in the state. Direct emissions from vehicle tailpipes, intrastate aviation, and other transportation sources account for 37.7%[6] of statewide emissions in 2022. Emissions from this sector decreased by 5.2 $MMTCO_2e$ (3.6%) compared to 2021, primarily due to a greater share of fuels used for on-road transportation being produced from non-fossil resources. When upstream emissions from oil extraction, petroleum refining, and oil pipelines in California are included, transportation is responsible for 48.0% of statewide emissions in 2022.

Emissions from the electricity sector account for 16.1% of the Inventory in 2022. Emissions from this sector decreased by 2.6 $MMTCO_2e$ (4.1%) compared to 2021, despite a year-over-year increase of 8.5 TWh (2.7%) in electricity generation to meet increased demand. Continued growth of in-state solar generation and increases to in-state hydropower and

[6] The transportation sector represents direct emissions from in-state fuel combustion by on-road vehicles, intrastate flights, trains, water-borne vessels, and a few other smaller 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.

imported wind power were more than sufficient to meet increased overall demand. Fossil gas-powered generation decreased by 2.7 TWh (2.5%).

The industrial sector accounted for 19.6% of California’s 2022 GHG emissions. This sector saw a decrease of 1.5 $MMTCO_2e$ (2.0%) from 2021 to 2022, most notably in the oil and gas production sector. Commercial and residential emissions, which accounted for 10.6% of the state’s total, saw an increase of 0.7 $MMTCO_2e$ (1.7%) from 2021 to 2022.

The high-GWP gases sector accounted for 5.7% of California's 2022 GHG emissions. High-GWP gases continue to replace ODS that are being phased out under the 1987 Montreal Protocol [7]. However, emissions from this sector have been stable from 2020-2022, which is a notable change from 2000-2020 when emissions grew every year. Agriculture sector emissions accounted for 8.0% of the state’s total in 2022 and decreased by 0.5 $MMTCO_2e$ (1.7%) from 2021 levels. This was mostly due to a greater share of the sector’s diesel fuel use being produced from non-fossil resources and 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 $MMTCO_2e$ (1.8%) from 2021 to 2022.

Figure 4 shows emissions trends by Scoping Plan sector for 2000 to 2022. Figure 5 shows 2022 emissions by Scoping Plan sector and sub-sector.

Figure 4. Trends in California GHG Emissions.

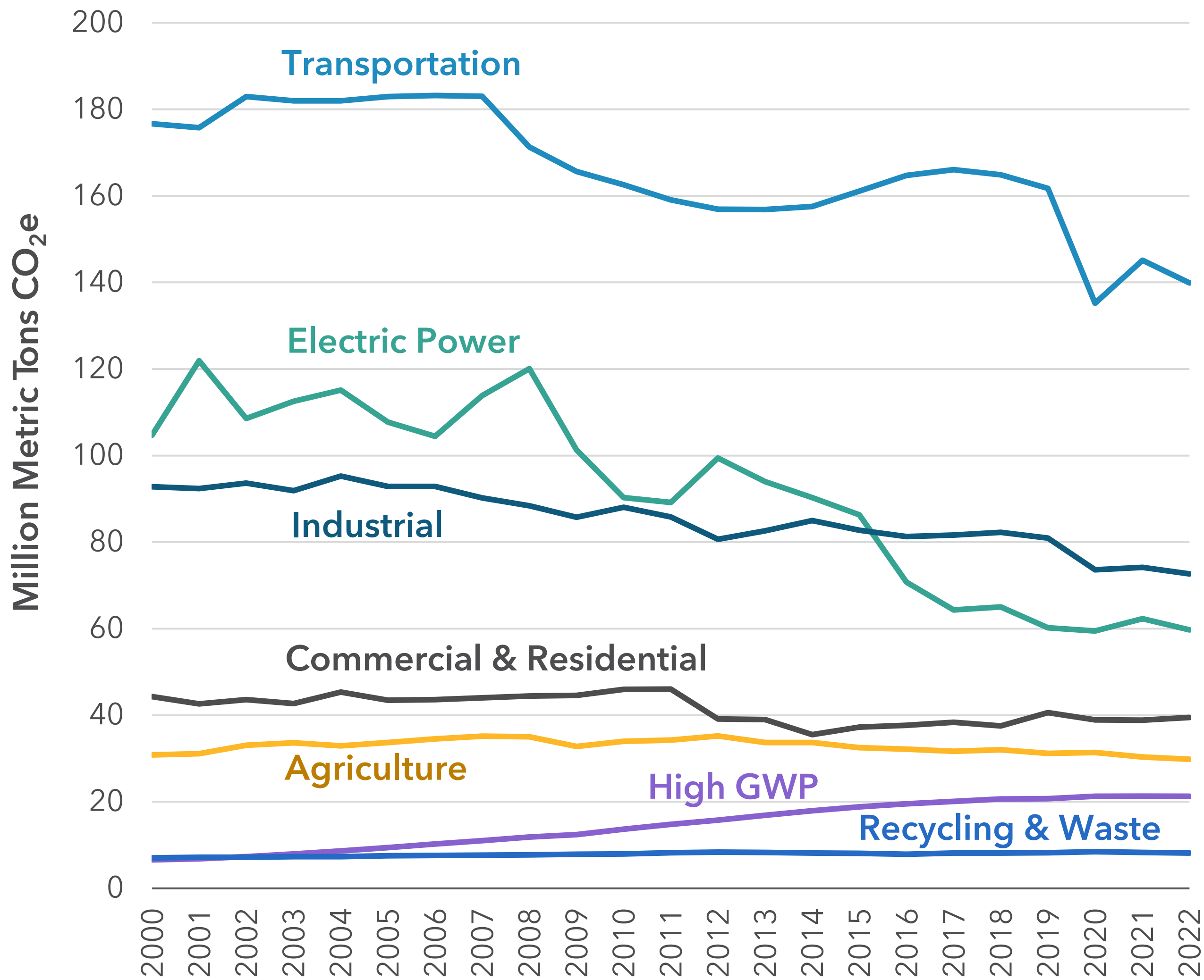


Figure 4 shows changes in emissions by Scoping Plan sector between 2000 and 2022.

Figure 5. 2022 GHG Emissions by Scoping Plan Sector and Sub-Sector.

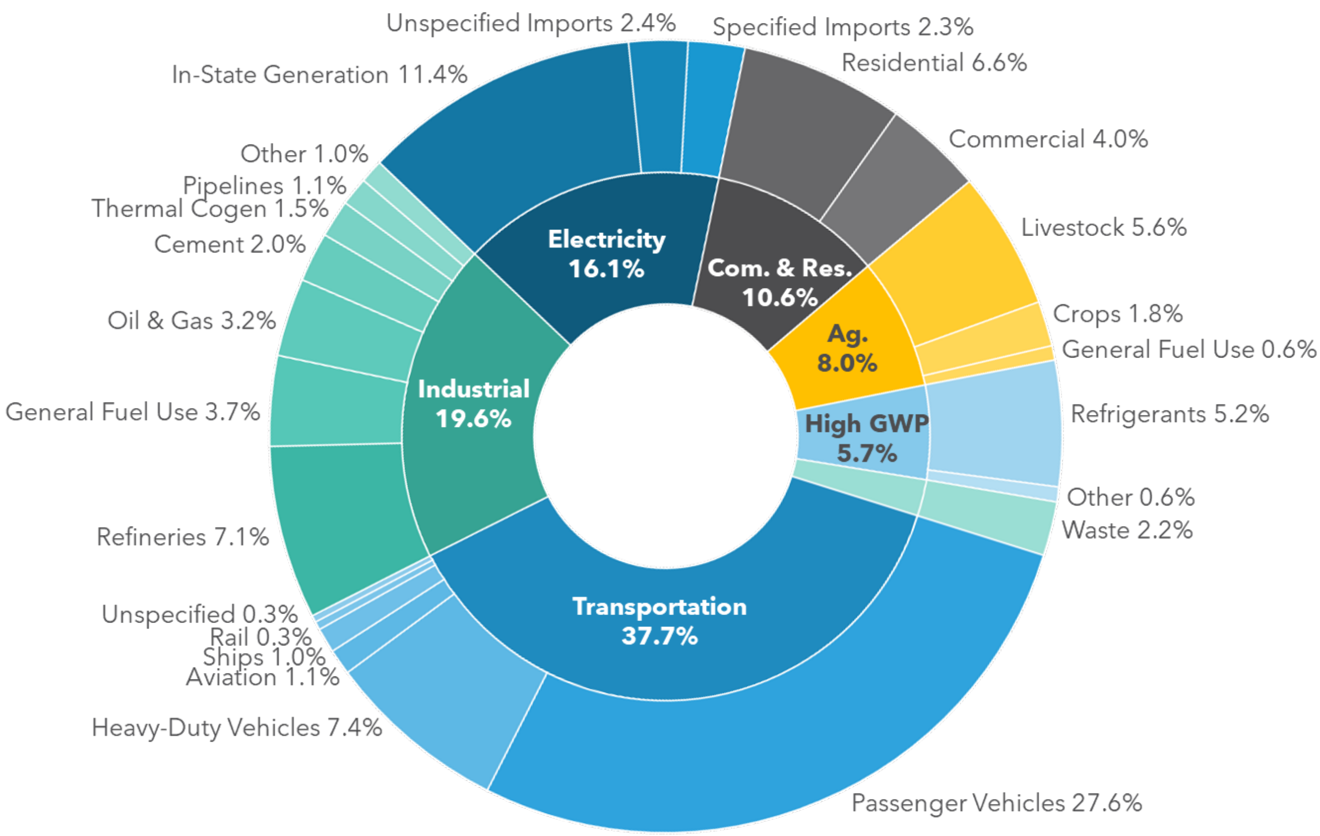


Figure 5 shows 2022 GHG emissions by Scoping Plan category. The inner ring shows the Scoping Plan sectors, while the outer shows the sub-sectors. Values do not sum to 100% due to independent rounding.

Transportation

The transportation sector remains the largest source of GHG emissions in 2022 at 37.7% of total emissions. Overall, transportation sector emissions decreased 5.2 MMTCO_2e (3.6%) from 2021 levels due to reductions of 5.7 MMTCO_2e (4.2%) from on-road transportation and 0.2 MMTCO_2e (15.4%) from rail, which were partially offset by a 0.7 MMTCO_2e (21.7%) increase from intrastate aviation. The transportation sector includes emissions from in-state fuel combustion by on-road vehicles, intrastate flights, trains, water-borne vessels, and a few other smaller sources. [7], [8], [9]

As shown in Figure 4, emissions from the transportation sector have generally decreased since their peak in 2006 but have experienced periods of both emissions growth and decline. Several factors can influence transportation sector emissions. These include vehicle miles traveled (VMT), vehicle GHG emissions rates, the number of zero-emission vehicles on the road, and the amount of fuel derived from non-fossil resources. Year-to-year changes in economic conditions can also impact the amount of transportation fuel used across the state.

The decrease in 2022 brings emissions to their second lowest level of the inventory time series. One factor that contributed to emission reductions from on-road sources in 2022 was a decrease in the amount of fuel used. This decrease occurred despite increased VMT [12] and was observed both for heavy- and light-duty vehicles. The amount of gasoline blend used on-road decreased by 1.4% while the amount of diesel blend used decreased by 2.4%. Meanwhile, the percentage of on-road diesel blend produced from non-fossil resources increased from 30% to 41%. These two factors were the key drivers of the decrease in the sector's emissions. Reductions from on-road sources were partially offset by 0.7 $MMTCO_2e$ in emissions growth (21.7%) from intrastate aviation due to increased fuel use, which returned to the level seen in 2019 prior to the COVID-19 pandemic. Figure 6 shows an overview of GHG emissions from the transportation sector by sub-sector.

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[7] Emissions from the following sources are not included in the 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 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.

[8] The following emissions are not included or tracked in the 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 program.

[9] 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 6. Transportation Sector Emissions by Sub-Sector.

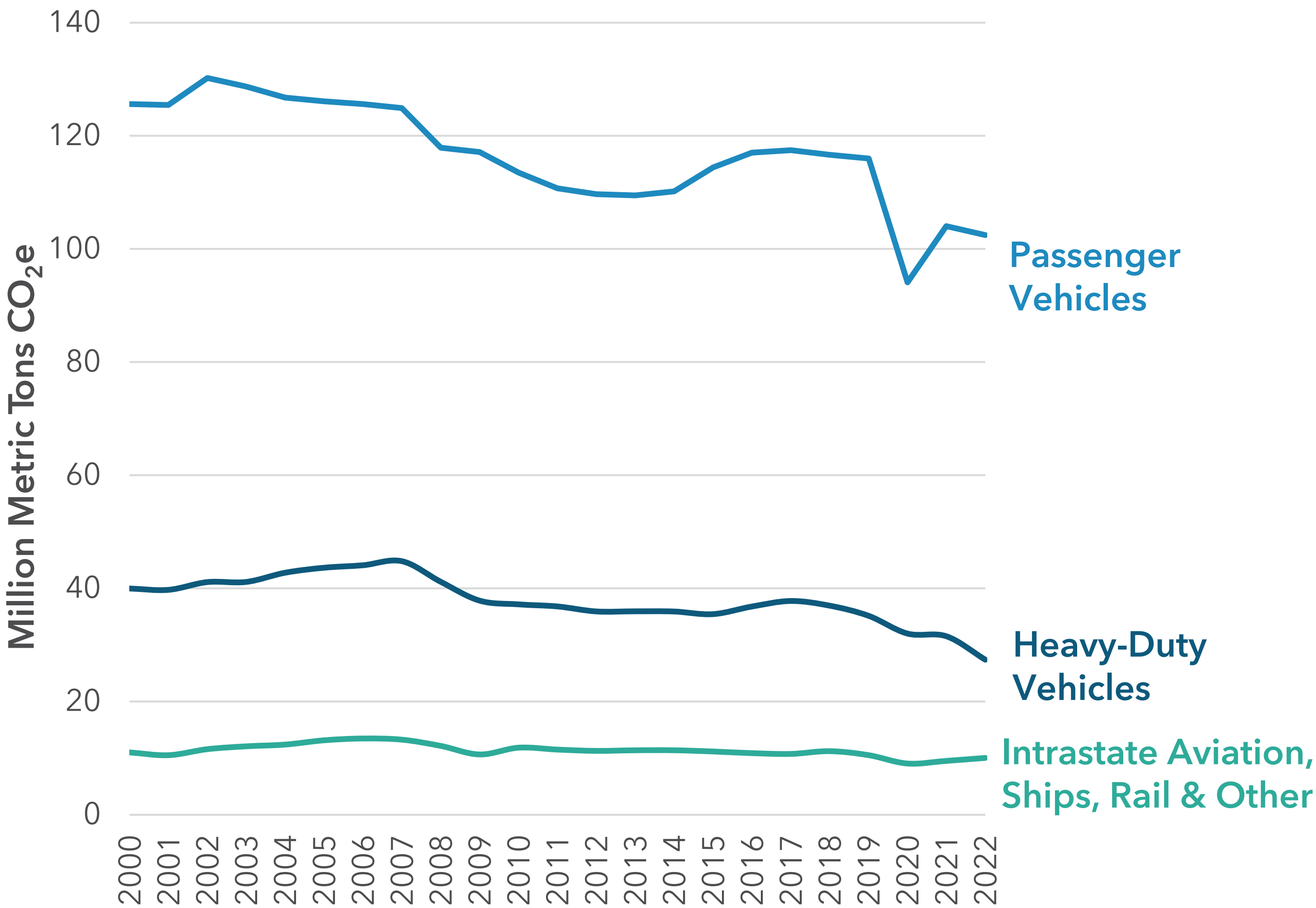

Figure 6 shows emissions by transportation sub-sector. "Passenger Vehicles" include passenger cars, light-duty trucks, medium-duty trucks, motorcycles, and natural gas-powered vehicles. "Heavy-Duty Vehicles" include heavy-duty trucks, buses, and motor homes.[10] Within "Intrastate Aviation, Ships, Rail & Other," aviation and ships each account for approximately 40% of 2022 emissions, rail accounts for approximately 10%, and the remainder consists of lubricant consumption, liquified petroleum gas combustion, and diesel combustion by unspecified sources. Fuel combustion emissions from specified off-road sources within the agriculture, commercial and residential, and industrial sectors are assigned to the respective sectors.

The emissions rate (gCO_2e/mile) of California's gasoline light-duty vehicles[11] improved from 441.5 gCO_2e/mile in 2009 to 356.3 gCO_2e/mile in 2022. New model year gasoline light-duty vehicles in 2022 emit 17.8% less GHGs per mile than in 2011 [13]. In addition, there

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[10] Additional details about some of these vehicle classes can be found in https://ww2.arb.ca.gov/sites/default/files/2023-08/user_guide_emfac2007.pdf.

[11] Light-duty vehicles include passenger cars, light-duty trucks, and medium-duty trucks.

were 647,000 light-duty battery electric vehicles (BEV) in the state in 2022, representing 43.8% growth from 2021 [14]. Figure 7 shows the transformation of California's light-duty fleet, with significant strides being made in emissions rate and zero-emission vehicle adoption.

Figure 7. Light-Duty Fleet Transformation.

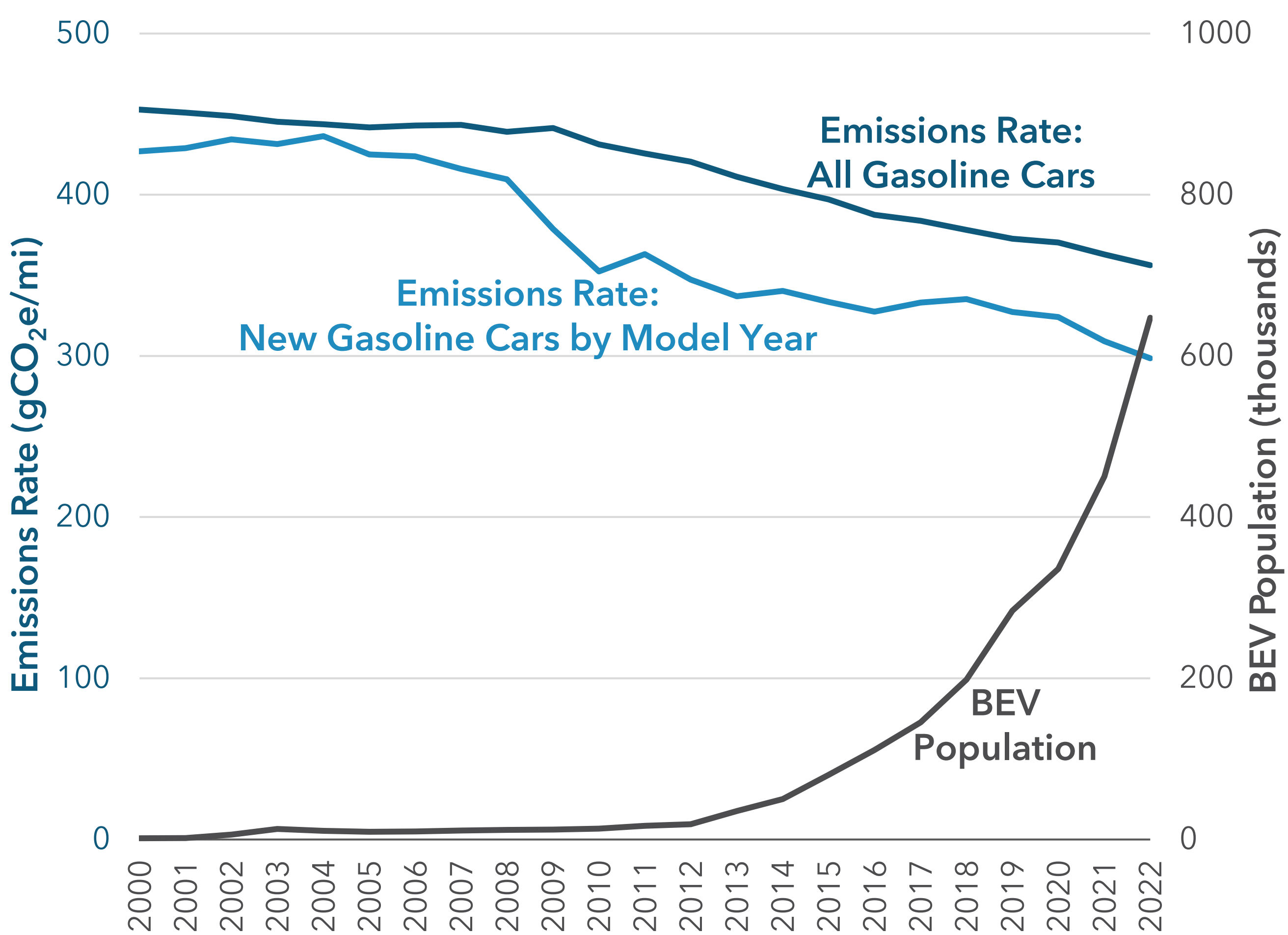

Figure 7 shows the emissions rate of California's gasoline-powered light-duty vehicles and the growth in BEVs. "Emissions Rate: All Gasoline Cars" is the average GHG emitted (in gCO_2e) per mile traveled for all gasoline-powered light-duty vehicles in California in the specified year. "Emissions Rate: New Gasoline Cars by Model Year" is the average GHG emitted (in gCO_2e) per mile traveled for vehicles in the specified model year achieved in the specified year. "BEV Population" includes vehicles that do not carry any fuel (e.g., gasoline and hydrogen) or any other energy source onboard [14].

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 37.7% in 2022, 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 1.1% in 2019 to 13.1% in 2022. Without biofuels, California tailpipe fossil CO_2 would be 20.9 MMT higher in 2022.

Figure 8 and Figure 9 show the trends in emissions and fuel used in gasoline-powered passenger vehicles and diesel-powered heavy-duty vehicles, respectively. Total fuel combustion emissions, inclusive of both the fossil component (dark blue line) and bio-component (blue shaded region) of the fuel blend, track trends in fuel sales. Consistent with the IPCC Guidelines for National GHG Inventories (IPCC Guidelines) [5], 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 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 [11]. 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.

[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.

Figure 8. Trends in Passenger Vehicle Gasoline Emissions.

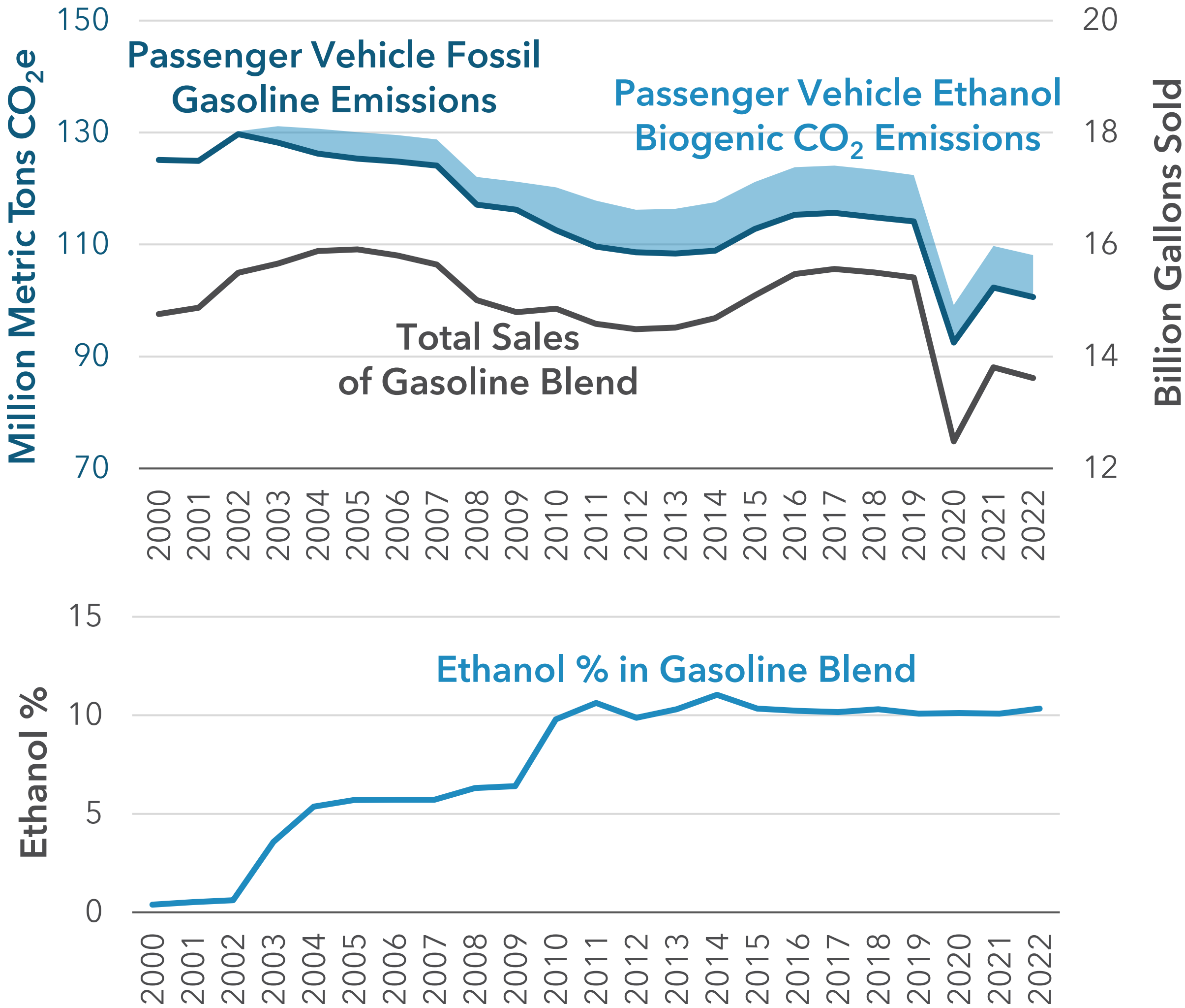

Figure 8: In the top panel, the blue shaded region represents CO_2 emissions from the ethanol component of the gasoline fuel blend. The dark blue line includes all GHG emissions from the fossil gasoline component of the fuel blend, as well as the CH_4 and N_2O emissions from the ethanol component. "Total Sales of Gasoline Blend" includes gasoline used in any type of vehicle, 93% of which is used in passenger 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 9. Trends in Heavy-Duty Diesel Vehicle Emissions.

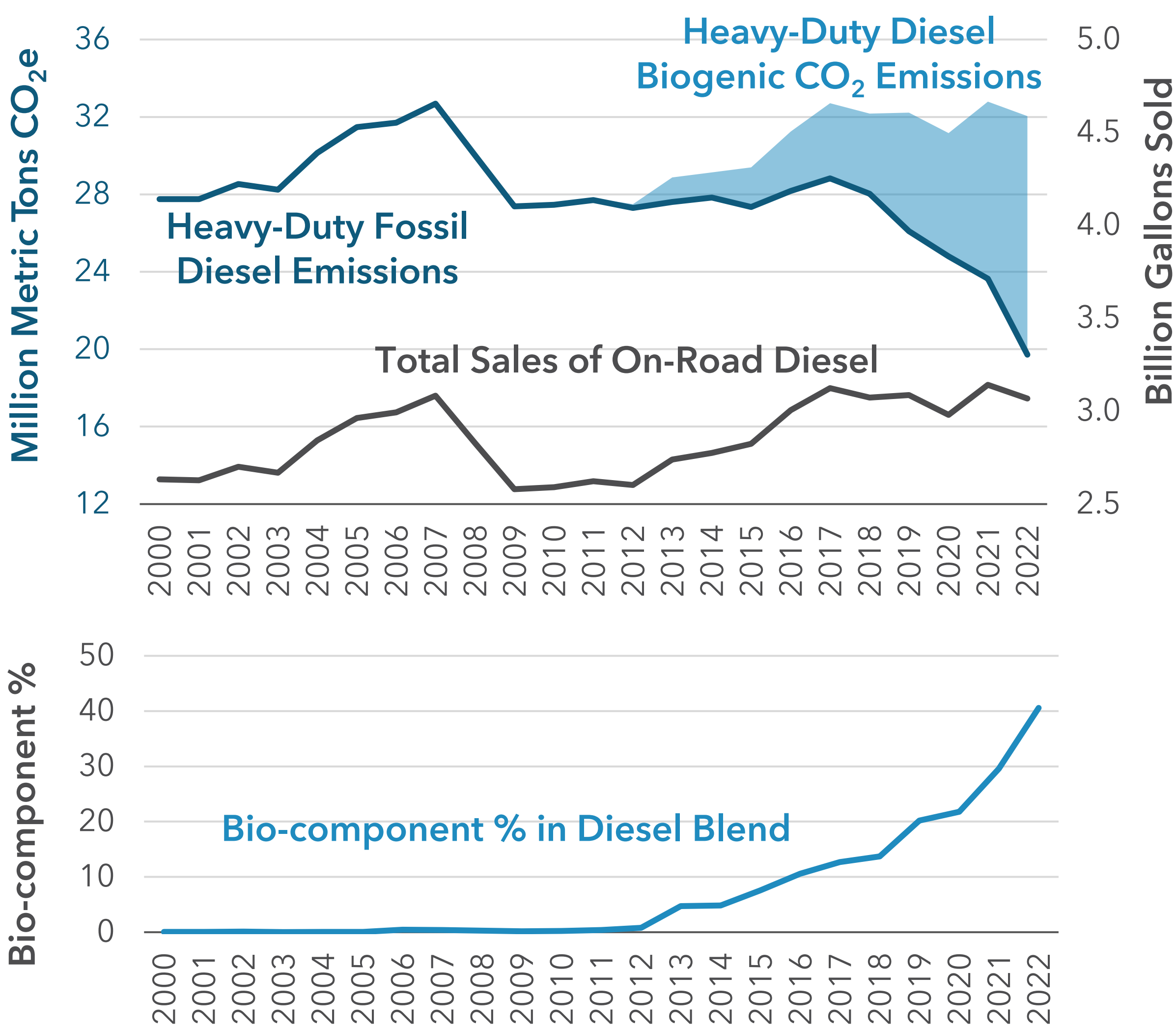

Figure 9: In the top panel, the blue shaded region represents CO_2 emissions from the biogenic component (biodiesel and renewable diesel) of the diesel fuel blend. The dark blue line includes all GHG emissions from the fossil diesel component of the fuel blend, as well as the CH_4 and N_2O emissions 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 16.1% of 2022 statewide GHG emissions. The 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 Program and the Cap-and-Trade Program continue to incentivize the dispatch of renewables over fossil fuel generation to serve California's load. The state continues to see growth in battery storage that takes advantage of excess renewable power that can be dispatched to the grid when needed. Battery storage increased from 2021 to 2022 by 2.4 GW (75%) [15]. 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.

Figure 10 shows California's electricity sector emissions broken out between in-state and imported sources. Figure 11 shows the overall GHG intensity of electricity generation for California and for in-state and imported sources separately.

Figure 10. GHG Emissions from the Electricity Sector.

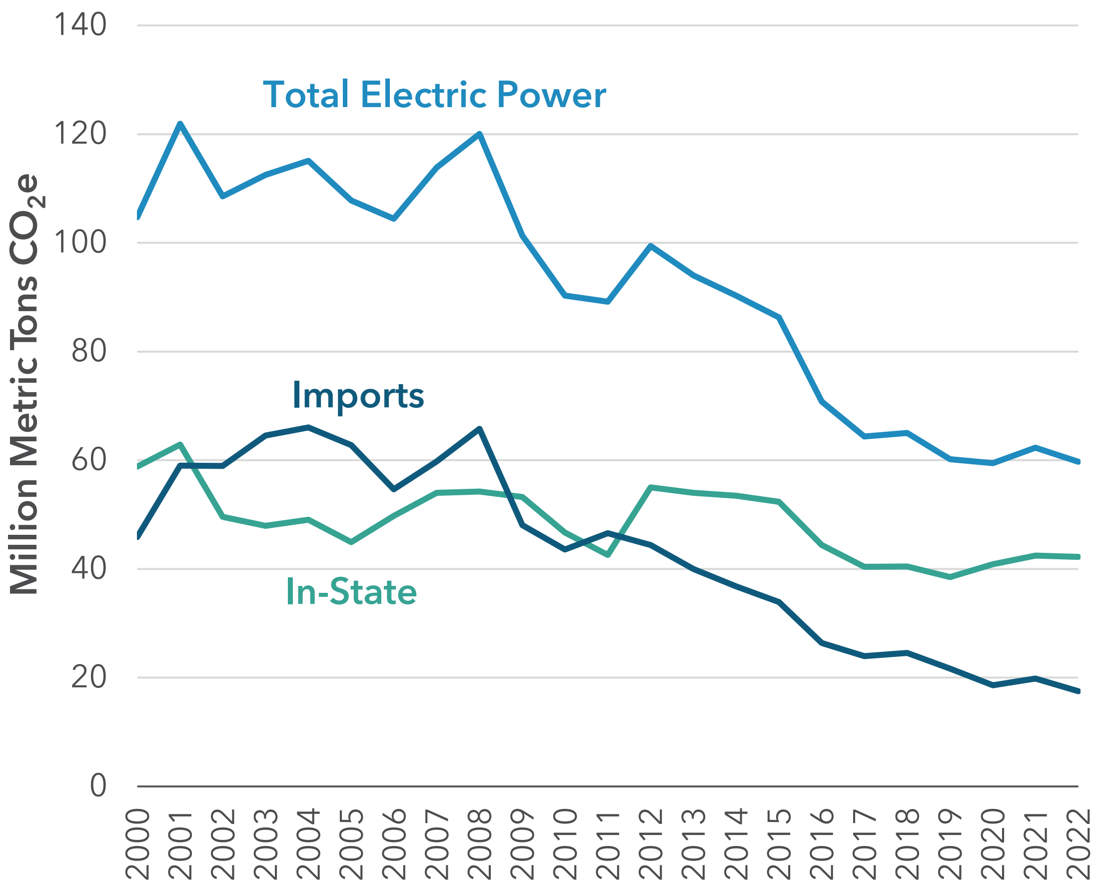

Figure 10 shows trends in emissions of in-state electricity generation, emissions associated with electricity imported from outside of California, and the total electricity sector emissions, which is the sum of in-state generation and imports.

Figure 11. GHG Intensity of Electricity Generation.

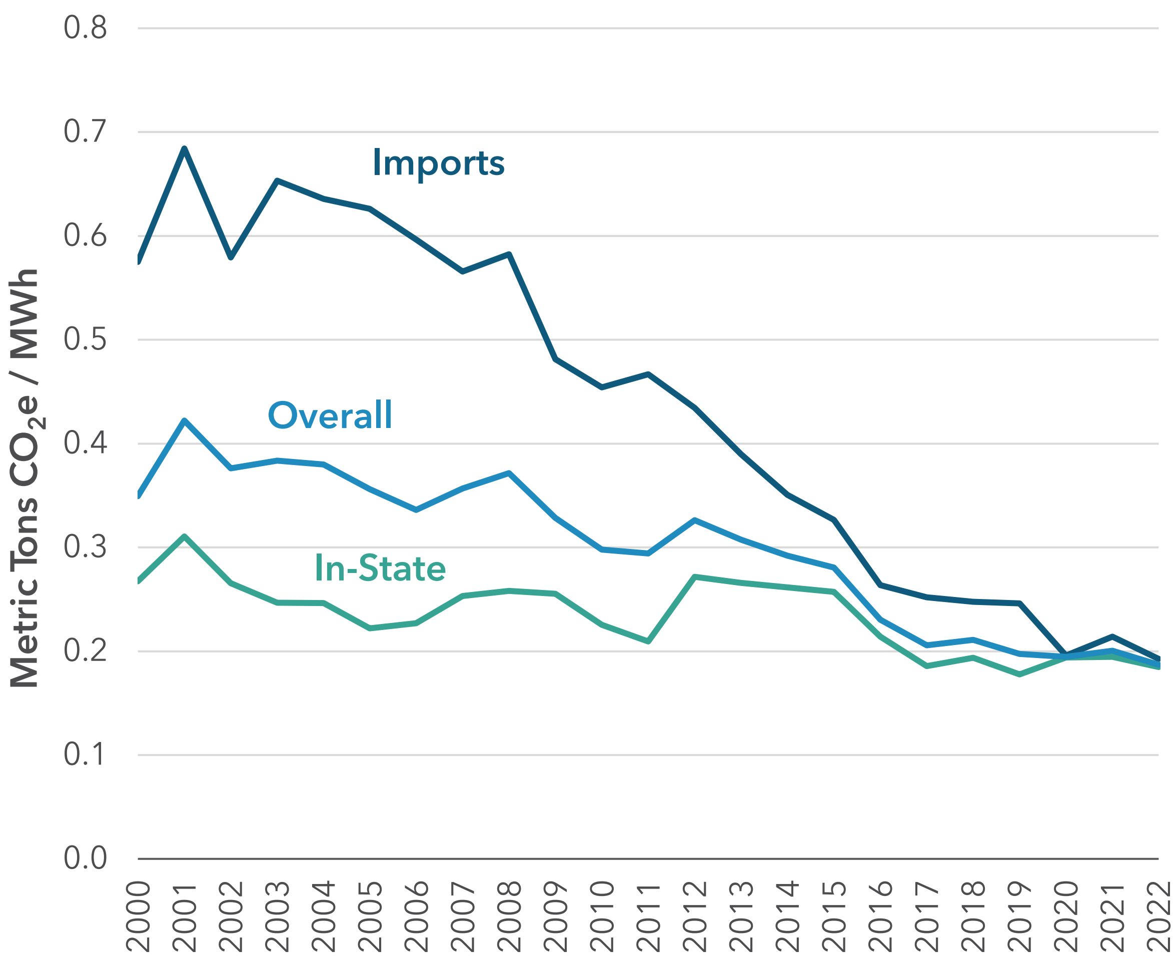

Figure 11 shows trends in GHG intensities of in-state electricity generation, electricity imported from outside of California, and the overall GHG intensity aggregating both in-state generation and electricity imports.[13]

Total electricity sector emissions decreased from 2021 to 2022 due to increases in solar power and hydropower generated in-state and an increase in imported wind power. California continued the trend of increasing in-state renewable generation and increasing imports of solar and wind power. In 2022, 49.7% of total electricity generation (in-state generation plus imported electricity) came from solar, wind, hydropower, and nuclear

[13] All three 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 small-scale solar generation (including rooftop). The denominator of the "Overall" intensity is the total electricity generated in California plus total imported electricity.

power; another 3.2% came from asset controlling suppliers (ACS),[14] which imported low GHG intensity electricity consisting primarily of hydropower.

In-state solar generation grew 15.0% in 2022 compared to 2021. Between 2011 and 2022, in-state solar generation saw significant growth as small-scale photovoltaic solar generation (including rooftop solar)[15] increased by a factor of 15 [16] and total solar generation (commercial-scale plus small-scale) increased by a factor of 24 during that period [16][17]. In-state wind energy generation ramped up through 2013 and has remained relatively constant from 2013 through 2022 [17]. Figure 12 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.

[15] Small-scale photovoltaic solar generation consists of facilities with a generating capacity of less than 1 MW.

Figure 12. In-State Hydro, Solar, and Wind Electricity Generation.

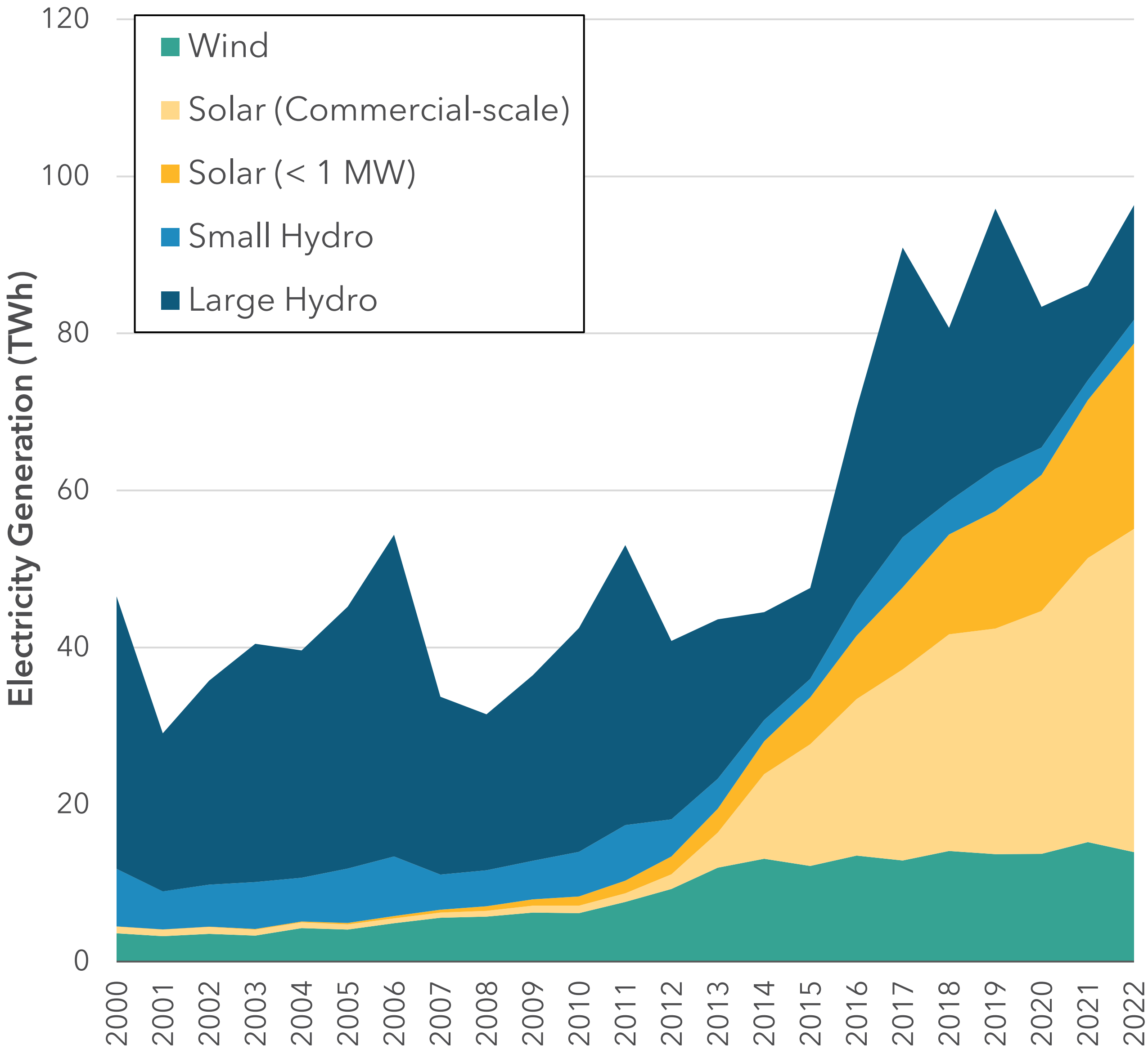

Figure 12 shows the amounts of electricity generated by California's in-state wind power projects, large commercial-scale solar power projects, small-scale solar power projects with less than 1 MW of generation capacity (including rooftop solar panels), and hydropower generation stations in TWh (1 TWh = 10^9 kWh).

Trends in total in-state generation plus imported generation by source are presented in Figure 13. Historically, fossil-fueled electricity generation has varied annually in part based on year-to-year fluctuations in hydropower generation. More recently, growth in solar and wind power has helped to meet growth in overall demand even during low hydropower years.

Figure 13. Total Electricity Generation (In-State and Imports) by Source.

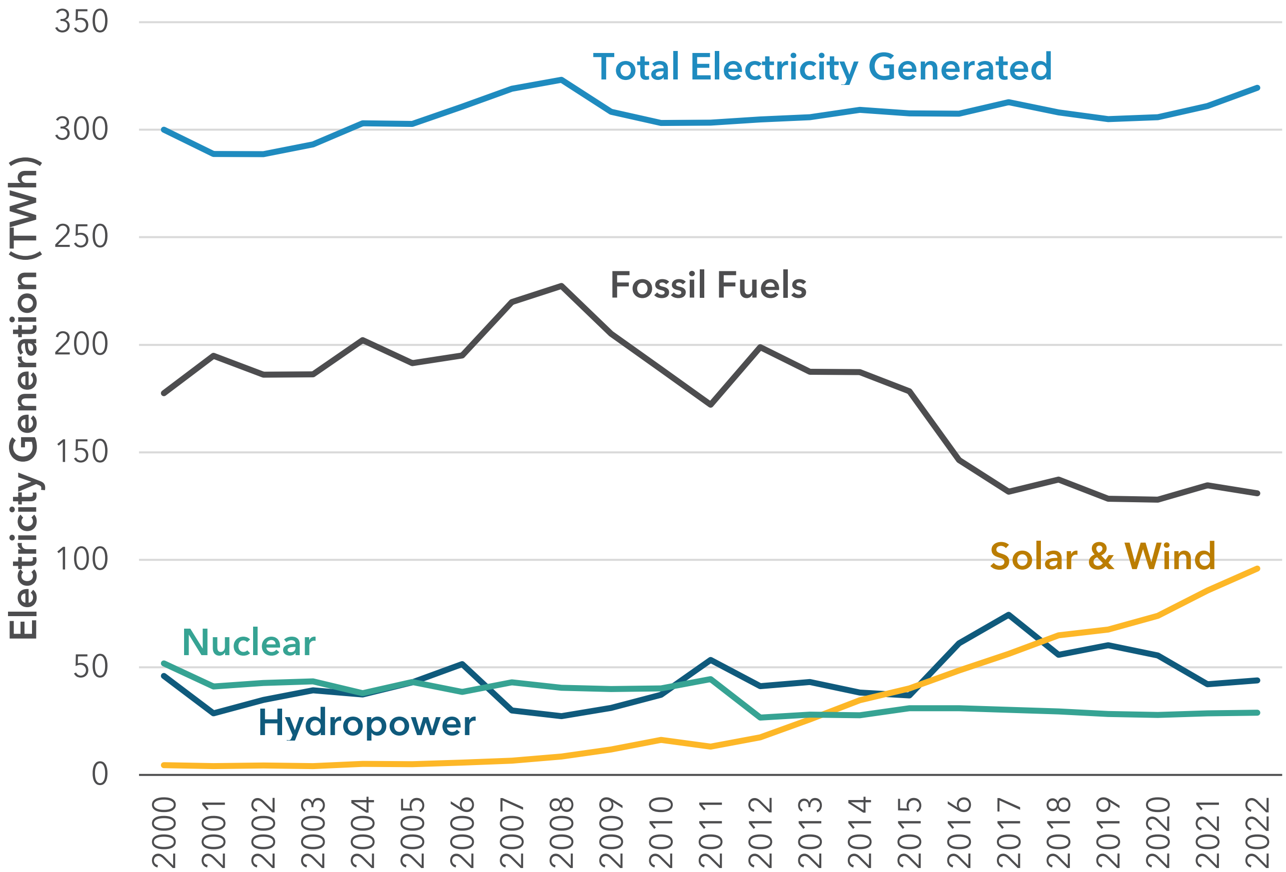

Figure 13 shows the total amount of electricity generated (in-state plus imported) as well as the amount generated from fossil fuels, from hydropower, from solar and wind (combined), and from nuclear power. "Fossil Fuels" consists primarily of fossil gas but also includes coal, oil, petroleum coke, distillate, and imports from unspecified sources. "Hydropower" includes imports from asset-controlling suppliers which imported low GHG intensity electricity consisting primarily of hydropower. Electricity generated from biomass, geothermal, and waste heat recovery are not shown separately in the figure but are reflected in "Total Electricity Generated."

Industrial

Emissions from the industrial sector contributed 19.6% of California's total GHG emissions in 2022. 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. The refining and hydrogen production sub-sector represents the largest individual source in the industrial sector, contributing 36.1% of the sector's total emissions in 2022.

As shown in Figure 4, industrial sector emissions decreased 1.5 $MMTCO_2e$ (2.0%) from 2021 to 2022, bringing emissions to the lowest of any point during the inventory time series. Figure 14 shows trends by sub-sector within the industrial sector over time. Oil and gas production emissions decreased by 0.9 $MMTCO_2e$ (7.0%) from 2021 to 2022, reflecting a continued downward trend in oil production [18].

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

Figure 14. Industrial Sector Emissions by Sub-Sector.

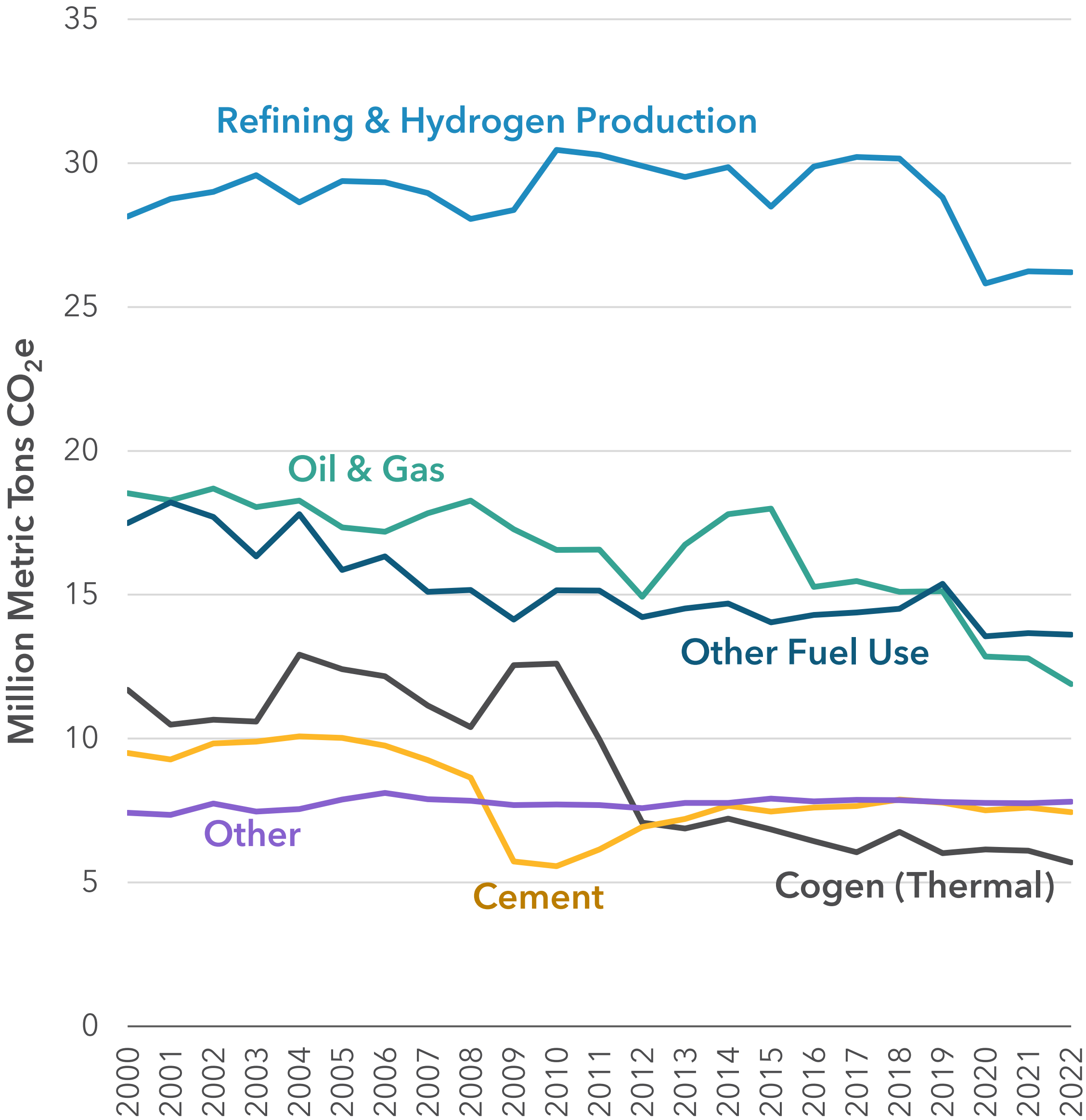

Figure 14 shows emissions by industrial sub-sector. The "Other Fuel Use" category includes emissions from combustion of fuels used by sub-sectors not specificied elsewhere in this figure. The "Other" category includes fugitive and process emissions from sub-sectors not already shown in the figure. The "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 sector 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 this sector are accounted for in the electricity sector, and emissions of high-GWP gases used for purposes including refrigeration and air conditioning are included in the high-GWP 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, economic conditions, and the number of residential housing units.

In 2022, emissions from the commercial and residential sector increased by 0.7 $MMTCO_2e$ (1.7%) compared to 2021. Within the commercial sub-sector, emissions increased by 0.8 $MMTCO_2e$ (5.6%) during this time, returning to the level seen in 2019 prior to the COVID-19 pandemic. That emissions growth was partially offset within the residential sub-sector where emissions decreased by 0.1 $MMTCO_2e$ (0.5%). Figure 4 presents the sector-wide emissions trend while Figure 15 presents emissions trends from the commercial and residential sub-sectors along with heating degree days (a proxy for the amount of energy needed for space heating) [19].

[17] "Behind-the-meter" emissions include natural gas leaks after the gas passes through building-level gas meters. 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.

Figure 15. Commercial and Residential Sector Emissions by Sub-Sector.

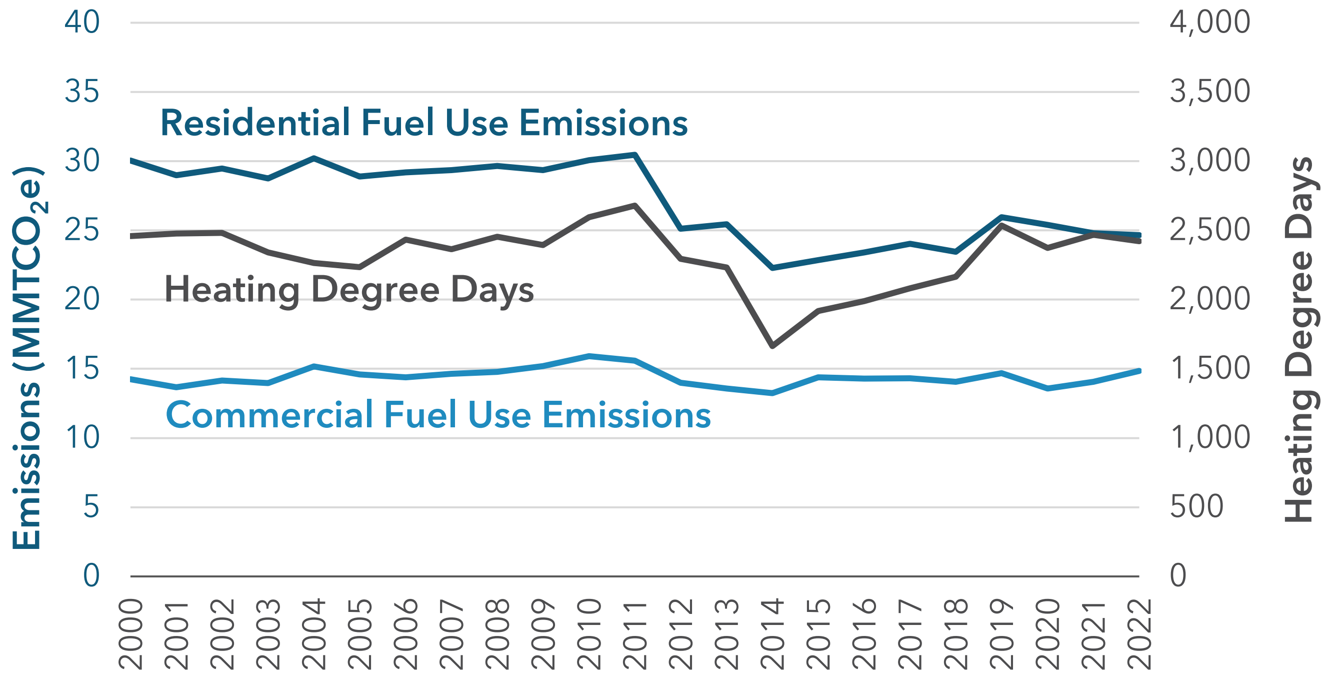

Figure 15 shows emissions from the commercial and residential sub-sectors and heating degree days, a proxy for the amount of energy needed for space heating.

Commercial floor space has grown by 25.6% since 2000 [20], yet emissions from fuel use, much of which is used to heat this space, have seen relatively small changes. Figure 16 shows commercial 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. As shown in Figure 17, the number of occupied residential housing units has grown steadily from 11.9 million units in 2000 to 13.6 million units in 2022 [21]. Emissions per housing unit have generally decreased since 2000 but do fluctuate with the need for heating as illustrated by the heating degree days index in Figure 15.

Figure 16. Commercial Sub-Sector Fuel Use Emissions per Unit Floor Space.

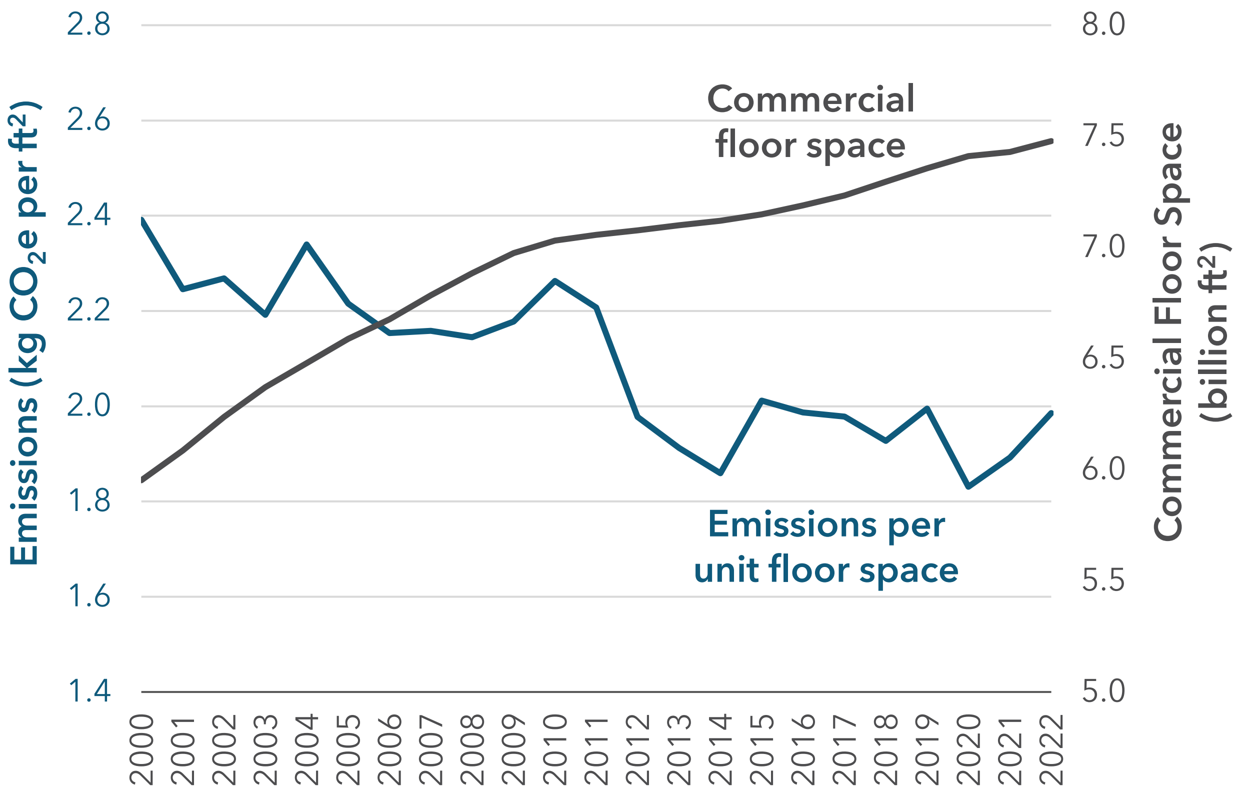

Figure 16 shows total square feet of commercial floor space and the emissions per square foot. Only commercial sub-sector emissions from fuel use are included in the figure.

Figure 17. Residential Sub-Sector Fuel Use Emissions per Residential Housing Unit.

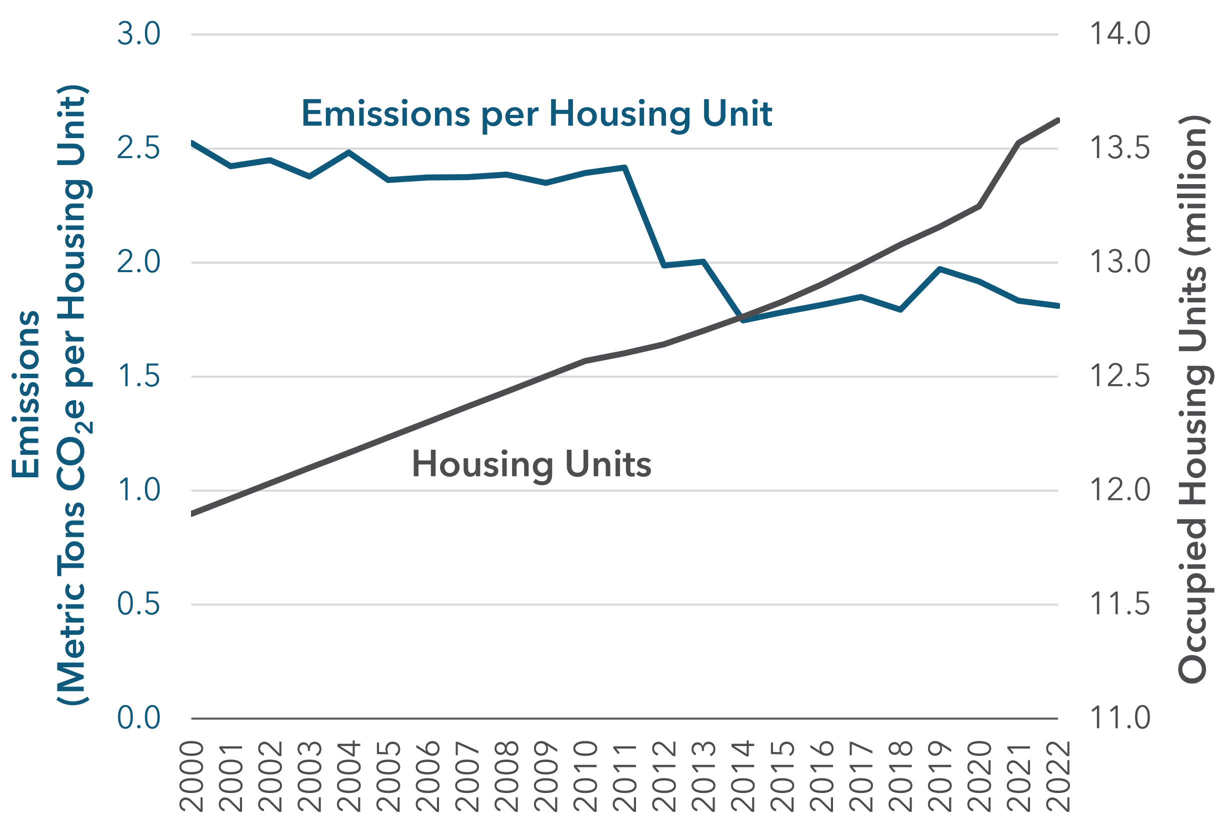

Figure 17 shows the number of occupied residential housing units and emissions per housing unit. Only residential sub-sector emissions from fuel use are included in the figure.

Agriculture

California's agricultural sector contributed 8.0% of statewide GHG emissions in 2022, 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 3.0 $MMTCO_2e$ (12.6%) to 20.9 $MMTCO_2e$ as of 2022. Livestock emissions are almost entirely CH_4 generated from enteric fermentation and manure management, and most of the livestock emissions are from dairy operations. The 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 driven by factors including population decreases and increased implementation of anaerobic digesters at California dairy operations in response to increased State incentives that began in 2015. 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 2022, over 80 anaerobic digesters were operational and managed at least 14.9% of the statewide dairy population's manure.

Crop production accounted for 22.7% of agriculture sector emissions in 2022. Emissions from the growing and harvesting of crops have generally declined since 2000. The long-term trend of emissions reduction from 2000 to 2022 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 18 presents emissions from the agriculture sector, broken out by sub-sector. The trend in total agriculture sector emissions is displayed in Figure 4.

Figure 18. Agriculture Sector Emissions by Sub-Sector.

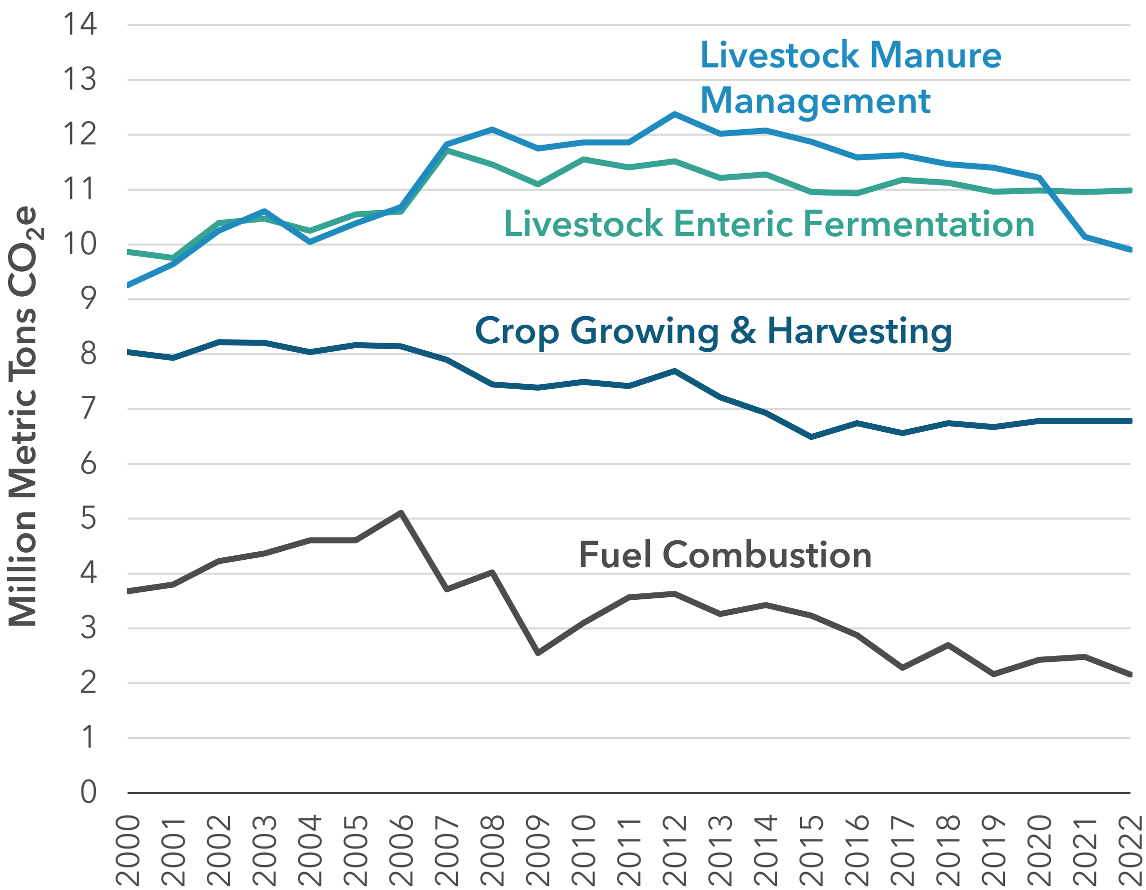

Figure 18 presents the trends in emissions from livestock manure management, livestock enteric fermentation, crop growing and harvesting (fertilizer use, soil preparation and disturbance, and crop residue burning), and fuel combustion (water pumping, heating buildings, processing commodities, and tractors).

High Global Warming Potential Gases

In 2022, high-GWP gases comprised 5.7% 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 98.1% 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 2022, refrigeration and air conditioning equipment contributed 91.5% of ODS substitutes emissions.

As shown in Figure 19, emissions of ODS substitutes grew from 2000–2020. The steady growth occurred as these gases replaced ODS being phased out under the Montreal Protocol [7]. 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.

Emissions of ODS substitutes grew steadily from 2000-2020 but have changed very little since then. There are four main sub-sectors within the ODS substitutes category: transportation, commercial, industrial, and residential. From 2021 to 2022, 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 19 shows emissions from ODS and ODS substitutes from 2000–2022 while total emissions from the high-GWP sector are shown in Figure 4. Figure 20 shows emissions of ODS substitutes by sub-category for 2022.

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

Figure 19. Trends in ODS and ODS Substitutes Emissions.

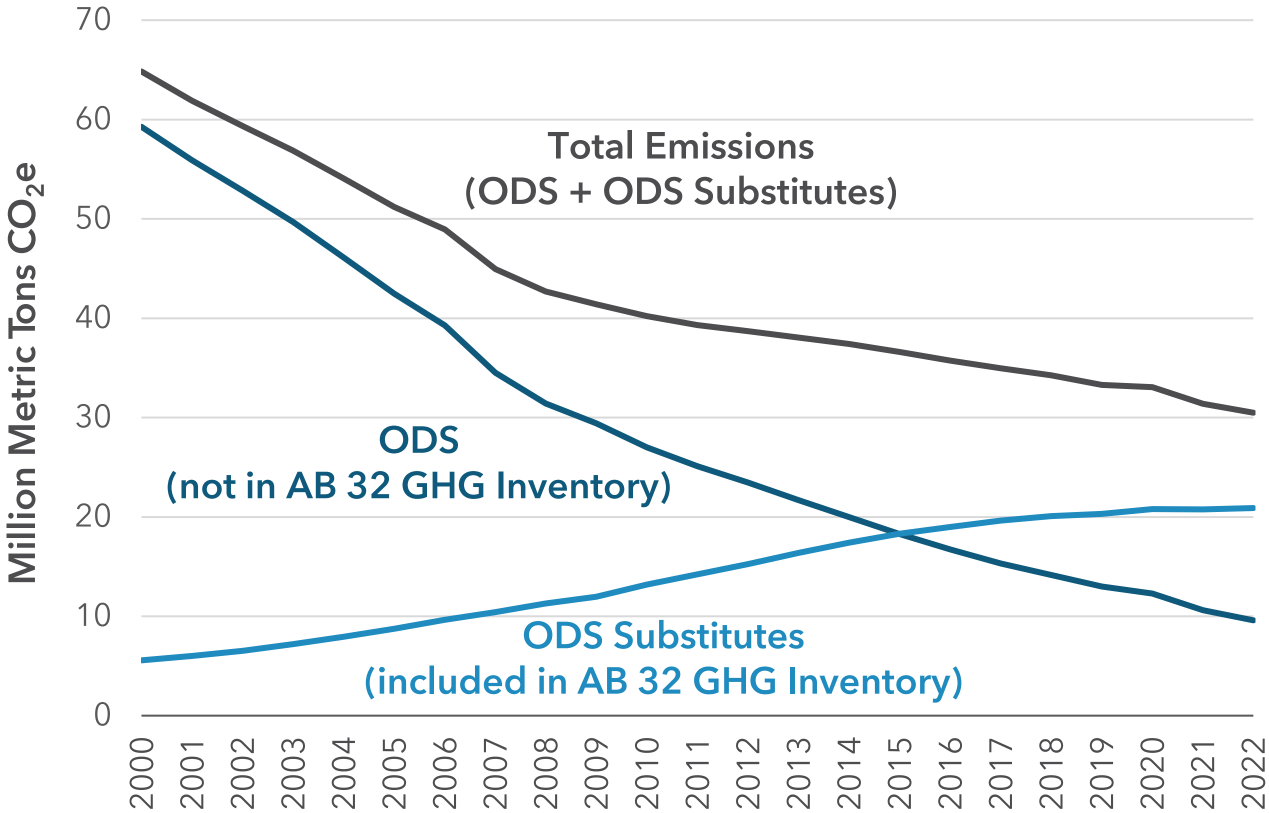

Figure 19 presents the trends in emissions from ODS substitutes, ODS, and their sum ("Total Emissions"). ODS are GHGs; however, they are not included in the Inventory.

Figure 20. ODS Substitutes Emissions by Category.

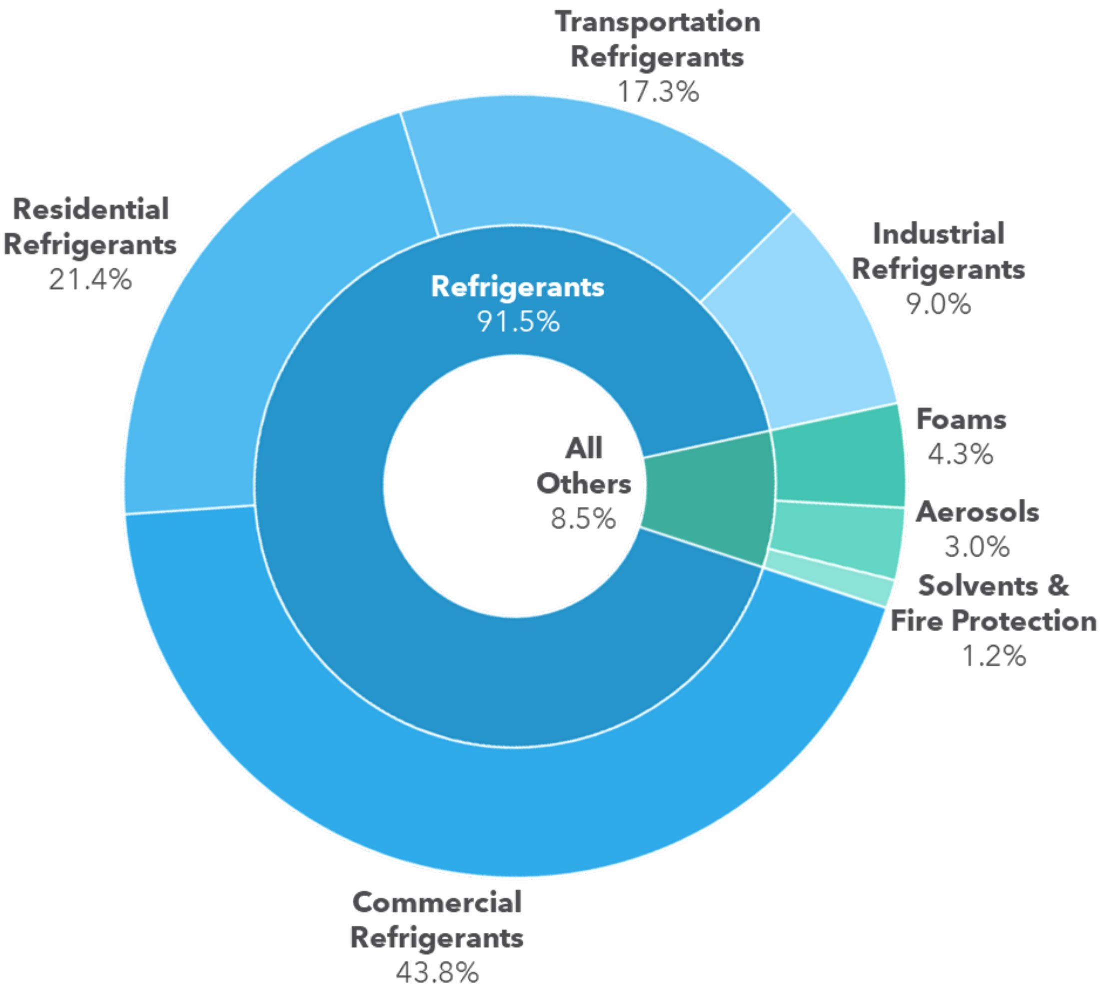

Figure 20 presents the breakdown of ODS substitutes emissions in 2022 by product type and sector in which they are used. Refrigerant use accounts for the majority of ODS substitutes emissions.

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 15.9% since 2000 and comprised 2.2% of California's GHG emissions in 2022. Landfill emissions are primarily CH_4 and accounted for 96.4% of the emissions from this sector in 2022. Compost production facilities produce the remaining 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 a peak of 46 million short tons in 2005, then declined until 2012. After 2012, deposited waste amounts increased to a peak of 41 million short tons in 2019 [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 4 shows the trend in total emissions from the recycling and waste sector. Figure 21 and Figure 22 show trends in landfill emissions and activities that drive emissions.

Figure 21. Landfill Methane Emissions.

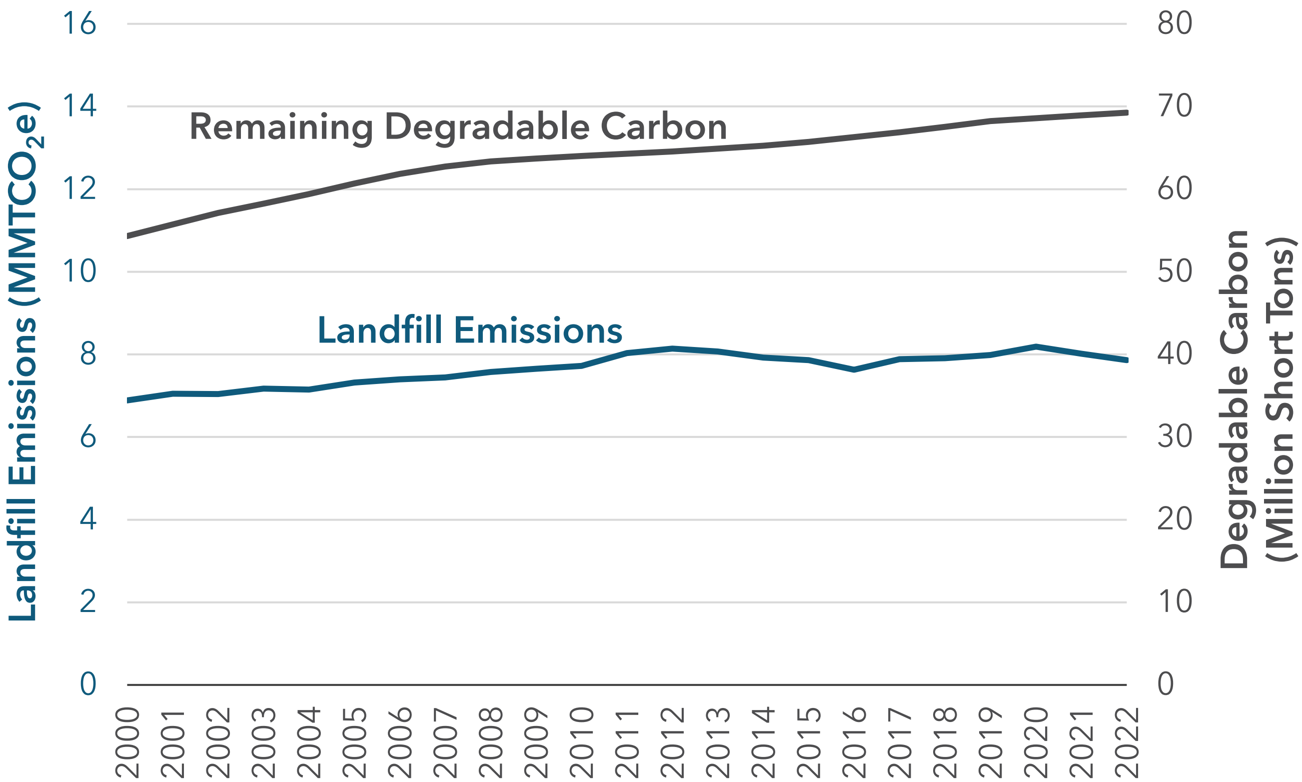

Figure 21 presents trends in landfill emissions and the amount of degradable carbon remaining in California landfills. The latter drives the emissions generated by landfills. The color of a trend line matches the color of its corresponding vertical axis label.

Figure 22. Landfill Waste.

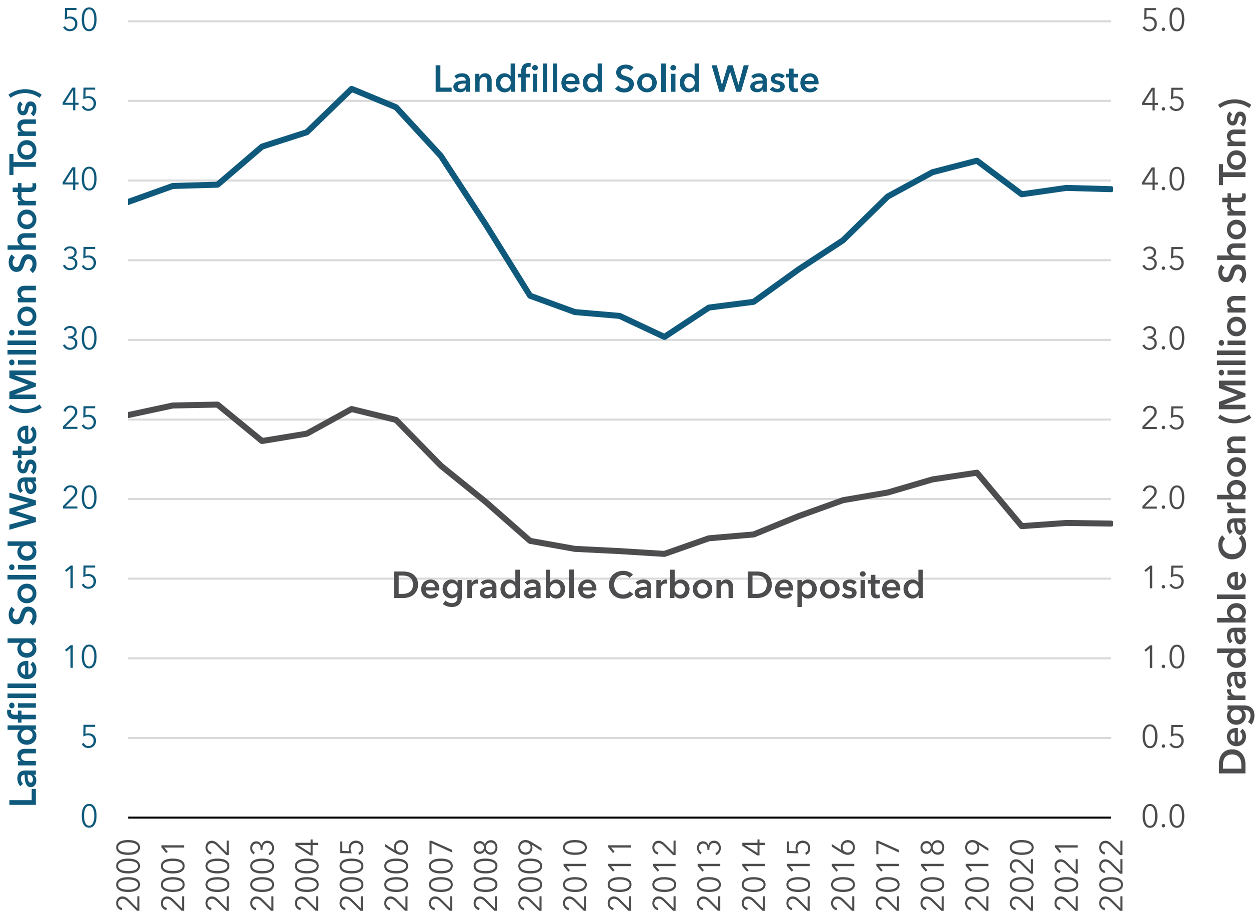

Figure 22 presents the annual amount of solid waste deposited into California landfills and the amount of degradable carbon contained in the solid waste. The vertical axes are color coded to match each trend line.

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 2021 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 2023 edition, total 2021 emissions were estimated to be 381.3 $MMTCO_2e$. In the 2024 edition, recalculation revised the 2021 emissions to 380.4 $MMTCO_2e$, reflecting refinements and updates to methodology and information gained since 2023. Analyses of emissions trends, including the emissions decrease of 9.3 $MMTCO_2e$ between 2021 and 2022, are based on the recalculated numbers in the 2024 edition of the Inventory. A description of the method updates is available in the Inventory Updates for the 2024 Edition of the AB 32 GHG Emissions Inventory - Supplement to the Technical Support Document.

Global Warming Potential Values

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.

Data Sources 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 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 Inventory each year. All data sources used to develop the Inventory are listed in supporting documentation on CARB's Current California 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 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 Economic Sector/Activity Categorization and the Scoping Plan Categorization side-by-side. Detailed data for these categorization schemes can be accessed from CARB's Current California GHG Emission Inventory Data webpage.

Figure 23. 2022 GHG Emissions by Economic Sector.

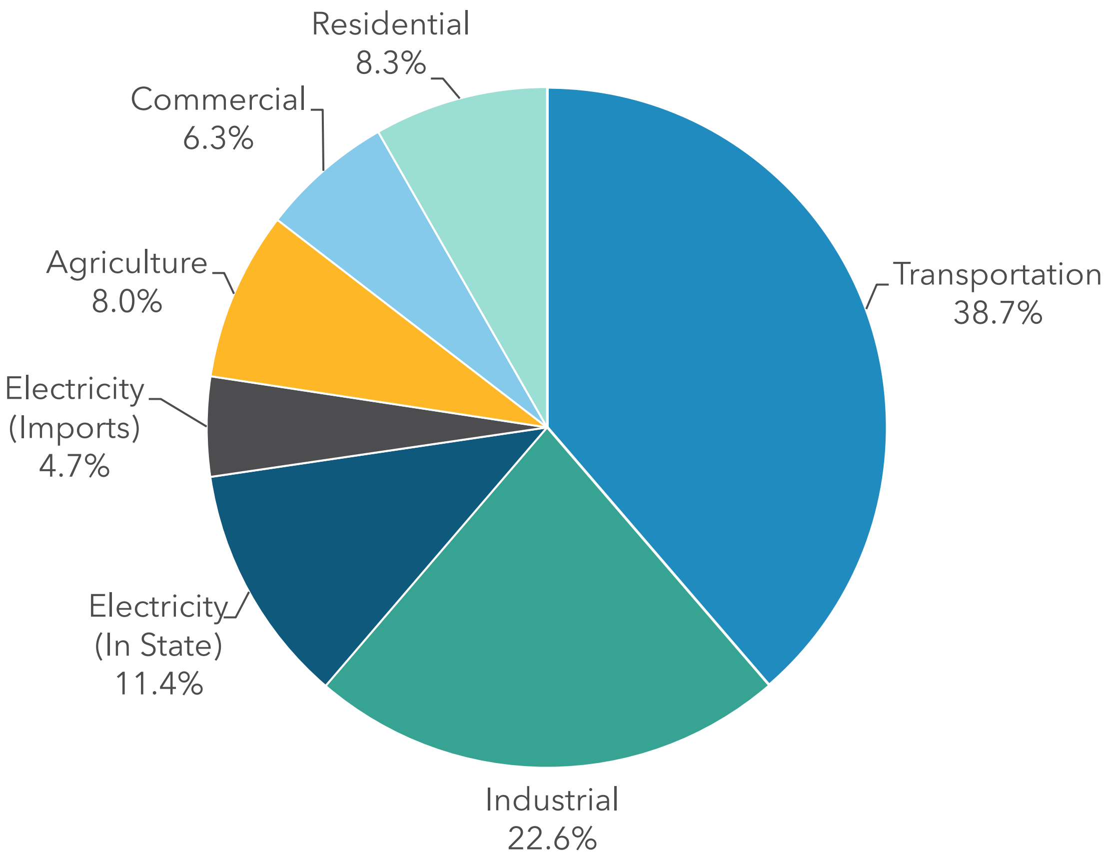

Figure 23 shows the relative size of 2022 emissions by sector using the Economic Sector/Activity Categorization scheme.

Figure 24. 2022 GHG Emissions by Scoping Plan Sector.

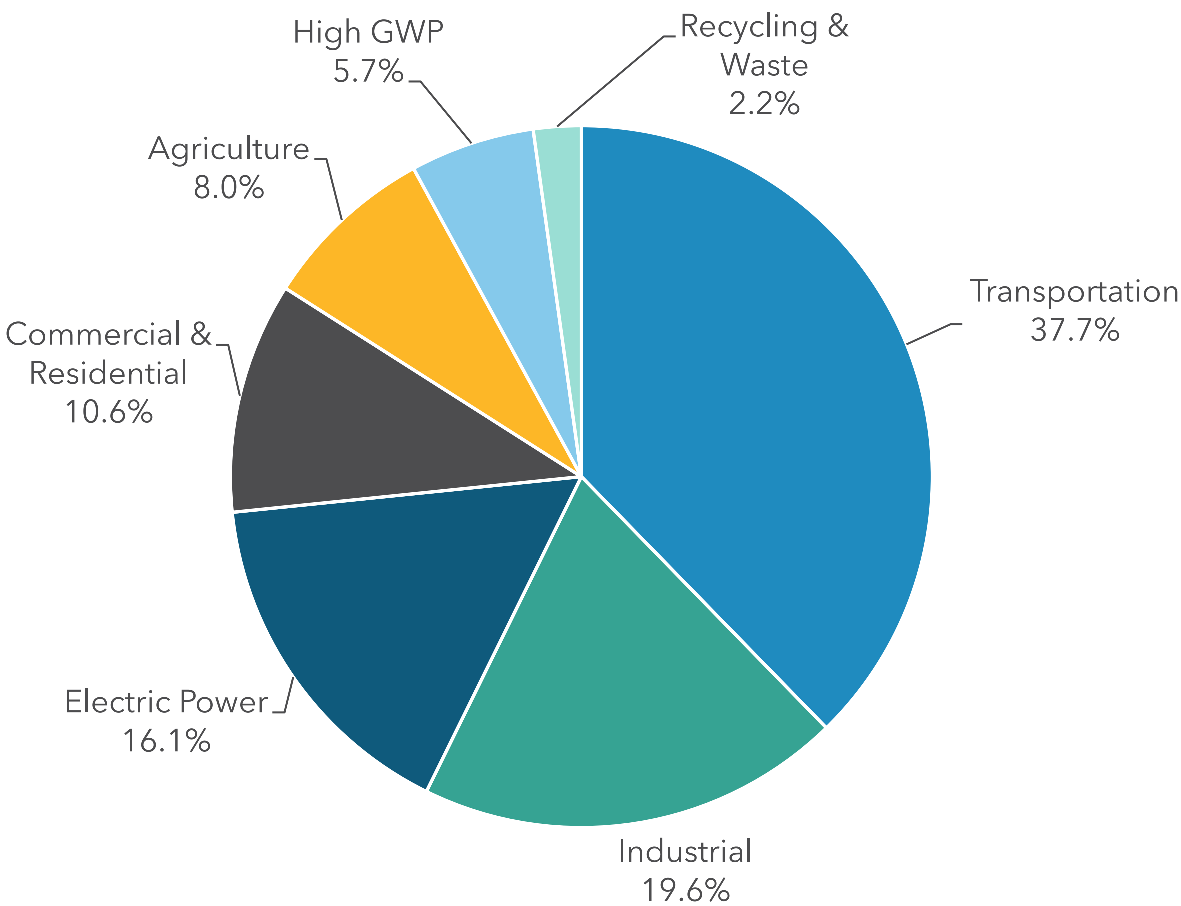

Figure 24 shows the relative size of 2022 emissions, organized by the categories in the AB 32 Scoping Plan.

Uncertainties in the AB 32 GHG Inventory

CARB is committed to continually working to reduce the uncertainty in the 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 [4] (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 the 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. 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	[1] [2] [11]
Figure 2	[10] [11]
Figure 3	[10] [11]
Figure 4	[11]
Figure 5	[11]
Figure 6	[11]
Figure 7	[13] [14]
Figure 8	[11]
Figure 9	[11]
Figure 10	[11]
Figure 11	[11] [16] [17]
Figure 12	[16] [17]
Figure 13	[16] [17]
Figure 14	[11]
Figure 15	[11] [19]
Figure 16	[11] [20]
Figure 17	[11] [21]
Figure 18	[11]
Figure 19	[11]
Figure 20	[11]
Figure 21	[11]
Figure 22	[24]
Figure 23	[11]
Figure 24	[11]

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