

Original Paper

California Greenhouse Gas Emissions Reduction Targets (2030 and 2050): Trends, Projections and Analysis

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Abstract

Fossil fuels are the primary sources of energy powering economic development globally. Increased fossil fuel consumption produces Greenhouse Gas Emissions (GHG) which build in the atmosphere and trap heat irradiated from the Earth. The increased concentration of these gases causes global warming and extensive climate disruptions. This study examined GHG emissions data from 2000-2017 to evaluate whether California will meet GHG emissions reduction target of 40% below 1990 levels by 2030 as mandated by California's Executive Order B-30-15. California's ability to reduce GHG emissions to 80% below 1990 levels by 2050 (Executive Order S-3-05) was also evaluated. Results indicate that transportation, electric power, industrial and commercial/residential) GHG emissions reductions declined by small magnitudes in the 18-year period (0.17% to 2.49%). In agriculture, refrigerant and recycling/waste agencies, emissions reductions increased in the 18-year period (0.08% to 0.8%). For 2030 and 2050 emissions reductions targets, no emissions category sector will achieve the targeted reduction. The highest emissions reduction amounts discrepancies between observed and expected were in transportation, industrial and commercial/residential sectors (2030); and in transportation, industrial and agricultural facilities (2050). An analysis of current trends and technological developments in each emissions sector is presented to guide and structure future emissions target reductions.

Keywords

GHG emissions, mmtCO₂e, reduction targets, cap and trade, fossil fuels, decarbonization

1. Introduction

Global economic growth is directly linked to increased energy consumption. International efforts to limit the increase in global mean temperature to well below 2°C and to “pursue efforts” to avoid a 1.5°C temperature rise requires a transition to net-zero emissions energy systems by 2050 (Tong et al., 2019). For the past five decades, the main sources of energy powering economic development in many countries have primarily been fossil fuels that include oil, coal and natural gas. Increased fossil fuel consumption produces gas emissions like CO₂, methane (CH₄), water vapor, nitrous oxide (N₂O), and ozone (O₃). These gases rise into the atmosphere and prevent (or trap) heat irradiated from the Earth from escaping into the outer reaches of the atmosphere. Increased concentration of these gases causes global warming which brings about extensive climate disruptions (climate change). Climate change is a change of climate attributable directly or indirectly to human activity, which in addition to existing natural climate variability, alters the composition of the global atmosphere for extended long periods of time typically decades (UNFCCC, 2020a).

Climate changes affects the planet in a variety of ways including altering global wind circulation patterns and ocean current cycles. These changes cause extensive rainfall disruptions in many areas causing drought, severe heat waves, extended rainfall, severe hurricanes, and extensive fires in many parts of the globe. Due to the expected impacts of climate change, progress achieved in global population health in recent decades is at risk of reversal (Watts et al., 2018). **Climate change** is already contributing to higher air pollution levels, deforestation, ocean acidification, increased wildfires, expansive droughts, intense heat waves and sea-level rise, which threaten the health and livelihoods of citizens (EUC, 2020). Vulnerable populations like indigenous peoples and people whose mode of existence is primarily reliance on agriculture and other regions such as small island developing states and the Arctic, are more vulnerable to its impacts (Watts et al., 2018). Similarly, efforts by countries in achieving key Sustainable Development Goals (SDGs) under the United Nations 2030 Agenda for Sustainable Development are seriously curtailed by climate change (UN, 2020).

Climate change affects world food production, disease vectors that are agents of disease, biodiversity, and damage to marine and freshwater environments like coral reef bleaching. For example, the World Health Organization (WHO) estimates that without climate adaptation, nearly 7.5 million more cases of stunted children by 2030 and 10.1 million by 2050 due to undernutrition caused by decreased food supply (WHO, 2020). With a mission of reducing their reliance on non-renewable sources of energy like coal and oil, many countries have been seeking alternative sources of renewable energy like solar, nuclear, geothermal, wind and hydropower. In addition to developing renewable energy, under the United Nations Inter-Continental Panel of Climate Change (IPCC), many countries have vowed to stabilize their greenhouse gas emissions to sustainable levels and eventually carbon neutrality.

As noted by Haszeldine et al., there are three options for humanity in how to deal with the impacts of climate change: 1) do nothing, and await practical consequences; 2) develop and deploy engineering

technologies to increase reflectance of solar radiation; and 3) reduce the rate of CO₂ emission and recapture large quantities of CO₂ already emitted (2018). To respond to the challenges posed by climate change, two main strategies have been adopted by many countries: mitigation and adaptation. *Mitigation* refers to the reduction of magnitude of future climate change by cutting greenhouse gas emissions like developing renewable energy sources, reduction of energy consumption, and enhancing greenhouse gas sinks like afforestation (IPCC, 2014). *Adaptation* refers to preparation and dealing with the negative consequences of climate change (for example, protecting coastal zones from sea-level rise) as well as taking advantage of the positive consequences of climate change (increased food production in areas are too arid for agriculture) (Demski et al., 2017).

Climate Neutral Now (CNN) is an “initiative launched by UN Climate Change in 2015 to encourage everyone in society to take action to help achieve a climate neutral world by mid-century, as enshrined in the Paris Agreement”. (UNFCCC, 2020b). According to UNFCCC, the Inter-Governmental Panel on Climate Change (IPCC)—operating under the UNFCCC umbrella—works with governments, non-governmental organizations, and citizens towards global climate neutrality by addressing their own climate footprint in three main ways: 1) monitoring greenhouse gas emissions (carbon footprint); 2) deciding on actions that will reduce those emissions; and, 3) compensating for those emissions that cannot be avoided using UN certified emissions reductions (a form of carbon credit) (UNFCCC, 2020b).

As per the 2015 Paris Accord, the IPCC advocated emissions reduction targets of 80% below 1990 emission levels to stabilize global greenhouse emissions to a sustainable level. The majority of countries in Europe are striving for between 60% to 80% reduction by 2050. More than 110 countries representing up to 75% of global emissions have ratified the Paris Accord agreeing to work together to collectively reduce greenhouse gas emissions sufficiently to slow global warming. This sustained progress would ensure reduction of greenhouse gas emissions sufficiently to a steady state where by 2100 greenhouse gases in the atmosphere are approximately constant or decreasing (Erickson, 2017). In the United States, a number of states have adopted the same emission reduction measures tweaked to accommodate the needs of state governments, corporations, non-governmental organizations, and private citizens. As of 2020, the Center for Climate and Energy Solutions notes that 23 states and the District of Columbia have implemented statewide greenhouse gas reduction targets (CCES, 2020). Despite the withdrawal of the US from the Paris Accord, these states have vowed to uphold the U.S. commitment of reducing emissions 26 to 28 percent below 2005 levels by 2025 (CCES, 2020).

In the state of California (CA), the former Governor Arnold Schwarzenegger issued Executive Order S-3-05 of 2005, to reduce greenhouse gases by 80% below 1990 levels by 2050. In April 2015, Governor Edmund Gerald “Jerry” Brown signed Executive Order B-30-15 to reduce emissions to 40% below 1990 by year 2030. This legislation was enacted to ensure that California’s 2050 commitments (as per EO S-3-05) remain on target. According to the California Air Resources Board (CARB), CA

has made tremendous strides in reducing harmful air pollutants and cutting down on greenhouse gas emissions from industry, energy production, transportation and other sources (CARB, 2020a). To ensure sustained progress in emissions reduction, the CARB has maintained annual greenhouse gas (GHG) inventories from the year 2000. The California Global Warming Solutions Act of 2006 (AB 32) requires reporting of GHG emissions by major sources. Excluding natural GHG sources, this inventory provides estimates of anthropogenic emissions within the state in addition to emissions associated with imported electricity. Maintaining and updating California's GHG inventory is a charge given by the state to CARB (ARB, 2020b). The inventory includes estimates for carbon dioxide (CO₂), methane (CH₄), nitrous oxide (N₂O), and fluorinated gases with long lifetimes and high global warming potentials (high-GWP) like hydrofluorocarbons (HFCs), perfluorocarbons (PFCs), sulfur hexafluoride (SF₆), and nitrogen trifluoride (NF₃) (CARB, 2020a). Starting in 2009, emissions reporting in CA requires independent verification of GHG emissions data reports by CARB-accredited verification bodies. The CARB provides annual webinar training sessions regarding emissions requirements so that corporations and entities producing emissions can participate.

In 2017, California's most recent inventory data shows annual emissions measured at 424 mmtCO₂e. The changing climate has particularly affected the state in many ways: 1) worsening wildfires which are destroying lives, property, and disrupting businesses; 2) prolonged dry spells and droughts especially between the years 2012-2016; 3) with more than 840 miles of coast line and at least 85% of Californians living/working in coastal counties, there is significant risk of sea level rise and flooding; 4) resulting health consequences of droughts, wildfires and flooding; 5) California accounts for over 13% of the nation's total agricultural value, thus disruption of the state's food supply is a big concern; and, 6) there are significant effects on natural ecosystems primarily disruption of life-support systems and wildlife species.

Reviewing the emissions data reduction rates from various sources between 2010-2017, this study hypothesized that the CARB's 2030 emissions reduction targets (40% below 1990 levels; and 80% below 1990 levels by 2050) on state of emission reduction as required by the Executive Order B-30-15, would not be met if the current rates of reductions continue. Using the current rates of emissions reductions observed in the last 18 years as a baseline, the study made future projections about meeting the 2030 and 2050 targets. An analysis of current trends and technological developments in the transportation industry, power generation and use, general industry, commercial and residential sector, and the agricultural, refrigerant and waste/recycling sectors are presented. It is hoped that these suggestions will help the State authorities and agencies contributing to emissions develop strategies to boost the annual rates of emissions reductions in the years ahead.

2. Method

Using the emissions data from 2000-2017, the study's first null hypothesis was that the total yearly greenhouse gas emissions *observed* in each emissions category from 2018 to 2030, were no different from those *expected* if California met the Executive Order B-30-15 (EO) interim greenhouse gas reduction target of 40% below 1990 levels by 2030. Reaching this interim 2030 target would ensure California meets its target of reducing greenhouse gas emissions to 80% below 1990 levels by 2050 (Executive Order S-3-05). The chi-square goodness of fit test (Zar, 2009) was used to test whether there were differences between the *observed* and *expected* emissions reduction rates between 2018-2030.

The study's second null hypothesis was that the total yearly greenhouse gas emissions *observed* in each emissions category from 2018 to 2050, were no different from those *expected* if California met the Executive Order S-3-05 of 2005 with a greenhouse gas reduction target of 80% below 1990 levels by 2050. The chi-square goodness of fit test (Zar, 2009) was used to test whether there were differences between the *observed* and *expected* emissions reduction rates between 2018-2050. Existing CARB data from 2000-2017 was reviewed from each emission category (agencies in transportation, electric power, industrial, commercial and residential, agriculture, agencies producing gases with high warming potentials, and recycling/waste agencies).

The following parameters were noted and used in the statistics calculated:

- i. The 1990 total emissions given by CARB for California was 427 million metric tons of carbon dioxide equivalent (mmtCO₂e).
- ii. Total emissions for 2017 amounted to 424 mmtCO₂e, which is not significantly different from the total emissions amount in 1990 of 427 mmtCO₂e. Thus, the 1990 amounts were used to project annual percentage emissions for each category (transportation, electric power, industrial, etc.).
- iii. The annual mean percentages for each category were then calculated and used to project reduction rates for the years 2018-2030 assuming they would remain the same (*observed* reductions).

Assuming the CARB projected 40% reduction by 2030, emissions reductions for the period 2018-2030 were calculated using the mean percentages for each category (*expected* reductions). Assuming the CARB projected 80% reduction by 2050, the mean percentages for each category were used to calculate the *observed* and *expected* reductions for the period 2018-2050.

With these calculations, the questions guiding this study were:

- 1) Were the *observed* 2030 emissions reductions in each category different from those *expected* with the projected 40% below 1990 levels?
- 2) If the differences were significant, CA would not meet the targeted emissions reductions proposed by the ARB by 2030. How short were the emission amounts relative to the 2030 target?

How long would it take CA to reach the 2030 targets assuming the same rates of reduction as observed?

- 3) Likewise, were the *observed* 2050 emissions reductions in each category different from those *expected* with the projected 80% below 1990 levels?
- 4) If the differences were significant, CA would not meet the targeted emissions reductions proposed by the ARB by 2050. How short were the emission amounts relative to the 2050 target? How long would it take CA to reach the 2050 targets assuming the same rates of reduction as observed?
- 5) What annual reductions amounts would be required if CA were to meet the 2050 reduction targets (80% below 1990 levels)?
- 6) What mitigation actions would be needed for CA to stay on the 2050 target (cap/trade, carbon tax, education, monitoring, incentives, funding [loans, grants], policy changes, and others)?

3. Result

Using the available CARB data for the years 2000-2017 annual mean percentage reductions for each category were calculated as shown (Table 1). In four of the categories (transportation, electric power, industrial and commercial/residential) emissions reductions declined in the 18-year period, although only by small magnitudes (0.17% to 2.49%). In the other three categories (agriculture, refrigerant and recycling/waste agencies) emissions reductions had increased in the 18-year period (0.08% to 0.8%).

Table 1. Annual Mean Percentage Reductions for Various GHG Emissions Categories

Category	Mean % emissions reduction
Transportation	-0.32
Electric Power	-2.49
Industrial	-0.47
Commercial and Residential	-0.17
Agriculture	0.08
High Global Warming Potential	0.8
Recycling and Waste	0.09

The mean percentage emissions reduction rates calculated in the various emissions categories (Table 2) indicate that by the year 2030, no emissions category will have achieved the targeted reduction. The three highest emissions reduction amounts discrepancies between observed and expected were found in transportation, industrial and commercial/residential facilities. The three highest *percentage* differences between the observed and expected reductions were found in HGW potential emissions industries which emit gases like R-22—the most common refrigerant today; recycling/waste generation agencies;

and agriculture (Table 2). Overall, there was a significant difference between the observed and expected emissions reduction amounts for 2030 (Chi-square=86.44, dg=6, $p < 0.05$). This significance disproves the first hypothesis of this study of no difference between total observed and expected mean emissions reductions by year 2030.

Table 2. Observed and Expected Emissions Reductions in Various Categories (Assuming 40% Emissions Reduction below 1990 Levels by 2030; Units in mmtCO₂e)

Emissions Category	2030		40% below 1990	
	Observed	Expected	Difference	% Short
Transportation	162.95	101.61	61.34	37.6
Electric Power	44.94	36.51	8.43	18.8
Industrial	84.08	53.39	30.7	36.5
Commercial and Residential	40.2	24.62	15.58	38.8
Agriculture	32.75	19.46	13.29	40.6
High Global Warming Potential	22.07	12.04	10.04	45.5
Recycling and Waste	9.01	5.35	3.66	40.7
Total	396	252.96		

Assuming the mean emissions reduction rates observed between 2000-2017 persist, commercial/residential agencies, transportation agencies, and industry would take the longest time to achieve the 2030 emissions reduction targets (286, 147 and 96 years respectively, Table 3).

Table 3. Projected Emissions Reductions Durations in Various Categories (Estimated Using the Mean Percentage Emissions Reduction Rates Observed between 2000-2017 [to Reach 40% of 1990 Emissions Levels by 2030]; Units in mmtCO₂e)

Emissions Category	2030 (emission rates)	Duration (years) (following current reduction rates)	Year Achieved (40% emission levels reached)
Transportation	162.95	147	2177
Electric Power	44.94	83	2113
Industrial	84.08	96	2126
Commercial and Residential	40.2	286	2316
Agriculture	32.75	**	**
High Global Warming Potential	22.07	**	**
Recycling and Waste	9.01	**	**

** Mean percentage reduction rates increased between 2000-2017 (thus ignored in these projections)

If current emissions reduction trends continue as observed in the period 2000-2017, the mean percentage emissions reduction rates in the various emissions categories indicate that by the year 2050, no emissions category will have achieved the targeted reduction (Table 4). The three highest emissions reduction amounts discrepancies between observed and expected were found in transportation, industrial and agricultural facilities. Commercial/residential facilities emissions reductions were a distant fourth. The three highest *percentage* differences between the observed and expected reductions were found in industrial, transportation and electric power generation facilities (Table 4). Overall, there was a significant difference between the observed and expected emissions reduction amounts for 2050 (Chi-square=2345, dg=6, $p < 0.05$). This highly significant result disproves the first hypothesis of this study of no difference between total observed and expected mean emissions reductions by year 2050.

Table 4. Observed and Expected Emissions Reductions in Various Categories (Assuming 80% Emissions Reduction below 1990 Levels by 2050; Units in mmtCO₂e)

Emissions Category	2050		80% below 1990	
	Observed	Expected	Difference	% Short
Transportation	152.81	15.5	137.31	89.9
Electric Power	27.11	5.56	21.55	79.5
Industrial	76.51	5.69	70.82	92.6
Commercial and Residential	38.85	15.37	23.47	60.4
Agriculture	33.29	8.15	25.14	75.5
High Global Warming Potential	25.89	7.78	18.1	69.6

Recycling and Waste	9.18	3.75	5.43	59.2
Total	363.64	61.81	137.31	89.9

Assuming the mean emissions reduction rates observed between 2000-2017 persist, transportation agencies, industrial and commercial/residential facilities would take the longest time to achieve the 2050 emissions reduction targets (713, 556 and 542 years respectively, Table 5).

Table 5. Projected Emissions Reductions Durations of Four Categories with Decreasing Emission Reductions (Estimated Using the Mean Percentage Emissions Reduction Rates Observed between 2000-2017 [to Reach 80% of 1990 Emissions Levels by 2050]; Units in mmtCO₂e)**

Emissions Category	2050 (emission rates)	Duration (years) (following current reduction rates)	Year Achieved (80% emission levels reached)
Transportation	152.81	713	2763
Electric Power	27.11	63	2113
Industrial	76.51	556	2606
Commercial and Residential	38.85	542	2592

** Four categories highlighted because of their steady emissions reduction progress between 2000-2017

To reach the targeted 2050 emissions reduction levels of 80% below the 1990 levels, the seven GHG emission categories must have annual emissions reductions of at least the amounts shown in the column labelled “expected reductions/year” for the years 2018-2050 (Table 6). To reduce overall emissions reductions to the targeted 2050 levels, the greatest emissions reductions achievements must be realized in three main categories: transportation, industrial and electric power. The mean emissions reduction amounts per category based on the 2000-2017 levels are shown in the last column. While mean emissions reductions were decreasing annually by the amounts shown in the last column for the first four categories (negative), the mean amounts were increasing in the last three categories (agriculture, HGW potential, and recycling/waste).

Table 6. Expected Annual Emissions Reductions by Category between 2018-2050 Based on the 2017 Emissions Reduction Amounts (Units in mmtCO₂e)

	2050 (80% below 1990 levels)	2017 (emission levels)	Expected emissions reduction amounts to reach 2050 target (totals)	Expected reductions (per year)	Observed mean reduction rates (per year)
Transportation	15.49	169.91	154.4	4.67	-0.58
Electric Power	5.56	62.43	56.84	1.72	-2.36
Industrial	5.69	89.44	83.71	2.53	-0.44
Commercial and Residential	15.37	41.12	25.73	0.78	-0.16
Agriculture	8.15	32.45	24.25	0.73	0.08
High Global Warming Potential	7.78	19.96	12.12	0.37	0.76
Recycling and Waste	3.75	8.97	5.15	0.16	0.09

Projections indicate that for CA to reach its 2050 emissions targets of 80% below 1990 levels by the year 2050, total annual emissions must be reduced by the percentages shown for the next 33 years (Table 7/Figure 1). For comparison, the actual total percentage emissions reductions per year are shown (assuming emissions reduction rates remain the same as in the period 2000-2017).

Table 7. Actual and Required Total Annual Percentage Emissions Reduction in Each Emissions Category between 2018-2050 (to Achieve 80% Total Emissions Reduction below 1990 Levels by 2050)

Year	Total% Required emissions reductions	Total% Projected emissions reductions	Year	Total% Required emissions reductions	Total% Projected emissions reductions
2018	2.59	0.57	2036	4.85	0.45
2019	2.66	0.56	2037	5.09	0.44
2020	2.73	0.55	2038	5.37	0.44
2021	2.81	0.54	2039	5.67	0.43
2022	2.89	0.54	2040	6.01	0.43

2023	2.97	0.53	2041	6.4	0.42
2024	3.06	0.52	2042	6.83	0.42
2025	3.16	0.52	2043	7.34	0.41
2026	3.26	0.51	2044	7.92	0.41
2027	3.37	0.5	2045	8.6	0.4
2028	3.49	0.5	2046	9.41	0.4
2029	3.62	0.49	2047	10.38	0.39
2030	3.75	0.48	2048	11.59	0.39
2031	3.9	0.48	2049	13.1	0.38
2032	4.06	0.47	2050	15.08	0.38
2033	4.23	0.47			
2034	4.42	0.46			
2035	4.62	0.45			

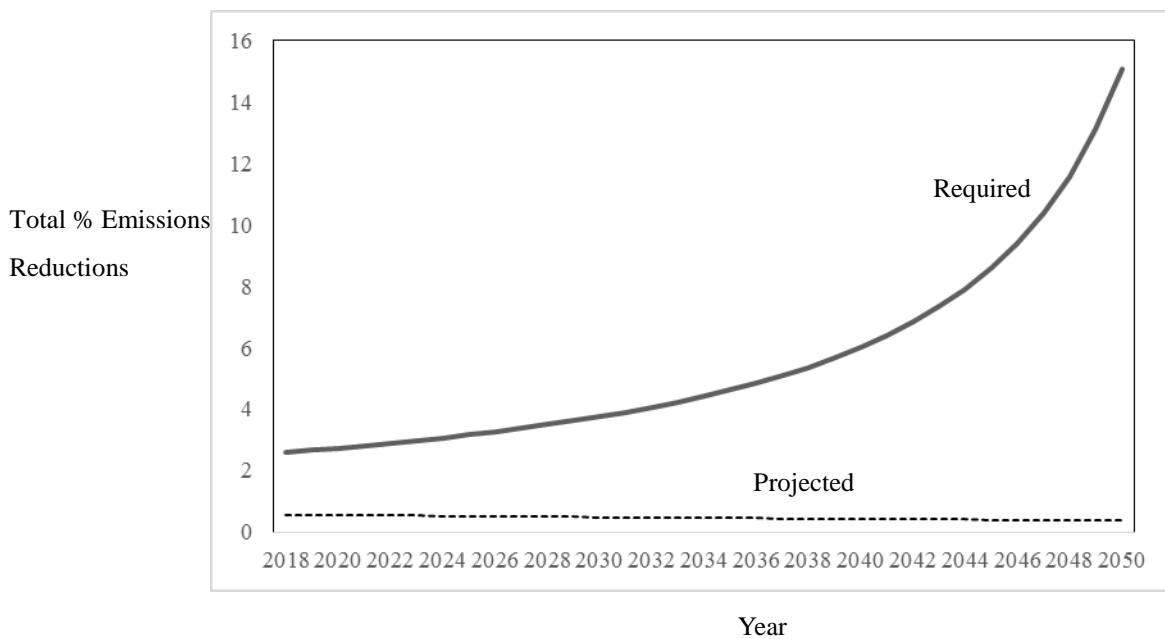


Figure 1. Actual and Required Total Annual Percentage Emissions Reductions in Each Emissions Category between 2018-2050 (so as to Achieve 80% Total Emissions Reductions below 1990 Levels by 2050)

4. Discussion

Reduction of greenhouse gas emissions greatly improves ambient air quality. Policies to mitigate climate change by reducing Greenhouse Gas (GHG) emissions can yield public health benefits by also reducing emissions of hazardous co-pollutants, such as air toxics and particulate matter. Although

GHGs like carbon dioxide impacts health indirectly through alterations of climate, they are not directly harmful due to the typically low outdoor concentrations they are commonly found (Cushing et al., 2018). However, GHG emissions from fossil fuels combustion are accompanied by other hazardous co-pollutants such as Particulate Matter (PM), ozone-forming Nitrogen Oxides (NO_x), and Volatile Organic Compounds (VOCs) that cause increases in mortality due to respiratory and cardiovascular diseases (Cushing et al., 2018). The short- and long-term health benefits accruing from decreases in GHG emissions from fossil fuel combustion greatly improve local air quality; and evidence that the economic cost savings of reduced air-pollution-related illnesses and death outweighs the costs of GHG mitigation abounds (Smith & Haigler, 2008; Nemet et al., 2010).

Air pollutants have been implicated in cancer etiology, premature mortality, asthma, chronic obstructive pulmonary disease, cardiovascular disease; aggravate existing chronic conditions like type-2 diabetes; and raise risks of Alzheimer's disease and dementia (Apte et al., 2015; Erickson & Jennings, 2017; Erickson, 2017). Air quality regulations in the US in the past two decades have greatly reduced emissions from traditional polluting sources, such as Sulfur Dioxide (SO₂) and Nitrogen Oxides (NO_x) from coal-fired power plants and on-road transportation. Resulting from these emission reductions, the national average annual particulate matter concentration has declined by 42% from 2000 to 2015 (EPA, 2019).

The results of this study clearly indicate that unless the State of California changes course in emissions reductions in the years ahead with more focused strategies (discussed below); it will not meet the targeted (and IPCC-agreed) emissions reductions by 2030, 2050 and beyond as anticipated. While emissions reductions in all categories were challenging during the 18-year period, there was some progress in transportation, electric power, industrial and commercial/residential categories. However, as shown in Tables 1 and 2, the actual reductions are not enough to meet targets. According to CARB, the overall trends demonstrate that the carbon intensity of California's economy (the amount of carbon pollution per million dollars of Gross Domestic Product [GDP]) is declining. CARB asserts that from 2000 to 2017, the carbon intensity of California's economy has decreased by 41 percent from 2001 peak emissions while simultaneously increasing GDP by 52 percent (2020a). However, this is just a positive way of looking at emissions trends—since a decline in economic output hurts jobs and people's livelihoods. It is difficult to anticipate a situation where jobs will be preserved as the economy grows while at the same time emissions reductions are significantly declining.

This study found that if current mean emissions trends in each sector persist in the decades ahead, California total GHG emissions will be short of targets by 143 mmtCO₂e (in 2030, Table 2) and 302 mmtCO₂e (in 2050, Table 4). This is consistent with what other studies have reported. For example, the 11th annual California Green Innovation Index that California will meet its 2030 climate targets more than three decades late (in 2061) and could be more than 100 years late in meeting its 2050 target if the average rate of emissions reductions from the past year persists (Next 10, 2020). The discussion below

will focus on current trends and developments in each of the sectors contributing most to US and California's total CO₂ emissions. In the light of this study, an analysis of the current US and global technological trends and developments is presented to help inform conversations regarding boosting emissions reductions in the future.

Transportation Sector

Transportation activities accounted for 28.8 % of U.S. greenhouse gas emissions in 2017. The largest sources of transportation greenhouse gas emissions in 2017 were passenger cars (41.3%); freight trucks (22.7%); light-duty trucks, which include sport utility vehicles, pickup trucks, and minivans (17.8%); commercial aircraft (6.5%); other aircraft (3.1%); ships and boats (2.4%); rail (2.2%); and pipelines (2.2%) (EPA, 2020). The sector remains the largest source of GHG emissions in California and for the 18-year period mean emissions reductions were only 0.32 mmtCO₂e per year (Table 1). It remains about 38% short of meeting the emissions reduction target for 2030 (Table 2); and 90% short of meeting the 2050 target (of emissions 80% below 1990 levels, Table 4). With the business-as-usual model (mean emissions reductions tagged at 0.32 mmtCO₂e), it will take 147 years to reach the 2030 targets (year 2177); and 713 years to reach the 2050 target (year 2763).

As noted by CARB, direct emissions from vehicle tailpipe, off-road transportation mobile sources, intrastate aviation, rail, and watercraft account for 40 % of statewide emissions in 2017. About 90 % of emissions in the transportation sector come from passenger vehicles (69%) and heavy-duty vehicles (22%). The remaining emissions have come from a variety of other sources, including ships, airplanes, and rail (Taylor, 2018; CARB, 2020b). Since vehicle transportation is responsible for most of the emissions (smog and particulates in the air) in urban areas, the quality of air can substantially be improved by electric and (to a lesser extent) hybrid vehicle technology. California can remain hopeful since electric vehicle technology has dramatically increased in many countries in the last decade. To its advantage, one major electric car company (Tesla) is based in California. According to industry sources, Tesla sold 245,240 vehicles in 2018; and about 145,846 of this total were "Model 3s", the company's midsize, four-door sedan that started production in 2017 (CarSalesBase, 2020).

The International Energy Association (IEA) estimates that in 2018, the global electric car fleet exceeded 5.1 million, up 2 million from the previous year and almost doubling the number of new electric car sales (2020). The world's largest electric car market is the People's Republic of China, followed by Europe (e.g., in Norway more than 25% of new car sales are electric vehicles) and the US (IEA, 2020). In the US, combined local and global sales have increased by 518% between 2012-2016 (Erickson, 2017). At least 40% of those sales are reported to be in the state of California where air quality control is more stringent than the rest of the US. For example, by 2045 California expects all commercial trucks to be electric as they account for 70% of pollution and 80% of diesel soot, despite numbering only 2 million of the roughly 30 million vehicles registered in California (GCR, 2020).

A number of policies (including in California), have been enacted nationwide to help with GHG emissions reductions within the transportation network. These have focused on use of lower carbon fuels (including biofuels, advanced diesel, natural gas, hydrogen [for fuel cells], and electricity), targeted programs for light- and heavy-duty vehicles, and overall reduction of miles travelled per vehicle. The State has provide financial assistance to fuel consumers, vehicle manufacturers and fuel producers within the transportation industry willing to adopt lower emissions technologies, while others have focused on raising costs for using higher emissions technologies. However, despite these policies, emissions reductions are still lower than need to be to meet published 2030, 2045 and 2050 emissions targets.

Despite the slow progress in emissions reductions observed in California particularly in the transportation sector, there are several reasons to remain optimistic. Battery technology has greatly improved as seen in the development of solid state batteries that do not have liquid electrolytes raising the potential to increase energy density and reduce cost (Motavalli, 2015). These batteries have increased the range of new cars compared to earlier models and prices of new electric vehicles have declined. The development of EV charging infrastructure for electric vehicles is fast changing making travel distances of more than 200 miles possible with electric vehicles. The installation of electric vehicle supply equipment (EVSE) to allow fast charging along major highways, workplace and at home are the three most important infrastructure needs (Erickson et al., 2017). Newer developments like solar technology and wireless charging (where the electric vehicle is parked over a pad) added to this growing EVSE infrastructure, are added incentives to attract consumers to EVs and increase sales. Other incentives that will improve EV adoptions are solar energy storage in parking facilities in offices, schools, sports and entertainment events that attract many people. As is already happening—albeit at a slower pace—California must remain at the forefront of all these developments by incentivizing, financing, adopting, mandating, and monitoring incorporation of these new technologies within the transportation network.

Electric Power Sector

According to CARB, emissions from the electric power sector comprise 15 % of 2017 statewide GHG emissions divided into two broad categories: emissions from in-state power generation (including cogeneration emissions) and emissions from imported electricity (2020a). For the 18-year period (2000-2017) mean emissions reductions in the electric sector were the highest in all sectors at about 2.49 million metric tons of CO₂e per year (Table 1). Despite this, electric power utilities remain about 19% short of meeting the emissions reductions target for 2030 (Table 2); and 80% short of meeting the 2050 target (of emissions 80% below 1990 levels, Table 4). With the business-as-usual model (mean emissions reductions tagged at 2.49 mmtCO₂e), it will take 83 years to reach the 2030 targets (year 2113); and 63 years to reach the 2050 target (year 2113).

One critical front helping California with emissions reductions is the increased adoption of renewable energy sources. California leads the nation in electricity production from renewable energy sources primarily solar, geothermal and biomass (USEIA, 2020a). In the decades ahead, the continued development of renewable energy alternatives (especially wind, solar, geothermal and hydropower) will remain a major force in greenhouse gas emissions reductions. The retirements of older, less-efficient fossil fuel units, availability of renewable energy tax credits, and the continued decline in the capital cost of renewables will fuel increased adoption of clean energy in the years ahead. Projections show that by 2050, renewable energy will contribute about 38% of total electricity generation in the US comprised of solar (46%), wind (33%), hydropower (14%) and geothermal (3%) sources (USEIA, 2020b).

California state legislature already passed Senate Bill 350 (2015), which requires all utilities in the state to source half of their electricity sales from clean, renewable sources such as wind, solar, geothermal, and bio-power by 2030. Referred to as the Renewables Portfolio Standard (RPS) program, the bill requires that 60% of retail sales of electricity in California come from eligible renewable resources by 2030, and 100% by 2045. The RPS stimulates clean technology investment and innovation, and by ensuring the market for renewable energy in California will continue to grow, it creates a favorable climate for developers, investors, and planners of renewables projects (USEIA, 2020a). As of 2017, just over half of total generated electricity (in-state and imported) came from zero-GHG sources (solar, wind, hydropower, and nuclear) (CARB, 2020a). If this trend is sustained, the state may reach the 2045 target of zero emissions in electricity generation.

Industrial Sector

The main industries with the bulk of emissions in California are oil refineries, oil and gas corporations, combined heat and power cogenerating industries, mixed industries utilizing petroleum products, cement, and pipeline. For the year 2017, emissions from the industrial sector contributed 21% of state's total GHG emissions, with refineries and hydrogen production representing the largest individual source contributing 33% of the sector's total emissions (CARB 2020a). For the 18-year period (2000-2017) mean emissions reductions in the industrial sector were about 0.47 million metric tons of CO₂e per year (Table 1); making this sector about 37% short of meeting the emissions reductions target for 2030 (Table 2), and 93% short of meeting the 2050 target (of emissions 80% below 1990 levels, Table 4). With the business-as-usual model (mean emissions reductions tagged at 0.47 mmtCO₂e), it will take 96 years to reach the 2030 targets (year 2126); and 556 years to reach the 2050 target (year 2606).

Projections up to 2050 indicate that the industrial sector's energy consumption will grow by about 1.0% per year on average with coal consumption declining, while natural gas and hydrocarbon gas liquids consumption will grow fastest (reflecting strong supply growth and relatively low prices). The bulk chemicals industry (like heat, power and feedstocks) energy use will grow by about 1.6%

accounting for about 35% of total U.S. industrial energy consumption by 2050. The iron and steel industry energy use is projected to decline by 19% while the paper industry will increase energy consumption by 11%. Other industries like lime and cement, refining, glass and aluminum smelting are projected to remain stable in energy use over the same period (USEIA, 2020c).

California's Cap-and-Trade Program

Globally, cap-and-trade has emerged as the favorable and main regulatory mechanism for pricing carbon and reducing GHG emissions from large stationary sources that emit more than 25,000 metric tons of CO₂e per year (for example, refineries, cement production facilities, oil and gas production facilities, glass manufacturing facilities, and food processing plants) (CARB, 2020c). The program achieves the goals of economic development and carbon emissions reduction through both government and market regulation (Jiang et al., 2019). The California cap-and-trade system allows CARB to set an allowable total amount of emissions over a certain period and issue tradable emission permits. The program is estimated to account for less than 20% of all emission reductions under AB 32 (CARB, 2020c). California's program is very similar to other cap-and-trade programs, although at the practical level several detailed differences reflect active efforts by California policy-makers to avoid flaws perceived in other similar systems such as the world's largest carbon pricing regime (European Union Emissions Trading System), and the US East Coast's Regional Greenhouse Gas Initiative (Bang et al., 2017). The program regulates carbon dioxide, methane, nitrous oxide, and fluorinated GHGs from power plants, refineries, industrial facilities, fuel suppliers, and other entities that emit over 25,000 metric tons of CO₂e of GHGs per year, not including biogenic CO₂ (Cushing et al., 2018; CARB, 2020c). Under a cap-and-trade system, regulated companies must surrender tradable emission permits (called "allowances") equal to the amount of GHGs they emit. Typically, one allowance equals one metric ton of CO₂ equivalent (CO₂e). To ensure accumulated gains over time, the cap on emissions is set by the total allowances issued designed to decrease over time. The program creates a powerful economic incentive for significant investment in cleaner, more efficient technologies and applies to emissions that cover approximately 80 % of the State's GHG emissions (CARB, 2020c). It reduces GHG emissions from major sources by setting a firm cap on statewide GHG emissions while employing market mechanisms to cost-effectively achieve the emission-reduction goals. The total number of allowances provided by CARB each year is equivalent to the annual allowance budget specified by AB32.

As described by CARB (2020c), three types of GHG emissions are covered by the cap-and-trade program: local direct emissions within the state, indirect emissions from electricity imported from outside state, and geographically distributed emissions from fuels such as gasoline and natural gas which started in 2015. Beginning in 2013, industries were required to hold allowances equal to their GHG emissions (1 allowance=1 metric ton of CO₂e). During the first compliance period of 2013-2014, more than 90% of allowances were freely allocated, with the balance auctioned or reserved for price

containment. To meet a cumulative GHG reduction target of 15% from 2015 to 2020, the total number of allowances in circulation (“cap”) was planned to decrease by 3%-3.5% annually. Companies could also meet 8% of their compliance obligation by purchasing GHG emission reduction credits generated by offset projects located in the US (1 offset=1 metric ton of CO₂e). Regulated firms could be required or incentivized to purchase offsets that are linked to local projects that reduce GHG emissions, while also improving air quality in the regions where their facilities are located. Such local offset projects could include electrification of railyards and ports, cleaning up truck fleets, development of solar cell parking roof arrays, or financing retrofits to reduce GHGs and co-pollutant emissions from other local emission sources. Such local offset projects could enhance government oversight and promote community partnerships in project monitoring and emission verification. Nevertheless, offsets have been cited as capable of undermining improvements to local air pollution by undercutting financial incentives for industries to reduce emissions on site (Cushing et al., 2018). Cutbacks in the use of more carbon intensive energy sources imported from outside the state (such as electricity generated from coal-fired rather than natural gas power plants) could also be used by regulated entities to meet emission reduction goals in lieu of in-state reductions (CARB, 2020c).

The cap-and-trade program also covers fuel distributors (natural gas/propane fuel providers and transportation fuel providers) to address emissions from transportation fuels and from combustion of other fossil fuels. Facilities that do not adhere to program requirements are subject to stringent penalties (CARB, 2020c). As has been observed in the European Union, emissions permits are readily affordable for most sectors thus failing to incentivize polluters to reduce carbon emissions, and invest in abatement technology. Monitoring compliances and enforcement by CARB has not been consistent, plus the complex and unnecessarily costly red tape industry has to go through in their emissions reporting. CARB must ensure that industrial operators use the most cost-effective emissions-reducing technologies to curb emissions to air, water and soil. As seen in the European Union, carbon prices are not market competitive perhaps due to oversupply of permits and/or decreased demand due to decarbonization among regulated polluters. As long as carbon markets are not viewed by industry as effective and credible regulatory policy for the future, it will not be enough to industrial-distance from carbon-intensive production (Cushing et al., 2018; Bayer & Aklin, 2020).

The overall number of emissions allowances in the California’s cap-and-trade program need to be lowered to increase the pace for emissions cuts. For example, the European Union’s Emissions Trading System plans to lower allowances by 26% starting 2021 (EU, 2020). Funding must be made available to accelerate the development of promising innovative technologies and breakthrough creativity in the industrial sector. The current achievements of the cap-and-trade program (among other measures) can hardly be viewed as successful in cutting emissions judging from the mean percentage emissions reductions from various sectors as reported in this study (Table 1). Research suggests raising the minimum price for permits that industries must purchase under the state’s cap-and-trade law to emit

greenhouse gases. Analysts note that carbon price generates favorable economic and social impacts, but policymakers express concerns over a political backlash if prices rise too much or too fast (Busch & Orvis, 2020). Economic benefits due to carbon pricing are caused by the incentive to avoid low-value energy use, which translates to reduced energy consumption. Currently, cap-and-trade carbon trading in auctions stand at \$19 (2020), projected to be \$29 (2030) if current trends continue. The lowest projected carbon price level for 2030 is \$26; mid-level \$63; and highest level \$101 (Busch & Orvis, 2020).

The cap-and-trade market system is far from a perfect mechanism for GHG emissions reductions. Efficient climate regulation as has been argued by some economists and environmental justice advocates requires deeper GHG reductions in areas where the health benefits of co-pollutant reductions are maximized. However, as reported by Cushing et al. (2018), this cannot be accomplished with the geographically unrestricted trading characteristic of cap-and-trade in which all GHG reductions are treated equally regardless of where they occur. Unless the location and co-pollutant intensity of GHG emissions are incorporated into the design of a cap-and-trade system, carbon trading could also potentially widen social inequities in exposure to localized hazardous co-pollutants because GHG-emitting facilities, which are disproportionately located in disadvantaged communities, are able to purchase allowances or offsets rather than reduce their emissions. California's climate policy could better harmonize efforts to reduce GHGs with improvements to local air quality, and that market-based strategies in general could provide greater overall benefits by incentivizing localized GHG reductions especially in disadvantaged and highly polluted neighborhoods (Farber, 2012; Boyce & Pastor 2013; EPA, 2017; Cushing et al., 2018; Pan et al., 2020).

Jiang's et al.'s study (2019) highlighted several other limitations of the California's cap-and-trade program. First, the potential positive health effects (co-benefits) accruing from the regulation are small, but can be improved by limiting the use of offsets to no more than 49% of total emission reductions (Jiang et al., 2019). This according to the study would encourage on-site greenhouse gas reductions, targeting offsets with positive health co-benefits to California's vulnerable communities, and maximizing the auction of emission allowances. Enhanced environmental health surveillance systems to monitor future impacts and to ensure that no population bears a disproportionate health burden from the cap-and-trade program are recommended (Jiang et al., 2019). Third, cap-and-trade is not designed to lower criteria pollutants but to lower GHG emissions, as observed when entities use offsets to meet their emissions cuts. Modifications to the regulation will ensure locational equitability in health benefits. Fourth, cap-and-trade offers individual entities a high degree of freedom in attaining emission reduction targets offering flexibility but no health equitability. Fifth, the program mitigates climate change but such policies cannot be used to justify exacerbation of existing health disparities in communities which are already challenged by the need for adaptation to climate change (Jiang et al., 2019).

Commercial/Residential Sector (CR)

Greenhouse gas emissions from the commercial and residential sectors are dominated by the combustion of fossil fuels in households and commercial businesses such as space heating, cooking, and hot water or steam generation (EPA, 2020). Residential buildings use energy for cooling, heating, lighting, refrigeration, clothes and dishwashing, cooking, water heating, and appliances. For the 18-year period (2000-2017) mean emissions reductions in this sector were the lowest in all sectors at about 0.17 million metric tons of CO₂e per year (Table 1). As a result, this sector fell 38% short of meeting the emissions reductions target for 2030 (Table 2); and 60% short of meeting the 2050 target (of emissions 80% below 1990 levels, Table 4). With the business-as-usual model (mean emissions reductions tagged at 0.17 mmtCO₂e), it will take 286 years to reach the 2030 targets (year 2316); and 542 years to reach the 2050 target (year 2592).

The Centre for Climate and Energy Solutions (CCES) notes that in the last 49 years nationwide, rising population has led to the addition of a net average of 1.4 million completed homes a year, with total stock at 70.3 million as of 2017 (CCES, 2020). Carbon dioxide emissions from fossil-fuel combustion by the residential sector increased 7.8% from 1990 to 2015 (reflecting a 5.5% decrease in direct, and a 15.4% increase in indirect, emissions). In 2015, more than 85% of the sector's direct emissions were from on-site fossil-fuel combustion, with most of the remainder resulting from leaks of hydrofluorocarbons commonly used as refrigerants. Rising indirect emissions result from increased population, housing stock, and communications technologies in homes. Largely due to energy efficiency and improved building codes, residential energy consumption is expected to remain largely unchanged despite population growth projections of 22.8% by 2050 (CCES, 2020).

Commercial buildings use energy for ventilation, lighting, refrigeration, cooking, cooling, water heating, computer and office equipment, and heating. CCES estimates that between 1979 to 2012, the number of commercial buildings rose by 40%, and the amount of floor space increased by 70%. Further, from 1990 to 2015, total CO₂ emissions from fossil-fuel combustion from the commercial sector increased 20.4%, as direct emissions rose 13.2% and indirect emissions increased 23.3%. In 2015, a little more than half of the direct emissions came from on-site fossil-fuel combustion (CCES, 2020). Commercial floor space is projected to grow by 40.5% from 2016 to 2050 and commercial energy consumption by 19.7%. Direct emissions are projected to rise by 20.4% driven by the increased use of natural gas, while indirect emissions are projected to decrease by 5.9%. While more electricity will be used for information technology and telecommunications, HVAC-related electricity use is expected to drop by 33% due to energy efficiency and population migration to the southern and western parts of the US. In addition, lighting intensity is expected to drop 56% due to increased efficiency from LED bulbs. On-site electricity generation from solar photovoltaic panels and combined heat and power will also reduce the commercial sector's demand for grid electricity (CCES, 2020).

The substitution of electricity for direct fossil-fuel combustion and improved energy efficiency, including through wider deployment of “intelligent efficiency” technologies provides major opportunities to decarbonize the buildings sector. However, some fundamental challenges remain including upfront costs, long payback periods, and “split incentives” among builders, owners, and occupants. Electrification of end uses will be a key pathway to reducing emissions and using electricity for heating, cooling, and hot water needs, instead of burning natural gas or fuel oil, can greatly reduce a building’s emissions. Since buildings undergo several phases over their lifetime, including design, construction, operation, and retrofits, opportunities abound to improve energy efficiency and reduce emissions by: 1) adopting more natural lighting, 2) sourcing construction materials with less embodied carbon, 3) changing consumer behavior and electricity usage patterns to reduce energy demand, and, 4) planning major retrofits over the life of the building including improving building envelopes and window insulation to control for air and moisture and optimizing the cost and performance of LED lighting (CCES, 2020).

Residential and commercial buildings represent one of the highest energy consumption fields in the world and in developed countries, between 20% and 40% of the total energy consumed relates to buildings (Moreno et al., 2014). The benefits of energy-efficient buildings to limit the global temperature rise to “well below 2°C” is imperative—if no action is taken to improve efficiency, global energy demand is projected to rise by 50% by 2050 (Foggia, 2018; Gan Vincent, 2018). Energy consumption in buildings emit close to 30% of the CO₂ emissions, while about 6% of the total emitted pollutants occur as a result of fuel consumption in households. Thus, a reduction in a building’s environmental impact can lead to significant environmental benefits (Delavar & Sahebi, 2020). Over time buildings undergo several phases in design, construction, operation, and retrofits, thus, opportunities abound to improve energy efficiency and reduce emissions. For example, designing a building to use more natural lighting, using construction materials with less embodied carbon, influencing consumer behavior and electricity usage patterns to reduce energy demand, or planning major retrofits over the life of the building.

Technological advances can increase energy efficiency by improving building envelopes and window insulation which help control air and moisture flow, and optimizing the cost and performance of LED lighting. include Many buildings occupants’ lack of awareness and information about energy use will continue to be major challenges in energy efficiency. In addition, many commercial and residential properties monitor energy costs or embed them in rental charges which reduces transparency in energy use frustrating efficiency amongst occupants. Most properties have electricity smart meters in the U.S. but there is some resistance experienced in smart metering due to cost, privacy and accuracy concerns. On the positive side, many companies now offer hardware, software, and services to help commercial and residential users benchmark their energy usage against peers to make better-informed decisions (Di Foggia, 2018; CCES, 2020). Other challenges encountered are that people who construct, own, and

occupy buildings will vary over time and buildings undergo different phases over their lifetime. For example, the builder (or owner) of a newly constructed building may not install the most energy efficient appliances or equipment, whereas the buyer or renter will be responsible for energy costs in the facility. This split incentive tends to favor lower upfront costs despite the net lifetime savings that could be achieved through greater energy efficiency. Upfront costs may also be an obstacle to switching existing buildings to alternative fuels or technologies such as heat pumps. In both the commercial and residential sectors, potential financial incentives for such investments include: streamlined loan processes, rebates, favorable loan terms, weatherization assistance for low-income households, property assessed clean energy (PACE) funds, and tax credits for both installing on-site renewable energy and pursuing specific green building certifications (Gan Vincent, 2018; CCES, 2020; Delavar & Sahebi, 2020).

Agriculture, Refrigerant and Recycling/Waste Sectors

Agriculture

The three major areas where emissions reductions have slightly increased in the 18-year period from 2000-2017 are agriculture, refrigerant and recycling/waste agencies, Table 1. The three sectors were found to be 41%, 46% and 41% respectively short of the 2030-targeted emissions reductions; and 76%, 70% and 59% respectively short of the 2050-targeted emissions reductions (Tables 2 & 4). The substantial contribution of food consumption to climate change necessitates urban action to reduce the carbon intensity of the food system, which contributes about 20-30% of global GHG emissions necessitating action to reduce the carbon intensity of food production and consumption (Mohareb et al., 2018).

Greenhouse gas emissions related to agriculture totaled 582 million metric tons in 2017, up slightly from prior-year levels, but down 2% from a decade ago (EPA, 2019). Productivity in agriculture was 270% greater in 2017 than in 1948, and 136% greater than 1990, while total farm inputs were mostly unchanged from 1948, and only marginally higher than in 1990 (EPA, 2019). Innovations in animal and crop genetics, chemicals, equipment, and farm organization have enabled continuing output growth without adding much to inputs (USDA, 2020). The agriculture end-use sector includes a variety of processes including methane (CH₄) and Nitrous Oxide (N₂O) emissions from enteric fermentation in domestic livestock, livestock manure management, rice cultivation, agricultural soil management, and field burning of agricultural residues; as well as Carbon Dioxide (CO₂) emissions from liming and urea fertilization. In 2017, agricultural soil management was the largest source of N₂O emissions, and enteric fermentation was the largest source of CH₄ emissions in the United States. This sector also includes small amounts of CO₂ emissions from fossil fuel combustion by motorized farm equipment such as tractors (EPA, 2019).

California's agricultural sector contributed approximately 8% of statewide GHG emissions in 2017, mainly from methane (CH₄) and nitrous oxide (N₂O) sources. Sources include enteric fermentation and

manure management from livestock, crop production (fertilizer use, soil preparation and disturbance, and crop residue burning), and fuel combustion associated with stationary agricultural activities (water pumping, cooling or heating buildings, and processing commodities). Livestock accounted for approximately 60% of agricultural emissions, which were generated primarily in the form of CH₄ from enteric fermentation and manure management. Dairy facilities are a major source of GHG emissions in California, accounting for roughly 60% of agricultural emissions. About 40% of CH₄ emissions come from natural sources including wetlands, mostly in tropical regions and cold parts of the planet such as Siberia and Canada, lakes and rivers; natural geological sources on land and oceans such as gas-oil seeps and mud volcanoes; and smaller sources such as termite mounds in the savannas of Africa and Australia. Luckily, about 90% of CH₄ is destroyed through oxidation in the lower atmosphere by reacting with hydroxyl radicals.

CARB reports that agricultural emissions in 2017 were 16% higher than 2000 levels with crop production accounting for 20% of all agriculture emissions in 2017 (2020a). **A more climate-friendly land use strategy for California will encourage the agriculture sector** develop climate-smart agriculture practices. It will also support forest management practices that promote reforestation efforts (especially expanding urban tree-planting) which can store vast quantities of carbon sequestered from the atmosphere. Research in carbon sequestration indicates that U.S. forests will continue sinking carbon for many years, although recent research indicate that due to increased forest disturbances (like drought, wildfires and the spread of diseases), slower forest growth, and other factors the CO₂ absorption rate may begin to decline (Belenky, 2016). California aims to expand carbon sequestration in natural and working lands, defined as including forests, rangelands, farms, wetlands, and soils (CARB, 2020b).

These efforts can be supported with financial incentives, by regulation and monitoring, education/training/demonstration centers, and provision of agricultural inputs with lower emissions (like fertilizers). While the manufacture of synthetic nitrogen fertilizers produces a significant source of greenhouse gas emissions, its application is also an important factor contributing to direct N₂O emissions from agricultural soils (Chai et al., 2019). Increased N₂O stimulates microbes in the soil to convert nitrogen to nitrous oxide at a faster rate than normal. Encouraging farmers to embrace changes in fertilizer use and agricultural practices will help to mitigate the release of nitrous oxide into the atmosphere. On a positive note, U.S. farmers and ranchers are today producing more crops, livestock, fruits and vegetables, fuel and fiber than ever before while using less water, protecting against erosion and conserving more soil, avoiding nutrient loss, increasing wildlife habitat and improving biodiversity while using less cropland. Farmers also contribute to reductions in greenhouse gas emissions by sequestering carbon in that soil. In addition to sequestration, livestock producers have greatly enhanced their sustainability efforts by investing in methane digester technology—reducing methane emissions into the atmosphere and producing renewable energy (AFBF, 2020).

Refrigerants

In 2017, California's refrigeration and air conditioning equipment contributed 90% of ozone depleting substance substitutes emissions. These are primarily hydrofluorocarbons (HFCs) used in refrigeration and air conditioning equipment, solvent cleaning, foam production, fire retardants, and aerosols. Due to their high global warming potential and refrigerant charge leaks from the system, refrigeration and air conditioning systems have high, negative environmental impacts (Beshr et al., 2017). Refrigerants are fluids used in refrigeration cycles to cool a space like a room, office building, or warehouse. They work by capturing heat and releasing it to another space using thermodynamic phase changes where fluids change to a gas or vice versa in the refrigeration cycle. Refrigerants are used primarily in refrigerators/freezers, air conditioning, fire suppression/explosion systems, cleaning solvents, propellants, foam blowing, sterilants, adhesives, coats and inks. There are numerous industrial, commercial and residential uses of refrigerants including commercial ice machines, chillers, cold storage warehouses, household refrigerators/freezers, ice-skating rinks, motor vehicle air conditioning, retail food refrigeration, refrigerated transport, vending machines and water coolers among others (Kasera & Bhaduri, 2017; McLinden et al., 2017; EPA, 2020).

Hydrofluorocarbons (HFCs), currently used as refrigerants in air-conditioning systems, are potent greenhouse gases, with high values of global warming potential. Highly commercialized in the 1990s as replacements for the ozone-depleting CFCs and HCFCs, HFCs are now the dominant refrigerants in new refrigeration, AC and heat-pump equipment (McLinden et al., 2017). The Kigali Amendment to Montreal Protocol requires the participating parties to gradually reduce HFCs use by 80 % to 85 % by the late 2040s. The substances controlled by the Protocol are ozone-depleting substances with high global warming potentials including CFCs, halons, other fully halogenated CFCs, carbon tetrachloride, methyl chloroform, HCFCs, methyl bromide, and HFCs (UN, 2020).

According to the American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE), the most common refrigerant families include methane/ethane series, ethers, propane, cyclic organic compounds, nitrogen compounds, and inorganic compounds (2020). Refrigerant blends include zeotropes and azeotropes (mostly designated "R-" series like R-22, R-404A, R-407A, R-410A, etc.). Refrigerants like R-22 are often thousands of times more polluting than CO₂, and in 2010, the Environmental Protection Agency (EPA) implemented a ban on the production and import of R-22. It has a 100-year Global Warming Potential (GWP) of 1,810, almost 2,000 times the potency of CO₂. For comparison, a pound of R-22 is nearly as potent as a ton of CO₂ (Taylor, 2018). Illegal for use in US starting from January 01, 2020, R-22 has several replacements approved by the EPA due to their zero-ozone depleting potential including tens of them as listed by the EPA like R-404A, R-407B, R-407C, R-407F, R-410A, R-410B, etc. (2020).

Ideal substitutes for refrigerants that are free of all environmental and safety concerns, are chemically and thermally stable, and perform efficiently, are extremely unlikely to be found. As a result, trade-offs

among desired outcomes, will be necessary to achieve balanced solutions (Calm & Didion, 1998; Mota-Babiloni et al., 2016). For California to make progress with refrigerant emissions, progress will come with the state's EPA continued progress in regulation and monitoring, financial incentives to defray industry adoption costs of lower warming potential refrigerants, and education/training both for industry, and commercial/residential consumers.

Recycling/Waste Sectors

Reduction of emissions from energy consumption through recycling saves energy for less energy is needed to extract, transport, and process raw materials; and to manufacture products when people reuse things or when products are made with less material. The reduction of emissions from incinerators can be achieved by diverting certain materials from incinerators through waste prevention and recycling. Landfills emit CH₄ and waste prevention and recycling (including composting) divert organic wastes from landfills, reducing the amount of methane released.

As trees store carbon in wood (carbon sequestration), waste prevention and recycling of paper translates to leaving more trees standing in the forest. As noted by the EPA (2020), waste prevention and recycling in the US can make a significant contribution to reducing GHG gas emissions. The waste reduction and recycling initiative initiated and coordinated by the US EPA is expected to contribute at least 5% of the total greenhouse gas emission reductions. These can be enhanced by specific programs as follows: 1) *WasteWi\$e*, a voluntary partnership between EPA and US businesses, state and local governments, and institutions to prevent waste, recycle, and buy and manufacture products made with recycled materials. 2) *Pay-As-You-Throw* Program where the EPA provides technical and outreach assistance to encourage communities to implement pay-as-you-throw systems for solid waste. Residents are charged based on the amount of trash they discard creating an incentive for them to generate less trash and recycle more. Waste reductions of 15-28% have been reported in some communities with this program. 3) Developed with EPA support, the *EPA/Chicago Board of Trade Recyclables Exchange* is an online exchange that helps develop markets for recyclable commodities, thereby diverting more materials from the waste stream. 4) The EPA has also funded over 20 projects that demonstrate innovative waste reduction approaches with potential to achieve significant carbon emissions reductions (EPA, 2020).

Programs such as these launched by EPA and others have accrued climate benefits of waste management options in waste prevention, recycling, composting, incineration, and landfilling. The GHG emissions associated with managing ten types of waste materials (office paper, newspaper, corrugated cardboard, aluminum, steel, plastics, food scraps, and yard trimmings) were estimated. The study concluded that waste prevention is the best management option, with recycling the next best approach to reducing emissions. For example, the EPA estimates that increasing the country's national recycling rate from its current level (27%) to 35% reduces GHG emissions by 11.4 mmtCO₂e over landfilling the same material (EPA, 2020).

Practical Implications

California's policy-makers call for tightening California's low-carbon fuel standard, expanding programs to reduce methane emissions from dairy farms, increasing reforestation efforts, and lowering the amount of carbon that industry can release under the cap-and-trade program. The state needs to chaperone investments in modernizing the energy sector, boosting energy efficiency, and facilitating transitioning into a zero-carbon economy for older industrial systems. Some of the innovative strategies that can be implemented in California and have been proposed elsewhere particularly in European Union (EU, 2019) are:

- a) Promotion of a circular economy in California where material use is reduced, reused and recycled especially in resource intense sectors like electronics, textiles, construction and plastics.
- b) Decarbonization and modernization of California's energy-intensive industries especially in steel and cement production.
- c) Stimulation and development of new market avenues for the consumption of climate neutral and circular products, and green financing options.
- d) Promoting energy use efficiency, climate-proofing buildings, strict regulation of building energy use, and increased digitalization of provided services.
- e) Preservation of biodiversity in ecosystems, reduced or zero-pollution targets for industry, creation of toxic-free environments for citizens, and substantial reduction or total elimination of urban pollution by industry.
- f) Elimination of fossil fuel state and federal subsidies especially in the utilization of high emissions fuels by industry, and stricter pollution enforcement in the transportation sector. For example, zero tolerance of truck idling on truck stops, highways and in urban centers.
- g) Funding for research and development of innovative sustainable solutions, education and training in schools, mid-level educational, and higher educational institutions.

For California to meet its GHG emissions targets in 2030 and 2050, the current policy framework must be reviewed, adjusted, mandated and monitored. As shown in Tables 1 and 7, California must raise its current rate of emissions reductions (currently totaling 0.57 mmtCO₂e/year) six-and-half times (to 3.75 mmtCO₂e/year) by 2030; and by twenty-six-and-half times (to 15.08 mmtCO₂e/year) to meet the 2050 target. With the climate change effects already being experienced in the state projected to get worse in the decades ahead, many of the current and future innovative technologies and trends discussed above in the seven emissions sectors will be crucial in meeting these emissions cuts obligations. Busch and Orvis (2020) highlight a package of six policies that in addition to reducing GHG emissions, they will generate significant economic and health benefits. The first three policy recommendations strengthen existing policies (cap-and-trade, clean energy use, zero emissions vehicles); the next three are suggested (accelerating building electrification, zero emission performance standard for industrial

sector heating, and new emissions standards for cement and concrete production—since cement is the largest source of coal combustion in California).

Although California's ambitions must remain strong and optimistic to serve as a model for other states, and a testing ground for new policies and innovations, a number of emissions reductions challenges are projected in California in the years ahead. The 2018 wildfires are reported to have produced more than nine times greater emissions than were reduced across the entire state's economy between 2016 and 2017—with wildfires contributing more than the commercial, residential or agriculture sectors did in 2017. Recycling rates were also reported down in the state, and landfill emissions have been increasing since 2004 as commercial, and residential waste generation rises (Next 10, 2020). There are also uncertainties in the coming years especially at the national level. The Trump administration is currently preparing to take the final steps to pull the US out of the Paris Climate Agreement. A legal battle by the administration is also currently waiting to roll back California's emissions standards for new vehicles—despite the fact that cars and trucks make up about one-third of the GHG emissions in California.

California is the most populous state in the nation, has the largest economy in the nation (fifth largest economy in the world), and is second only to Texas in total energy consumption (USBEA, 2018). Despite not wanting to hurt the economy, California must continue with its commitment to make significant, steady and impactful progress in GHG emissions reductions in the years ahead in all the seven emissions sectors.

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