ENERGY, ENVIRONMENT, AND NATURAL RESOURCES

ACHIEVE A ZERO-CARBON ECOMONY IN 25 TO 30 YEARS WITH IMPROVED ENVIRONMENT QUALITY, ECONOMIC PROSPERITY, AND EQUITY

An In-Depth Analysis of the Facts, Origins and Trends of Energy, Environment, and Natural Resources in California

CALIFORNIA 100

VISION & STRATEGY FOR THE NEXT CENTURY

ABOUT CALIFORNIA 100

The California 100 Initiative envisions a future that is innovative, sustainable, and equitable for all. Our mission is to strengthen California's ability to collectively solve problems and shape our long-term future over the next 100 years.

California 100 is organized around 15 policy domains and driven by interrelated stages of work: research, policy innovation and engagement with Californians. California 100's work is guided by an expert and intergenerational Commission. Through various projects and activities, California 100 seeks to move California towards an aspirational vision—changing policies and practices, attitudes and mindsets, to inspire a more vibrant future.

This California 100 Report on Policies and Future Scenarios was produced as part of California 100's research stream of work, in partnership with 20 research institutions across the state. California 100 sponsored grants for data-driven and future-oriented research focused on understanding today and planning for tomorrow. This research, anchored in California 100's 15 core policy domains, forms the foundation for the initiative's subsequent work by considering how California has gotten to where it is and by exploring scenarios and policy alternatives for what California can become over the next 100 years.

The California 100 initiative is incubated through the University of California and Stanford.

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UC Berkeley, Goldman School,
Center for Environmental Public Policy (CEPP)

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The Center was established in 2001 due to growing student interest in environment, energy, and climate policy. The Center's research and publications have addressed a wide variety of challenges associated with climate change, clean energy, environmental justice, and the interactions between pollution control and the economy. CEPP's focus areas in recent years include: air pollution hotspot abatement in minority neighborhoods of Oakland; green public finance; transportation electrification; port and freight pollution; and, electric power sector decarbonization. The Center's staff, consultants, graduate student researchers, and partner organizations work to synthesize scientific, economic, technical, social, financial, and political information to advance policy reform. CEPP collaborates with scientists, community-based organizations, elected and appointed officials, industry representatives, academic leaders and students. The Center is directed by David Wooley, whose experience in government, philanthropy, law and industry help shape the Center's research agenda. Dan Kammen of UC Berkeley's Energy Resource Group serves as Faculty Advisor.

ENERGY, ENVIRONMENT, AND NATURAL RESOURCES

ACHIEVE A ZERO-CARBON ECONOMY IN 25 TO 30 YEARS WITH IMPROVED ENVIRONMENTAL QUALITY, ECONOMIC PROSPERITY, AND EQUITY

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EXECUTIVE SUMMARY

A prosperous and livable California depends on a stable climate and clean energy supplies - for transportation, buildings, water, industry, and agriculture. In the face of accelerating climate change, the state must transition its electricity, transportation and water systems, building stock, and industrial output to **zero-carbon technologies**. That transition has begun. California has established itself as a global leader in the critical task of reducing global greenhouse gas (GHG) emissions and is beginning to adapt to climate change. There are 30 to 50 years of work ahead to succeed. It will not be easy, but solutions are within our grasp to solve the climate crisis and produce very large employment and public health benefits.

While some elements of this transition were gradually laid over the past two decades, it is only in recent years that these efforts slightly bent the emissions curve downward. A sense of urgency about climate has risen in the face of the surging wildfire, flooding, drought, heat and storm events, not just here but across the U.S. and globally. The Intergovernmental Panel on Climate Change (IPCC) Report issued during the drafting of this paper reiterates in stark terms that there are only 10 to 20 years to deeply cut emissions and to avoid the worst impacts from climate change. There is also a growing urgency to adapt coastlines, farmland, water systems, and buildings to increased heat, sea level rise, drought, storm intensity, flooding and other effects of climate change. Similarly, California's Fourth Climate Change Assessment determined that a business-as-scenario usual will have significant negative economic repercussions for California's agriculture, tourism and health care sectors. (Bedsworth, Cayan, Franco, 2018).

Policy makers and the public in the U.S. are paying attention to climate change. Californians believe that climate change is real, caused in large part by human activity, and that clean energy investment can help (Marlon, Howe, Miltenberger, 2020). Polling in June 2020 by the Pew Center found that two-thirds of Americans think the government should do more to protect climate (Tyson and Kennedy 2020). Almost one-third of Americans live in counties declared a disaster **during the summer of 2021** by the Federal Emergency Management Authority (FEMA) from wildfire, flooding, heat-events, and hurricanes (Kaplan and Tran 2021).[1] According to the Washington Post:

[1] Nearly 1 in 3 Americans experienced a weather disaster the summer of 2021. Climate change has increased the severity of storms, fires, hurricanes, coastal storms and floods. https://www.washingtonpost.com/climate-environment/2021/09/04/climate-disaster-hurricane-ida/

Surveys show that concern about climate change has been steadily rising among Americans for the past decade. In a 2019 poll from The Washington Post-Kaiser Family Foundation, 63% of people who said their area had been affected by severe storms, droughts or extremely hot days identified climate change as a "major factor." A slightly smaller fraction, 54 percent, viewed climate change as a major contributor to wildfires in their area (Kaplan and Tran 2021).

It is also true, however, that a sense of optimism is warranted regarding our ability to dramatically reduce greenhouse gases and transition to a zero-carbon economy. Optimism is driven by many studies that confirm the economic and public health benefits. Zero-emission technologies such as solar and wind generation and electric cars and trucks were once thought too expensive to be practical. Now, these technologies often cost less than fossil-dependent engines and power plants. In a few years, these clean energy options and others will be much less expensive, even without counting health and environmental benefits. These changes will also bring important **equity** benefits. Electrification of trucking, port and freight operations will largely eliminate air pollution hot spots in minority communities.

It is the same with building systems. LED lights, heat pumps for heating and cooling, on-site renewables and battery storage improve building performance and lower costs. Other sectors of the economy, once thought "hard to decarbonize," have near- and mid-term options:

- low or zero carbon liquid and gaseous fuels are emerging and already in use for aviation (Skibell 2021); [2]
- ships and locomotives have options for battery, hydrogen and other alternatives to fossil fuels;
- industry can both reduce carbon emissions and sequester CO2 in products, geology and soil.

California is on the edge of a climate-driven reindustrialization. New markets and industries, built on the state's culture of **technology innovation** and research capacity, are here already in vehicle and battery manufacturing, low carbon fuels, water and energy efficiency, and renewable energy. Crisis is opportunity. Today, climate research, consumer sentiment, corporate responsibility, and youth activism animate an American can-do attitude about climate stabiliza

[2] In early September 2021 President Biden reached an agreement with major U.S. airlines to cut airplanes' GHG emissions 20% by 2030. This is part of a broader set of cross-agency actions to decarbonize the aviation sector — and the economy — by 2050. Transportation is the largest source of planet-warming pollution in the United States, and aviation makes up 11% of those emissions. The plan is to produce and deploy 3 billion gallons of sustainable aviation fuels (SAF) made from feedstocks which have lower life-cycle emissions than fossil jet fuel by 2030.

tion, driving changes in investment, procurement, [3] behavior, and government policy. The transition to a zero-carbon economy, however, requires a wide range of supportive policies on vehicle charging infrastructure, building decarbonization, financing, and electric power markets, carbon sequestration, industrial innovation and fuel production and use. (Rojas, Hiller, Maynihan, 2020).

Events in recent years remind us of the urgent need to address the **racial equity** issues and injustices that permeate U.S. society. **Equity issues** are everywhere, and are particularly evident in climate, energy and natural resource policy. Air pollution that plagues communities of color is often co-emitted with greenhouse gases (GHGs). Low-income communities in the U.S. and worldwide are often the first to suffer from climate change and least able to adapt to its effects. Workers displaced from fossil-based industries are often from low- or middle-income communities of color. Well-planned climate mitigation and adaptation can relieve these health and safety burdens and transition oilfield, refinery and auto maintenance workers to new, living wage employment. It's essential to prioritize climate investments to reduce community exposure to fossil fuel emissions, transition fossil industry workers and help the most vulnerable adapt to heat and flooding effects of climate change.

It is impossible to comprehensively address these topics in a single paper. We do not spend many words to convince readers of the need to act. Instead, we use this space to show where we have been and where we can go for solutions to climate change in **technology**, natural resources, and policy.

INTRODUCTION, CONTEXT & SCOPE

This paper was written during a period of unprecedented global attention to the problem of climate change and humanity's response to it. In August 2021 the IPCC issued its latest report, describing climate change as an urgent crisis and urging rapid action to reduce emissions. Record setting floods (Germany, China, Tennessee), heat events (Pacific Northwest of the U.S.), drought (Southwest U.S.), extreme cold (Texas), wildfires (Western U.S., Siberia, Southern Eu-

[3] The State of California currently has a Buy Clean requirement in place for key construction materials used in state funded infrastructure projects. See assembly bill (AB-137, Sections 23-25) signed into law on July 16, 2021.

rope) now beset virtually every region of the world. Society already feels the impacts of climate change, and failure to urgently reduce emissions will affect human well-being far into the future - likely for centuries (IPCC). The IPCC report was prepared for the November 2021 round of international negotiations on climate in Scotland.

Climate change is mostly addressed by interventions to reduce or capture GHG emissions (mitigation). This paper emphasizes that society must match mitigation with adaptation. This transition will be costly. In the energy sector alone, cost estimates for the U.S. are between $4.5 trillion and $5.7 trillion in 2030, or about a quarter of the U.S. debt (IER). In the electricity and transportation sectors, however, these costs are largely offset by avoided fossil fuel costs.

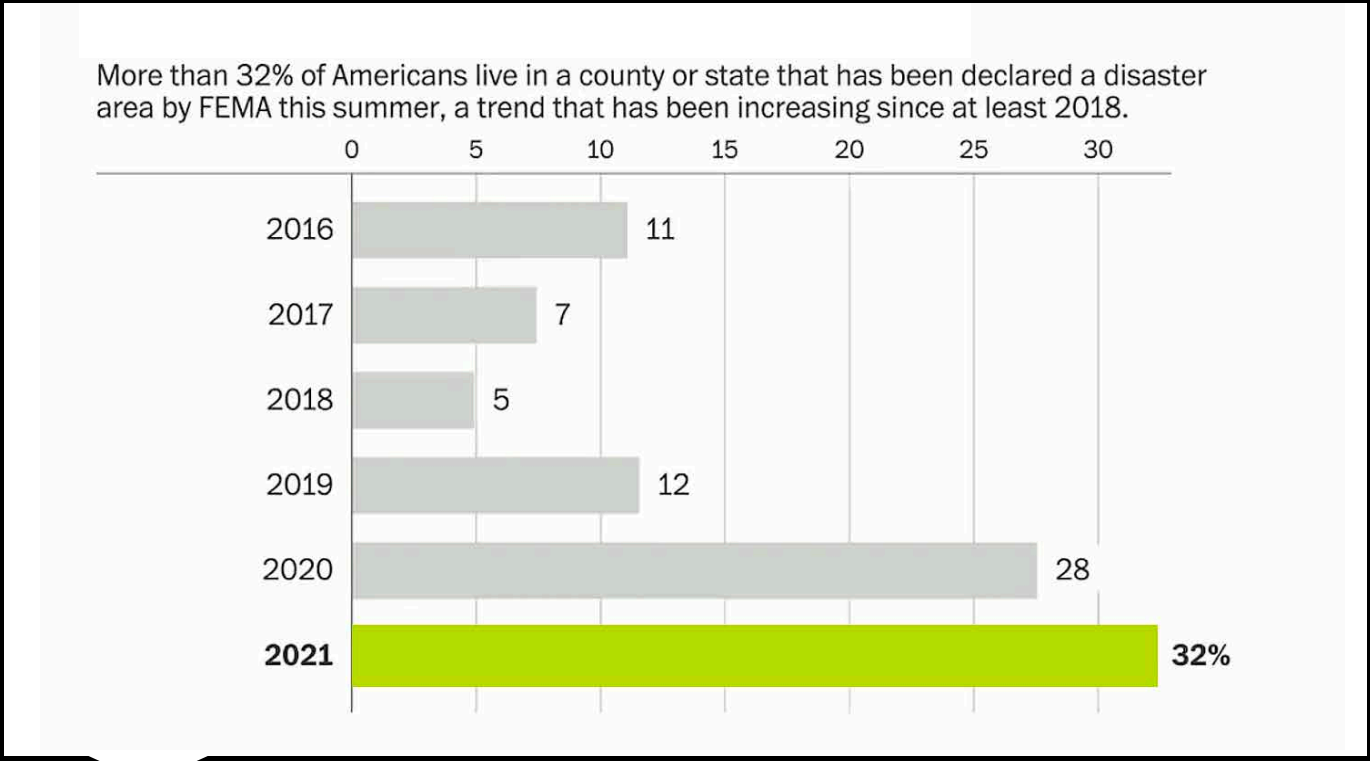
In August 2021, the U.S. Senate passed, with bipartisan support, an infrastructure bill that contains large new funding for climate mitigation and adaptation. The U.S. House of Representatives (House) is expected to approve a parallel bill in Fall 2021. The House passed and the Senate is working on a budget resolution that will further increase funding for climate mitigation and adaptation. Federal agencies are pursuing a wide range of policy reforms and budget reallocations. These include rules on climate risk disclosure for financial investment, GHG emission standards for methane sources, power plants, vehicles, and manufacturing. Corporations worldwide, including ones that once staunchly resisted action on climate, have set goals and invested to reduce their impact on climate and to adjust to the unavoidable risks. In California, massive wildfires and extreme drought drive new investment and policy changes to phase-in zero-emission cars and trucks, microgrids, water conservation, and building standards that encourage or require carbon-free equipment for homes and businesses.

This paper focuses on role of **technology** and policy to reduce GHG emissions and adapt to climate change, with particular emphasis on existing and **emerging technology** in:

- Electric Power
- Transportation
- Water
- Buildings
- Manufacturing
- Adaptation

Other important sectors, including waste, are beyond the scope of this report but should be considered in policy analysis. Although we do not focus on efforts to change behavior in this paper, it is clear that **technology** alone will not solve the problem and that people will need to

Figure 1 **More People Living in Designated Disaster Areas**



SOURCE: FEMA, Census, ANDREW BA TRAN / THE WASHINGTON POST

Nearly 1 in 3 Americans experienced a weather disaster the summer of 2021. The Washington Post. Available at: https://www.washingtonpost.com/climate-environment/2021/09/04/climate-disaster-hurricane-ida/

consume less, travel less and differently, conserve water, change diets, and other behavior patterns— either out of a sense of public service or because conditions increasingly force us to change the way we live.

This paper has clear overlap with other papers within the California 100 series. The objective is to complement the work of teams preparing papers on:

- Advanced technology and basic research
- Economic mobility, workforce, and inequality
- Health and wellness
- Housing & community development
- Transportation and urban planning

It is not possible in the time and page limitations of this project to comprehensively describe the challenges of climate changes to these interacting sectors of the California economy. We necessarily had to narrow this discussion to the most impactful and relatively well-developed options to reduce GHG emissions and adapt systems to climate change. Hence, we do not address a wide range of potential technologies and approaches that are on the distant horizon. But clearly, some of these will be important, and strong research funding from state and federal government and corporations will be important in the short and long term.

Our discussion of the agricultural sector is limited to changes needed to reduce GHG emissions and adapt to climate change concerning water supply and land use. Fisheries, ocean, and forests are important natural resources in California, but time did not allow us to address the climate implications for these resources. This is unfortunate since these sectors have important adaptation needs and present opportunities for zero-carbon energy supply and carbon sequestration.

The discussion below serves as a foundation for California 100's Report on Policies and Future Scenarios for Energy, Environment, and Natural Resources. It's important to note at the outset that a business-as-usual policy scenario is unquestionably catastrophic for future generations, and California's actions have the potential to sway other states and national governments. There is a long history of California leadership on pollution control, climate policy and scientific research, product development and commercial and market innovation. That **innovation** has positively influenced many other jurisdictions in the U.S. and internationally. In other words, it is critical for the state to get this right and find effective ways to export knowledge, thereby making climate mitigation and adaptation easier for many others globally (Kizer, Bushman 2019).[4]

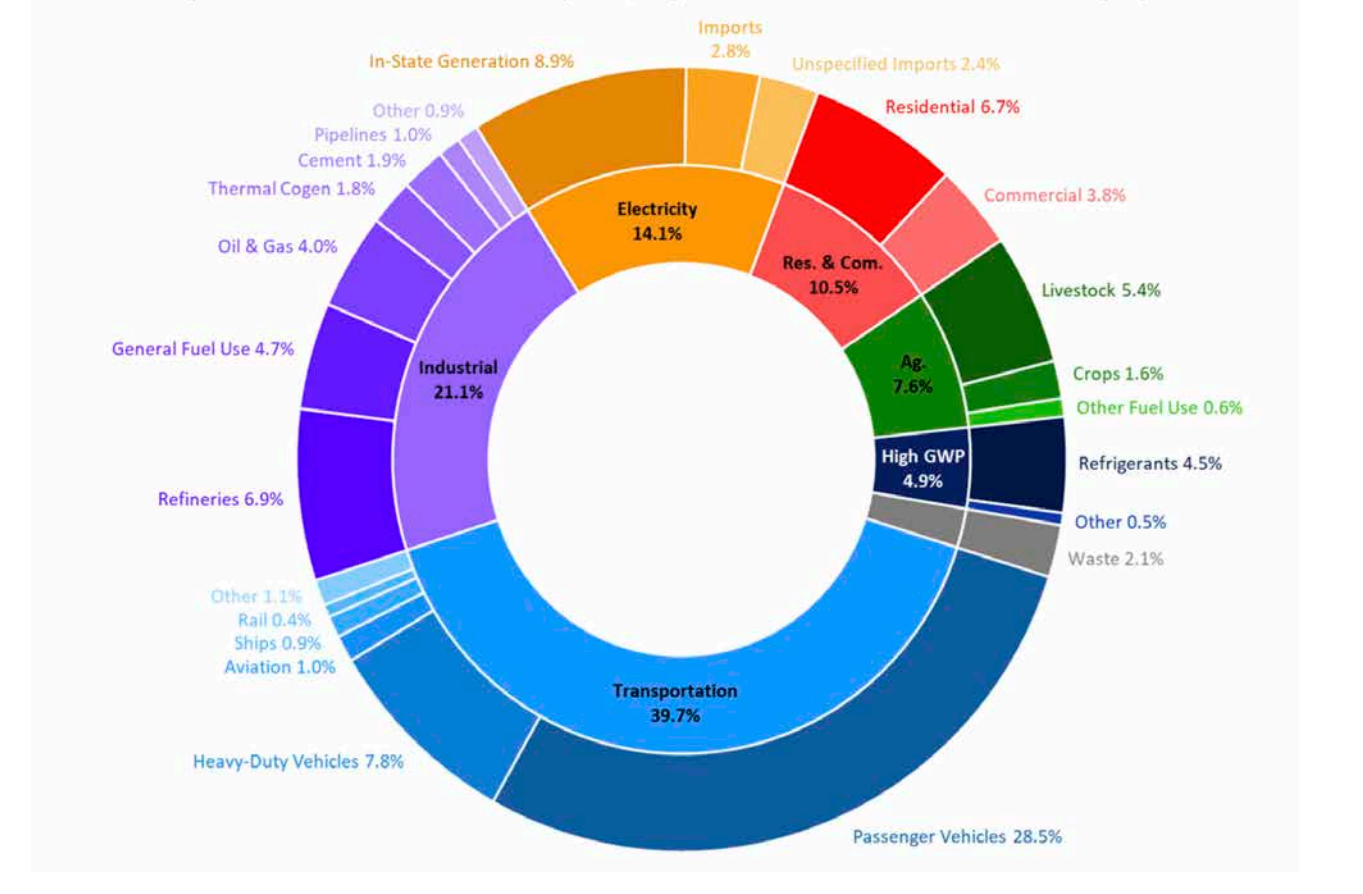
Where we have been, and where are we going with fossil fuels in California

It is a time of rapid change in the California energy sector. By the term "energy sector," we refer to several categories of energy production and use that are increasingly interactive: electric power, transportation, buildings, industry and water. Not long ago, road transport energy use was entirely separate from the energy used in the electric power sector and from energy use in buildings. Buildings were exclusively consumers of energy produced remotely and delivered by wires and pipelines.

[4] "California has robust energy innovation infrastructure including an active private sector, strong workforce, world-class research universities, four national laboratories, and major philanthropies that are aligned with the goals of decarbonization. It has multiple supportive state entities, including the California Energy Commission, the California Air Resources Board, and the California Public Utilities Commission."
Energy Futures Initiative, Optionality, Flexibility & Innovation: Pathways For Deep Decarbonization In California, page xxi.

These historic silos and one-dimensional energy flows are ending. Today's electricity system sharply overlaps with transportation, due to the advent of electric vehicles. Those vehicles will increasingly interact with building energy systems, receiving electric power from buildings to charge batteries and at times using the batteries to power the buildings. Buildings are no longer just served by remote electric power plants. A growing number of residential, commercial and industrial buildings produce electric power on-site with solar and send power back into the electric distribution system after meeting on-site loads. Electricity has powered lighting and appliances in buildings for over 100 years, but two-thirds of buildings in California use gas furnaces and water heaters. Today, electric heat pump technology is eroding the historically dominant role of fossil gas ("California State Profile and Energy Estimates 2021") for space heating and domestic water heating and has potential to largely eliminate use of gas in buildings.

Figure 2 **2019 GHG Emissions by Scoping Plan Sector and Sub-Sector Category**

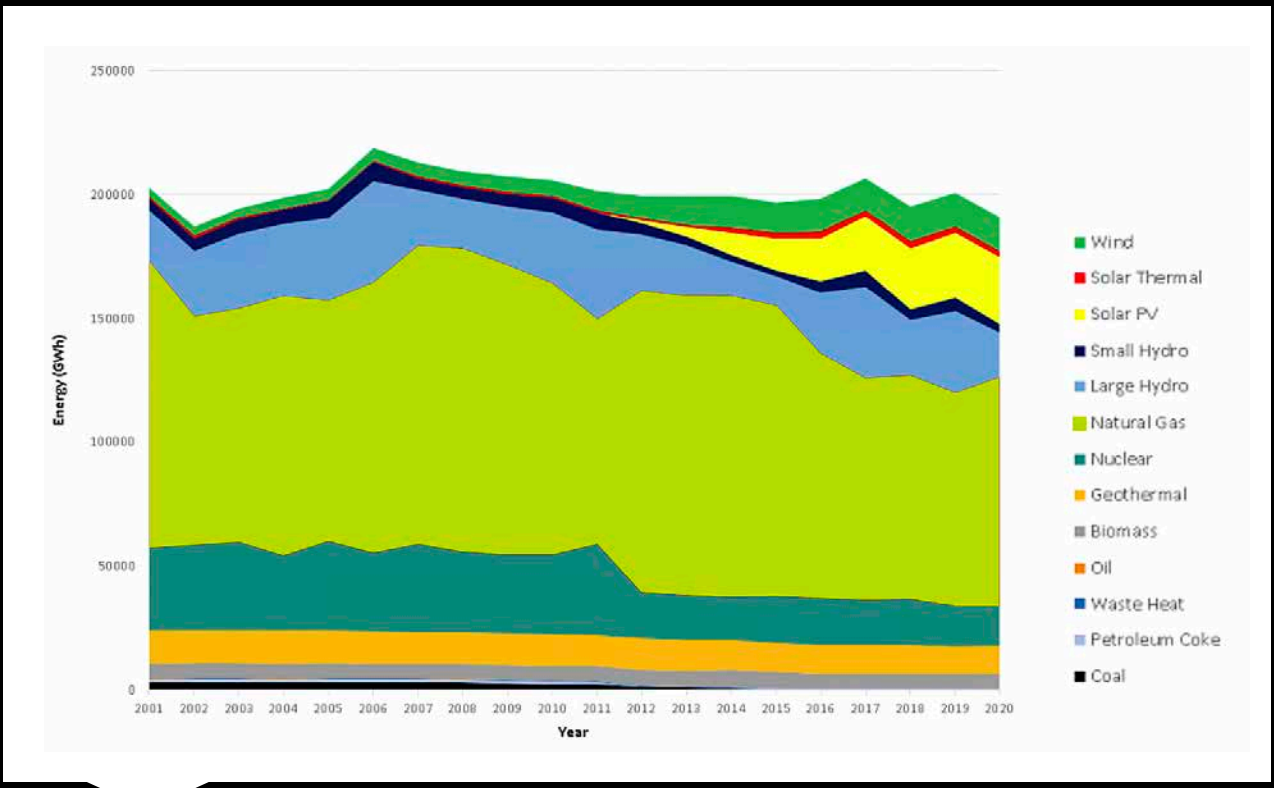


SOURCE: "California Greenhouse Gas Emissions for 2000 to 2019". California Air Resources Board. July, 2021.

This de-siloing also applies to water supply and wastewater systems. Largely powered by centralized, fossil fueled electricity production and transmission ("water-energy nexus"), water systems consume a large percentage of the electric power supply in California. Today, however, water supply and treatment are increasingly powered by distributed and utility-scale wind and solar generation, microgrids, water recycling and efficiency technologies. Wastewater systems have begun to interact with food waste management and irrigation. Methane recovered from water treatment can (via combustion turbines or fuel cells) power wastewater plants, nearby ports, and industrial plants; or be "steam reformed" into renewable hydrogen for industrial and transportation uses.

Change is not new to the California energy sector. Coal was historically a major source of electric power for California, often delivered as electricity via interstate power lines from distant coal plants. Today, coal power is a very small part of the electric supply mix in California and going to zero. It's been replaced by renewable energy and gas.

Figure 3 **In-State Electric Generation by Fuel Type**



SOURCE: "Electric Generation Capacity and Energy". California Energy Commission. 2019.

A similar fate faces California's oil industry. Petroleum was widely used as a power plant fuel until the 1970's oil crisis. Once the largest oil producing state, California still ranks 7th among U.S. states and has the third highest oil refining production nationally (Deschenes 2020).[5] Only about one-third of the crude oil refined in California comes from California, the rest is imported from Alaska and about a dozen other countries (Deschenes 2020). [6] California has the fifth largest share of crude oil reserves in the country, and the refining segment is the largest source of GHG emissions within California's industrial sector.

Despite a long-term decline of California crude oil production, transportation fuel production contributes 25% of the state's criteria air pollutants and toxic air contaminants from point sources and 11% of the state's GHG emissions. Activity from this sector is concentrated in a few counties where disadvantaged communities constitute a large share of the population. **Equity** considerations, related to employment opportunities and the health burden of pollution, will play a central role in any decarbonization. [7]

California's refineries produce—from both in-state and out-of-state crude sources—virtually all the refined crude-based transportation fuels consumed in the state (Deschenes and Deshmukh 2021). [8] California's transportation sector consumed 15.4 billion gallons (366 million barrels) of gasoline (including ethanol), 3.7 billion gallons (88 million barrels) of diesel, renewable diesel, and biodiesel, and 3.7 billion gallons (88 million barrels) of jet fuel. The state was ranked second among all U.S. states in total petroleum consumption and was the largest consumer of jet fuel.

[5] California's oil extraction has declined at an annual rate of 6.9 million barrels since its peak at 395 million barrels in 1985, when California was the third largest crude-oil producer in the U.S. By 2017, California's crude oil production ranked fourth among U.S. states, at 175 million barrels, and by 2019 it ranked seventh, at 156 million barrels. Since 2000, GHG emissions per barrel of oil extracted has risen by 30%, reflecting higher emissions associated with extracting oil from declining oil reservoirs, particularly through enhanced oil recovery methods that rely on fossil gas steam injection.

[6] Due to rapidly falling in-state crude extraction, California's refineries have increasingly turned to foreign imports of crude oil. In 2017, crude oil produced within California constituted only 31% of crude oil consumed by California refineries. In 2019, crude oil imported from foreign sources contributed 83% of all out-of-state crude to California refineries, and 58% of total crude consumed (56% of total crude consumed in 2017 or 355 million barrels). Saudi Arabia had the largest share in 2019 (26%), making up 13% of total crude oil supply to California's refineries. California refiners used about 11.3 million barrels of Russian crude in 2021. (LA Times, *California's high gas prices have a little-known ingredient: Russian oil*, March 9, 2022.)

[7] Emissions from transportation fuel supply industries are concentrated in a few areas in the state, and the percentage of disadvantaged communities tends to be higher in the five counties with the highest levels of criteria pollutant and toxic air contaminant (TAC) emissions from transportation fuel supply facilities.

Thirty-three percent of total fuel production by California refineries was exported to other states and nations from 2013–2017. (Karas 2020, 19% of gasoline and diesel). If in-state demand for refined petroleum products falls faster in California than elsewhere (due to vehicle electrification), California refiners may simply maintain production and increase exports. There is no policy currently in place to address GHG emissions from refineries. This is due to weaknesses in the offset provisions of the state's CO_2 cap and trade program and is one of the biggest gaps in state policy regarding GHG emission control.

The oil industry will have to change if the state moves toward a zero-carbon economy. Unless oil and fossil gas stay in the ground, earth temperatures will rise 4-5 degrees and make many areas of the planet uninhabitable by the end of this century. Solutions are coming. Electrified cars and trucks are, or shortly will be, much cheaper to operate than gas and diesel-fired internal combustion engines (ICE). Oil is about to lose its main market, and climate change policies will hurry its exit, particularly in California. [9]

The biggest problem with oil is not how to stop using it, but: 1) how to clean up the residual pollution from 120 years of drilling, spilling and refining; and, 2) how to put tens of thousands of workers from oil fields (Deschenes and Deshmukh 2021), [10] refineries, [11] and gas/diesel distribution (Deschenes 2021) [12] to work doing something else. There are 20 years of employment for oil field workers to plug all the wells (Boomhower 2018), clean up drilling sites, toxic waste dumps and contaminated ground water. Some refinery workers will keep jobs making carbon free liquid fuels. For the remainder, the replacement jobs must pay a living wage. The job losses in the industry will be gradual and so there is time to plan a fair transition for these workers; but planning is needed today to avoid adverse impacts, particularly in Central Valley communities.

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[8] California's transportation fossil fuels supply sector:

- contributed 0.89% of California's gross domestic product (GDP), or $25.24 billion in 2017.
- emitted 47 million metric tons of carbon dioxide equivalent (Mt of CO2e), 11.1% of the state total; 0.05 Mt of criteria air pollutants, 23% of the state total from point sources; and 0.002 Mt of toxic air pollutants, 26% of the state total from point sources.
  - GHG emissions from oil extraction contributed 17.2 Mt CO2e, 4.1% of the state total, and
  - GHG emissions from the refining segment contributed 29.8 Mt CO2e, 7.0% of the state total.
- employed 38,271 workers, 0.20% of the state total.

Due to its reliance on heavy crude, California's refineries emit 19% to 33% more GHGs per barrel of crude refined than refineries in other major refining areas in the US (2011 data). (Deschenes, Olivier, et al. Enhancing equity while eliminating emissions in California's supply of transportation fuels.)

[9] California regulations to phase out internal combustion engines in vehicles are already in play, though gaps remain. GHG emissions associated with gasoline and diesel exports need to be more effectively capped and gradually reduced, either through direct regulation or requirements to produce increasing amounts of zero and low carbon fuels.

Prioritizing vulnerable communities for both a just transition and immediate relief from health impacts resulting from proximity to fossil fuel emissions is essential.

Figure 4 **Marginal Cost of Operation - Comparison with Wholesale Electricity Price**

SOURCE: "Stranded Assets in Power Generation". California Carbon Info. September, 2021.

[10] Oil extraction directly supports close to 12,000 FTE job-years, an additional 11,405 FTE job years through indirect effects (including employment in non-contracted construction industry), and 9,618 through induced effects. In total, the extraction segment supported 31,320 FTE job-years in 2019. (Deschenes, Olivier et al, Enhancing equity while eliminating emissions in California's supply of transportation fuels, California Carbon Neutrality Study 2. page 58.)

[11] The refining industry directly supports 5,571 FTE job-years (2019). (Deschenes, Olivier et al, Enhancing Equity, page 59.)

[12] More than 60,000 workers are employed in gas stations in California.

Fossil gas (Seelye and Stockman 2018) [13] will have a similar fate as oil, though one that is more complicated. Fifteen to 20 percent of gas burned in California is used to produce oil, using steam injection into oil bearing geology. The fate of the two fuels is linked. Much of the gas consumed in California is produced from oil wells. Fossil gas' main market is as an electric power plant fuel. That market is projected to shrink in the near term due to competition from renewable generation and storage technologies which produce electricity at lower cost than gas power plants. [14] The Marginal Cost of Operation graph (above) shows that gas generation will not compete in wholesale markets by or before 2030, and will be used only (and compensated) for limited hours annually as reserve capacity or to meet Resource Adequacy requirements in California.

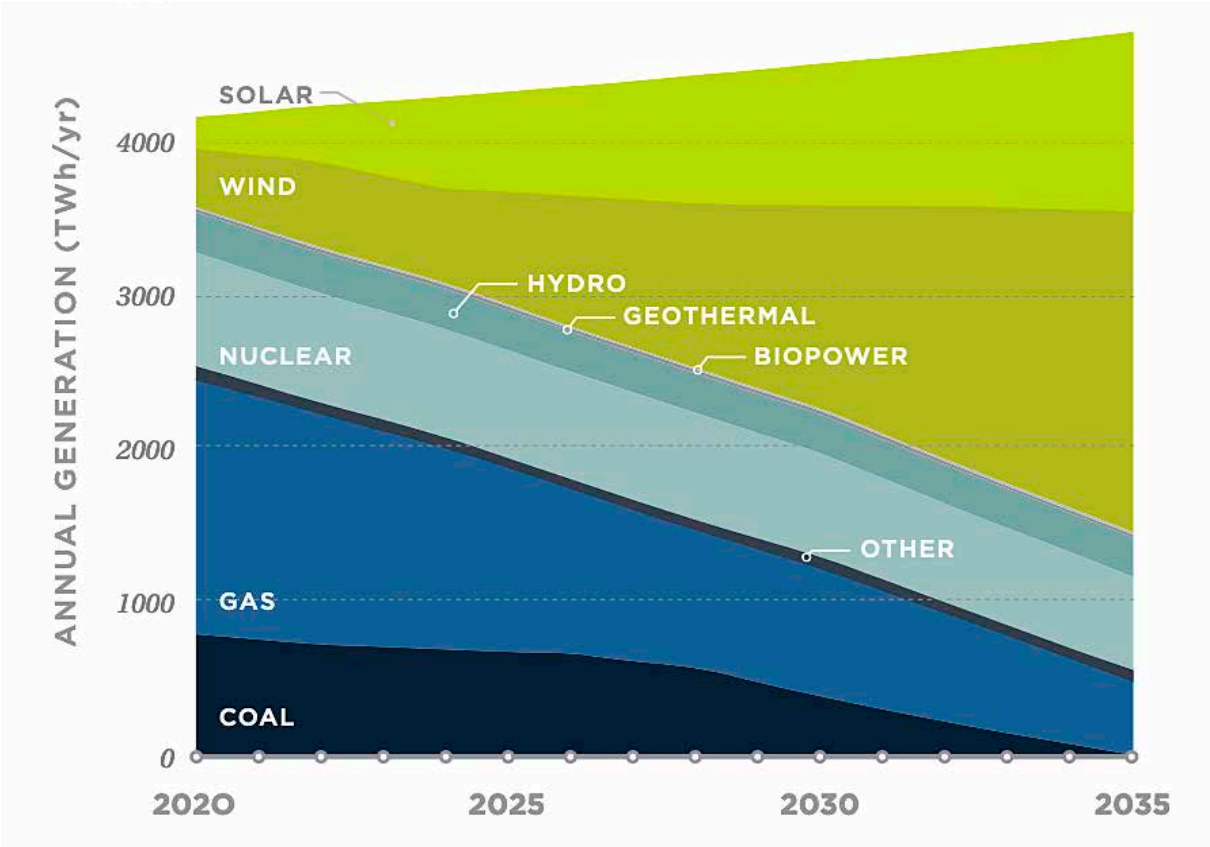
With proper policy support, renewables, battery storage and other forms of clean generation technologies will reduce gas in national electricity generation to about one-third of what it is today by 2035. In 15-25 years, the remaining gas will be phased out in favor of higher levels of renewable generation coupled with new forms of long duration storage (perhaps powered by hydrogen produced from electricity and water) and demand response. "Demand Response" refers to services and incentives that shift customers' electric power demand to match output of low-cost renewables, and away from peak demand periods, when fossil gas generation tends to operate.

The reduction in gas use in California is likely to be at least this steep and likely more so as battery and other storage technologies increasingly compete against gas as the marginal energy resource. Electrification of the transportation, building and industrial sectors helps cost-effectively decarbonize the power sector by lowering the seasonal variation in demand.

[13] We prefer to avoid the term "natural gas," as there is nothing natural about it. Gas is a highly refined product, which releases harmful pollutants when burned and it explodes. "Since 1998, at least 646 serious gas distribution episodes have occurred across the country, causing 221 deaths and leaving nearly a thousand people injured, according to data from the Pipeline and Hazardous Materials Safety Administration." www.nytimes.com.

[14] The figure embedded in text is from a PowerPoint presented in a California Carbon webinar on September 14, 2021, Stranded Asset in Power Generation across California's Carbon markets (Rocha and Jain 2021).

Figure 5 **Annual Generation | 90% Clean**



SOURCE: Phadke, E Amol; Umed Paliwal, Nikit Abhyankar, Taylor McNair, Ben Paulos, David Wooley, Ric O'Connell. "2035 Report: Plummeting Solar, Wind, And Battery Costs Can Accelerate Our Clean Electricity Future". Goldman School for Public Policy. June 2020.

The Annual Generation figure from *2035Report.com* describes a policy driven trajectory for reduced fossil fuel use in the U.S., that can be achieved with no increase in cost of electric service.

Gas use in buildings will also decline, as **electric heat pumps and induction technology** gradually replace existing gas furnaces, water heaters and stoves. Heat pumps are already far cheaper to install than gas infrastructure in new buildings and eliminate indoor air pollution and safety hazards (imagine the impact of a large earthquake on gas lines inside buildings and under streets). Heat pumps and induction stoves also have important economic benefits for existing building owners - particularly if the shift occurs when gas appliances reach end-of-life life.

In California, the transition away from fossil fuels in the electric sector is likely to be faster than the rest of the nation. About 90% of fossil gas consumed in California today is imported from other states. To meet state climate goals, the use of fossil fuels including fossil gas will need to decrease by 80% or more by 2050 (Aas et al 2020). That represents fewer consumer dollars going on a one-way trip down a gas or oil well somewhere else. There is an economic and environmental imperative to get rid of it in favor of zero-carbon replacements.

The big problem for gas is what to do about all the pipeline infrastructure and **equitably** cover transition costs. Maintenance of gas lines under the streets is expensive, but essential to prevent methane leaks and explosions. Ultimately California should shrink this infrastructure through strategic retirement of pipeline sections (e.g., those needing expensive repairs) and provide financial support to help customers convert to heat pumps and induction stoves. But as consumers gradually abandon gas systems some pipeline maintenance costs will not go down. This could cause the remaining customers (many of whom will be low-income) to bear rate increases. Hence, it is important to carefully plan gas distribution infrastructure shrinkage and address the stranded costs in a way that does not overburden low-income consumers. See discussion below in Subsection III, Buildings, for solutions to this problem.

Some argue in favor of repurposing gas distribution for renewable methane delivery. While this may have some marginal benefit in the short term, there is simply not enough feedstock capacity to support methane production at a scale to replace fossil gas. Moreover, those feedstocks are better used to produce aviation fuels and other energy needs that can't be powered with electricity.

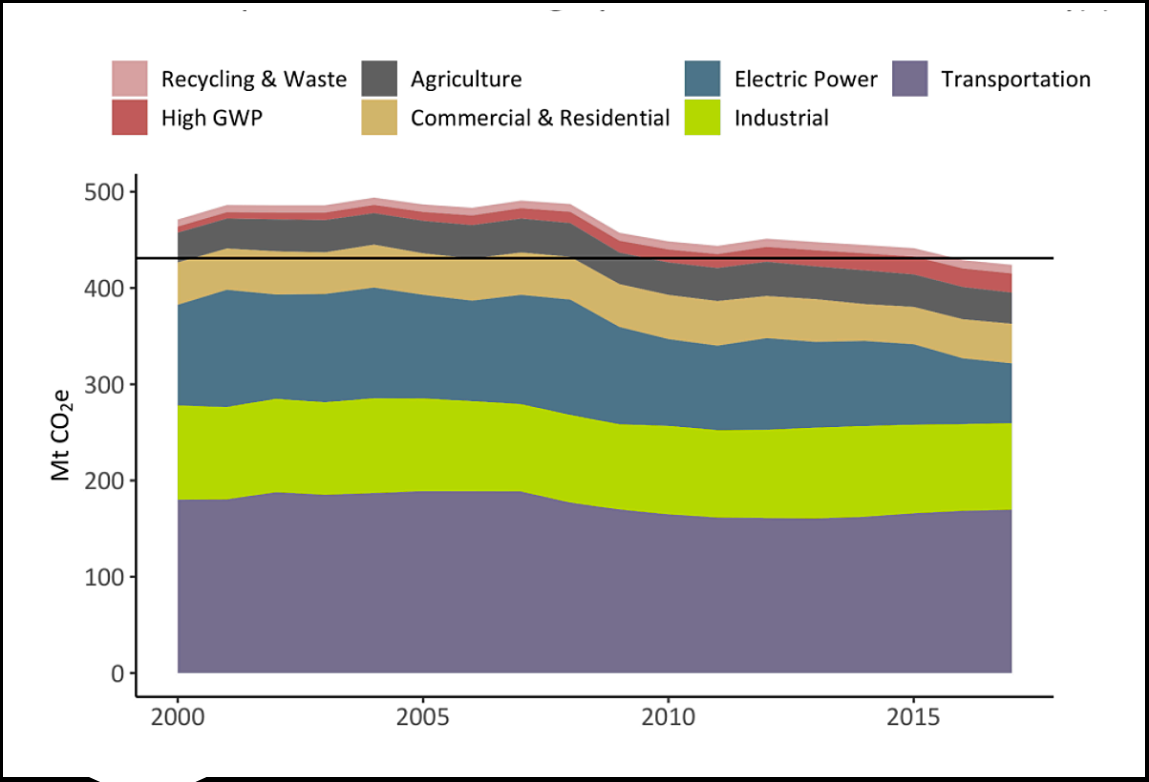
Some argue that fossil gas can be replaced by renewable hydrogen for use in passenger vehicles and buildings. This is highly unrealistic. Hydrogen can't be introduced into gas pipelines (beyond a few percentages of volume) because it will simply leak out of pipes designed to hold the much larger fossil gas molecules. It would be absurdly expensive to establish new pipelines to send hydrogen into buildings. Renewable hydrogen is too expensive to compete with electricity for cars. Renewable hydrogen clearly will have important markets, principally to replace fossil gas in industrial processes, and as a feedstock for aviation fuel. However, like renewable methane, the renewable hydrogen potential does not justify retaining expensive existing fossil gas infrastructure systems.

Can We Really Achieve a Net-Zero Carbon Economy in California? Yes, and at a profit. California has already achieved strong momentum toward a zero-carbon energy sector. We have achieved double digit reductions in the electric sector since 2006. This is partly a result of earlier clean energy policies, principally energy efficiency, building standards, appliance and equipment standards, R&D and early renewable energy subsidies, going back almost 30 years.

These policies halted growth in electric and gas demand and served as the foundation for later success driven by a suite of world class regulations, including:

- A cap on carbon emissions in electric power and heavy industries, accompanied by an emission allowance trading system that both puts a price on carbon (similar in effect to a carbon tax) and generates hundreds of millions of dollars for clean energy research, and market-based incentives for clean technologies;
- Progressively stricter vehicle emission standards, that recently include requirements for vehicle manufactures and fleet owners to sell increasing numbers of zero-emission vehicles;
- Methane emission controls on oil and gas production, and gas distribution systems;
- Renewable portfolio standards that require utilities to use progressively higher levels of wind, solar and other renewable generation.

Figure 6 **California GHG emissions**



NOTE: California GHG emissions in million metric tons CO_2 equivalent (Mt CO_2e) per year by sector from 2000 to 2019. California's 2020 GHG emissions target of 431 MtCO_2e, set by AB 32, is indicated by the horizontal black line. **SOURCE:** CARB Emissions Inventory.

The energy sector, however, is only part of the problem. On an economy wide basis, the effect of the state's climate and clean energy policies on GHG emission is, admittedly, very disappointing.

We have only reduced total GHG emissions by about 8-9% after trying hard to do so for 15 years. Nevertheless, there are several reasons why California is poised to accelerate decarbonization of the economy.

Figure 7 **Compares Annual Statewide GHG Emissions to the 2020 GHG Limit.**

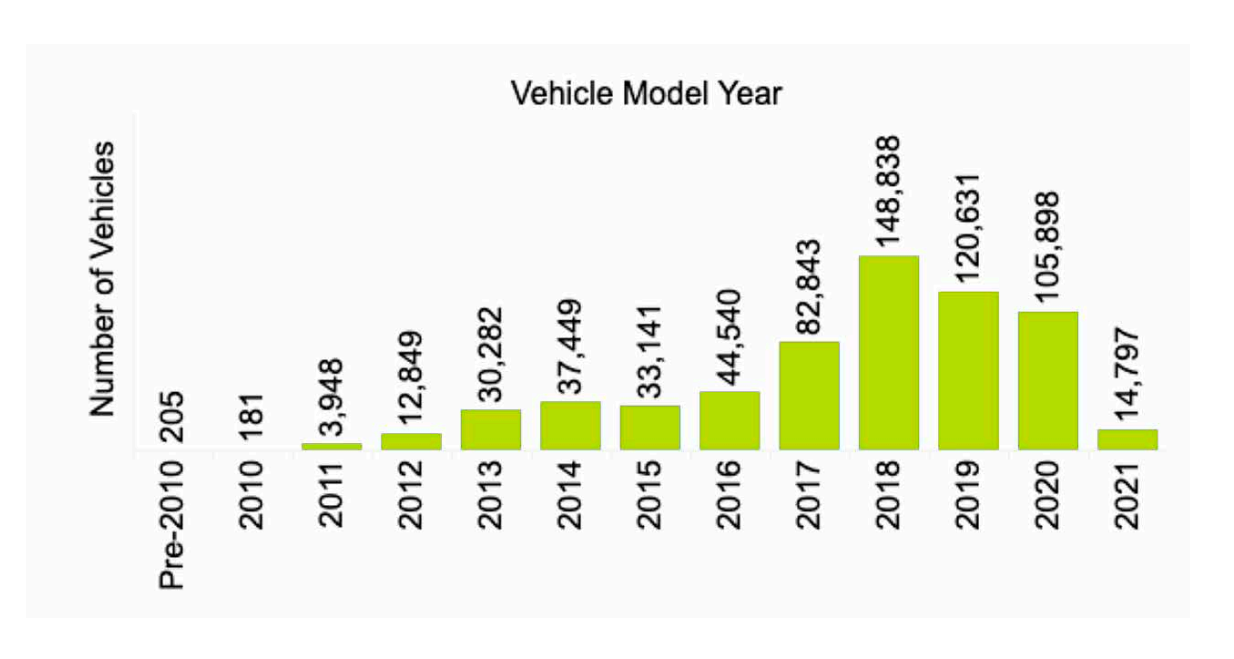
NOTE: This graph shows California's annual GHG emissions from 2000 to 2019 in relation to the 2020 GHG Limit required by the California Global Warming Solutions Act (Assembly Bill 32). In 2016, California's GHG emissions dropped below the 2020 GHG Limit and have remained below the 2020 GHG Limit since that time.

SOURCE: "California Greenhouse Gas Emissions for 2000 to 2019." California Air Resources Board. July, 2021

The transportation sector has until recently been hard to decarbonize. GHG emissions rose in recent years, when an increase in overall vehicle travel overwhelmed the effect of state vehicle

efficiency standards. But that was before electric passenger vehicles, which are now rapidly gaining market share. In 2021 over 250,000 new electric cars were sold in California (battery electric, plugin hybrid electric, and fuel cell electric).

Figure 8 **California Battery Electric Vehicle Sales**



SOURCE: "Zero Emission Vehicle and Infrastructure Statistics." California Energy Commission. Last Updated: April 30, 2021.

Progress in other hard to decarbonize sectors includes the following:

- Electric trucks are being manufactured in California and are gaining share worldwide in small and medium truck markets (Lowell and Culkin 2021). By 2025 electric, and potentially, hydrogen trucks will be competitive even for heavy duty and long-haul freight service.
- Fossil fuel use in aviation and shipping has been increasing for several years, overwhelming efficiency gains in aircraft and maritime engines and operations - but new international mandates and emerging technologies are creating a pathway toward zero emission flight and ocean voyage over the next 10-20 years.

- In buildings, **heat pump technology** is gaining market share due to its economic advantages, and modern state and local building code requirements.
- In industry, **new technology** is under development to achieve large emission reductions in cement, steel, refining, agriculture and chemical industries. Many of these **innovations** involve electrification, and new production processes that use renewable hydrogen.
- California has many emerging options to capture and sequester carbon emissions to offset past and present GHG emissions. Captured carbon can be sequestered in soils, forests and in products like cement, chemicals. It can be used to make zero-carbon aviation and shipping fuels.

In the following sections we go into more detail on how to make progress toward a zero-carbon in each of the major sectors of the California economy. **The objective is to eliminate net GHG emissions economy-wide by 2050, with deep reductions by 2030 and 2040, while maintaining prosperity and conserving natural resources.**

This report also discusses the need for adaptation to the impacts of climate change, particularly in relation to water resources. Cutting net carbon emissions to zero will limit, but not completely avoid, impacts driven by historic emissions. We are already seeing these impacts in the form of increased drought, storm, and heat intensity. The state needs to find a balance between climate mitigation (emissions control) and adaptation.

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SECTORS

I. ELECTRIC POWER & ROAD TRANSPORTATION

Main Takeaways:

- Decarbonizing the transport sector (heavy duty trucking and refining in particular) is the single most impactful action needed to improve environmental justice, equity and public health for communities of color in California.
- Electric power and road transportation are relatively easy sectors to decarbonize. They are the foundation for the economy-wide energy transformation needed to secure environmental and economic security for Californians.

- Electric power and road transportation can achieve zero carbon emissions by 2035-2040 with large net consumer savings and employment gains.
- Renewables, energy storage and energy efficiency are the primary drivers for decarbonizing the electric sector. Fossil gas does not help except as a limited back-up power source in the early stages of transition to zero emissions.
- Electric vehicles, including electric long-haul trucks, are the most cost-effective technology for decarbonizing the road transport compared with biofuels, fossil gas, and fuel cells.

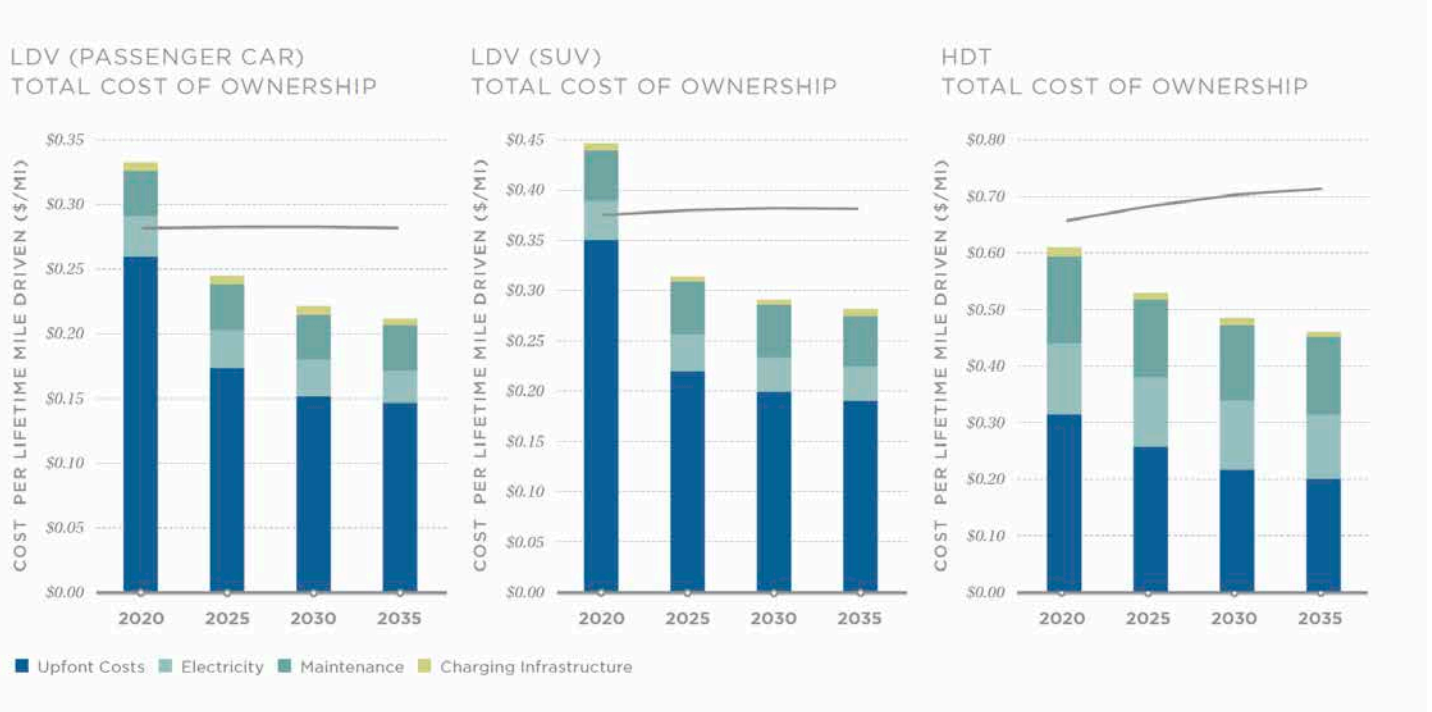
Sector Facts

When people or societies need to make a big change, it's always smart to start with the steps that pay for themselves. This section describes decarbonization potential for California's road transport and electricity supply sectors. We discuss them together here, since these sectors become highly interactive with each other in a transition to zero-carbon. In short, these sectors are relatively easy to decarbonize. There are also clear pathways to end fossil fuel use in aviation, ships, and rail, though these aspects of transport are not addressed in this report.

The fuel cost savings of moving away from gasoline and diesel engines in vehicles are enormous. A study by University of California, Berkeley in April of 2021 analyzed the national economic, human health, environmental, and electric grid impacts of a future in which ground transportation is all-electric (Phadke et al. 2021). Findings from the report include:

- Heavy duty electric trucks (HDT) already have a Total Cost of Ownership (TCO) advantage over diesel trucks, and light-duty EVs will overtake ICE vehicles in TCO terms within five years. In addition, light-duty EVs will reach upfront price parity with their ICE counterparts in the mid- to late-2020s, while electric HDT's will approach upfront price parity with diesel trucks in the mid- to late-2030s;
- Nationally, policies to electrify of cars and trucks yield cumulative economic savings of approximately $2.7 trillion through 2050 compared to a No New Policy scenario. This is equivalent to an average household savings of approximately $1,000 per year over the next 30 years;

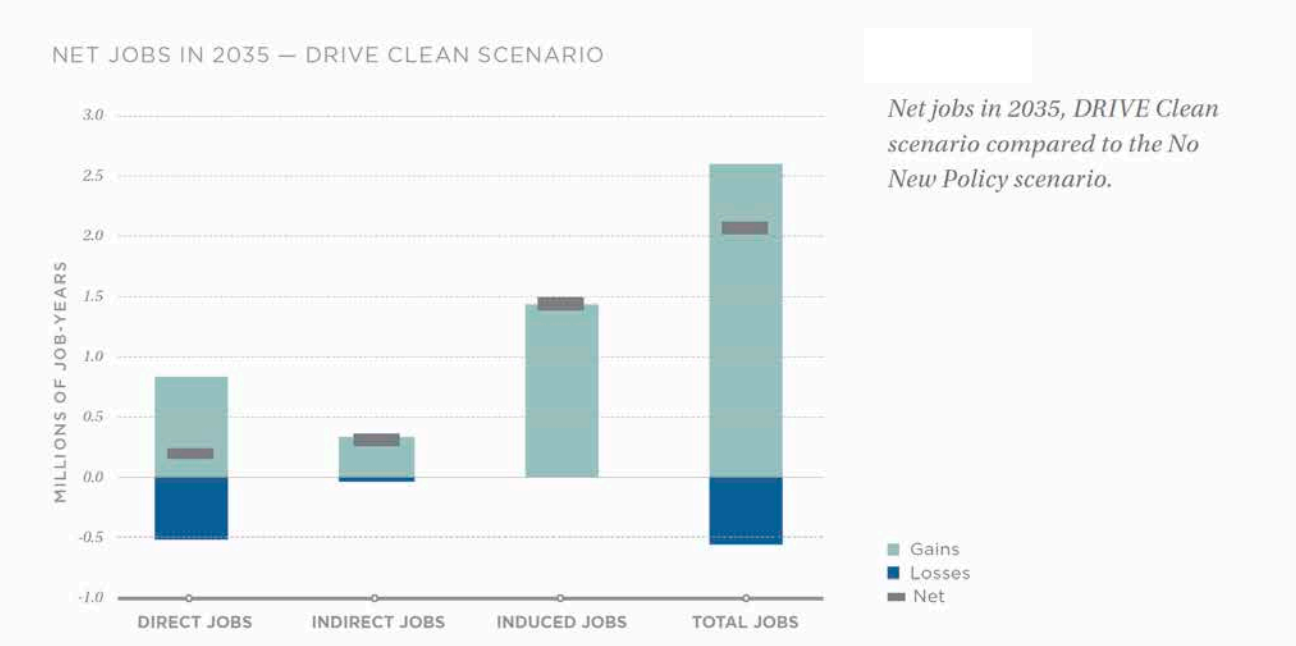
Figure 9 **TCO for EVs (bars) vs. ICE vehicles (lines), showing TCO parity achieved by 2023 for LDVs (left and center) and an existing TCO advantage for HDTs (right). Upfront costs include taxes. Maintenance cost of EVs include battery replacement costs.**



SOURCE: Phadke, Amol and Nikit Abhyankar. 2021. "Plummeting Costs and Dramatic Improvements In Batteries Can Accelerate Our Clean Transportation Future". April 2021.

- Electrification of transportation nationally would avoid approximately 150,000 premature deaths and produce nearly $1.3 trillion in health and environmental savings through 2050;
- U.S. ground transportation sector CO_2 emissions would fall by 60% in 2035 and by 93% in 2050, relative to 2020 levels. Total transportation sector emissions fall by 48% in 2035 and by 75% in 2050, relative to 2020 levels;
- Road transport electrification drives large increases in net employment as electric vehicle manufacturing expands and the electric grid adds new renewable energy and battery storage resources. The study estimates job gains from 2020 through 2035, peaking at over two million jobs in 2035. Consumer cost savings in the transition to electric vehicles similarly increases jobs in the economy;

Figure 10 **Net Jobs in 2035 — Drive Clean Scenario**



SOURCE: Phadke, Amol and Nikit Abhyankar. 2021. "Plummeting Costs And Dramatic Improvements In Batteries Can Accelerate Our Clean Transportation Future". April 2021.

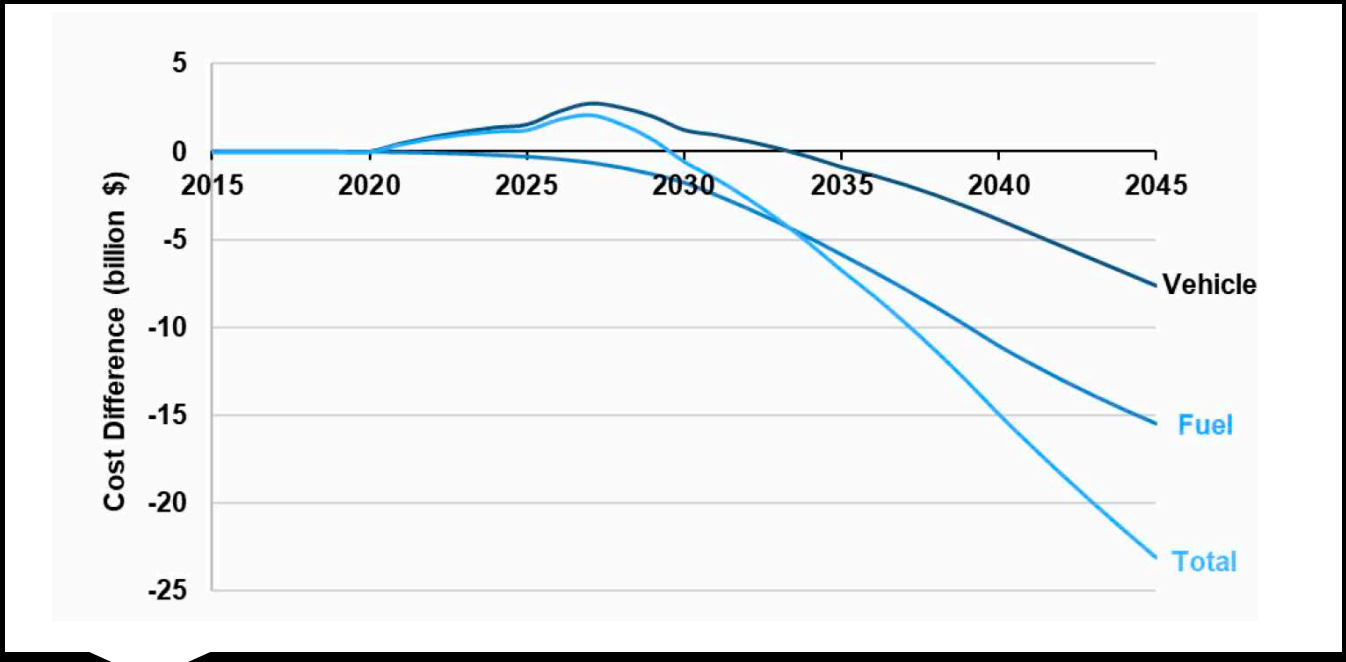
- Battery charging infrastructure can be built cost-effectively to serve a gradually growing population of electric cars and trucks;
- Global and domestic supply chains can satisfy accelerated EV and battery production;
- Electric grid impacts of electrified transport are manageable.

Achieving these results requires a set of national and state policy reforms involving vehicle standards and financial support for charging infrastructure. California has already adopted strong policies that will end sales of fossil fuel passenger vehicles and trucks by 2035, via Governor Newsom's Executive Order (N-79-20) for 100% ZEV sales by 2035. Other measures and rulings to require fleet and maritime port drayage truck conversion to zero-emission are underway as well. Additional goals set by the state include:

- A mandate that operations of medium- and heavy-duty vehicles shall be 100% zero-emission by 2045, and 2035 for drayage trucks;
- Framework for investor-owned utilities to spend low-carbon fuel standard credit revenues on charging infrastructures, pilots, and **resilience**, with a focus on environmental justice communities.
- The Advanced Clean Truck rule, adopted in June 2020, requires truck manufacturers to sell zero-emission trucks as an increasing percentage of their annual California sales from 2024 to 2030 and require 100% zero-emission new medium and heavy-duty truck sales by 2045.

A detailed study of road transport, commissioned by the State Legislature and completed in 2021 by UC Berkeley's Institute for Transportation Studies contains an estimate of cost savings from

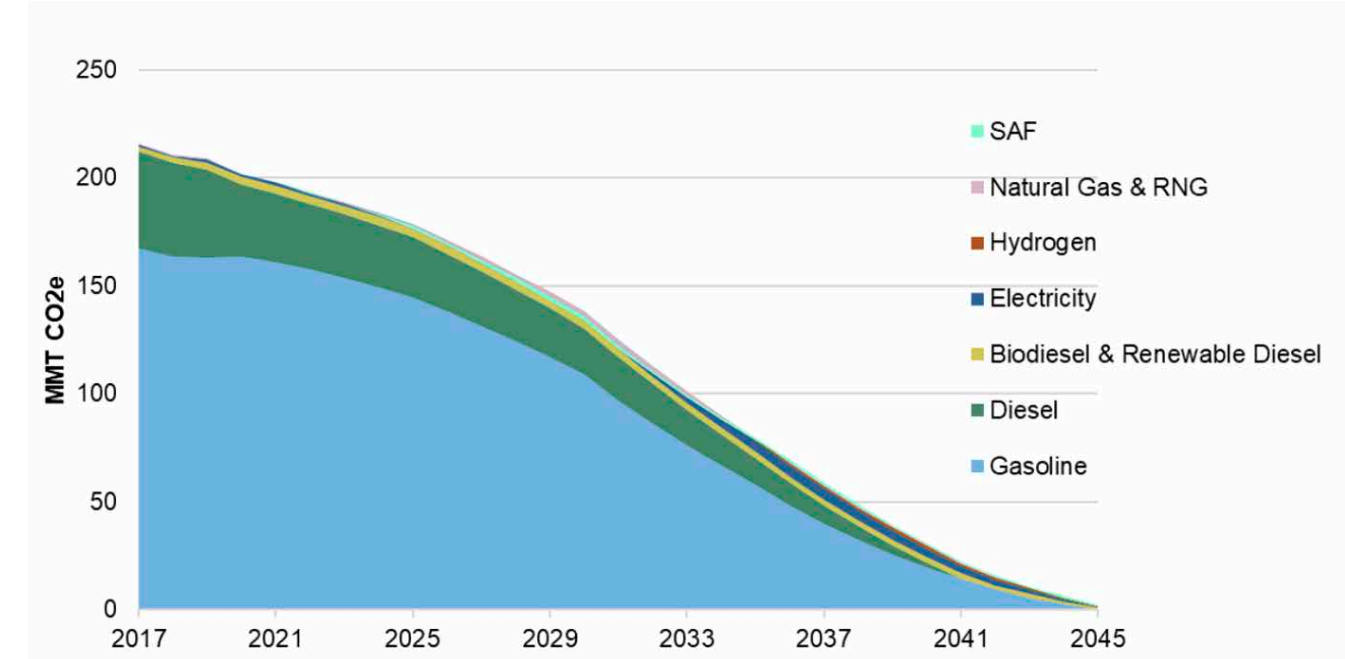
Figure 11 **Differences between the LC1 and BAU scenarios (i.e., LC1 minus BAU) in expenditures on vehicles and fuels. Higher vehicle purchase costs through 2030 result in a net high expenditure level of around $10B, but after 2030, ZEV vehicle savings on both purchase and fuel cost are lower than in the BAU, resulting in net cost savings of close to $177B from 2030 to 2045.**



SOURCE: Brown, A. L, Sperling, D., Austin, B., DeShazo, JR, Fulton, L., Lipman, T., et al. "Driving California's Transportation Emissions to Zero". 2021.

transportation electrification (Brown and Sperling 2021). The overall finding is that combined vehicle and fuel costs for the [Central Low Carbon] (LC1) scenario are higher over the first 10 years ($10 billion cumulative from 2020 to 2030), and thereafter lower due to the reduced costs for fuel and improved **vehicle technology** ($177 billion savings cumulative from 2031 to 2045, for a net of $167 billion, 2020 to 2045). In 2045, the single-year total costs are approximately $23 billion lower in the LC1 scenario. This report is less optimistic on near-term cost savings than the 2021 U.C. Berkeley report cited, but both show very large cost savings from vehicle decarbonization and forecast an end to fossil fuel vehicle sales and full decarbonization in about the same time frame.

Figure 12 **GHG emissions in the LC1 scenario. Life cycle CO2 is close to zero by 2045, with remaining emissions from biofuels, as H2 and electricity related emissions reach nearly zero. (RNG, renewable natural gas; SAF, sustainable aviation fuel).**



SOURCE: Brown, A. L, Sperling, D., Austin, B., DeShazo, JR, Fulton, L., Lipman, T., et al. "Driving California's Transportation Emissions to Zero". 2021.

Origins and Trends

Vehicle markets are changing quickly, partially in response to California's policy lead. For example, General Motors (GM) plans to exclusively offer electric vehicles by 2035, ending production of cars, trucks, and SUVs with diesel- and gasoline-powered engines (Wayland 2021). GM plans

to release 30 new EV models globally by 2025. Several other manufacturers have also made significant new investments in new EV production lines.[15]

Large amounts of public (federal and state) and private funding are already available to incentivize zero-emission vehicle purchases and finance charging infrastructure. However, we do not contend that this transition will be effortless or quick. California's road transport sector in 2021 was still 86% fueled by petroleum products. Much of the emission reductions will occur as existing vehicles gradually age-out over 10-15 years. Certainly, the build-out of a massive vehicle charging infrastructure will be difficult, and some new policy reforms are needed. The emission reductions forecast by UCB-ITS's low carbon scenario would require policies to:

- Increase the sales mandate on automakers on a pathway to rapidly move to 100% ZEV sales;
- Encourage consumers to buy ZEVs, with both monetary and non-monetary incentives, including the possible use of revenue-neutral feebates that encourage sales of ZEVs;
- Ensure that (subsidized) new and used electric vehicles are not leaving the state and that "used" gasoline and diesel vehicles are not being imported into California to circumvent ZEV policies;
- Incentivize charging at off-peak times;
- Favor the purchase and use of ZEVs by underserved individuals and overburdened communities;
- Policies to achieve a 15% reduction in per capita Light-duty vehicle (LDV) Vehicle miles Traveled (VMT) in 2045.

The state also needs policies and some technical research to establish systems of "managed charging," or charge management systems (CMS), to optimize the interaction between vehicle batteries and the electric grid and to reduce charging costs. Despite these existing gaps, California is well on the road to moving fossil fuel from vehicle transport.

There is a similar story regarding electric power decarbonization. Another study by UC Berkeley from June 2020, examined the costs and benefits of getting to a 90% reduction in GHG emissions from electric power generation nationally by 2035 (Phadke et al. 2021). Results from the study included:

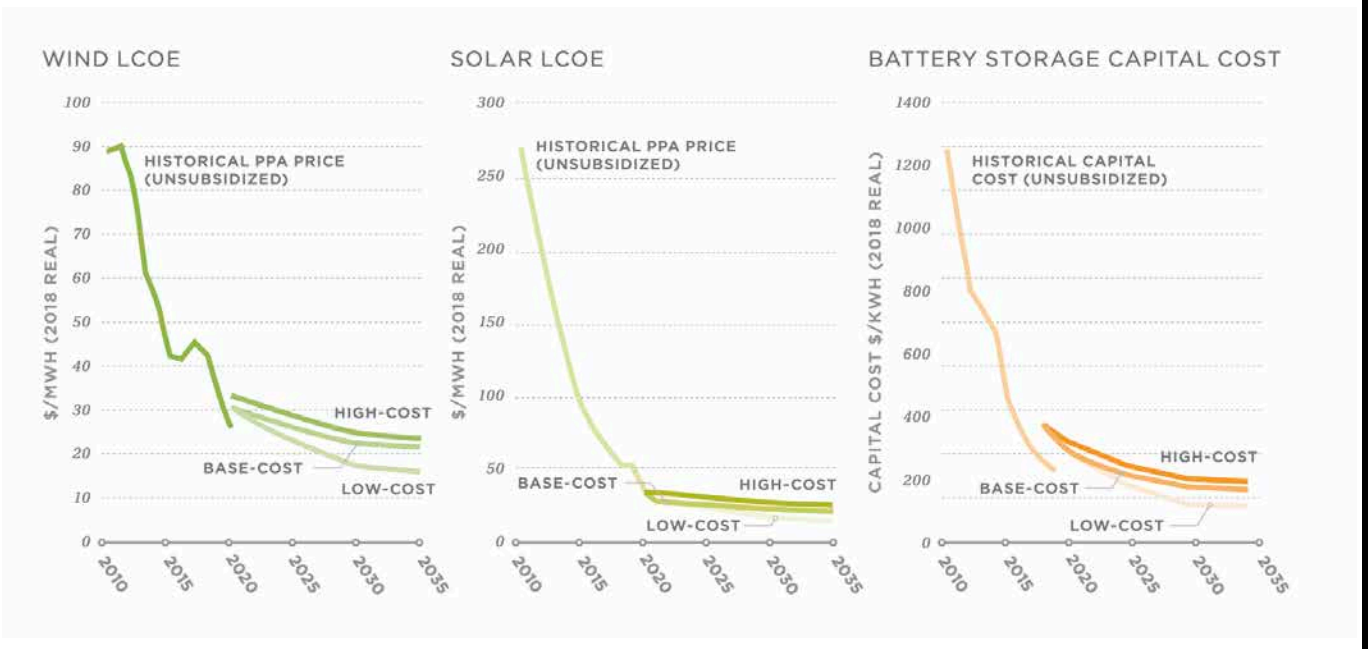
- Battery and renewable energy costs dropped very fast in recent years and dramatically changed the prospects for rapid, cost-effective expansion of renewable energy. At the same time, battery energy storage also dropped in price to become a viable option to integrate high levels of wind and solar generation into electricity grids;

[15] See, https://www.forbes.com/wheels/news/automaker-ev-plans/.

- A 90% carbon free electric generation sector is dependable without any coal plants or new fossil gas plants;
- Electricity cost from a 90% clean grid are lower than today's costs;
- A 90% clean grid would avoid $1.2 trillion In health and environmental damages, including 85,000 premature deaths, through 2050;
- It is feasible for the U.S. to expand renewables needed to achieve 90% clean electric power by 2035;
- A 90% clean electric grid would significantly increase energy sector employment.

Additionally, earlier studies projected deep decarbonization of electric power systems to be achievable by 2050—a timeline that would also hinder decarbonization of the buildings, industrial, and transportation sectors and fail to avoid catastrophic impacts of climate.

Figure 13 **Historic and Projected Wind and Solar Generation (Leveled Cost of Energy) and Battery Capital Costs**



SOURCE: Phadke, Amol and Nikit Abhyankar. 2021. "Plummeting Costs and Dramatic Improvements In Batteries Can Accelerate Our Clean Transportation Future". April 2021.

As was the case with road transport, significant new policy reforms would be needed to achieve decarbonization nationally, but California has already adopted most of the policies needed to decarbonize its electric power supply. The California Energy Commission SB-100 Joint Agency Report found that getting to 100% renewable and zero-carbon energy would have tremendous health benefits, namely through the reduction in criteria air pollution including ozone and particulate matters. It also presents opportunities for investing in local resilience and reliability amidst a changing climate, advancing equity through affordability of energy for vulnerable populations, and investing in high-quality jobs and careers in the clean energy industry.

SB 100 (de Leon, 2018) and predecessor bill SB 350 (de Leon, 2015) set California's commitment to procuring 60% of all electricity from renewable sources by 2030 and 100% from carbon-free sources by 2045. These bills are driving power sector decarbonization alongside companion policy, such as SB 32 (Pavely, 2016) and AB 32 (Nunez, 2006) for statewide GHG reduction goals, California's Cap-and-Trade Program, the state's Renewable Portfolio Standard that targets 60% renewable energy procurement by 2030, the GHG Reduction Fund, and more.

There are additional policy and implementation steps needed to get fossil fuel and GHG emissions out of the electricity mix. Some steps California still needs to take include:

- Developing more renewable generation capacity, building on California's existing base;
- Securing long-term seasonal storage resources. A hydrogen production, storage and generation complex in Utah is being planned by California's largest municipal utility (LADWP) and other smaller scale projects are in play within the state;
- Reinforcing transmission infrastructure;
- Optimizing access and use of regional hydro power capacity;
- Reforming policy and price incentives to radically expand Demand Response services that shift load away from peak hours;
- Expanding distributed renewable generation and storage along with microgrids to relieve pressure on grids and improve **resilience**.

Road transport and electricity generation are 56% of California's GHG inventory. While there are important financing and implementation steps ahead to decarbonize these sectors, California is well-positioned to cut its GHG emission by more than half just from these two sectors, by 2035-2040. Moreover, a large part of the California's industrial emissions is from refineries. When the transport sector is electrified, industrial emissions would decline significantly.

Do we need hydrogen or renewable liquid fuels (e.g., biodiesel, renewable diesel) to achieve this? The simple answer is no with several exceptions. Hybrid engines, fossil gas and fuel cell vehicles powered by hydrogen derived from fossil gas will not achieve large reductions compared to existing gasoline and diesel engines. There is an insufficient supply of very low-GHG biofuels, biogas, and e-fuels to decarbonize ICE vehicles (Bieker 2021). Energy losses associated with converting electricity to renewable hydrogen (RH2) and from RH2 to heat or electricity make it unlikely for wide scale use in transportation. Hydrogen is not cost effective for decarbonizing buildings (Saadat 2021), principally because it is hard to deliver it into buildings and because heat pumps are a low-cost way to replace gas use in buildings.

Nevertheless, it is important to gain experience with the hydrogen fuel cycle. Hydrogen does have a role to play in decarbonizing high-carbon manufacturing: metals, fertilizer, aviation fuels (RH2+CO2). Second, there are uncertainties in battery raw material supply and cost, some of which are supplied from other countries that are not predictably stable suppliers for the large increase in supply to meet vehicle battery demand. The chemistry used for vehicle batteries is rapidly evolving and may solve these supply issues, but it is difficult to predict the future of international trade. Renewable hydrogen may be competitive for some long-haul trucking, locomotives and transoceanic ships, though several barriers need to be overcome, including cost reductions in hydrogen transport, storage and refueling infrastructure.

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II. INDUSTRY & MANUFACTURING

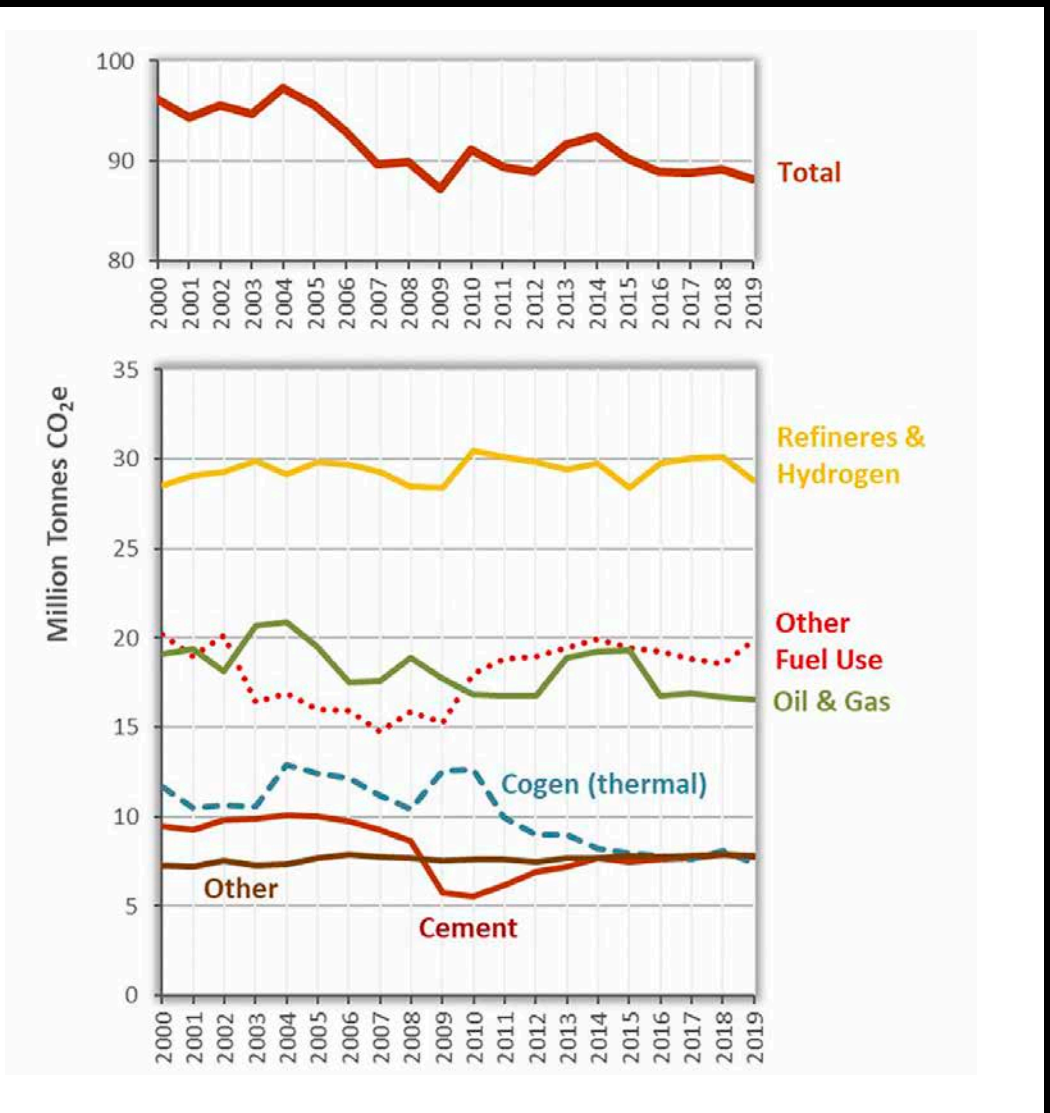
Main Takeaways

- Re-industrialization of California has begun in response to policies to decarbonize electric power and transportation and could spread to other industrial sectors. State and private investment is needed to seed new low carbon industries in CA, particularly with regard to renewable hydrogen feedstocks.
- Industry presents opportunities to reduce GHG emissions, and sequester the remaining emissions in products, soils, plants and in geologic formations. This will boost the state economy through new **technology** and markets.
- Numerous economic benefits would follow from industrial decarbonization including: reduced reliance on imported fuels and materials; jobs in California from production of zero carbon products or raw materials that are currently imported.
- Potential for carbon sequestration in soils is huge, and would have side benefits of improved agricultural productivity, rehabilitation of degraded farmlands, and increased or stabilized agricultural employment.
- The state should financially support carbon-capture-sequestration-hydrogen-hubs (CCSH) to attract industries that produce or use hydrogen in industrial processes and can supply captured CO2 in a form ready for geologic sequestration. Hub would also attract research and manufacturing of products produced from CO2 recycled from the atmosphere or emissions, and production of green hydrogen for zero carbon fuels (Global CCS Institute 2016).

Sector Facts

Manufacturing industries are responsible for a high percentage of GHG emissions globally, nationally and in California. Direct emissions are divided between process-related and energy-related emissions, while indirect emissions are those associated with external (grid) electricity and heat generation. The world emits about 43 billion gigatons (Gt/yr) of CO2 annually (2019) from all human activities, including agriculture and land use (The World Counts 2021).

Figure 14 **California Industrial CO2 Emissions 2019**



SOURCE: California Air Resources Board, *Greenhouse Gas Emissions 2000-2019, Trends of Emissions and Other indicators*, July 28, 2021.

Figure 15 California Manufacturing Output, in Billions of Dollars, 2008-2018

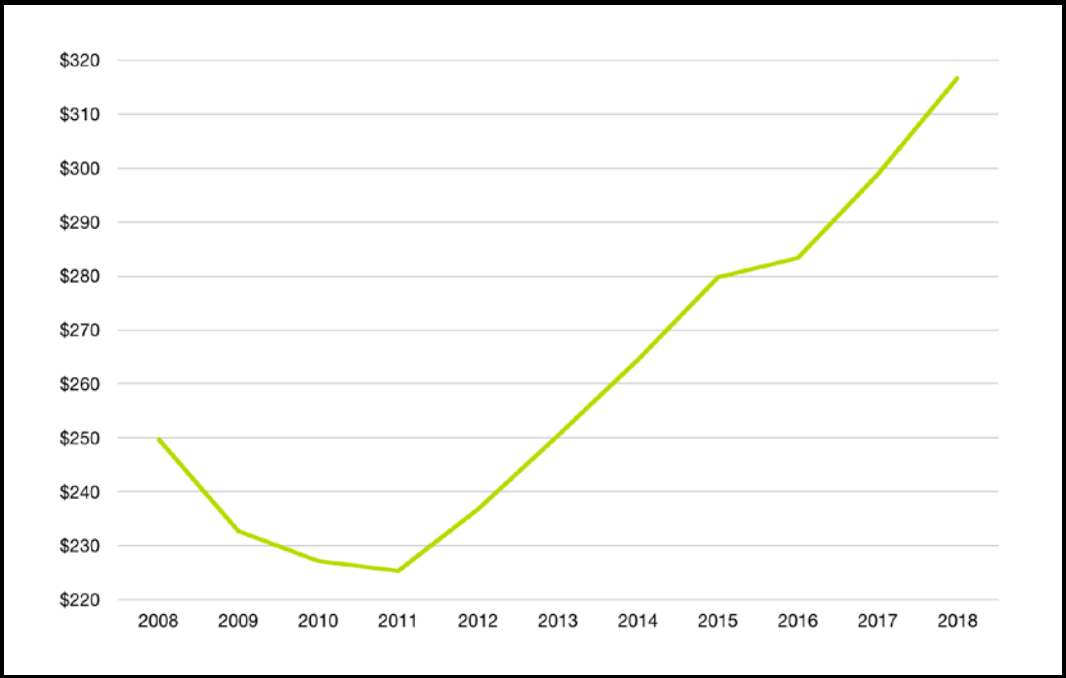
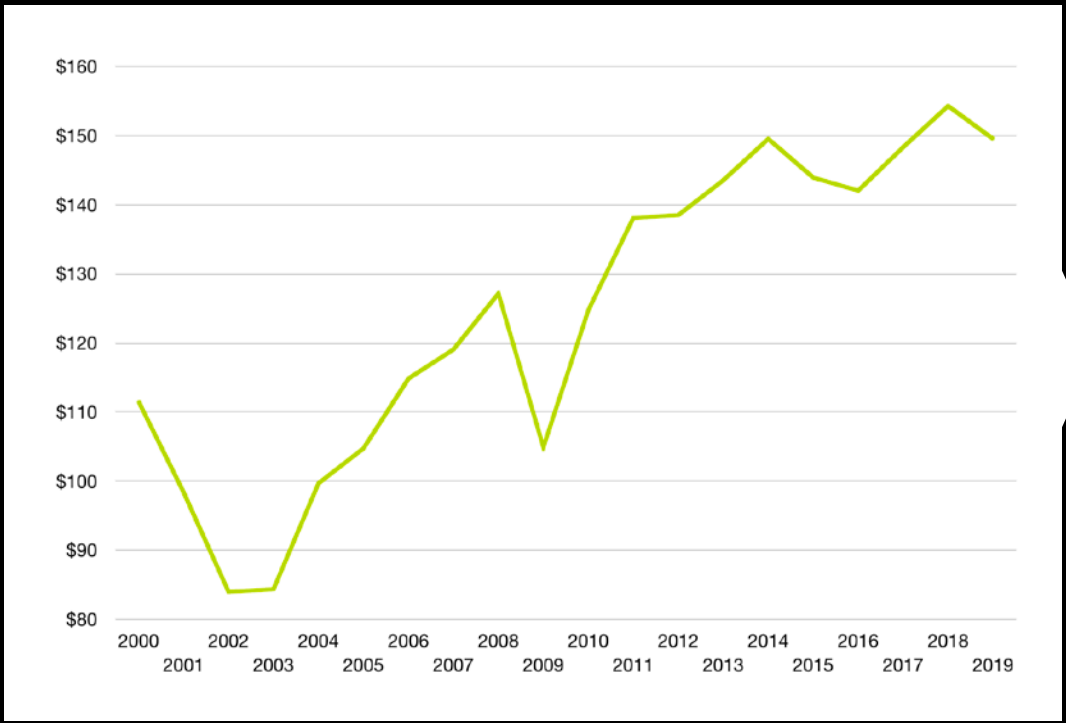


Figure 16 California Manufactured Goods Exports, in Billions of Dollars, 2000-2019

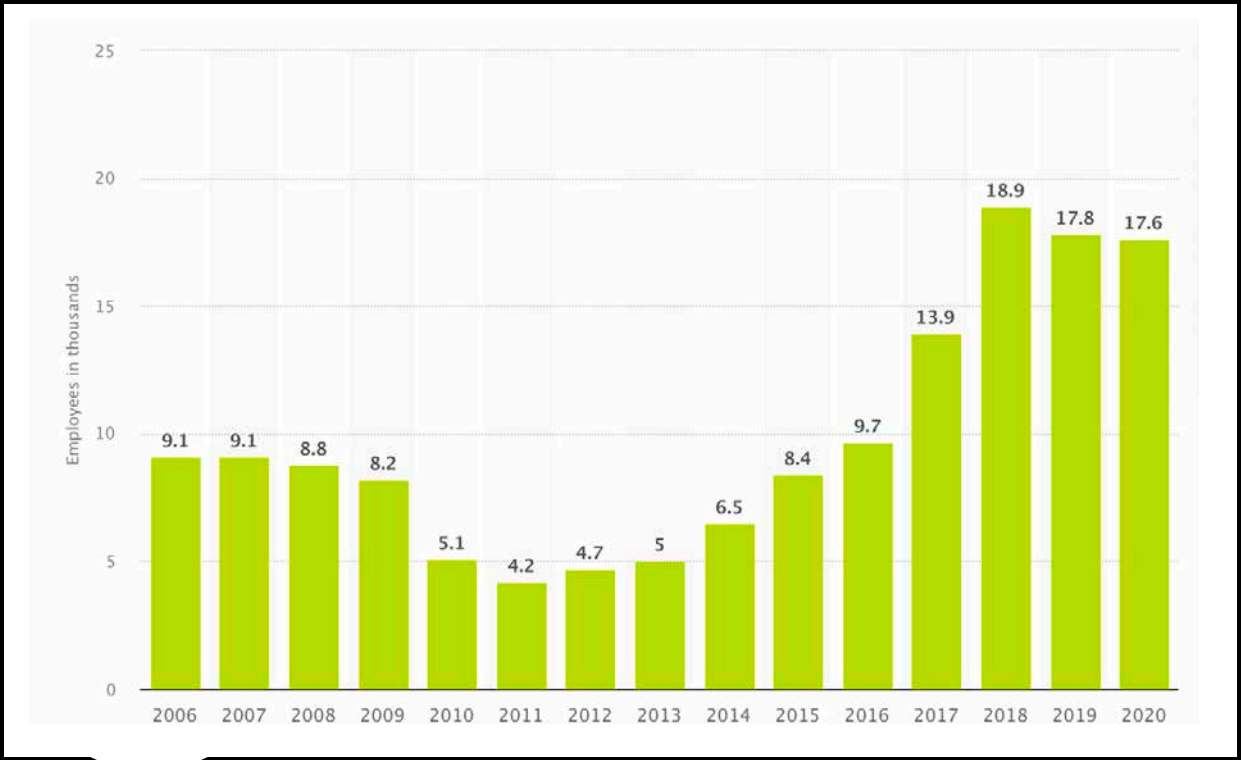


SOURCE:
National Association of Manufacturers, 2020 California Manufacturing Facts.

https://www.nam.org/state-manufacturing-data/2020-california-manufacturing-facts/

Although manufacturing has declined in California since the 1990s, the state still ranks among the states with the highest manufacturing base and production (Girardi-Schachter 2019). [17] California hosts 13% of the total manufacturing firms in the U.S. (Gregg Profozich 2020). Manufacturing in California is growing, particularly in relation to clean energy elements of the industrial base (E2). [18]

Figure 17 **"Average number of employees in motor vehicle manufacturing in California from 2006 to 2020".**



SOURCE: Statista, August 2021.

NOTE: This figure shows the average number of employees in motor vehicle manufacturing in California from 2006 to 2020 (in 1,000s).

[17] California consistently ranks among the top 10 states for manufacturing in the U.S. www.globaltrademag.com. "California is the state with the largest manufacturing economy in an absolute sense, as it alone accounted for 13.4 % of all compensation earned by manufacturing workers and 11% of all U.S. manufacturing jobs in 2010." www.nist.gov. Manufacturers in California account for 10.67% of the total output in the state, employing 7.66% of the workforce. Total output from manufacturing was $316.76 billion in 2018. In addition, there were an average of 1,338,000 manufacturing employees in California in 2019, with an average annual compensation of $109,875.79 in 2018. www.nam.org

[18] Entering 2020, California's clean energy economy had grown for five straight years with clean energy jobs growing to make up 3% of the state's entire workforce. Clean energy employs nearly six times as many workers as work in fossil fuel extraction and generation. Median hourly wages for clean energy jobs also are about 29% higher than the statewide median wage. In 2020, electrical vehicles (EV) were the state's most valuable export, producing nearly $5.7 billion in revenue, eclipsing California's venerable aerospace industry for the first time. Clean energy jobs are one of the most geographically diverse employment sectors, with employment in all 58 California counties. E2, Clean Jobs California. August 2020.

> "With more manufacturing jobs than any other state, California has a diverse manufacturing base. Its innovation ecosystem, positions the state well to take advantage of a resurgent interest in domestic manufacturing. This is especially true for **advanced technology** products and those that depend on custom design and rapid response to markets" (Bay Area Council, Economic Institute).

It will not be possible to achieve a zero-carbon economy in California without large net GHG emission reductions in the manufacturing sector. While industry is typically described as a hard to decarbonize sector, new technologies are emerging that could reduce and ultimately eliminate GHG emissions in manufacturing. Solid progress toward this future is already happening through decarbonization of the electric sector.

> "Industrial decarbonization is a daunting challenge given the relative lack of low-carbon options available for "hard to decarbonize" industries such as iron and steel, cement, and chemicals. Hydrogen, however, offers one potential solution to this dilemma given that it is an abundant and energy dense fuel capable … as either feedstock or fuel for the manufacture of products, such as steel, cement and chemicals." (Griffiths, et al. 2021.)

For hydrogen-dependent industrial activities (i.e., hydrogen is used in oil refining and chemical production), decarbonizing hydrogen production itself is one of the primary ways to reduce the carbon intensity of industrial processes. For high-temperature heat applications in industries such as cement, metals, glass, and ceramics, decarbonization via low-carbon hydrogen is also possible.

Agriculture is another major source of the world's GHG inventory. Crop and livestock production on farms contributes more than 50% of the methane (CH4) and 75% of the nitrous oxide (N2O) emissions from human activity globally. Emissions from upstream and downstream activities, such as fertilizer manufacturing, food transport, processing, retail and waste disposal, increase the magnitude of these already relevant impacts. Food systems generate about one-third of total anthropogenic emissions (Tubiello et al 2021).

Origins and Trends

It's little wonder that California has a high carbon industry base. The home of American car culture required a system of freeways and bridges, the need for which never stopped growing and created never-ending infrastructure maintenance cycles and increasing demand for concrete

and steel, diesel, and petroleum products. California loved the car so much that in the 1950s it allowed powerful institutions to abandon mass transit systems in favor of congested highways and drivers. As a result, California has been a leading state producer of crude oil and refined petroleum products for more than a hundred years, with refineries along the coast and in the Central Valley.

As a leading producer of agricultural products, California has for decades relied on high carbon chemical fertilizers and pesticides, a water system that uses a third of all electric power consumed in the state, and an agricultural economy powered by diesel equipment. The nation's fundamentally materialist culture, combined with two world-class natural harbors in California, fostered import industries which today handle 40% of all the goods imported to the U.S., through ships, harbors and trucks powered by diesel and "bunker fuel."

The result of these realities includes:

- frequent and deadly smog emergencies in the LA basin and Central Valley;
- air pollution hotspots surrounding freeways, ports, warehousing, predominantly injuring low income and racial minorities too poor to move away or forced to live in pollution by red-lining and housing discrimination;
- high exposure of farm workers to pesticides;
- a growing dependence on oil imported from Alaska and Middle East;
- dying fisheries;
- diminishing groundwater resources;
- loss of 90% of the original fresh and saltwater wetlands and corresponding ecosystems (Zwillinger 2017); [20]
- the second largest GHG inventory among the U.S. states (second only to Texas).

At the heart of all this is California's industrial sector and the consumer demand that drives it.

Agriculture makes up 7% of California's GHG emissions (CO2, Methane, and Nitrous Oxide), and there are many ways to reduce these emissions. Changes in farming practices (irrigation, cover crops, tilling) can reduce N2O, methane and CO2 emissions and sequester carbon in soils. Synthetic fertilizer, today primarily manufactured from fossil fuels, can be made with zero carbon feedstocks.

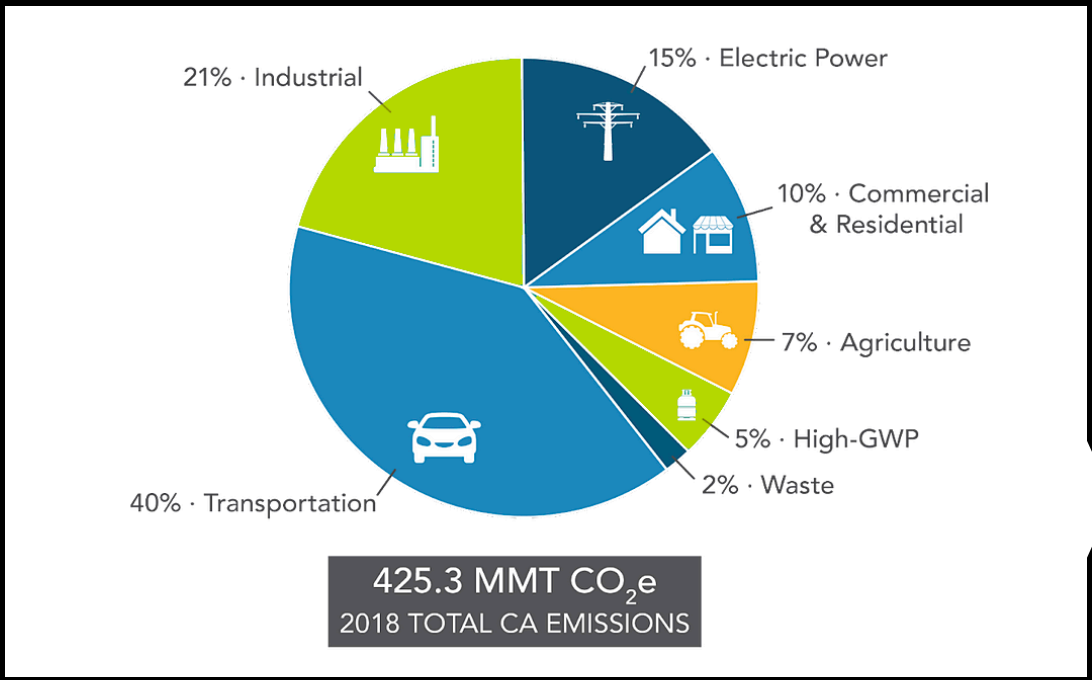
[20] In the 100 years, California has lost 4 million acres of wetlands to dammed rivers, developed floodplains, farmland and urban expansion. Defenders of Wildlife, California's Disappearing Wetlands Face New Perils, 2017.

Farm equipment can be electrified. Changes in irrigation practices can conserve water and reduce energy consumption. Like oil, this sector is hard to decarbonize, not because we lack the **technology** or science, but rather because of the political power of the sector to resist change.

Of course, the future is not as bleak as the past. California is tackling its air pollution problem aggressively, providing leadership to other states, the U.S. national government and the world. The state's efforts have spurred development of **technology** on a wide range of pollution control, energy efficiency and water efficiency products and services. California has a solid start on decarbonizing the electric power sector and could end sales of fossil fueled vehicles in the 2030s. Its universities and businesses have fostered an advanced culture of **innovation** and research capacity. California was one of the first states to implement climate policies and today has some of the most aggressive targets for GHG emissions in the world. It has one of the lowest per capita GHG emission rates among the states. Consumers increasingly choose food products produced with organic or **sustainable** methods. Water use in California agriculture is becoming more efficient.

All of this is a solid base from which to pivot away from a fossil and pollution-based economy. And there is a lot left to do, particularly in manufacturing and agriculture which together produce about 30% of the state's GHG emission inventory. These sectors are historically difficult to decarbonize and the state's carbon cap-and-trade system has had little effect on these sector's emissions to-date.

Figure 18 **California Greenhouse Gas Emissions for 2000 to 2019**



SOURCE: California Air Resources Board. July, 2021.

This is not the place to detail the opportunities to reduce GHG in industry and manufacturing. The following discussion provides just a glimpse of decarbonization technologies in these sectors; to make the point that while harder and perhaps longer term, there is every reason to believe that virtually all industrial sectors in California and globally can be decarbonized in time to avoid the worst impacts of climate change.

The biggest industrial contributions to global GHG emissions come from production of metals, cement, and fertilizer.

> **Of the "harder-to-abate" ~35% of global CO2 emissions, roughly one-fifth comes from making iron and steel, one-fifth from making and curing cement, and one-tenth from making chemicals—60% fertilizers and thermoplastics (Lovins 2021).**

All these products can be decarbonized by changing feedstocks and production processes, a transition likely to occur in steps over time. While there remain technological barriers to this transition, the largest barriers are not **technology**, but rather cost, market structures and politics.

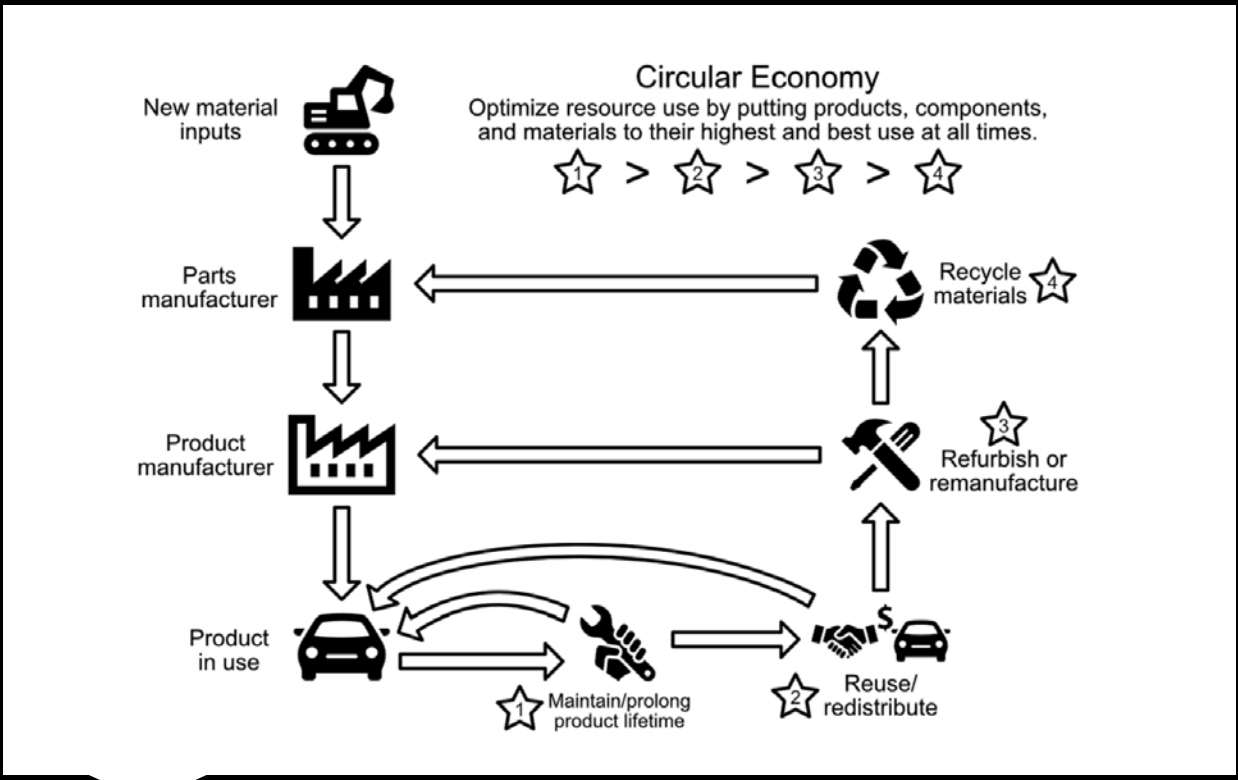
Metals

Steel is one of the most energy-intensive industries, contributing 11% of total global CO2 emissions. If steel were a country, it would be the third-largest contributor of carbon dioxide, behind the U.S. and China (Volvo 2021). Technologies are emerging to produce steel without the need for coal or fossil gas, using fossil-free electricity and hydrogen. For example, renewable hydrogen could be used as a reagent (instead of methane) in the direct reduction of iron to produce sponge iron, which could be used directly in an electric arc furnace (Rissman et al 2020). While California has no primary steel plants, it procures large amounts of steel for infrastructure and produces large amounts of scrap metal. Hence procurement standards for publicly funded infrastructure could help move steel production to a lower carbon intensity. [21]

A large portion of metal supply in California comes from recycling of steel, aluminum and other metals. According to 2019 research from Cambridge University, adopting stronger circular economy principles would reduce GHG emissions and avoid the need for 37% of primary steel production. The same is true for other industrial sectors described below.

[21] See footnote 3 on page 12 regarding California's Buy Clean program.

Figure 19 **Circular Ecomony**



SOURCE: Rissman, Jeffrey et al. "Technologies and policies to decarbonize global industry: Review and assessment of mitigation drivers through 2070". April 2020; citing "Towards a circular economy: business rationale for an accelerated transition". Ellen MacArthur Foundation. 2015.

Cement & Concrete

GHG emissions from eight cement plants in California amounted to 7.8 MMT CO2e in 2019 (1.8% of California's emissions inventory). There are multiple ways to reduce the GHG emissions from cement production or reduce the amount of cement needed for making concrete. Information for this section is derived in part from an unpublished paper produced by Project 2030 (February 2021). The report includes strategies to:

- Incorporate more uncalcined limestone in the cement mix to produce limestone-blended Portland cement.
- Reduce GHG emissions from cement production by using biomass or low carbon hydrogen to generate process heat instead of fossil fuels to improve the thermal efficiency of cement-making equipment and electrifying cement kilns.

- Apply waste CO2 in the curing process of concrete to either reduce the amount of cement needed or absorb CO2 back into the cement.
- Capture CO2 from flue gases from cement plant heat sources and from chemical reactions (limestone calcination during clinker production) and geologically sequestering captured CO2.
    - Geologic sequestration facilities could be part of a California CCS and hydrogen hub designed to advance a wide range of GHG reduction technologies that procure or use CO2 and green hydrogen.
- Use captured CO2 to create Supplementary Cementitious Materials (SCMs) (to replace fly ash derived from coal combustion). Mineralized waste CO2 can be used as aggregate to be blended into cement. [22]
- Permanently sequester carbon dioxide by injecting it into concrete as it is mixed.
- Mineralize fines derived from concrete recycling and use in cement production.
- Adopt new Portland cement processes to make it easier to capture CO2.

The wide range of potential technologies to reduce GHG from cement and concrete suggests several key state policy options. These are listed in our Energy, Environment, and Natural Resources report.

Chemicals, Plastics and Oil Refining

Chemical, plastic, and oil industries use large amounts of fossil fuels and hydrogen derived from fossil gas. In California, heavy crude oil is refined into gasoline and diesel fuel using hydrogen derived from fossil gas. In this instance, renewable hydrogen could substitute as a step toward decarbonizing the refining sector. This would complement recent actions to close fossil-based diesel refineries and open biodiesel production in the San Francisco Bay Area.

In the chemicals industry, considerable GHG emission reduction has been achieved by switching to lower-carbon fuels, improving energy efficiency, and using catalysts to reduce emissions of nitrous oxide (N2O), an important GHG. Feedstock substitution can replace fossil fuel feedstocks in chemical plants. Substitute options include biomass (including dried, inedible plant material such as wood, grasses, agricultural byproducts, and industrial byproducts from saw

[22] Availability of blast furnace slags and fly ashes is expected to decrease due to declining coal-fired power generation and decreasing demand for pig iron.

and paper mills), captured CO2, and waste plastics processed by alkaline hydrolysis or pyrolysis. The state should also consider regulations requiring or incentivizing green hydrogen use in these industries (Rissman et al 2020).

Chemicals production can be decarbonized using a variety of new methods. In the many industries that use hydrogen as a feedstock, renewable hydrogen can replace hydrogen produced from steam reformed pipeline fossil gas. Chemical plants can achieve net zero carbon operations using carbon capture and sequestration systems. A priority for California is to foster a market and infrastructure for production, storage and use of renewable hydrogen produced from electrolysis or steam reformed renewable methane - infrastructure that can also be utilized for some elements of transportation.

Another opportunity is to use industrial carbon capture technologies like calcium- and iron-based chemical looping, combined with renewable hydrogen and oxygen production for economic bulk production of net-zero emitting synthetic hydrocarbons. Renewable hydrogen can be used to produce inorganic fertilizers. There are also many opportunities for electrification, concentrating-solar systems for high temperature process heat (Ardani et al 2021), [23] energy efficiency and waste reduction to reduce GHG in chemicals and refining operations.

Agriculture and Soil Carbon Capture

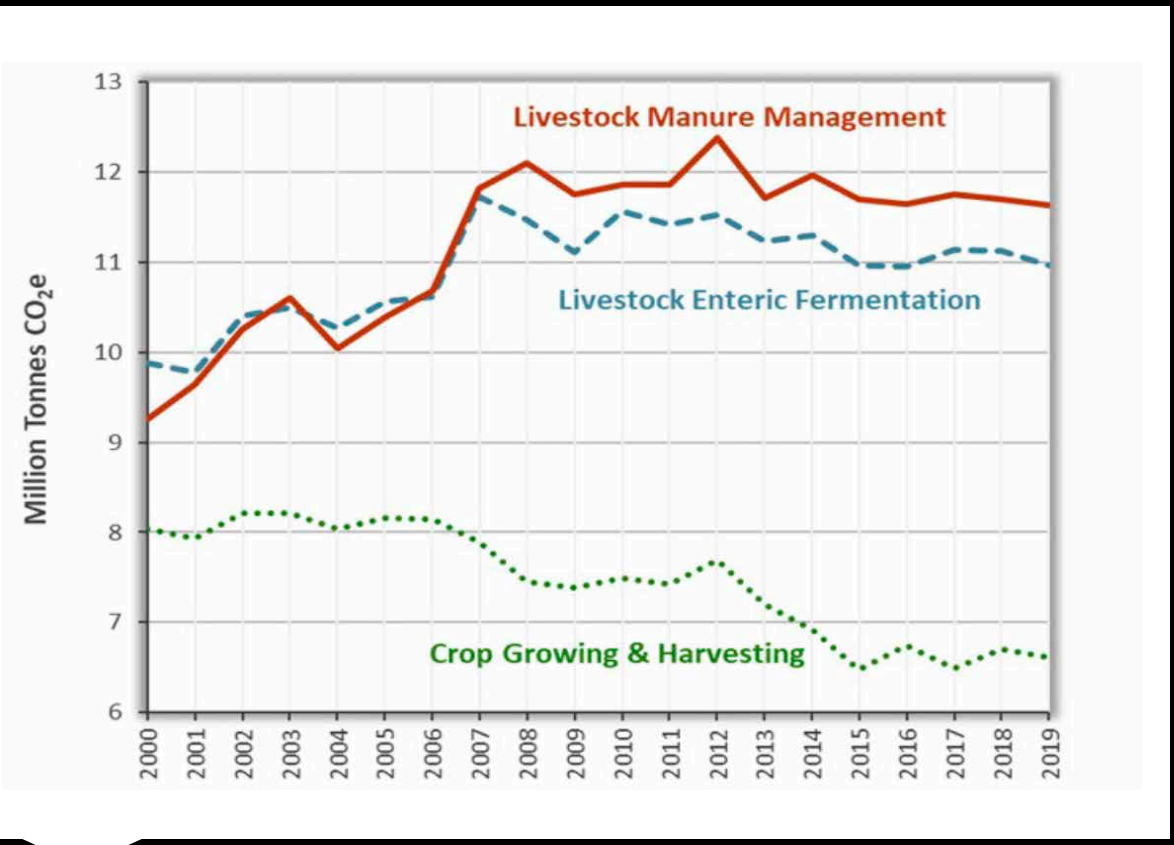
The agriculture industry presents multiple opportunities for climate mitigation and adaptation. These include electrification of farm equipment and crop transport, low- or zero-carbon forms of fertilizer, methane capture from manure operations, and water conservation. These topics are generally covered in other parts of this paper. Hence, this section will address a less well-known opportunity to reduce GHG emissions in farming and land management. We focus here primarily on agricultural lands, but there are parallel opportunities in forestry and wetland restoration.

California's lands represent both a source and a potential sink for carbon. Agriculture accounts for 8% of the total California GHG emissions (CARB 2021). Forty-three million acres of California's

[23] Most of California has very good concentrating-solar potential. https://www.seia.org/initiatives/concentrating-solar-power. According to USDOE: "Concentrating solar-thermal (CST) technologies have great potential to decarbonize the industrial sector because they can directly produce steam and other high-temperature fluids for integration with thermally driven industrial processes, including steel, cement, and bulk chemicals. These three industries represent 15% of the total fossil consumption by the industrial sector and 5% of total fossil fuel consumed, which is nearly 10% of all carbon dioxide emitted in the United States." RFI from DOE Solar Technology Office September 13, 2021, referencing US DOE, Solar Futures Study, September 2021, pages ix, 17 and 130. www.energy.gov

land are devoted to agriculture, [24] half as croplands and half as grazelands (CARB 2018). While most of the sector's GHG emissions are attributed to livestock manure and fermentation, cropland management contributes 20% of agriculture's GHG emissions. The main sources for croplands are fertilization, soil preparation and crops burning (CARB 2021). At the same time, soils harbors half of California's carbon pools, while the rest is stored in biomass (CARB 2018). Indeed, soils can take up carbon as well as release it in a dynamic equilibrium regulated by biology and geochemistry. Plant residues, manure, and compost act as a natural carbon input, while decomposition and combustion of woods or crops release carbon as CO2 into the atmosphere.

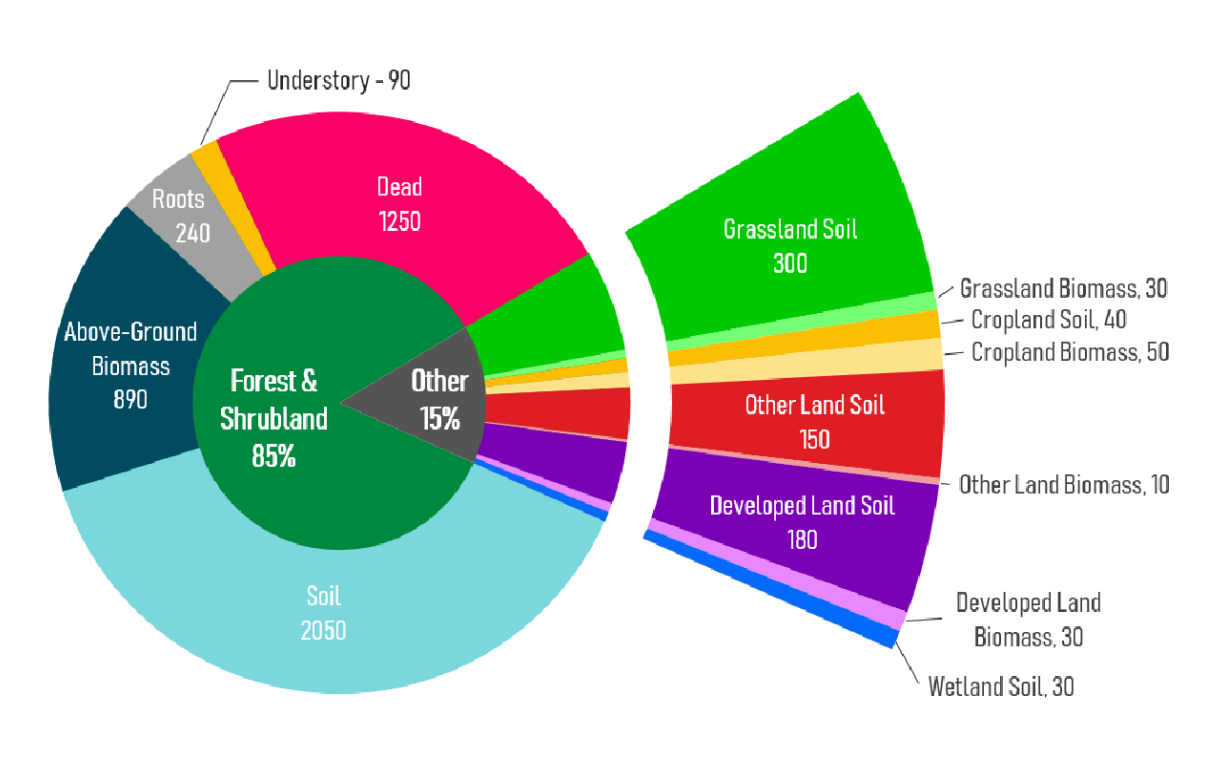
Figure 20 **California Greenhouse Gas Emissions for 2000 to 2019**



SOURCE: "California Greenhouse Gas Emissions for 2000 to 2019". California Air Resources Board. July, 2021.

[24] See https://www.cdfa.ca.gov/agvision/docs/Agricultural_Loss_and_Conservation.pdf.

Figure 21 **An Inventory of Ecosystem Carbon in California's Natural and Working Lands**



SOURCE: "An Inventory of Ecosystem Carbon in California's Natural & Working Lands". California Air Resources Board. 2018..

Global warming and land conversion are driving depletion of soil carbon stocks in California. Climate change exacerbates carbon loss from soils (Hicks et al. 2017, Melillo et al. 2017, Crowther et al. 2016) and California's lands are at high risk. As little as 4% of Californian cropland is currently managed under no-till or conservation tillage, and only 1% with cover cropping (NAAS 2017). California's grassland carbon sinks are threatened to shrink by 40% by 2100 under the current land management practices and land conversion rates, a condition further exacerbated by prolonged drought conditions (Byrd et al. 2015).

Figure 22 **Proportion of Cropland Acres in No-Till or Conservation Tillage**

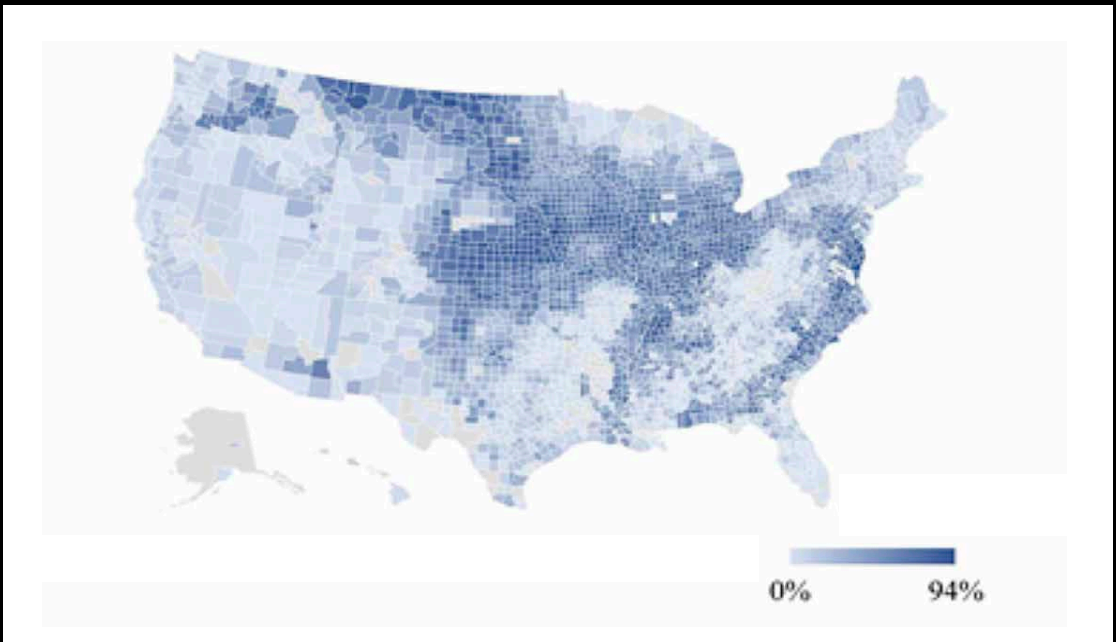
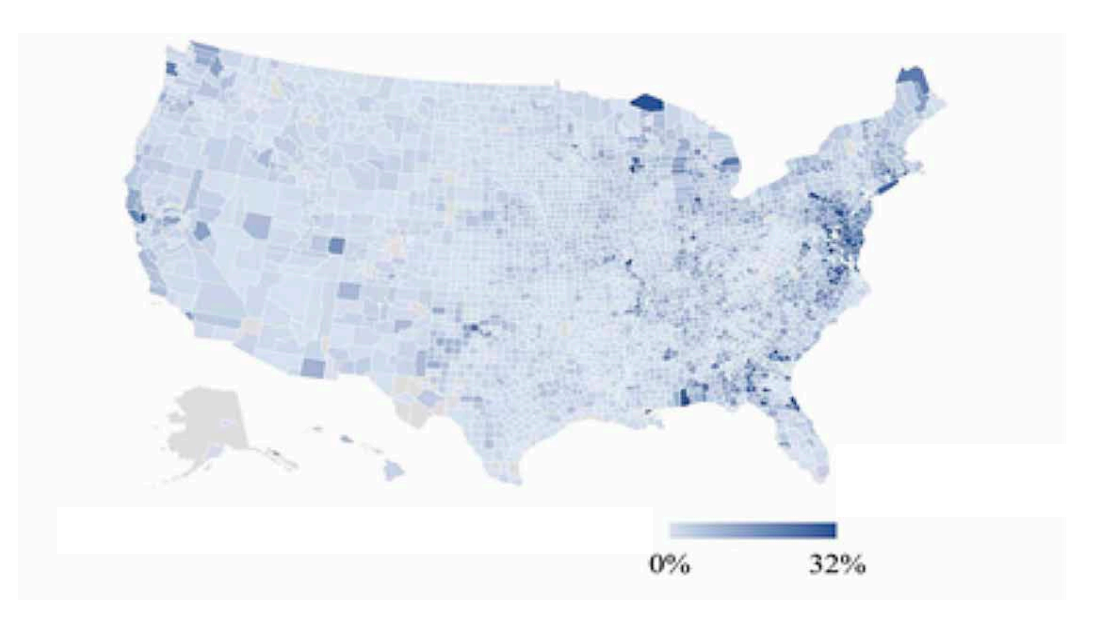


Figure 23 **Proportion of Cropland Acres in Cover Crops**



SOURCE: "2017 Census of Agriculture". U.S. Department of Agriculture National Agricultural Statistics Service. April 2019.

California has identified natural lands solutions as key drivers towards its GHG reduction goals. Governor Brown's executive order B-55-18 (2018) set a 2045 target for California's carbon neutrality, and there is ongoing discussion on whether such a target can be accelerated to 2035. In addition, Senate Bill 32 (2016) set a 40% GHG reduction target by 2030 vs 1990, and Senate Bill 1386 (2016) indicated soil carbon capture as a critical measure to achieve the target. In October 2021, California's Natural Resource Agency released a Draft Natural and Working Lands Climate Smart Strategy to implement Governor Newsom's Executive Order N-82-20. The strategy is designed to accelerate use of nature-based solutions to reduce GHG emissions and adapt to climate change (Nature-Based Climate Solutions 2021). Newsom's executive order directed state agencies to coordinate efforts to identify land management actions that help achieve carbon neutrality, improve public health and safety, and expand economic opportunity. In 2021, the state legislature adopted a multi-year $15 billion budget for climate investment programs, much of which is dedicated to land-based climate mitigation, climate-smart agriculture, carbon sequestration and adaptation projects (Office of the Governor 2021).

California's agricultural land has been increasingly vulnerable to climate change and to development pressure. After 1950, California's farmed land and land productivity has been steadily declining, due in part to scarcer water resources (Thompson 2009). Assembly Bill 857 (2003) set agricultural retention as a state priority, while the California Farmland Conservancy Program (CFCP) has mobilized investments to acquire and put under conservation easement only less than a hundred thousand acres. Meanwhile, carbon content in soils has been declining. Estimates from the NWL inventory show a 2% decline in soil carbon pools from 2000 to 2010, mainly attributed to decomposition of organic matter in the Sacramento-San Joaquin Delta and to disturbances stemming from land development and non-conservative agricultural land management practices (CARB 2018).

In recent years, global attention shifted towards the opportunity of sequestering carbon in soil by restoring depleted carbon pools and by protecting the existing ones. Countries use IPCC's guidelines for GHG inventories (IPCC 2006) to estimate carbon pools and sequestration potential for agriculture, forestry, and other lands. Soil carbon capture techniques include:

- **Traditional:** cover cropping, no-tillage, manure/compost addition and rewetting soils have a global potential of 2-5 GT CO2/year (Bossio et al. 2020, Paustian et al. 2019, Griscom et al. 2017, Hartemink et al. 2014).
- **Frontier technologies:** biochar, perennial grain crops and selected annual crops with a large root system have a global potential of 8-9 GT CO2/year but require additional research. Biochar is a solid carbon-rich coproduct of biofuel produc-

tion, is resistant to microbial decomposition, and effective in stably storing carbon underground (Wang et al. 2016). Biochar has beneficial effects on productivity on slightly acidic, coarse textured soils (Jeffrey et al. 2011).

Soil carbon sequestration enriches soils with organic matter, increases soil health and fertility (Lal 2002) and improves water retention (Knapp M. et al. 2012).

California has a legacy of land conservation programs and policies. The California Compliance Market Offset Program, a sub-program within the California Air Resources Board cap-and-trade program, allows offsets for natural and working lands carbon sequestration practices, including cultivation and forestry management practices.

California has a lands-based carbon capture potential of 174 MMT CO_2e by 2030 (17% of the GHG reduction goal) and 514 MMT CO_2e by 2050 (13% of the GHG reduction goal) (Cameron et al. 2017, Marvin et al. 2018). California's croplands, on average, store low levels of organic carbon due to the warm and dry climate (Hengl et al. 2017) but have a high potential for storing additional carbon under land conservation management practices (Zomer et al. 2017). Substantial capture potential (up to +12%) (Tautges et al. 2019). Compost amendment to grassland is an effective strategy to increase carbon sinks (Ryals et al. 2015). Riparian revegetation provides a good and cost-efficient method of CO_2 capture ($19.75/t$CO_2$) (Lewis et al. 2015). Cover cropping, manure and conservation tillage can reduce GHG emissions by 0.45-1.7 M MTCO_2e /year (De Gryze et al. 2009).

In recent years, increasing resources have been devoted to land conservation and carbon farming. Recent policy objectives seek to increase soil resilience and resistance to droughts and fires, enhance productivity and maximize carbon capture potential of land management and carbon farming. In 2014, the state invested $600 million of the California Climate Investments into Natural and Working Land projects with a cumulative carbon capture potential of >4.3 MMT CO_2e. Principal programs funded include:

- **Forest Health Program** (CAL Fire) supports the long-term capture of carbon in forests, limiting the loss of carbon from wildfires.
- **Sustainable Agriculture Conservation** (Strategic Growth Council and Conservation) finances programs to reduce GHG emissions from land conversion for $120 million.
- **Healthy Soils Program (HSP)** (CDFA) funds projects that align with the CDFA's Healthy Soils Initiative. The program has $50 million from 2016 to 2019 from the

California Climate Investment and from the California Drought, Water, Parks, Climate, Coastal Protection and Outdoor Access for All Act of 2018. So far, 646 projects have been funded ($41 million), 56k+ acres of soils protected, and 0.1 MMT CO2/year sequestered. HSP financed projects must prove reduced GHG emissions and/or increased organic carbon levels.

- **Wetland Restoration for GHG reduction program** (Department of Fish & Wildlife)
- **Climate Ready program** (Coastal Conservancy)

The federal government has financed initiatives linked to soil carbon storage. USDA's Environmental Quality Incentives Program (EQUIP) (Natural Resource Conservation Service) has provided several billion dollars of financial incentives and assistance ($14 billion from 2009 to 2018) to help farmers adopt agriculture and forestry conservation practices. The 2018 Farm Bill, which expires in 2023, budgets up to $2.25 billion a year (+20% vs 2019) for these programs. An additional $42 million has been allocated for the FY 2021 to support conservation initiatives for drought affected states, including California.

A detailed action plan for soil carbon capture is underway within California's decarbonization strategy. The 2020 Executive Order (N-82-20) requires CARB to set a carbon sequestration target for natural and working lands within the next AB 32 Scoping Plan. See: California 2030 Natural Working Lands Climate Change Implementation Plan (NWL CCIP), issued in 2019 (CARB, 2019). The NWL CCIP sets cumulative GHG emission targets for soil carbon capture, and drafts a cross-agency implementation plan. According to the 2019 Plan, GHG emissions from land must be reduced by 84 MMT CO2e by 2045 and sets goals for 2030, 2045 and 2100 with an implementation guideline for each method, region, and agency involved. Measurement, accountability, and progress tracking towards the 2030 and 2045 goal is a key pillar of the program. Expected benefits will be calculated using the CALAND (Di Vittorio et al. 2019) and COMET-Planner tools (USDA 2019). The Governor signed legislation (SB 27) to implement this goal in September 2021 (Martinez 2021).

Even though increasing resources are being invested and clearer goals are underway, researchers need to quickly identify reliable carbon quantification methods and viable carbon market structures. Implementation at scale of the NWL CCIP targets requires progress on methodological and practical issues in the quantification of soils carbon sinks, including the development of new forms of Amines that can lower cost of carbon capture. Carbon pool measurements are subject to high variability due to small-scale variation of organic carbon content (FAO 2019), and rigorous sampling protocols are needed to minimize measurement errors.

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III. BUILDINGS

Main Takeaways:

- The building sector is one of the largest sources of GHG emissions in California and presents a large and ultimately cost-effective means to reduce carbon emissions and in the process improve housing stock.
- A critical lever is to remove fossil gas as an end-use from existing buildings. Technologies are available today to construct all-electric new buildings, and increasingly to electrify existing buildings, with cost savings.
- Key equity and affordability issues must be addressed as existing gas infrastructure is gradually shrunk to meet lower demand.
- Fossil gas, hydrogen and biogas have no role in building decarbonization outside of a few niche applications for biofuels in agricultural buildings and operations, wastewater systems, and associated vehicle fleets.

Sector Facts:

Residential and commercial buildings are responsible for over 20% of California's GHG emissions (Lamm and Elkind 2021). California is the second largest consumer of fossil gas in the country and leads the nation in new service hook-ups, importing around 90% of the gas it consumes (Building Decarbonization Coalition 2019). California's buildings are primarily serviced by electricity and fossil gas, each responsible for about half of energy use across the sector. Combustion of gas and related methane leaks contribute more than one-half of all emissions from single-family homes, with space and water heating accounting for more than 90% of the gas usage. Space heating accounts for most emissions in single-family homes, while water heating accounts for most emissions in multifamily homes. In commercial buildings, including restaurants, offices, warehouses, schools, and any nonresidential space excluding industry and agriculture, fossil gas is the primary fuel used for space heating, water heating, and cooking (Kenney et al 2021).

A much smaller part of statewide emissions comes from the use of propane, kerosene, diesel, and wood in rural parts of the state where there is limited or no gas distribution infrastructure. The remainder of building sector GHG emissions comes primarily from hydrofluorocarbon (HFC) leaked from refrigeration, space conditioning equipment and carbon embedded in build-

ing materials (Kenney et al 2021). Because California's electricity supply is relatively low-carbon and the state has set goals to fully decarbonize it, onsite electricity usage is on the decline as a contributor to building sector emissions. That leaves building gas use as the major remaining source of GHG emissions in the building sector.

California Residential and Commercial Buildings (Kenney et al 2021).

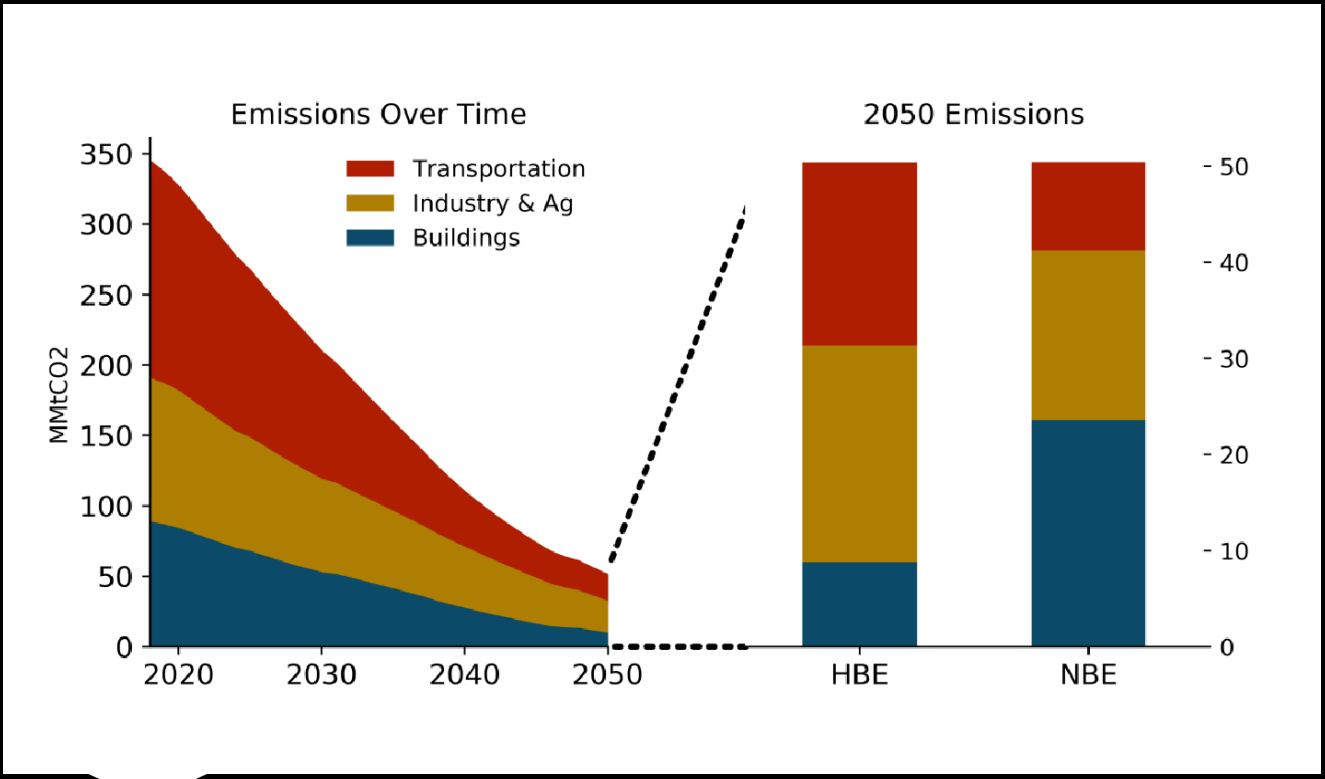
Residential Units in CA: 18.7 million

- Annual electricity consumption: 93,522 GWh
- Annual gas consumption: 4,562 MM therm

Commercial space in CA: 7,392 million sq. ft.

- Annual electricity consumption: 105,174 GWh
- Annual gas consumption: 2,130 MM therm

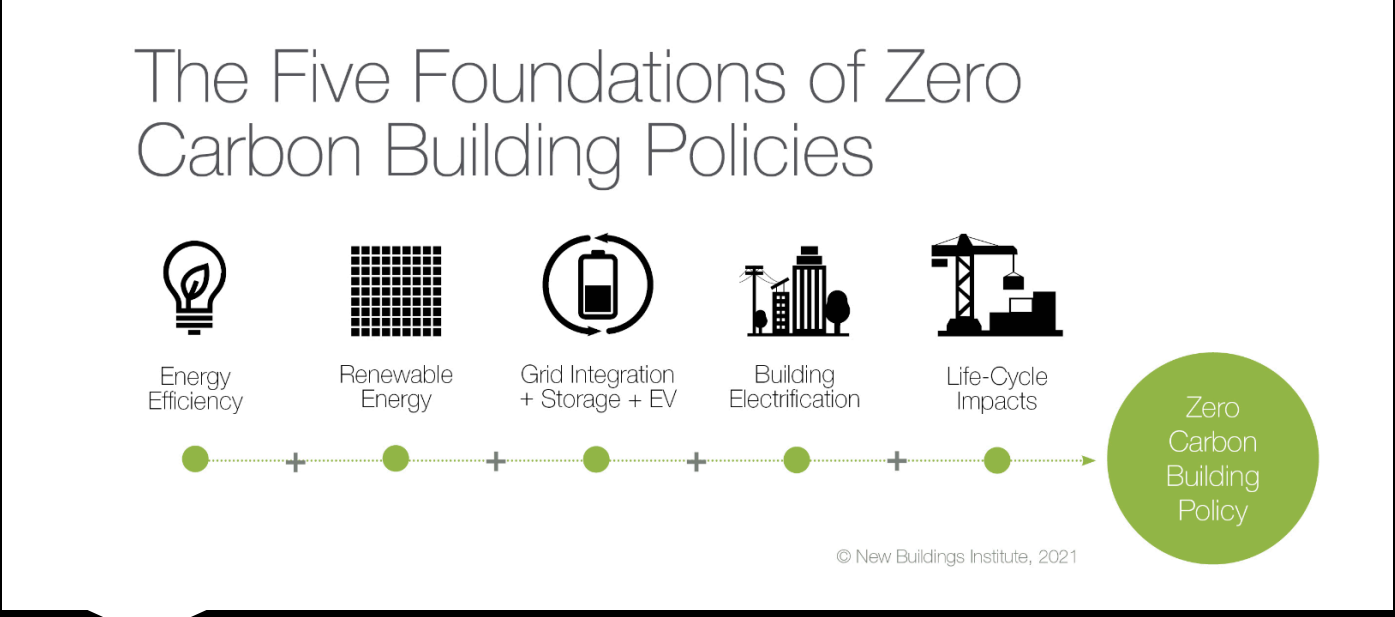
Figure 24 **GHG Emission Reductions Needed, by Sector**



SOURCE: Aas, et. al. "The Challenge of Retail Gas in California's Low Carbon Future," 2020.

Decarbonization experts agree that building electrification (removing gas from buildings and powering them with a zero-emission electric generating sector) is one of the most viable and cost-effective strategies to achieve carbon neutrality. In all the long-term GHG reduction scenarios evaluated by Energy and Environmental Economics (E3), [25] electrification of buildings, and particularly the use of electric heat pumps for space and water heating, leads to lower energy bills for customers over the long term than the use of gas. The High Building Electrification scenario, where gas demand in buildings falls 90% by 2050 relative to today, is lower cost than the No Building Electrification scenario by $5 billion to $20 billion in 2050 (Aas et al 2020). The modeling assumes there will be no retirement of existing fossil gas pipeline infrastructure until after 2030, and that all infrastructure will continue to be paid for in the interim. If the state takes a proactive approach to decommissioning segments of gas infrastructure, the high building electrification scenario will be lower cost compared to a No Building Electrification scenario as early as 2030.

Figure 25 **Five Foundations of Zero Carbon Building Policies**



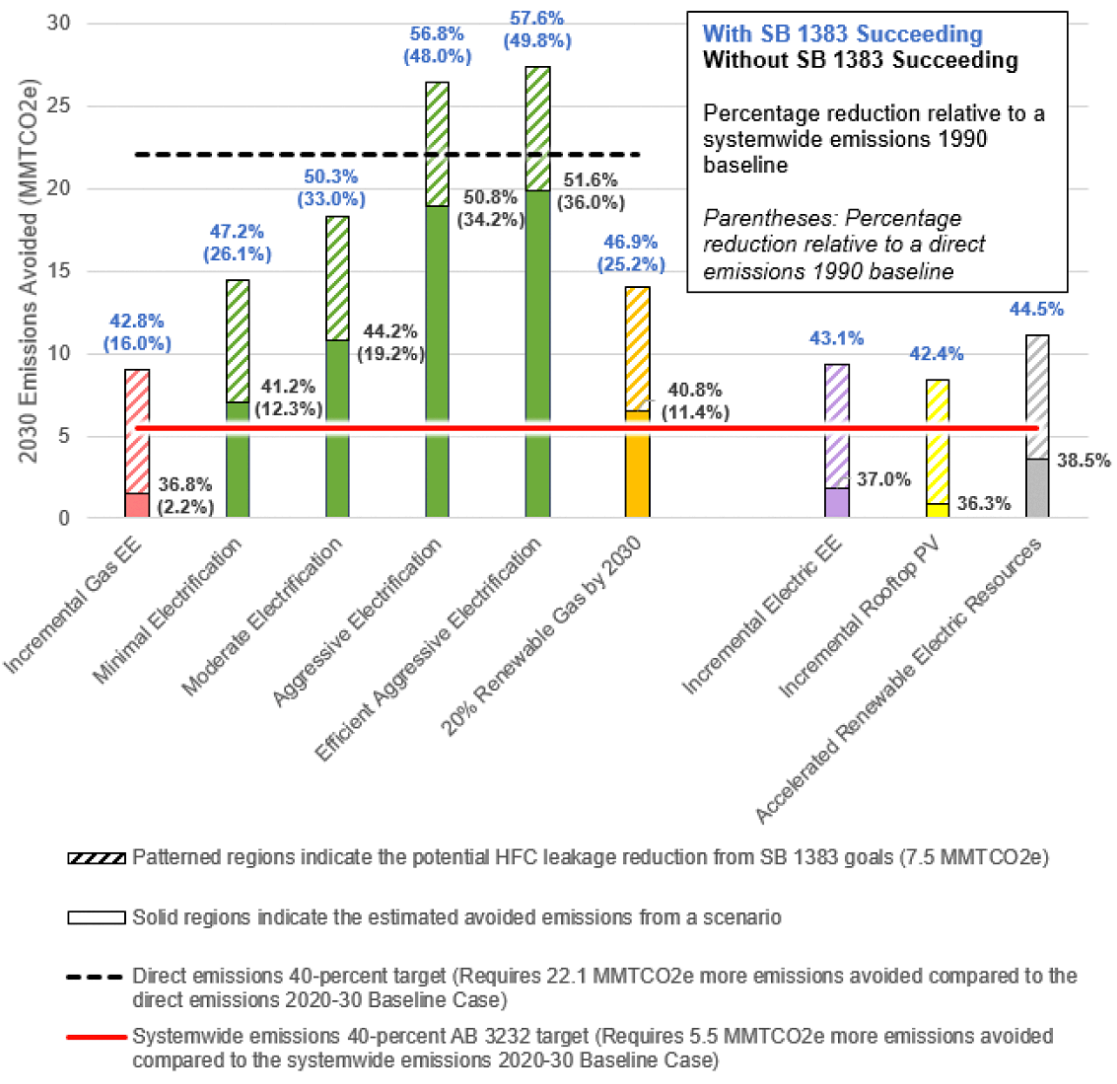
SOURCE: Edelson. "Making the Transition From Zero Energy To Zero Carbon Building Policies". 2019.

[25] Research done on behalf of the California Energy Commission.

As the Energy Commission's 2021 Building Decarbonization Assessment evaluates in the below figure, aggressive building electrification scenarios (paired with energy efficiency measures) provide by far the most efficient and effective path toward meeting 2030 goals compared with any other combinations of simple gas and electric efficiency.

Figure 26

Annual GHG Reduction for 2030 Relative to the Direct and Systemwide 40 Percent Emission Targets



SOURCE: Kenney, Michael et al. "California Building Decarbonization Assessment". August 2021.

Building electrification also improves outdoor air quality and public health, particularly in the winter when nitrogen oxide emissions from gas combustion in buildings and power plants contribute to secondary fine particulate matter (PM 2.5) pollution. This is especially problematic in the Los Angeles Basin and Central Valley, where atmospheric conditions tend to retain and concentrate air pollution (Aas et al 2020).

Human exposure to gas combustion pollution, however, is not limited to the outdoors. Research by the Rocky Mountain Institute demonstrated that more than half of all U.S. households have gas appliances, which emit a wide range of air pollutants. The result is poor indoor air that is often more polluted than outdoor air. Homes with gas stoves have nitrogen dioxide concentrations that are 50%-400% higher than in homes with electric stoves. The research also demonstrated how additional pollutants such as carbon monoxide, particulate matter, and formaldehyde from gas appliances can cause negative health effects that exacerbate respiratory conditions. Study results show a 42% higher likelihood of asthma symptoms for children living in a home with a gas stove (Brady and Krasner 2020). Two-thirds of California homes lack stove ventilation systems. Populations who spend large portions of their time indoors at home, an increasingly common reality due to COVID-19 and wildfire smoke, are at particularly high risk.

Electrification of buildings also results in other significant safety and resiliency benefits, including reducing methane leakage from gas distribution pipelines and oil/gas production. Reducing gas use in buildings will help avoid the need for gas infrastructure that periodically experiences catastrophic failure (e.g., the notorious 2010 San Bruno pipeline explosion and the Aliso Canyon leak, but also many smaller accidents affecting individual buildings) (Gridworks 2019). The FracTracker Alliance tracked 329 gas explosions between 2010 and 2019 nationwide, which resulted in 140 fatalities, 656 injuries, and over $5 billion in damages (Kelso 2020).

Research by Inclusive Economics has demonstrated that robust residential and commercial decarbonization statewide could result in an additional 12,400 full-time electricity generation and distribution jobs, compared with 5,400–6,800 fewer full-time gas distribution jobs. The transition will also require up to 100,000 full time workers in the construction industry and up to 4,900 full-time manufacturing workers. This totals to 64,200–104,100 jobs annually related to building electrification, after accounting for losses in the gas industry (Jones et al 2019).

Technology to Decarbonize Buildings

Cost-effective, reliable, and high-performing electric technologies are already commercialized and readily available. The Building Decarbonization Coalition estimates that space conditioning and water-heating electrification upgrades could have an average total cost in the range of $12,000 to $25,000 per household, even before additional efficiency improvements. These savings are greatest when equipment is replaced on burn-out, meaning as part of already expected appliance replacement. The Electric Power section of this report provides additional detail on the benefits that electrification has over time, as clean energy costs continue to drop.

The below chart provides useful estimates on the total household costs and savings of major electrification retrofits:

Table 1

Expected Household Capital and Operating Cost Impacts of Selected Clean Energy Investments with No Co-Benefits or Other Value Streams Included.

CURRENT ESTIMATES PER HOUSEHOLD VALUES	HEAT PUMP SPACE CONDITIONING	HEAT PUMP WATER HEATER	ROOFTOP SOLAR	6% EFFICIENCY PACKAGE	16% EFFICIENCY PACKAGE
Investment cost (a)	SF: $13,679–20,663 LRMF: $6,785–15,016	SF: $3,599–4,662 MF: $3,349–4,388	$3,000–5,000 / kW[14]	SF: $1,980	SF: $8,733
Incremental investment cost (b)	SF: $(2,948)–1,377 LRMF: $(1,743)–1,323	SF: $1,601–2,064 LRMF: $1,435–1,927	$3,000–5,000 / kW	SF: $1,980	SF: $8,733
Annual bill savings (c)	SF: $112–597 LRMF: $24–201	SF: $12–138 LRMF: $22–121	$170–350 / kW[15]	SF: $63	SF: $155
Measure life (yrs.) (d)	18	13	20	20	20
Lifetime bill savings (c*d)[16]	SF: $2,016–10,746 LRMF: $432–3,618	SF: $156–1,794 LRMF: $286–1,573	$3,400–7,000 / kW	SF: $1,260	SF: $3,100
Lifecycle savings – (lifetime bill savings minus incremental investment costs)	SF: $1,857 - 10,044 LRMF: $(1,074) - 5,429	SF: $(2,130) - (205) LRMF: $(1,895) - (318)	+$0–2,000 / kW	SF: $(720)	SF: $(5,633)

SF: Single family, LRMF: Low-Rise Multi-Family

SOURCE: Aas, et. al. "The Challenge of Retail Gas in California's Low Carbon Future". 2020.

Readily available all-electric technologies include:

- **Electric heat pumps for space heating and cooling (HVAC),** a single unit that replaces less-efficient existing fossil gas-fired heaters and air conditioning units (Billimoria 2019);
- **Heat pump water heaters (HPWHs),** which are two to three times more efficient than conventional electric resistance water heaters and cost-competitive with fossil fuel-powered systems;
- **Heat pump clothes dryers,** which are more efficient than traditional fossil gas-powered units and electric resistance models;
- **Electric induction stoves,** which exceed both traditional electric resistance and fossil gas cooktops in efficiency, while eliminating indoor air pollution; and
- **Building and appliance load management,** connecting appliances to the grid via smart meters for grid flexibility, boosting reliability, and reducing customer energy costs (CEC 2019).

Origins and Trends

Many state agencies, local governments, and legislative leaders acknowledge the multitude of benefits from deep building sector electrification and energy efficiency. In September 2018, Governor Brown signed two bills into law related specifically to GHG emissions from the building sector. Assembly Bill 3232 (Friedman) directed the CEC to prepare a Building Decarbonization Assessment in consultation with the CPUC, CARB, and the CAISO to assess the potential for the state to reduce building sector GHG emissions by 40% below 1990 levels by 2030. As a result of that report, the listed agencies are focused on a set of prioritized building decarbonization strategies - including building end-use electrification, decarbonizing the electricity generation system that powers those electrified buildings, investing in energy efficiency, reducing refrigerant leakage levels, decarbonizing the remaining portions of the gas system, and enabling demand flexibility (Aas et al 2020).

Secondly, SB 1477 (Stern, enacted in 2018) calls on the CPUC and CEC to develop two programs to reduce GHG emissions associated with buildings: the BUILD and TECH programs. The Building Initiative for Low Emissions Development (BUILD) Program advances low-emissions new construction, incentivizes heat pumps, energy efficiency, demand response, onsite solar and storage. At least 75% of the program's funding is focused on low-income communities. The

Technology and Equipment for Clean Heating (TECH) program targets existing buildings, with the goal of jumpstarting the market for low-emissions space and water heating technologies through "upstream" support for manufacturers, distributors, and vendors, consumer education and contractor training (Borgeson 2020).

In tandem, the CPUC opened a broad rulemaking on building decarbonization (R.19-01-011), focused on: 1) implementation of SB1477; 2) implementation of pilots to address new construction in communities damaged by wildfires; 3) coordination with the CEC on Title 24 Building Energy Efficiency Standards and Title 20 Appliance Efficiency Standards; and 4) establishing a building decarbonization policy framework (CEC 2019).

In 2021, at the Governor's request, the California Air Resources Board (CARB) initiated the next AB 32 Climate Change Scoping Plan to identify pathways for the state to achieve carbon neutrality by 2035, including strategies to reduce fossil fuel demand and supply. This 2035 target was set by executive order by Governor Newson, advancing the 2018 commitment by former Governor Brown's administration to reach carbon neutrality by 2045. The Scoping Plan is due in 2022 and will include updates to CARB's indoor air quality guidelines. The Bay Area Air Quality Management District (BAAQMD) and South Coast Air Quality Management District (South Coast AQMD) are also taking independent action in their districts, with a focus on Zero NOx appliances to strengthen gas appliance emissions rules and a specific rulemaking in BAAQMD focused on how to do so while achieving greater **racial equity.**

The CEC also passed in 2021 updates to California's Building Energy Efficiency Standards for new construction, additions, and alterations of residential and nonresidential buildings (Title 24). The 2022 Title 24 building code update does not include an all-electric mandate as many advocates wished, but does include a performance-based requirement for heat pump water heaters in the majority of climate zones in California; a requirement for electric readiness for all buildings that includes installation of space, electrical, and plumbing to enable future electrification upgrades; and stronger ventilation requirements for gas cookstoves to encourage the adoption of electric induction stoves (CEC 2019).

Among energy service providers, several of the state's Consumer Choice Aggregation (CCA) utilities have recognized the business opportunity in load growth and electric system management from electrification and taken steps to adopt aggressive building decarbonization plans. Examples include significant rebates and incentives, both for new construction and existing buildings, applicable to heat pump water heaters and dryers, induction ranges and cooktops, energy efficiency measures and more (Building Decarbonization Coalition 2020).

Pacific Gas & Electric (PG&E), as a dual-fuel utility, has been supportive of building decarbonization efforts with attention to strategic long-term planning to gradually decommission the gas distribution systems. SCE, an all-electric utility, is a major proponent of building electrification and has supported significant market transformation efforts. Conversely, SoCalGas, a gas-only utility, has been a strong opponent.

California also has nearly 30 municipal utilities and rural electric cooperatives. SMUD is a statewide if not nationwide leader on building decarbonization. They have revamped their energy efficiency programs to focus on electrification and updated all of their energy program metrics to focus on carbon savings (as opposed to energy savings). SMUD has committed to 100% electrification of buildings in their service territory by 2045, including an additional directive for 100% electrification of low-income homes by 2040.

Local governments in California have also ignited a broad movement among cities to phase gas out of new construction (Steele 2021). In July 2021, the City of Emeryville became the 48th city to commit to phase out gas in new buildings (Gough 2021). With one of the most progressive Climate Action Plans in the state, the City of Menlo Park passed an additional target of reaching a 95% transition from fossil gas to electric homes and buildings by 2030 and a pathway to fully electrify all low-income households by 2030 (Bailey et al 2021). The City of Berkeley, the first in the nation to pass a "reach code" eliminating gas use in new buildings, has had a similar focus on **equitable electrification** of existing buildings. It initiated a community engagement process to identify timelines to fully electrify disadvantaged homes using incentives and protections (including anti-displacement measures and other "**equity** guardrails." (City of Berkeley 2021).

Additional state and federal funding are crucial for bringing the benefits of building decarbonization to low-income, underserved, and disadvantaged communities. Successful existing programs include:

- the Low-Income Weatherization Program (LIWP) for Multifamily dwellings,
- BayREN's Bay Area Multifamily Building Enhancements Program,
- the Solar on Multifamily Affordable Housing (SOMAH) program,
- SMUD's Multifamily GoElectric program,
- MCE's Multifamily Energy Efficiency Program,
- the statewide TECH program,

- South Coast AQMD's Multifamily Affordable Housing Electrification Program (MAHEP), and
- the Tri-County Regional Energy Network (3C-REN) Multi Family Homes Energy Savings Program (CEC 2021).

While the state is making progress to establish policies, programs, and regulations needed to drive decarbonization of the building sector, there are many barriers and challenges ahead to full decarbonization. One of the most pressing challenges for the state in meeting its climate goals will be how to decarbonize the existing building stock. While continuing momentum around new construction policies will be important to drive market transformation and affordability of **low-emissions technology**, these policies don't address the existing 14 million residential single-family homes and multifamily units - 80% of which are connected to the fossil gas system, or the 7.5 billion square feet of commercial buildings statewide (Aas et al). To meet state goals, California will need to do the following:

1. **Drive down the costs and increase the accessibility and affordability of electric and low-emissions technology.**

All-electric new construction is already more cost-effective than gas alternatives in the state largely due to eliminating the cost of often expensive fossil gas piping infrastructure. Retrofitting older buildings with **all-electric technology**, though, will require robust funding and financing solutions and incentives. Many home retrofits will require electric panel upgrades and additional wiring. Cost assumptions for electric panel upgrades vary widely, with estimates ranging between $3,000 - $6,000 per household before labor costs. An estimated 60% of California households live in a building that will likely require a panel upgrade, 46% of whom are low-income.

2. **Level the playing field such that low-income and underinvested communities are enabled to upgrade their homes to all-electric alternatives.**

All challenges around retrofits are greater in lower-income and environmental justice communities. Low-income individuals often lack capital and capacity to retrofit buildings, live in multifamily structures, and suffer from higher existing rates of air pollution and environmental injustice (Lamm and Elkind 2021). One-third of California households do not have sufficient income to meet their basic costs of living, and a 2016 report from The Utility Reform Network found that, in that year, between 19 and 25% of California families were energy insecure (Manzo et al 2021). Electrification also continues to be more challenging for renters, who lack the decision-making

power to proactively switch. In 2019, 45% of Californians were renters and about 25% of Californians were renters living on low to extremely low incomes.

In presentations to the Energy Commission, the City of Berkeley's low-income efficiency program administrator, Association for Energy Affordability, and Sacramento Municipal Utility District all reported a variety of technical retrofit challenges specific to lower income housing that contribute to higher costs. Those included: poor envelope insulation and sealing, leaky HVAC ducts, lower capacity electric panels, asbestos, and more.

3. Design more equitable and sustainable rate structures to support electrification.

As customers begin to transition off of the gas system, the costs of maintaining existing gas distribution infrastructure will be spread over fewer and fewer customers. This has the potential to leave those least able to proactively transition bearing the burden of that increased cost.

On the flipside, the cost of maintaining a safe and reliable electric system continues to skyrocket each year, as worsening wildfire seasons require significant safety investment into electric infrastructure and electric utilities continue to invest in clean energy programs. Despite the increasing costs of maintaining the electric grid, though, E3 finds in their research that electrification of buildings leads to lower average energy bills for customers over the long-term (Aas et al 2020). Electrification of buildings and transportation will increase the total load, allowing costs to be spread over more customers.

4. Plan for a declining gas workforce and growing electric workforce.

The average salary for fossil fuel workers, nationwide, is estimated to be between $24.37 and $28.69 per hour (Lehmann 2021), compared with $24.48-$24.85 for clean energy jobs (including $24.44 for energy efficiency jobs) (E2 2020). High-road jobs that provide family-sustaining wages and benefits are critical for lifting families and communities out of poverty, and the workers with good jobs in the fossil fuel industry today must be treated with dignity by all stakeholders in the electrification movement.

5. Cost-effectively and safely decommission existing gas infrastructure and rethink gas utility business models.

As the state electrifies the building sector, gas demand and throughput will plummet. The result will be large swaths of decommissioned existing gas infrastructure and will demand creative frameworks to recover costs from assets that are decommissioned before end of useful life (stranded assets). New financial models are needed to incentivize gas and dual-fuel utilities

to decommission gas assets and ensure cost recovery of electrification cost and investment in stranded assets.

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IV. WATER

Main Takeaways

- Adapting to increased climate risk will require transformational changes to existing water management practices to simultaneously manage intensifying droughts and floods, to restore depleted groundwater aquifers, and to ensure safe, affordable, and reliable water access for all Californians (He et al. 2021).

- Total water demand will increase significantly with projected population increases and with it the demand for electricity and fossil gas. Good water policy is good climate policy:

strong water conservation and efficiency measures can simultaneously increase resilience to intensifying drought and reduce the GHG footprint of our water system.

- California has invested heavily to uncouple year-to-year water supply from regional water scarcity and variable precipitation, but climate change seriously threatens this balance. Large parts of the state's water infrastructure are aging, outdated, and at increased risk from climate impacts. Agriculture is particularly vulnerable to climate impacts.
- A comprehensive overhaul of our water data collection and management systems, increased coordination between our water and energy systems, and sustained investment in nature-based climate solutions and public health protections is necessary to aid a swift and just transition to a climate-resilient water system. Just as the state's climate policies have driven innovation in the energy sector, California's water policies are spurring innovation in water technology.
- California has only recently begun serious efforts to protect groundwater resources and that effort needs strong follow through from state and local governments. Water reuse is one of the most promising new supplies of clean water.

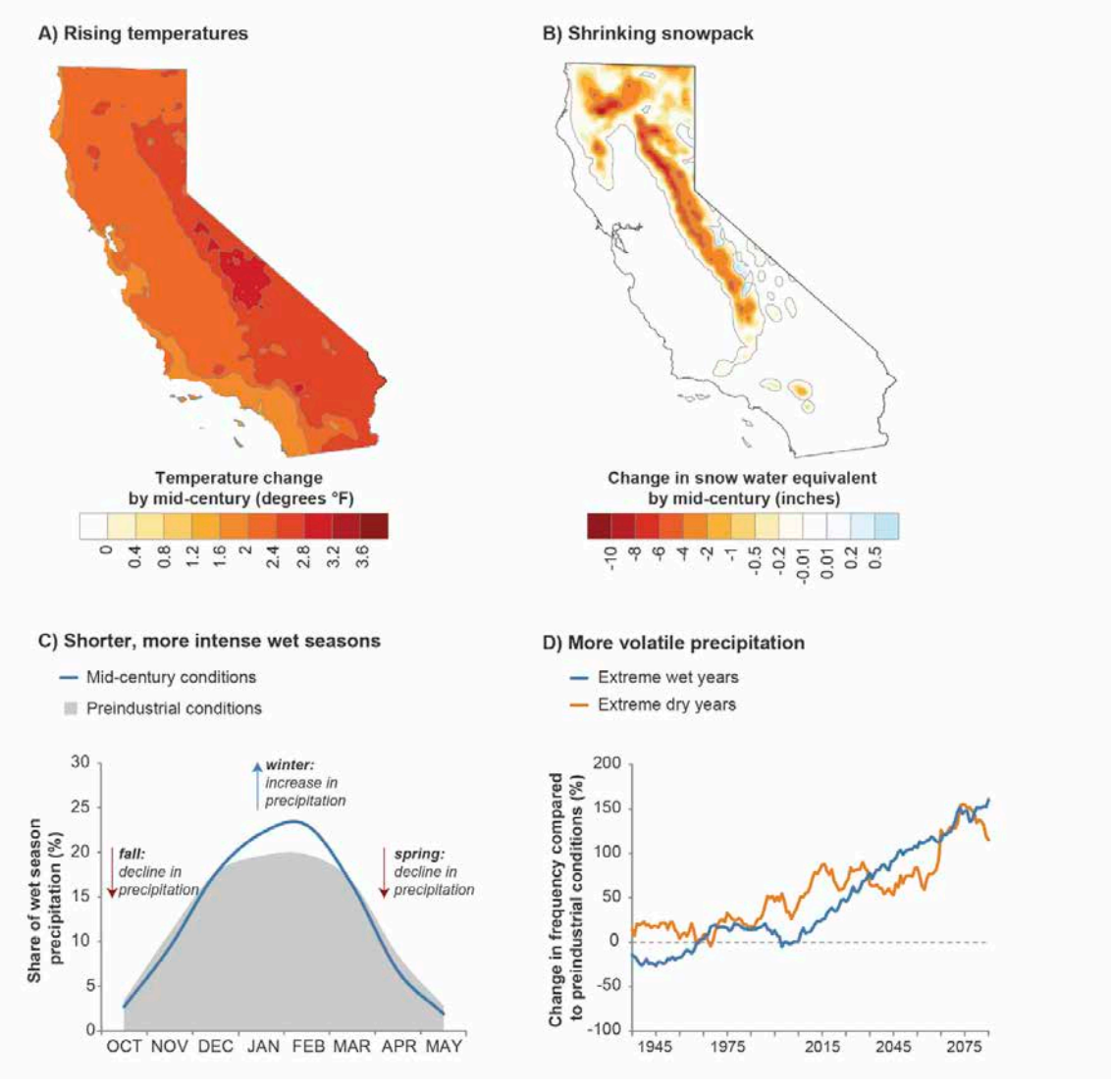
Sector Facts:

California has the most variable climate of any state in the country (Mount et al 2021). California tends to oscillate, sometimes drastically, between dry years and wet years, and drought is a natural and familiar feature of the state's climate. Regional climate differences within the state are also highly variable: the arid regions of southern California receive only about 5% as much rainfall in a typical year compared to some mountainous regions in the north (NOAA). Through one of the largest water conveyance systems in the world, water is delivered from where there is more of it, and relatively less demand, to where there is less of it, and greater demand. Herein lies one of the state's fundamental paradoxes—and one of its greatest climate vulnerabilities. For a century, California has largely been able to decouple regional water scarcity and variable precipitation from year-to-year water supply. Barring transformational changes to existing water management practices, climate change seriously threatens that balance.

Climate change is increasing water scarcity and the volatility of California's climate. As average temperatures rise in the state, average annual rainfall is expected to remain fairly stable, but the frequency of rainfall is expected to decrease (Bedsworth et al. 2018). When storms do occur, they will be more extreme, dropping more rain all at one time, and with less precipitation falling as snow (ibid.). These changes will have the effect of making both drought and floods more

intense and more harmful to society and the environment (ibid.). The 2012–2016 drought was the hottest in recorded history and the first two decades of the 21st century may constitute one of the driest periods in the last few thousand years, what some scientists call a "megadrought" (Mount et al. 2021, Williams et al. 2020). The 2021 water year was the driest in a century. Meanwhile, 1 out of 5 Californians live in a flood risk zone and climate change is increasing flood risk statewide (Mount 2017, First Street Foundation 2020, Huang et al. 2020).

Figure 27 **Climate Change and California's Water**



SOURCE: Mount et al. "Climate Change and California's Water." 2019a.

California grapples with chronic challenges related to water supply and management—and climate change makes these problems harder to solve. For decades, California has struggled with problems related to human and environmental water supply and management, including access to safe and reliable drinking water for all Californians as well as adequate water supply to maintain the health of native species and habitats. Increased climate volatility—dryer dry years, and wetter wet years—puts strain on our water system, limiting our ability to solve existing problems while reducing resilience to future climate impacts. California is experiencing, and mobilizing responses to, the negative, water-related impacts of climate change.

Physical Infrastructure: California's physical water infrastructure is aging, outdated, and increasingly vulnerable to the impacts of climate change.

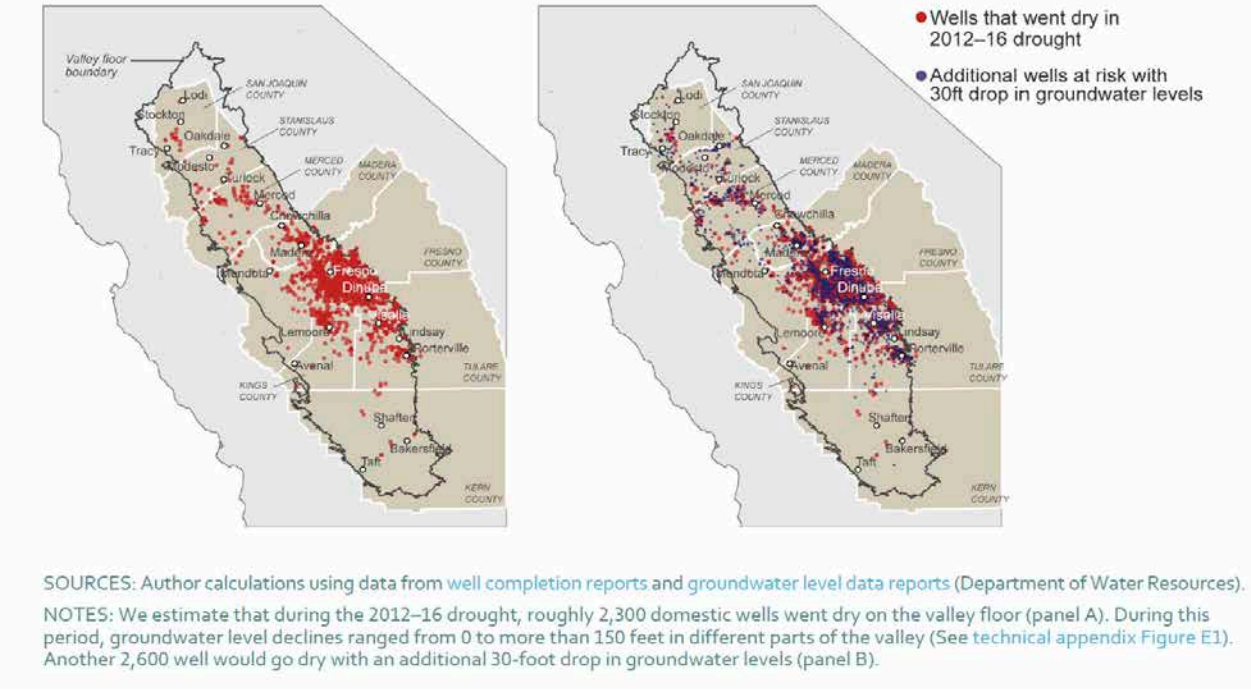
- Dams and reservoirs in California are aging and were not designed for current or forecasted hydrologic conditions (Escriva-Bou et al. 2019; Mount et al. 2019; PPIC 2019). Increased climate volatility will make it more difficult to manage reservoirs to fulfill competing objectives of water storage, flood protection, and environmental flows. Larger storms forecasted under climate change increase the risk of catastrophic dam failure, as witnessed in the 2017 Oroville Dam crisis.

- Unsustainable use of groundwater has caused significant land subsidence in many parts of the Central Valley, compromising critical water conveyance infrastructure such as the Delta-Mendota and Friant-Kern Canals. These impacts reduce the flexibility of our water system, increase operating costs, and have required millions, if not billions, in mitigation expenses (Escriva-Bou et al. 2020).

- Groundwater overdraft has also caused thousands of drinking water wells in the Central Valley to run dry, reduced water quality in other wells, and increased operating costs (Escriva-Bou et al. 2021). Thousands more wells could run dry in 2021 and beyond if the present drought persists, posing a drinking water crisis (ibid).

- The California Department of Water Resources is slowly advancing the long-debated Delta Conveyance Project through environmental impact review. This project would construct new water intake facilities in the north Delta and divert water via a single tunnel to the existing pumping plants in the south Delta. Project proponents argue that this new infrastructure is essential to increase resilience to climate and seismic impacts on water supplied through the Delta (DWR 2020). Critics argue that the project is overly expensive and will accelerate ecosystem degradation.

Figure 28 **Water and the Future of the San Joaquin Valley, 2019**



SOURCES: Author calculations using data from well completion reports and groundwater level data reports (Department of Water Resources).

NOTES: We estimate that during the 2012–16 drought, roughly 2,300 domestic wells went dry on the valley floor (panel A). During this period, groundwater level declines ranged from 0 to more than 150 feet in different parts of the valley (See technical appendix Figure E1). Another 2,600 well would go dry with an additional 30-foot drop in groundwater levels (panel B).

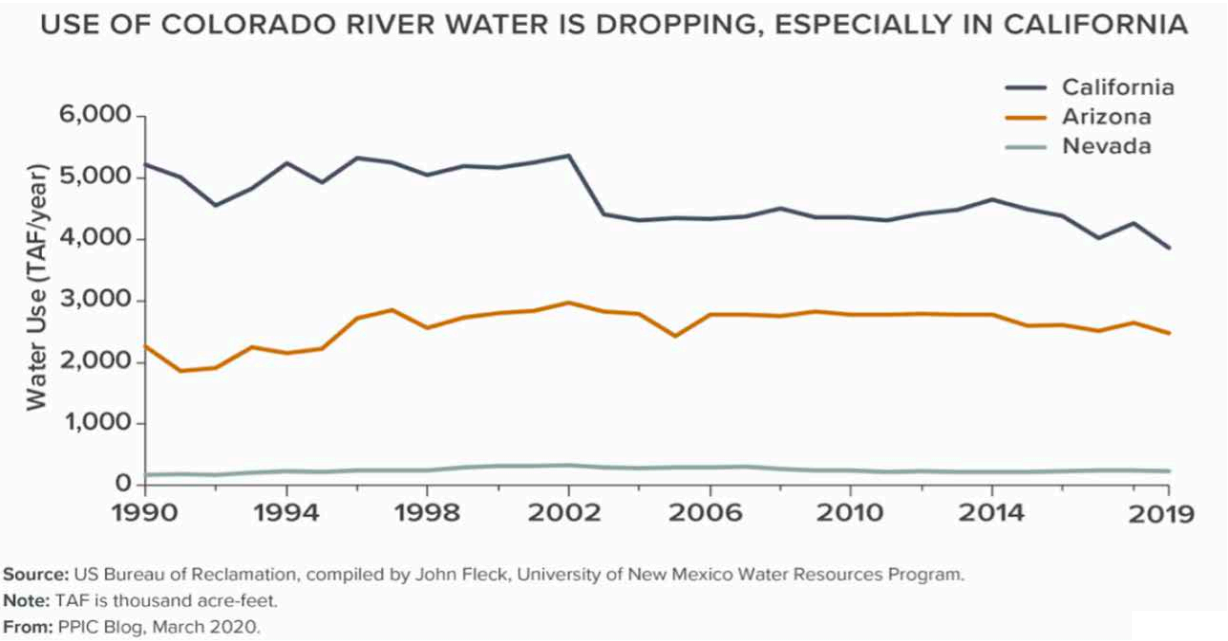
SOURCE: Hanak et al. "Water and the Future of the San Joaquin Valley." 2019

Topic Breakout: The Colorado River Basin and California's Water Future

The Colorado River Basin, spanning seven western states, supplies water for nearly 40 million people in two countries (the United States and Mexico), 29 tribal nations, and multiple National Wildlife Refuges and National Parks. Colorado River water supplies about a third of total use in Southern California cities, as well as some of the fastest-growing metropolitan areas in the country, like Phoenix and Las Vegas (PPIC 2018; US Census Bureau 2020). The River also supports important agricultural markets, including the Imperial Valley in California, which contributes roughly 90% of U.S.-grown winter vegetables (PPIC 2018; American Rivers). In addition, more than 4,000 MW of energy for Western states is available from hydroelectric power stations on the River (Bureau of Reclamation 2012).

However, legally-apportioned water use exceeds the total supply that the River can provide (PPIC 2018). This excess use, combined with severe and chronic drought across the American West, has led Lake Powell and Lake Mead, the Colorado River's major water storage reservoirs, to drop to all-time lows in 2021. Climate models predict that River supplies could dwindle by as much as 55% by the end of the century (Udall et al. 2017). Further demand reduction and conservation efforts will present tradeoffs. Environmental and public health conditions at the Salton Sea, an ecologically critical saline lake, are worsening. The lake has historically been maintained by irrigation runoff from farms in the Imperial Valley and agricultural water conservation measures are causing the lake to shrink (ibid). Reduced supplies from the Colorado River may also increase demand for supplies from the Sacramento-San Joaquin Delta, frustrating restoration goals.

Figure 29 **California's Colorado River Water Use**



SOURCE: Pottinger, Lori. "Why the Big Drop in California's Colorado River Water Use?" 2020.

Natural Infrastructure: California's forests, wetlands, and rivers serve as natural water-management infrastructure that provide habitat, flood protection, and water quality benefits to nature and society. Already in decline after a century of unsustainable management practices, climate change is making these ecosystems more vulnerable.

- California's Sacramento-San Joaquin Delta is the switchboard of the state's water system. It is from this major confluence that water is pumped south to supply the partial needs of two-thirds of Californians and over 3 million acres of farmland (PPIC 2018a). The Delta region itself is the largest contiguous area of prime farmland in the state and home to over 600,000 people (Delta Stewardship Council 2021). Agricultural reclamation has resulted in a loss of 95% of original ecosystems and what remains supports a critical biodiversity hotspot (ibid). The impacts of agriculture and water diversions have caused the Delta to sink for over a century, and many areas now sit well below sea level and behind 1000 miles of vulnerable levees (ibid.). Climate change impacts—sea level rise, water scarcity, and increased climate volatility—put this embattled region at even greater risk of saltwater intrusion, catastrophic flooding, and species collapse (ibid.; PPIC 2018a).

- California's forests provide flood control and water quality benefits to society, but many are overly dense and unhealthy after a century of fire suppression and intense drought (McCann et al. 2020). These conditions have increased the risk of large, destructive wildfires, events which can severely limit the ability of forests to provide ecosystem services (ibid). Severe fires increase the risk of erosion into reservoirs, which reduces water quality, and increase the risk of floods and landslides, as in the devastating 2018 Montecito landslides triggered by heavy rains following the Thomas Fire in Ventura County (ibid).

- California has lost 90% of its former wetlands and 95% of riparian habitat along rivers and streams which provide critical habitat and contribute to flood control, water quality, and groundwater recharge (Frayer et al. 1989; PPIC 2018b). Climate change is stressing these remaining ecosystems and reducing the quality of the ecosystem services they can provide (Mount et al. 2018).

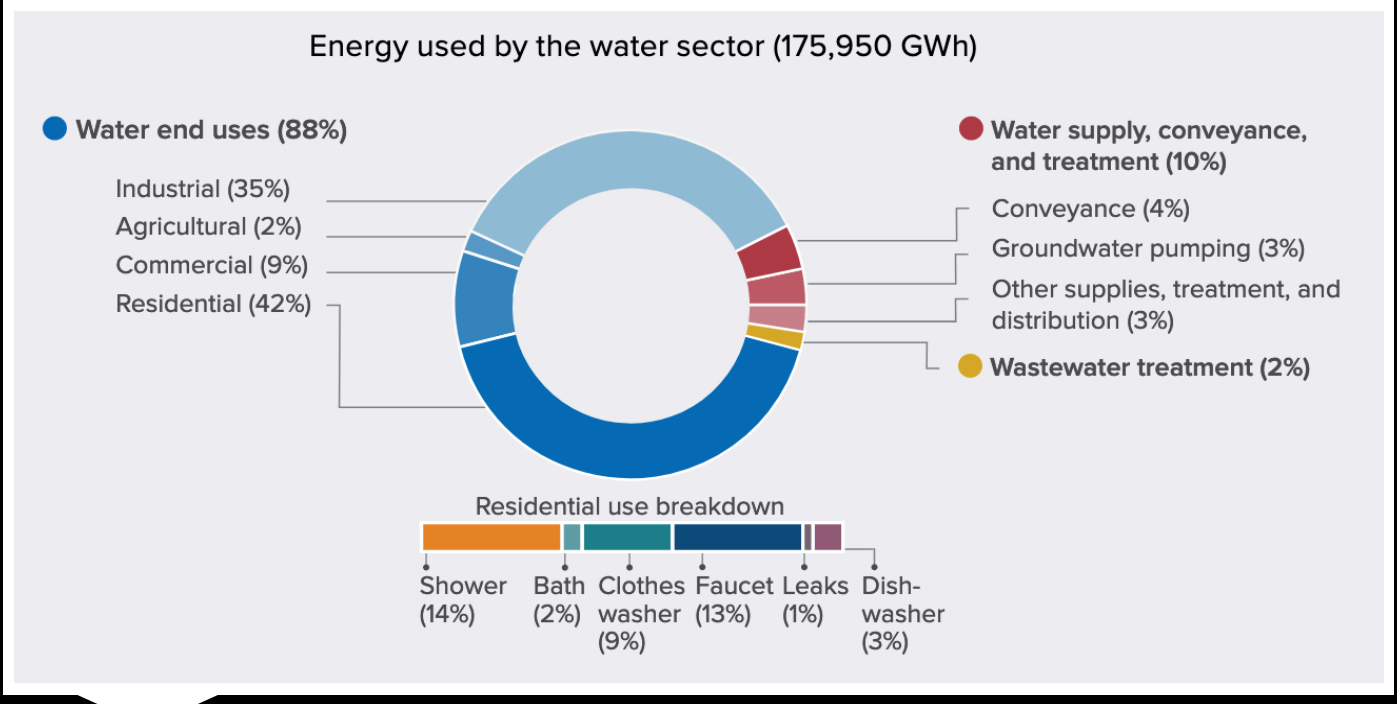
Energy: Our energy and water systems are codependent: water is an essential input into energy production, and energy is required for water conveyance, treatment, and end uses. Water conservation and efficiency gains greatly reduce water system GHG emissions.

- California's water system accounts for 10% of the state's GHG emissions, and 90% of that footprint is attributable to end uses, especially those that require heating water, like showers and industrial processes (Escriva-Bou 2016). A recent analysis by the Pacific Institute estimates that urban conservation and efficiency efforts could reduce water-related

electricity usage by 19%, fossil gas use by 16%, and GHG emissions by 41% cumulatively between 2015 and 2035 (Szinai et al. 2021).

- Rapid electrification of water heaters is one of the most effective ways to meet GHG goals in the water sector (Szinai et al. 2021).
- The energy savings due to urban water conservation during the 2012–2016 drought were estimated to be greater than the combined energy savings across energy efficiency programs managed by the state's major utilities during the same time period, and at less cost (Spang et al. 2018).
- Despite using significantly more water than urban California, agriculture's water use is far less energy-intensive (Szinai et al. 2021). If groundwater overdraft continues, however, the energy-intensity of agricultural water use will increase (ibid.). Electrifying pumps and coordinating usage to the timing of renewable production could reduce impacts on GHG emissions (ibid.).

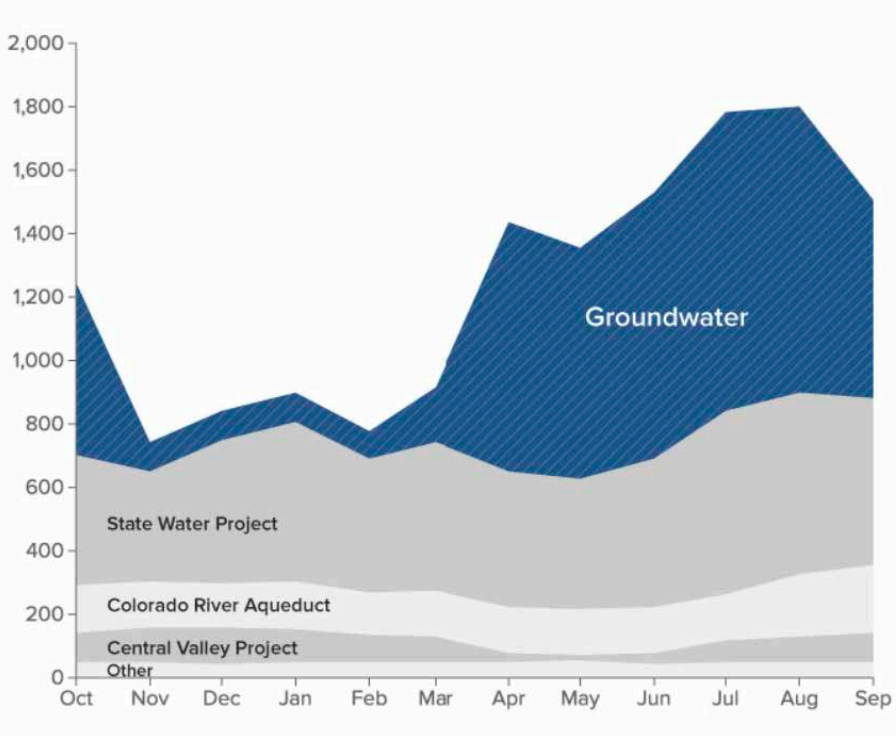
Figure 30 **California's Water Energy Nexus**



SOURCE: PPIC. "Energy and Water." 2016.

NOTES: The figure shows total energy used by California's water sector. Most energy consumed by California's water sector goes to residential use.

Figure 31 **Groundwater Energy Demand Peaks in Spring and Summer**



SOURCE: "Monthly Energy Use by Source of Water, in Gigawatt Hours." Source: Moran et al. Water in the West. 2014

- Lost hydropower production during the 2012–2016 drought cost California consumers hundreds of millions of dollars (Hanak, et al. 2015a). While renewables expand, reduced hydropower generation due to drought could increase interim reliance on compensating fossil fuel energy sources and increase GHG emissions (Herrera-Estrada 2018). Overall, the shift to renewables will increase the energy sector's resilience to drought (PPIC 2016).

Agriculture: Agriculture in California has made strides in water use efficiency, but the sector is still uniquely vulnerable to climate change. Over the next two decades, the sector will adapt to new groundwater **sustainability** requirements, which will ultimately make the sector more resilient. Climate change will make achieving sustainability more difficult.

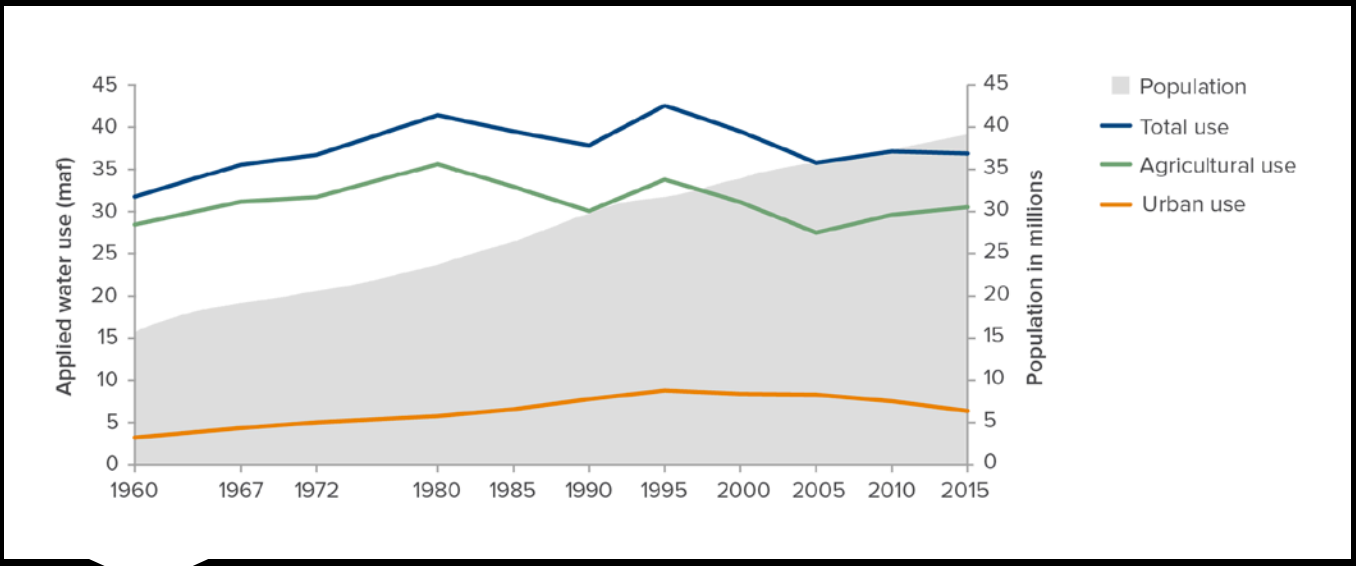
- Efficient irrigation technology has kept total agricultural water use in California relatively constant since the 1980s despite a significant increase in the economic value of crop pro-

duction (Szinai et al. 2021; Mount et al. 2019). Still, the agricultural sector consumes about 80% of all freshwater applied for human uses (California Department of Water Resources). While the greatest potential for water conservation exists in agriculture (e.g., through retirement of marginal farmland), these gains carry relatively fewer associated reductions in GHG emissions, compared to water conservation measures in urban California.

- Farming is a much smaller share of California's economy (1–2%) than in the past, which buffers the state from the economic impacts of drought: for instance, the California Legislative Analyst's Office concluded that the 2012–2016 drought did not significantly affect the state's economy or government revenues (Hanak et al. 2015; Sisney 2015). Still, regional impacts are acute and rising: the 2012–2016 drought resulted in billions of dollars in economic costs and tens of thousands of jobs lost in the agricultural sector (Lund et al. 2018; Hanak et al. 2015).

- The types of crops planted in California are shifting steadily towards relatively lucrative perennial fruits, nuts, and vines, which require long-term, uninterrupted irrigation (ibid.)

Figure 32 **Both Agricultural and Urban Water Use Have Fallen Over the Past Two Decades.**



SOURCE: Mount et al. "Water Use in California." 2019.

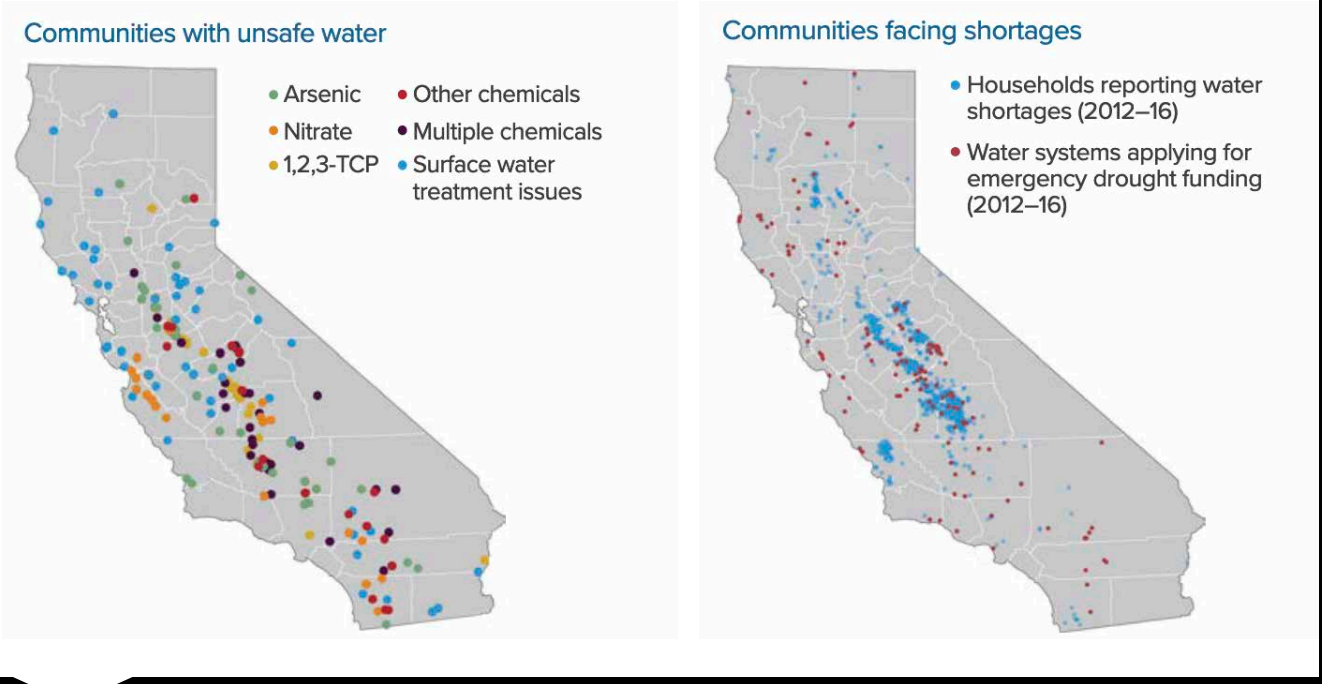
NOTES: Except for 2015 (a severe drought year), the figure reports estimate for normal rainfall years, Pre-2000 estimates are adjusted to levels that would have been used in a year of normal rainfall. Estimate are for water years (October to September).

These cropping changes harden water demand and increase vulnerability to more intense droughts in the future.

Public Health, Equity and the Human Right to Water: California struggles to ensure safe, clean, reliable, affordable, and accessible drinking water for all. Climate impacts will make this objective increasingly difficult.

- One million Californians currently lack access to reliable, clean drinking water (Chappelle et al. 2021). Most water systems that fail to provide clean or reliable drinking water serve small, rural communities of color in agricultural areas of the Central Valley (ibid.). These systems tend to rely on pumping groundwater from shallow wells which are particularly vulnerable to the impacts of intensifying drought. During the 2012–2016 drought, 150 small water systems in the state applied for emergency assistance (Mount et al. 2019).

Figure 33 **Drinking Water Safety and Reliability Challenges**



SOURCE: PPIC. "Priorities for California's Water." 2019.

- Groundwater contamination is a longstanding issue in California and is linked to groundwater overdraft and drought: as water levels fall in wells, the concentration of contaminants may increase. Thousands of groundwater wells across the state have unsafe levels of natural and human-generated contaminants, and without expensive treatment, some "forever" chemicals will persist and accumulate for centuries. Concomitant groundwater contamination and climate change compound public health risk.

- The consumer cost of water is rising in California at six times the rate of inflation, 12% of Californians are behind on payments, and total water debt has risen to nearly $1 billion (Bland 2018; Senator Bill Dodd 2021, Botts 2021). Water debt and potential water shutoffs disproportionately burden poor Black and brown communities (Botts 2021). Rising rates are driven by a combination of maintenance of aging infrastructure (see "Physical Infrastructure" above), expensive treatment of contaminated water, and the costs to secure additional water supply given increased scarcity, among other factors (Bland 2018). All three of these drivers are exacerbated by climate change.

Biodiversity: California's biodiversity is in trouble due to widespread habitat loss and other human impacts. Water-related climate impacts are exacerbating the biodiversity crisis.

- California is a biodiversity hotspot but many of our native species are in steep decline (CADFW). Hundreds of freshwater species in the state are currently vulnerable to extinction due to the combined impacts of human demand for water, pollutants, flood control, and land use change (Mount et al. 2019).

- Rising temperatures, declining snowpack, and longer dry periods, may push many of these species over the edge, including half of California's salmon and trout species, extinctions which will have significant impacts on commercial, recreational, and traditional fisheries (ibid.; Moyle et al. 2017). Investment in ecosystem restoration, for example through the San Joaquin River Restoration Program, has achieved small gains for endangered species, but intense drought threatens to overwhelm hard-fought progress (SJRRP 2020; Heyward 2021).

Origins and Trends

Water's storied place in Californian history is complex and far beyond the scope of this report. Nonetheless, understanding why our modern water system operates the way it does, it's inherent strengths and weaknesses—and the ways it can or cannot readily adapt to climate change—benefits from historical context. If components of California's water system today

seem archaic, they are: fundamental aspects have not changed, for better or worse, for a century or more. California's convoluted water rights system operates according to a unique hybrid of legal doctrines which provide the fundamental basis that determines who gets water, and who doesn't in scarcity; the legal frameworks governing surface and groundwater are not covered in detail here. What follows is a high-level synopsis of the landmark policies and events that have shaped our water system and contextualize the present.

Physical Infrastructure

As California's population exploded following the Gold Rush, the regional water supply succumbed to growing demand. Massive reclamation and public works projects were initiated in the early 1900s to import water from hundreds of miles away, including the Central Valley Project, and the Los Angeles and Colorado River Aqueducts; the State Water Project was added in the 1960s. These sprawling, interconnected systems are the major circuitry of today's "water grid," which includes nearly 1,500 dams, dozens of hydropower and pumping plants, and thousands of miles of canals.

The massive infrastructural projects of the 20th century have been very effective at uncoupling year-to-year water supply from the unpredictability of California's climate and lifted the state to become one of the largest agricultural producers and economies in the world. Meanwhile, California's major water projects have wrought lasting damage to Tribal and environmental resources, damage which we have an obligation to amend. Damming and channelizing rivers was once viewed as a signal of technological progress, but that perspective has shifted as our understanding of the services that intact ecosystems provide has matured.

The need for expensive safety retrofits coincides with a broader debate over whether doubling down on "hard" infrastructure projects is justified, considering a more volatile climate. Indeed, the movement to remove dams is accelerating: 100 have been removed in the last 30 years. Furthermore, aging infrastructure, engineered for hydrologic conditions which no longer exist, is increasingly expected to satisfy management criteria that it was not designed for.

If passed, the federal infrastructure bill currently in Congress would provide significant funding for water infrastructure improvements in California, including dam safety, water storage, and water recycling projects, amongst many other water system investments. In addition, corresponding legislation at the State and Federal levels has been introduced (Canal Conveyance Capacity Restoration Act and SB 559) which would split the tab on costs required to restore impaired water arteries in California, including the Delta-Mendota and Friant-Kern Canals.

Natural Infrastructure

California has been called the most hydrologically altered land mass in the world (Water Education Foundation). Virtually all of California's rivers are dammed, often many times over. The Central Valley, once a vast system of marshes fed by rivers flowing out of the Sierra Nevada, has been almost entirely converted to agriculture. The Colorado River does not reach the sea, Owens Lake is gone, and the San Francisco Bay Estuary has lost one third of its original size to infill. Parts of the San Joaquin River flow in reverse when Delta pumping ramps up and areas of the San Joaquin Valley floor have permanently subsided nearly thirty feet due to extraction of enough groundwater to fill Lake Tahoe. This vast alteration and degradation of aquatic ecosystems was frequently justified in the name of economic development while the impacts to marginalized communities and the environment were discounted, ignored, or overlooked.

Similarly, forest fires were actively suppressed in California since statehood to avoid economic waste (i.e., lost timber extraction) and prescribed and cultural burning were essentially banned. The important role of fire in forest ecology was not well understood by (settler) forest managers until the late 20th century. Widespread fuel accumulation due to fire suppression, along with rising temperatures and declining forest health, have ultimately led to today's catastrophic megafires.

In September 2021, Governor Newsom signed a $15 billion dollar climate budget package that will dedicate billions of dollars to climate-resilient natural infrastructure investments advancing flood protection, groundwater **sustainability,** drinking water protection, and forest health and wildfire preparedness.

Energy

California's energy and water systems have historically been managed separately, and still largely are today. The recent impacts of intense drought and water scarcity on disruptions to energy production; and the impacts of intensifying storms and power outages on disruptions to water treatment; are two examples of how climate change is requiring a more integrated approach.

Fossil gas water heaters are the single largest emitters of GHGs within the water management cycle and there is growing momentum to accelerate the transition from gas to electric heat pump heaters (Szinai et al. 2021). In 2020, the California Public Utilities Commission revised a policy that prevented utilities from offering incentives to go electric and approved $45 million from the state's Self Generation Investment Program budget for electric heat pump water heater rebates (ibid.). Additionally, several cities around California have passed regulations prohibiting fossil gas in new housing developments (ibid.).

Agriculture

Thanks to increases in irrigation efficiency, total agricultural water use in California has remained relatively flat since the 1980s despite a significant increase in the economic value of crop production (Szinai et al. 2021; Mount et al. 2019). However, agricultural water use trends are difficult to capture because the sector has been marked by lack of basic water-use data collection and standardized reporting relative to other industries (Cooley 2015; Cantor et al. 2018).

Perhaps most conspicuous is the absence, until 2014, of data collection and virtually any regulation related to groundwater pumping, despite groundwater making up 40% of total water use in an average year. The sector's resistance to regulation and reporting can be attributed to the substantial power that California agriculture has held in Sacramento and Washington D.C. Over the last century, this power has consolidated into fewer hands as farms have become fewer, larger, and a greater proportion—and their associated water rights—owned by corporations and private investors (Ferguson 2021).

Passed in 2014, the Sustainable Groundwater Management Act (SGMA) required the establishment of local groundwater management authorities (Groundwater Sustainability Agencies) and the preparation of a local **sustainable** groundwater management strategy (GSPs). Plans were submitted to the state in 2020 and are currently under review. It is unclear whether these plans will be sufficient to avoid further negative impacts. Meanwhile, groundwater accounting and entrepreneurism in water management and trading are expanding rapidly as GSAs are required to demonstrate measurable progress towards sustainability, or else face State intervention (see Hanak et al. 2019). In 2020, the first groundwater market in California started trading and the first water futures market in California launched (Heard et al. 2021; Kammeyer 2021).

Public Health, Equity and the Human Right to Water

Comprehensive water quality regulations were enacted in California in the 1960s and 70s (Hanak & Chappelle 2015). Principal among them was the Porter-Cologne Water Quality Control Act which empowered the State Water Resources Control Board and nine regional boards to set and enforce water quality standards. Since that time, additional state and federal laws and regulations have passed to address water quality impacts related to the use of pesticides, pollutants from farming, abandoned hazardous waste sites, and the chemical byproducts from hydraulic fracturing (ibid.).

Hundreds of aquifers in California are contaminated with a cocktail of natural and manmade chemicals, some of which will never break down ("forever" chemicals). Less than 10% of the

chemicals used in commerce today have been studied for human health effects and millions of new chemicals are created annually, all of which could eventually end up contaminating surface and groundwater (Green Science Policy Institute; Mulvaney 2017).

Established in July 2019, the Safe and Affordable Drinking Water Fund (SB 200, Monning) will receive an annual transfer of 5% of the State's GHG Reduction Fund (up to $130 million) until 2030 to address funding gaps and provide solutions to water systems to address both short- and long-term drinking water needs, especially those serving disadvantaged communities (SWRCB 2021). The Human Right to Water Data Tool (CalHRTW 1.0) complements other cumulative impact analyses (e.g., CalEnviroScreen) and will aid assessment of progress towards realizing California's landmark human right to water law (Balazs et al. 2021).

Biodiversity

While California has been a leader in considering climate change mitigation and adaptation into the scope of environmental review and other regulations, the existential threat that climate change poses to entire ecosystems threatens to overwhelm relatively localized protections provided by traditional conservation mechanisms. Hundreds of species that rely on freshwater ecosystems have declined significantly due to widespread habitat loss and other human impacts on our waterways.

Over time, the state and federal endangered species acts have increasingly been relied on as proxies to protect entire aquatic ecosystems, despite their narrow mandate of species recovery (Mount 2015). Given the threat climate change poses to whole ecosystems, the state's conservation paradigm is shifting from individual species recovery to ecosystem-scale management to prevent further biodiversity loss.

Governor Newsom's "30x30" executive order (N-82-20) calls for the state to conserve 30% of its land and coastal areas by 2030 in a manner that protects and restores biodiversity and accelerates natural and working lands solutions to the climate crisis. The order also established the California Biodiversity Collaborative, a partnership that will work to define what "conserve" means in practice and what areas should be prioritized.

The historic 2012–2016 drought revealed major gaps in the state's preparedness to respond effectively to prolonged, intense drought (Hanak et al. 2015; Green Nylen et al. 2018). Research into past State-level responses to drought reveals a pattern of ad-hoc and reactive approaches initiated after drought emergencies have arrived (Green Nylen, et al. 2018). The

state's water data collection and management system are incomplete and poorly organized (Cantor et al. 2018). For instance, three-quarters of California's watersheds do not have a government-operated streamflow gage and most agricultural groundwater wells are still not metered, though this is changing (SWRCB, 2021; Maynard et al. 2014). Information about who has a right to water diversions, how much water, and when it can be drawn on is notoriously difficult to ascertain (SWRCB 2021; Kiparsky et al. 2021).

The Open and Transparent Water Data Act (AB 1755) requires the Department of Water Resources, in consultation with other agencies, to create, operate, and maintain a statewide integrated water data platform and to develop protocols for data sharing, documentation, quality control, public access, and promotion of open-source platforms and decision support tools related to water data (CADWR). The California Water Data Consortium directly supports the implementation of the Open and Transparent Water Act and is taking steps to meet legislative milestones (CADWR, 2020).

Meanwhile, recent modeling studies suggest that conventional approaches to forecasting seasonal water availability will become increasingly unreliable under climate change (Livneh 2020). Official analyses that are used to determine the availability of water for a new use permit are still based on historic hydrologic conditions that the state left behind decades ago (SWRCB 2021). Without proactive State drought contingency planning, full accounting of climate change impacts in water rights administration, and transparent and interoperable data that allow water managers and users to prepare and plan for water scarcity, conflict over water resources will increase (SWRCB 2021; Kiparsky et al. 2021; Green Nylen et al. 2018).

Emerging and maturing technologies can aid California's transition to a more climate-resilient water sector. Just as the state's climate policies have driven innovation in the energy sector, California's water policies are spurring **innovation** in water technology.

- Wastewater reuse is a promising solution for addressing drought and climate resilience in California (Simon 2021; Huber-Lee et al. 2020). The State Water Resource Control Board is currently developing a regulatory framework for direct potable reuse (DPR) to be implemented by 2023 (SWRCB 2021b). By allowing recycled waste to be discharged directly into potable water supplies, potable reuse has the potential to provide an additional 1.1 million acre-feet of water per year and to serve more than 8 million Californians (Tooker 2017).
- While advances in desalination technology have greatly reduced the cost of producing desalinated water, the role of desalination within California's water supply strategy is yet to be determined. The State's 2020 Water Resilience Portfolio reflects this mixed outlook,

suggesting that desalination only be considered where cost effective and environmentally appropriate (California Natural Resources Agency et al., 2020). The Carlsbad Desalination Plant is the largest in California (and the Western Hemisphere) and produces 50 million gallons per day for the San Diego County Water Authority (SDCWA, 2021). In part due to the energy-intensity of desalination, SDCWA pays $2,200 per acre-foot of water from the plant; the same amount of water sourced from the Colorado River or Sacramento-San Joaquin Delta costs $1,200 per acre-foot (Robbins, 2019).

- Lastly, remote sensing and internet of things technology is increasingly deployed to monitor and optimize agricultural water use (Charles 2021).

Despite huge challenges related to water in a changing climate, there are signs that California is adapting and can continue to do so. California's urban areas are using less water despite a steadily increasing population and are more drought-resilient, the result of concerted conservation and storage efforts over the last few decades (Hanak et al. 2015). During the 2012–2016 drought, per-capita water use fell in accordance with mandated water cuts but did not rebound to pre-drought levels when the drought broke (ibid.). Accelerating efforts in water recycling, groundwater management, improved conveyance, and ecosystem-based restoration will increase our resilience to climate volatility.

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V. ADAPTATION

Main Takeaways

- Increasingly severe impacts of climate change make adaptation and disaster preparedness unavoidable.
- Adaptation requires participation from all levels of government as well as tribal and government partners.
- Climate change will disproportionately impact low-income communities and communities of color, and adaptation strategies must prioritize the needs of these communities.
- Costs of infrastructure investments to improve climate resilience are less than the costs of failing to adequately adapt and increased disaster spending.
- Distributed renewable energy generation and storage can support resilience hubs where electricity, cooling, shelter, refrigeration and communications can be maintained during grid, extreme weather and other emergencies.

Sector Facts

Adaptation to climate change is woven throughout this report as an underlying element of each section. This section addresses the long-term context and future trends of climate adaptation.

California is one of the biggest and most diverse states in the country making it uniquely vulnerable to climate change. Adaptation to climate change is increasingly becoming unavoid-

able as the U.S. and California face an uptick in climate change fueled natural disasters, such as floods, droughts, sea level rise, heatwaves, and wildfires.

Studies from California's Fourth Climate Assessment estimate that costs from direct climate impacts are likely to be in the tens of billions of dollars stemming from human deaths, damage to coastal properties, droughts and mega-floods (Bedsworth 2018). In 2020, the United States experienced a record 22 natural disasters with at least one billion-dollar in damages (NCEI 2021). In 2021, California experienced two billion-dollar disasters from flooding and the summer heatwave.

The state has approximately 1,100 miles of coastline (Sievanen 2018). Coastal counties account for 22% of California's area, 68% of the population, and 80% of the state's GDP (Sievanen 2018). California's coasts are already experiencing the impacts of climate change. In the past several years there has been a "historic marine heat wave, record harmful algal bloom, fishery closures, and a significant loss of northern kelp forests" (Bedsworth et al 2018). The Fourth Climate Assessment modeled many potential impacts from sea level rise. By 2100, without policy changes 31 to 67% of Southern California beaches may completely erode (Bedsworth et al 2018). Statewide, sea level rise damages could reach nearly $17.9 billion by 2050 from 20 inches of sea-level rise (95th percentile) (Bedsworth 2018). A 100-year flood with this sea level rise would nearly double the costs (Bedsworth 2018). A Union of Concerned Scientists model estimated in 2017 that over 20,000 homes were at risk of becoming chronically inundated by 2045 (Spanger-Siegfried 2018).

There can be deadly consequences if societies fail to prepare for sea level rise. In September 2021, 43 people were killed across the East Coast from flooding related to Hurricane Ida. Many of these were low-income people living in basement apartments (Plumer 2021). Investing in **resilience** measures that can mitigate significant flood damage from sea level rise is less costly than the impacts associated with failing to adequately adapt (LAO 2019).

California also faces a growing issue of water scarcity that is projected to intensify. The state experienced the worst drought on record in the last ten years, and currently 45% of California is facing what NOAA defines an "Exceptional Drought" (NOAA 2021),[26] forcing Governor Newsom to declare a regional drought emergency in 50 counties (Newsom 2021). The drought has led to severe water shortages in the Klamath Valley of Northern California (Marshall-Chalmers 2021). And in Southern California, the first ever water shortage was declared on the Colorado River (U.S. Bureau of Reclamation 2021) and the Lake Oroville reservoir had to take their hydroelectric

[26] The count for heat-related fatalities is still preliminary and will likely rise further.

generator offline for the first time (Nemeth 2021). These two sources supply about half of the water to the Metropolitan Water District of Southern California (The Metropolitan Water District of Southern California 2021). The fourth climate assessment projects that by 2100 the state could lose up to 65% of its snowpack as well as face a growing agrarian demand for water as soil moisture decreases (Pierce et al 2018).

Impacts from climate change as well as increased risks continue to rise and there has not always been a proportionate investment to adapt to the risk. California is facing increased dryness, rising temperatures, and increasing the threat from wildfires. Eight of the ten biggest fires in California have occurred in the last five years (California Department of Forestry and Fire Protection 2021). A good example of this failure to plan and invest is the utility industry and more specifically PG&E who had $30 billion worth of wildfire liability from several fires, including the 2018 Camp Fire which was started by a faulty powerline (Penn 2020) and became the most expensive and deadly fire in the history of California (CalFire). [27] One study in the Fourth Climate Assessment found that if greenhouse gases continue to rise the occurrence of extreme wildfires (burning over approximately 25,000 acres) would increase by nearly 50 percent, and the average area burned statewide would increase by 77% by 2100. The areas with the highest fire risk would see costs for wildfire insurance rise by 18% by 2055 as well as a decrease in the fraction of property insured (Bedsworth et al 2018).

Extreme heat will also be a problem for California. This summer's heat wave across the west killed at least 138 people. [28] From 1999 to 2009 there were 19 heat-related events that had significant impacts on human health including about 11,000 hospitalizations. One problem is that the National Weather Service did not issue a Heat Advisories for 13 of the events (Bedsworth et al 2018). According to the Fourth Climate Assessment, Heat-Health Events (HHEs) will continue to worsen throughout California. According to the Fourth Climate Assessment, Heat Health events are expected to happen four to ten times more often in the Northern Sierra region and occur an average of two weeks longer in the Central Valley by 2050 (Bedsworth et al 2018).

It is also important to remember that the impacts of climate change will not be experienced equally across all people. According to the EPA, socially vulnerable groups are disproportionately likely to be exposed to the highest impacts of climate change (EPA 2021). For example, as California experiences more extreme heat waves it will disproportionately impact low-income communities and communities of color, and access to adaptation strategies such as air condi-

[27] In 2017 those homes are worth a collective $15,064,667,511, house an estimated 50,661 people, and contribute $187,002,506 to the local property tax base.

[28] The count for heat-related fatalities is still preliminary and will likely rise further.

tioning will be critical (Roos 2018). Damage from wildfires disproportionately affects rural and low-income communities because of a lack of resources to invest in preventative measures or rebuild. Additionally, low-income workers may not be able to afford to take days off during days with bad air quality or extreme heat, or may have language barriers that prevent them from gaining knowledge about protective gear or legal rights (Roos 2018). Droughts in California also impact low-income communities and communities of color, particularly people in the Central Valley, where shallow wells have run dry or become contaminated (Roos 2018).

As California enters the next 100 years, its residents will begin to feel the effects of climate change much more acutely. It is imperative that California continues to be a leader on climate adaptation. Currently, there is very little national coordination surrounding climate adaptation and California has a chance to lead and continue to lead these efforts for the country. Additionally, adaptation is an environmental justice issue. The impacts of climate change are not going to be felt uniformly across the state and California has an obligation to work to prevent disparate climate impacts.

Origins and Trends

California has a long history of being a world leader on climate change mitigation efforts. However, climate adaptation efforts began in earnest about a decade ago. Since then, the state of California has created a solid foundation of knowledge, tools, and policy to help the state adapt at all levels and become more resilient to climate change.

Legislative and Policy Context

In relation to its climate mitigation efforts through emissions reductions, California's focus on adaptation is relatively recent. Beginning in 2005, the state began efforts to plan for climate change adaptation. The First California Climate Assessment was released in 2006 in accordance with Executive Order S-3-05 and focused mainly on providing support for reducing GHG emissions (Bedsworth et al 2018). The report led to the passage of AB 32 (CARB 2018). In 2008, Governor Schwarzenegger issued Executive Order S-13-08, which called for the California Natural Resources Agency (CNRA) to develop an adaptation strategy for the state (Schwarzenegger 2018). This led to the 2009 California Climate Adaptation Strategy, which summarized the best-known science on climate change impacts in the state, assesses vulnerabilities, and outlines possible solutions that can be implemented within and across state agencies to promote resiliency (CNRA 2009). In 2009, the Second California Climate Assessment was also released, and it made the case that climate change adaptation measures could save the state money (Bedsworth et al 2018). From the recommendations of the California Climate Adaptation Strategy, the Third Cal-

ifornia Climate Assessment was released in 2012 which had an improved accounting of climate change vulnerabilities and served as the basis for new adaptation laws (Bedsworth et al 2018). In 2014, CNRA issued an updated adaptation report and renamed the report Safeguarding California: California's Climate Adaptation Strategy. The report was updated a third time in January 2018 (CNRA 2018).

In 2015, Governor Brown issued Executive Order B-30-15 (Brown 2015), which called for the reduction of GHG emissions to 40% below 1990 levels by 2030 as well as defining resiliency and calling for a series of adaptation actions. Executive Order B-30-15 called for an update of California's Climate Adaptation Strategy every three years and charged each sector with developing an implementation plan. The Fourth Climate Change Assessment Report was released in 2018 and was designed to support adaptation actions with the goal of lessening economic impacts (Bedsworth et al 2018). Climate Justice and Tribal and Indigenous Communities reports were included in the assessment for the first time. The reports in the fourth assessment show how climate adaptation can reduce climate impacts to disadvantaged communities (Bedsworth et al 2018). In March of 2018, Governor Brown and legislative leaders announced a coordinated effort to develop solutions to make California more resilient to natural disasters and climate change. Part of the announcement was a commitment to work to ensure that future utility and public infrastructure is designed, constructed, and operated to maximize resilience to extreme weather events and natural disasters (Brown 2018). The announcement also included updates to liability rules and regulations for utility services considering the changing climate and the increased severity and frequency of extreme weather events (Brown 2018). These actions and the Fourth Climate Assessment lead to the passage of AB 2800 which created the Climate-Safe Infrastructure Working Group (Bedsworth et al 2018).

In 2019, Governor Gavin Newsom recommended a series of laws through the Governor's Strike Force Task Force report that were passed by the legislature and signed by the Governor. There were 22 bills passed that were mostly aimed at increasing the state's abilities to respond to wildfires and build energy resilience. Additionally, there have been new recommendations from Commission on Catastrophic Wildfire Cost and Recovery, including the recommendation that the state of California still needs to create a sustainable framework for paying for wildfire damages as well as a focused effort by local governments to address the growth of development in the most dangerous parts of the state. In 2020, SB 1320 codified the requirement of the California Climate Change Assessment every five years and Governor Newsom also signed Executive Order N-82-20 which called for accelerated climate action on California's lands and for building resilience across our state, climate smart land management is needed to achieve carbon neutrality, sustain our economy, protect food and water security, and support our unique biodiversity.

Adaptation Tools and Resources

California has developed several different assessment tools that regional and local planners could use to better account for climate change in future infrastructure investments. The Integrated Climate Adaptation and Resiliency Program (ICARP) is the primary source for all tools and information necessary for state, regional, and local governments to plan and implement climate adaptation efforts (OPR 2021). ICARP houses the state's Adaptation Clearinghouse. The Clearinghouse is supposed to be a centralized and accessible source of climate adaptation information for all levels of government including tribal governments. The clearinghouse includes and up-to-date compilation of planning guides, climate change research, case studies, and tools (OPR 2021).

The prime example of an **innovative** adaptation tool in the Clearinghouse is Cal-Adapt. Cal-Adapt was one of the primary recommendations of the 2009 California Climate Adaptation Strategy report. Cal-Adapt is a web-based climate adaptation planning tool designed to provide access to up-to-date, peer-reviewed, and high-quality science, information and data produced by California's scientific and research community (Cal-Adapt 2021). Within Cal-Adapt is a feature called "Local Climate Snapshot Tool." This feature is straightforward and designed for public use. The idea is that anyone can see a quick overview of the climate impacts in their area, such as temperature, precipitation, and wildfire projections. There are a variety of other tools and planning guides that are available through the Clearinghouse to help visualize and plan for sea level rise, extreme heat, and wildfire.

Nationally, NOAA has a great database of climate information as well as visualization on their website climate.gov. Beyond Federal agencies, the Georgetown Climate Center and the United States Climate Alliance both keep track of and summarize state level climate actions. These groups are helpful for pushing climate science forward as well as providing an aggregation of how states and localities address climate change in the US (CNRA 2018).

While California has made considerable headway in identifying recommended practices and necessary steps towards improved climate change adaptation, many of California's communities are still at high risk of climate disaster and adaptation measures are still underfunded and not fully implemented.
Recommendations from the Climate-Safe Infrastructure Working Group build on the Fourth Assessment findings to inform a robust and comprehensive approach to building for the future. The recommendations that will help guide the future of California state adaptation policy include:

- Infrastructure investments that address the greatest risks and investment gaps, as well as where investment can simultaneously reduce inequality and increase opportunity
- State funding to relevant agencies for continued climate change assessment and adaptation research
- Updated infrastructure standards, codes and guidelines to incorporate climate resiliency data (California Natural Resources Agency, 2018)

Currently, California's adaptation efforts are being coordinated by the California Natural Resources Agency (CNRA) and Governor's Office of Planning and Research Integrated Climate Adaptation and Resiliency Program (ICARP). The two agencies work to create a coordinated and holistic response to the impacts of climate change. They are required to publish a statewide strategy every three years that integrate state and local climate adaptation efforts, with a focus on **climate equity** (CNRA 2018). In accordance with AB 1482, CNRA and ICARP will soon release the 2021 California Climate Adaptation Strategy which will further seek to refocus California's adaptation efforts based on the latest research and **technologies.**

In 2021 the California legislature enacted SB 1 to create the state's first comprehensive sea level rise program, which will in turn help local governments mitigate the harmful effects of rising sea levels. The bill allocates $100 million per year towards mitigating negative environmental, social, and economic effects of sea level rise and expands an existing environmental justice grant program by $500,000 specifically for organizations working to manage sea level rise in disadvantaged coastal communities. These funding opportunities will play a critical role in prioritizing **equity** and actively implementing adaptation measures in California's most vulnerable communities.

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VI. CONCLUSION: ECONOMIC IMPERATIVES OF CLIMATE CHANGE FOR CALIFORNIA

Rather than a conventional conclusion, we use this space to emphasize the economic opportunities associated with a zero-carbon California economy.

Today's trade and shipping disruptions intersect with rising labor rates in China to make this an opportune time to reindustrialize California. The term "reindustrialize" is not optimal, since California already has a robust manufacturing sector. But in popular culture it is common to hear of all the industry that has left California (and the U.S.) since the 1980s. Indeed, some manufac-

turing has left, driven out in part by federal policies that encouraged offshoring and a failure of state and federal government to compete against economic development policies (and subsidies in Asian countries).

Today, however, labor costs are rapidly rising in China. [29] Labor is a declining element of manufactured goods, as industry embraces high-tech manufacturing processes. Clean energy and transportation policies play to California's strengths in scientific **innovation** and skilled workforces. Skilled workers and companies are naturally attracted to places with improving air quality, water quality, and climate resilience. Global disruption of shipping is likely to persist and animates on-shoring of manufacturing due to rising cost and time delays of trans-pacific shipping. [30] California industry is uniquely positioned to benefit from these circumstances due to the state's robust transportation links to many parts of the U.S. (Devroom 2014). [31] There are indications that manufacturing has begun to return to California (Maul 2020). [32]

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[29] We wish to emphasize that this interest in the on-shoring industry does not imply or support an anti-China bias. China and California have many beneficial trade relationships. China imports large amounts of manufactured goods and agricultural products from California. Conflict with China is not in the best interest of California. There are ways to influence human rights and environmental issues in China via trade and markets. Unfair competition issues can be addressed without attacking the people and government of China. California has many existing subnational research and policy dialogues with China. It is important to continue and enhance these contacts.

[30] Forty percent of imports into the U.S. pass through California ports.

[31] California has a number of policies designed, in part, to support reshoring of manufacturing. These include:

- "California Competes" program, which provides 180 million in tax credit for businesses that want to relocate or expand to California;
- Tax exemptions for certain industry sectors (e.g. furniture, machinery, fabricated metals, appliances and computers)
- "Made in California" program.

Tax credits/exemptions alone, however, are not enough to attract new industries to California and take advantage of rising labor, shipping and finance costs in Asia, and a "Buy America" sentiment in the U.S. https://blog.idrenvironmental.com/3-trends-impacting-california-manufacturers

[32] According to California Manufacturing Technology Consulting:

> ...before 2020, many manufacturers were considering moving back to the United States. Between 2010 and 2018, over 2,900 companies and 749,000 jobs were brought back to the U.S. due to reshoring. However, COVID-19 has reinvigorated reshoring efforts — the last several months have illuminated the consequences of depending on foreign nations for sourcing goods and emphasized the importance of diversification.

CMTC, Future Manufacturing Trends To Look Out For In 2021. See also www.scmr.com

Other economic opportunities arise from a zero-carbon economy.

- Renewable energy and electrification are, or will shortly, outcompete fossil fuels in the electric power and transportation sectors. Both sectors require or tend to prefer work-forces and production in proximity to markets. This is evident in the rise of electric vehicle manufacturing in California.
- Rising fossil gas prices and technical advances are rapidly narrowing the cost gap between renewable-hydrogen and fossil-based inputs to refining, metals, cement, fertilizer and other industries. Renewable hydrogen, like construction and renewable generation, is a hard to export supply chain because the it needs to be produced near the end uses.
- Local battery production and recycling has cost advantages over foreign and domestic competition, as does production of low carbon fertilizer and biomass feedstocks for aviation fuel.

The following are examples of manufacturing in California that are, or could be driven by climate policy, macro-economic trends, and consumer preferences for low-carbon products:

- Car and truck manufacturing
- Mining and processing of lithium, and other battery raw material
- Vehicle and grid support battery manufacturing (Alamalhodaei 2021)
- Renewable diesel and biofuels
- Lithium Battery recycling industries
- Electronic manufacturing
- Organic farming
- Low-carbon cement and fertilizer production
- Renewable hydrogen production and fueling infrastructure
- Forest products derived from forest wildfire resilience projects
- Oil and gas well closure and remediation
- Methane leak detection, capture and repair operations.

Climate mitigation and adaptation are also important to preserving other economic engines in California. Investments to increase climate resilience and environmental safety are critical to retention of tourism. Successful adaptation policies can stabilize or even lower insurance rates. Growing investor demand for climate friendly investment can, with policy changes, preserve access to capital, and potentially lower cost of capital for California enterprises and government bond issuers. Policies to increase urban density can revitalize cities and stem the fire and

flooding risks associated with sprawl. California's fisheries, timber, and agriculture depend heavily on a stable climate and policies to increase resilience from those impacts of climate change.

These are just a few examples of why a zero-carbon economy in California is not just an environmental imperative, but a jobs-and-economy one as well. We hope this paper, along with our Energy, Environment, and Natural Resources report, will help convince people that changes in government, corporate policy and individual behavior toward climate are important to the future of California.

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