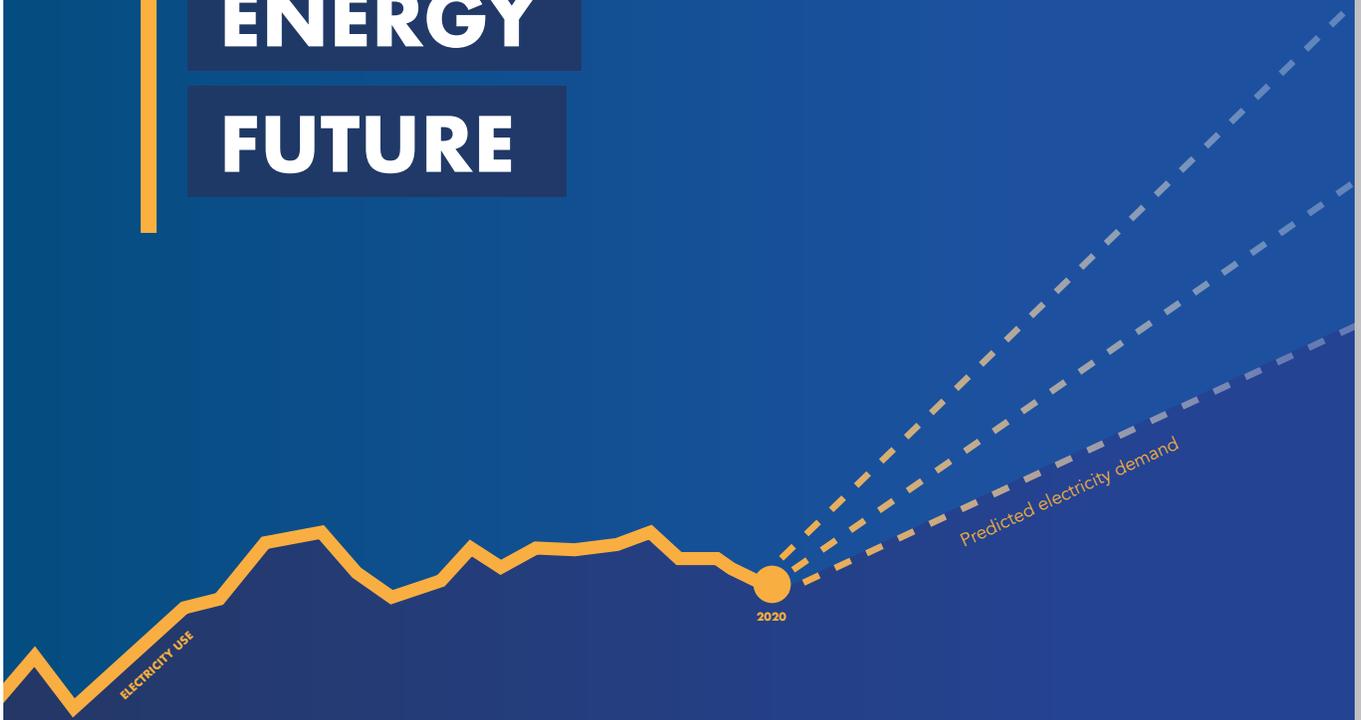


KEY CHALLENGES for

CALIFORNIA'S

ENERGY

FUTURE



8 CHALLENGES ON THE ROAD TO NET-ZERO
OVERVIEW • POLICIES • EQUITY

- 1 ELECTRIFICATION & GRID DEVELOPMENT**
- 2 UTILITY SCALE SOLAR & WIND**
- 3 RELIABILITY & THE NEED FOR CLEAN, FIRM POWER**
- 4 DECENTRALIZING THE GRID**
- 5 CARBON CAPTURE & STORAGE**
- 6 THE FUTURE OF THE NATURAL GAS SYSTEM**
- 7 DECARBONIZING TRANSPORTATION**
- 8 CAP-AND-TRADE**



CCST
CALIFORNIA COUNCIL ON
SCIENCE & TECHNOLOGY

Key Challenges for **CALIFORNIA'S ENERGY FUTURE**

Jane Long, PhD
Steering Committee Chair
Independent Consultant
& CCST Distinguished Expert

Rhianna R. Hohbein, PhD
Lead Author
CCST

Miriam Aczel, PhD
Author
University of California, Berkeley

Steering Committee

Michael Mastrandrea, PhD
Stanford University

Louise Bedsworth, PhD
UC Berkeley

Colin Murphy, PhD
UC Davis

Arun Raju, PhD
UC Riverside

CCST Project Leadership

Brie Lindsey, PhD
Project Manager

Sarah E. Brady, PhD
Project Director & Interim CEO

APRIL 2024

This document reflects the consensus view of the
Steering Committee members listed above.

Acknowledgements

This document has been prepared by the California Council on Science and Technology as part of its Disaster Resilience Initiative (DRI). CCST's Disaster Resilience Initiative is supported by an allocation of one-time funds from the State of California to accelerate the transmission of information between science and technology experts and policymakers to increase California's resilience to ongoing, complex, and intersecting disasters. Thank you to peer reviewers Catherine Garoupa White (Central Valley Air Quality Coalition); Michael Jarred (Regenerative Strategies Consulting); Elena Krieger (PSE Healthy Energy); Achintya Madduri (California Public Utilities Commission); and Daniel Sperling (University of California, Davis), and to Jane Park (California State Assembly) for serving as Report Monitor. Serving as a peer reviewer or report monitor does not imply endorsement of the document or its contents.

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ISBN Number: 978-1-930117-96-9
Key Challenges for California's Energy Future

Citation

California Council on Science and Technology. 2023. Key Challenges for California's Energy Future. Sacramento, CA. <https://ccst.us/reports/key-challenges-for-californias-energy-future>

About CCST

The California Council on Science and Technology is a nonpartisan, nonprofit organization established via the California State Legislature in 1988. CCST responds to the Governor, the Legislature, and other State entities who request independent assessment of public policy issues affecting the State of California relating to science and technology. CCST engages leading experts in science and technology to advise state policymakers—ensuring that California policy is strengthened and informed by scientific knowledge, research, and innovation.

Note

Key Challenges was first released by CCST in June 2023. It has since been updated to include key laws passed during the 2023 legislative session and more recent data (where available). The authors also sought to include any noteworthy updates for any previously described developing situations. The best of the authors' knowledge, it is current as of April 2024. The California Council on Science and Technology has made every reasonable effort to assure the accuracy of the information in this document. However, the contents of this document are subject to changes, omissions, and errors, and CCST does not accept responsibility for any inaccuracies that may occur.

Layout, figure design (6.1, 8.1), and cover by Mikel Shybut, PhD, for CCST. Front cover inspired by Section 1, Figure 1: Predicted growth in electricity demand (CEC, 2022).

For questions or comments on this publication contact:

California Council on Science and Technology
1017 L St, #438
Sacramento, CA 95814
916-492-0996
ccst@ccst.us
ccst.us

A Message from CCST

In early 2022, CCST consulted with more than 30 experts across California’s preeminent academic and research institutions as well as policy makers to identify which energy issues needed additional attention given existing policy conversations and importance to California’s clean energy future. This document provides **high-level summaries of eight key challenges** identified during these conversations.

Several of these challenges are intensely debated. In such cases, we seek not to recommend any particular path but instead to summarize the character of the debate and the central arguments put forth.

This document is not meant to provide a comprehensive technical assessment of these topics but rather preliminary introductions to key energy challenges for the state of California. It has been researched and written by select CCST staff and principal researchers under the guidance of a steering committee having an appropriate range of expertise, a balance of perspectives, and no conflicts of interest. Our hope is to inspire readers to take a deeper dive using other resources, including those highlighted at the end of each section. Where available resources are insufficient to address disagreement, CCST stands ready to work with its academic and research partners to bring additional clarity and relevant information to policymakers.

While Key Challenges can be read start-to-finish, we envisioned its primary use to be as a reference document. As such, each of the eight numbered sections were written to be stand-alone. However, the “Overview of California’s Energy Transition” provides important context. We suggest that it be read before readers consult any of the subsequent sections.

Key Challenges for California’s Energy Future

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Overview of California's Energy Transition

by the Key Challenges for California's Energy Future

Steering Committee:

Jane Long, PhD

Chair, Steering Committee

Independent Consultant & CCST Distinguished Expert

Michael Mastrandrea, PhD

Research Director, Climate and Energy Policy Program

Stanford Woods Institute for the Environment

Louise Bedsworth, PhD

Executive Director

Center for Law, Energy & the Environment,

UC Berkeley

Colin Murphy, PhD

Deputy Director

Policy Inst. for Energy, Environ., and the Economy, UC Davis

Arun Raju, PhD

Assoc. Research Engin. & Assoc. Director-Operations

Center for Environmental Research and Technology,

UC Riverside

The system of energy sources and applications we enjoy today has evolved over hundreds of years and has gone through multiple transformations over that period. Our complex energy system has many interacting technical and governance components. The current energy system emits greenhouse gases and causes other environmental impacts including air, water, and soil pollution. Low-income and communities of color disproportionately experience the negative impacts of our current energy system. Motivated by the dire and mounting risks of climate change and opportunities for a more prosperous, just, and healthy California, we are in the midst of a rapid transition of our energy system and other aspects of our economy that contribute to greenhouse gas emissions. Strong, rapid action guided by careful, evidence-based, and inclusive planning can help minimize the impact of climate change while securing a safe, prosperous, and equitable future for all Californians.

At a high level, decarbonizing energy has **three fundamental elements**:

1. Maximize efficiency and electrify energy use across sectors to the greatest extent possible.
2. Provide affordable, accessible, and reliable carbon-free electricity for a highly electrified economy.
3. Decarbonize activities that cannot be electrified by using clean fuels, efficiency, conservation, and better land use planning and infrastructure.

We are now entering an era of fundamental, large-scale structural changes to the energy system, during which the choices we make must ensure that the future energy system has adequate capacity and is both reliable and cost effective.

Beyond the cost and performance of individual elements in the energy system, decision makers will also need to consider the full system implications and tradeoffs of technology investment choices for reliability, affordability, the environment, and equity.

During this period of transformational change over the next 2-3 decades, we must ensure that the up-front costs of this transition do not create barriers that prevent communities from accessing clean energy technologies.

Since the negative impacts of current fossil-fueled energy and transportation systems disproportionately fall on disadvantaged communities, there is a tremendous opportunity for this transition to help reduce historical inequity and injustice as well.

California has led the nation in innovative climate policy implementation. Over the past two decades, the state has developed and implemented a multipronged strategy that has achieved substantial progress toward reducing California's greenhouse gas emissions, utilizing both sectoral policies and a Cap-and-Trade Program that operates across multiple sectors.¹ Through executive orders by the state's Governors and extensive action by the Legislature, California has set bold and legally binding goals to achieve deep reductions in greenhouse gas emissions by 2030 and carbon neutrality by 2045.

In 2022, CCST staff consulted with policymakers and more than 30 experts across California's preeminent academic and research institutions to identify energy issues that needed additional attention given policy conversations and their importance to California's clean energy future. This process identified eight high-level key challenges, which are explored across the eight sections of this document. These sections highlight major challenges and opportunities, environmental justice and equity considerations, and resources for more information. In the future, other topics could be added to this list of eight as needs and relevance arise. Neither the set of topics chosen for sections nor the sections themselves are comprehensive, but are aimed at succinctly summarizing the status, challenges, and potential solutions.

This Overview describes a framework for California's energy transition and highlights key issues that require attention. Of course, the complexities of this transition cannot be fully represented in a short Overview, nor can this document provide an exhaustive discussion of all relevant information. But it is intended to provide context for the subsequent sections that together can help inform policy making for sustainable, carbon-free, equitable energy for all Californians.

¹ See section 8. **Cap-and-Trade.**

1. Maximize efficiency and electrify energy use across sectors to the greatest extent possible.

For many activities that currently rely on fossil fuel use, electrification provides the best strategy for developing a carbon-free energy system and is a fundamental strategy for meeting California's climate goals.

Transportation and buildings have been the major focus of electrification to date. There are also electrification opportunities in other sectors including industry. This strategy is effective because it is possible to produce electricity from zero and near-zero greenhouse gas emission sources, and electrification solutions often offer efficiency gains compared to conventional fossil-fueled combustion.

In many cases, notably in transportation, more advanced and efficient technologies will replace emission-intensive ones. Investments in these technologies will pay dividends in the form of energy cost savings over the long run. In addition, the value provided by improved health from cleaner air and reduced climate change impacts will almost always outweigh the upfront costs. Attention must be paid to those who bear the costs to ensure equitable access and affordability.ⁱⁱ

2. Provide affordable, accessible, and reliable carbon-free electricity for a highly electrified economy.

Economic growth, population growth, and electrification are expected to increase demand for electricity. This demand can be tempered by continued attention to improving energy efficiency. California has abundant renewable resources. Rapid buildout of renewable energy, particularly utility-scale solar and wind generation, is a central strategy for California's electricity decarbonization. In siting utility-scale solar and wind, the state must meet clean energy needs while also supporting other land use priorities such as agriculture, wildlife conservation, and recreation. Given this, siting and permitting can take far longer than is consistent with the envisioned buildout rate. These projects also often require concurrent development of transmission to interconnect with the electricity grid.

California has a good understanding of the magnitude of the state's potential renewable energy resources, but it needs a realistic assessment of the magnitude of renewable energy that can be practically developed in the next decades given other environmental and social goals as well as legal, geographic, and transmission constraints. The next SB 100 Joint Agency Report, planned for release in 2025, will address the potential land-use impacts of its scenarios and is a step in that direction.ⁱⁱⁱ

Solar and wind power are central to California's carbon-free electricity strategy but present intermittency challenges from day to night and on a seasonal basis that can impact grid reliability if not effectively managed. California is deploying

ⁱⁱ See section 7. **Decarbonizing Transportation** for electrification of the transportation sector. See 6. **The Future of the Natural Gas System** for building electrification. See 1. **Electrification and Grid Development** for the impact of electrification on California's aging grid and the needs for grid upgrades to accommodate decarbonization.

ⁱⁱⁱ See sections 2. **Utility-Scale Solar and Wind Development**, 3. **Reliability and the Need for Clean, Firm Power**, and 1. **Electrification and Grid Development**.

energy storage, demand response, and other strategies to manage the shorter-term intermittency of these resources. Additionally, California will need clean, firm power to manage the longer-term intermittency of renewable energy, for example, in winter periods when renewable energy supply is at a minimum. Clean, firm power—such as geothermal power, power from clean fuels, nuclear power, or gas with carbon capture and storage—can be available whenever needed and for as long as needed.

Ultimately, a diverse electricity generation portfolio that also includes clean, firm power would be more resilient to seasonal fluctuations and extreme weather events. As important as clean, firm power is, all the primary technologies have environmental impacts, drawbacks, and obstacles—like any power. California will need to make some difficult but critical decisions in deciding how to incorporate clean, firm power into its electricity sector planning.^{iv}

As more vehicles and homes are powered by electricity, there will be increasing demand placed on California's electricity grid. These new and increasing demands require upgrades and expansion of a grid that is already challenged by wildfires, extreme heat, and weather events. Both transmission and distribution infrastructure will need to be upgraded to accommodate additional demand and new energy resources. Microgrids have also been identified as one way to increase energy reliability and energy resilience, particularly for communities that are disproportionately burdened by grid disruptions. If effectively leveraged, distributed energy resources can enhance energy resilience for consumers and the grid at large.^v

California needs careful thought about how to pay for the energy transition including necessary generation, energy storage, and upgrades to the grid. If many of these costs go into utility rates, load growth may not be adequate to keep costs affordable for consumers. Consequently, other funding mechanisms should be considered as well.

3. Decarbonize activities that cannot be electrified by using clean fuels, efficiency, conservation, and better land use planning and infrastructure.

Electrification is almost always the best option for decarbonization, but some activities that currently use fossil fuels cannot easily be electrified. These include some forms of heavy-duty transport, aviation, and some industrial applications that either require high quality heat or fossil fuels as feedstocks for producing other materials (like plastics and chemicals). For most of these applications, the most straightforward decarbonization path would be to replace fossil fuels with clean fuels. These clean fuels all require energy for production and tend to be quite expensive, but they provide a high degree of flexibility. While few clean fuels are truly carbon neutral, many offer the opportunity to significantly reduce greenhouse gas emissions.^{vi}

Hydrogen represents California's primary option for clean fuel, including either "green" hydrogen produced using renewable energy to split water molecules, or "blue" hydrogen formed from

^{iv} See sections **3. Reliability and the Need for Clean, Firm Power**, **5. Carbon Capture and Storage**, and **6. The Future of the Natural Gas System**.

^v See sections **1. Electrification and Grid Development** and **4. Decentralizing the Grid**.

^{vi} See sections **6. The Future of the Natural Gas System**, **5. Carbon Capture and Storage**, **3. Reliability and the Need for Clean, Firm Power** and **7. Decarbonizing Transportation**.

methane and requiring sequestration of co-produced carbon dioxide (CO₂).^{vii}

Hydrogen is an indirect greenhouse gas. In evaluating hydrogen as a clean fuel, care should be taken to ensure that the excess warming due to hydrogen leakage in various applications does not offset the benefit of using hydrogen as a clean fuel.

Limited alternatives for clean fuel might include a) synthetic hydrocarbons formed in a process that captures carbon from biomass or the atmosphere; b) biofuels, including advanced processes that do not use edible crops as feedstock; c) renewable hydrogen produced by electrolysis or steam methane reformation with carbon capture; or d) ammonia. The costs and consequences of these or other options require evaluation. Typically, clean fuels are more expensive and limited in supply compared to their fossil alternatives.

Choices for clean fuel require a full evaluation of unintended consequences and tradeoffs. Each proposed fuel choice will need life-cycle analysis that includes assessment of indirect impacts. Clean fuels will be limited, so California needs a highest and best use plan for whatever clean fuel can be brought to market.

Carbon capture and storage may be an option for decarbonizing some industries such as cement manufacturing. The cement industry is a major contributor of greenhouse gas emissions resulting equally from the use of fossil fuels to heat limestone and the CO₂ released from the heated limestone itself.^{viii}

While greenhouse gas emissions have declined in most sectors, transportation emissions have remained relatively static due to continued growth in vehicle miles traveled (VMT). Reducing

VMT—which can be accomplished by implementing more compact development patterns, supporting public transportation, and placing housing, jobs, and services in closer proximity to one another—is necessary to meet state greenhouse gas reduction targets. *SB 375* (Steinberg, 2008) requires regional planning organizations to develop Sustainable Community Strategies that lower emissions by facilitating walkability, biking, public transportation, transit-oriented development, and other land use strategies. However, funding constraints, housing shortages, and the inability to enforce Sustainable Community Strategies—among other factors—hamper the State's ability to reduce VMT.

Reducing VMT will require increased collaboration between state, local, and regional agencies to implement compact development patterns; funding for housing near jobs and services; investment in public transit, walking, and biking infrastructure; and robust public engagement.^{ix}

California has the legal and regulatory framework in place to decarbonize energy in the state by midcentury. Electrification and innovation can vastly reduce the use of fossil fuels and increase energy efficiency across many sectors. A combination of renewable energy, energy storage, and clean, firm power can decarbonize electricity production. For any applications that present challenges for electrification, clean fuels, efficiency, conservation, and land-use planning become critical and primary strategies to help California achieve its climate goals.

California needs strong, rapid implementation coupled with careful and inclusive planning for a more prosperous, just, and healthy future.

vii See sections **5. Carbon Capture and Storage** and **6. The Future of the Natural Gas System**.

viii See section **5. Carbon Capture and Storage**.

ix See section **7. Decarbonizing Transportation**.

Electrification & Grid Development

Grappling with an aging power grid and a rapidly expanding demand for electricity.

Overview

California's decarbonization strategy calls for vehicle and building **electrification***, but as more vehicles and homes are powered by electricity, there will be increasing demand placed on California's grid. The California Air Resources Board (CARB) estimates that electricity demand could increase in the state by 76% by 2045 (relative to demand in 2022).¹

The challenge of meeting these new demands comes alongside California's concurrent transition to 100% renewable and zero-carbon resources as mandated by *SB 100 (de León, 2018)* and the integration of **distributed energy resources** like rooftop solar. These new and increasing demands require upgrades and expansion of a grid that is already challenged by wildfires, extreme heat, and weather events.^{2,3}

Transmission infrastructure carries high-voltage electricity over long distances to distribution substations. These substations reduce the voltage and then transfer the power to distribution networks that deliver the lower voltage electricity over short distances to consumers. Both transmission and distribution infrastructure will need to be upgraded to accommodate additional demand and new energy resources. The California Independent System Operator (CAISO)—which oversees the operation of approximately 80% of California's bulk electric power system, transmission lines, and electricity market—estimates that adding and upgrading transmission lines to meet predicted demand will cost \$30.5 billion over the next 20 years.⁴

1 California Air Resources Board. (2022). 2022 Scoping Plan for Achieving Carbon Neutrality. Available at: <https://ww2.arb.ca.gov/sites/default/files/2022-11/2022-sp.pdf>.

2 California ISO. (2022). California ISO extends Flex Alert to Thursday, Sept. 1. Available at: <http://www.caiso.com/Documents/california-iso-extends-flex-alert-to-thursday-sept-1.pdf>.

3 California ISO, California Public Utilities Commission, and California Energy Commission. (2021). Root Cause Analysis: Mid-August 2020 Extreme Heat Wave. Available at: <http://www.caiso.com/Documents/Final-Root-Cause-Analysis-Mid-August-2020-Extreme-Heat-Wave.pdf>.

4 California ISO. (2022). 20-Year Transmission Outlook. Available at: <http://www.caiso.com/InitiativeDocuments/Draft20->

* Find **bold** words in the Glossary (Appendix A).

Increasing demand for electricity

Improved energy efficiencies will mitigate some growth in demand but will be insufficient to offset the predicted increase in demand from population growth, economic growth, and electrification efforts (see **Figure 1.1**).

A number of key policies are driving the adoption of electric vehicles in California. For example, Executive Order N-79-20 (2020) mandates that 100% of new vehicle sales be zero-emission vehicles (ZEVs) by 2035. CARB's Advanced Clean Cars II Regulation sets interim targets on the path to 100% passenger ZEVs by 2035,⁵ while the Advanced Clean Fleet Regulation establishes targets for medium- and heavy duty vehicles.⁶ Vehicle electrification will increase needs for grid upgrades to accommodate vehicle charging.⁷ For example, modeling suggests that the addition of 5 million ZEVs by 2030 would increase electricity demands by 10%⁸ if not managed with **demand response** technologies.

To support building decarbonization, the California Energy Commission (CEC) updated the Energy Code to encourage electric heat pumps and electric ovens over natural gas-powered appliances. Increasing numbers of California communities are discouraging or instituting bans on natural gas in new home construction (see **Section 6**).

As of 2020, 72% of households in California had air conditioning.⁹ As natural gas heaters are swapped for electric heat pumps—which also provide air conditioning in addition to space heating—this percentage is likely to increase. Increasing temperatures and heat waves caused by climate change will increase reliance on air conditioning.¹⁰

Carbon capture and storage (CCS), direct air capture of carbon, and the production of hydrogen via electrolysis are all energy intensive processes. Current forecasts, such as *CAISO's 20-year Transmission Outlook*, assume these technologies—should they come to play a prominent role in California's energy future—will use power generated onsite rather than drawn from the grid.¹¹ However, if they require grid power, these technologies will place an even greater demand on the power system.

Some newly electrified end uses (like electric vehicles and water heating) could be configured to draw energy from the grid only when energy costs are low and the grid is not stressed (because demand is low or because there is excess renewable energy being generated). This is known as **load shifting** and is a form of demand response that could help reduce the need for costly transmission and distribution upgrades. Demand response is covered in more detail in **Section 3**.

YearTransmissionOutlook.pdf.

5 California Air Resources Board. (2022). Advanced Clean Cars II. Available at: <https://ww2.arb.ca.gov/our-work/programs/advanced-clean-cars-program/advanced-clean-cars-ii>.

6 California Air Resources Board. (2023). Advanced Clean Fleets. Available at: <https://ww2.arb.ca.gov/our-work/programs/advanced-clean-fleets>.

7 Jenn, A., and Highleyman, J. (2022). Distribution Grid Impacts of Electric Vehicles: A California Case Study. *Iscience*, 25(1), pp. 103686.

8 Jenn, A., and Highleyman, J. (2022). Distribution Grid Impacts of Electric Vehicles: A California Case Study. *Iscience*, 25(1), pp. 103686.

9 U.S. Energy Information Administration. (2023). Highlights for Air Conditioning in U.S. Homes by State, 2020. Available at: [https://www.eia.gov/consumption/residential/data/2020/state/pdf/State Air Conditioning.pdf](https://www.eia.gov/consumption/residential/data/2020/state/pdf/State%20Air%20Conditioning.pdf).

10 Aufhammer, M. (2018). Climate Adaptive Response Estimate: Short and Long Run Impacts of Climate Change on Residential Electricity and Natural Gas Consumption. Available at: https://www.energy.ca.gov/sites/default/files/2019-11/Energy_CCCA4-EXT-2018-005_ADA.pdf.

11 California ISO. (2022). 20-Year Transmission Outlook. Available at: <http://www.aiso.com/InitiativeDocuments/Draft20-YearTransmissionOutlook.pdf>.

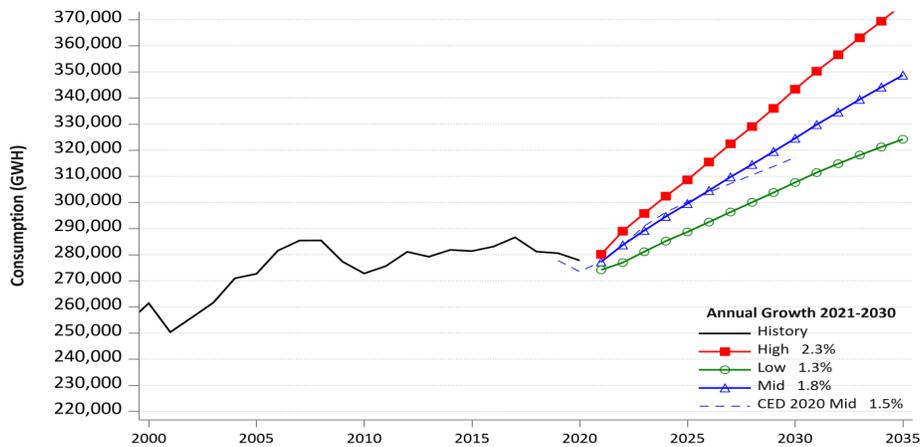


Figure 1.1. Predicted growth in electricity demand by 2035 compared to historical electricity consumption trends. Model includes low, medium, and high demand scenarios that reflect differing assumptions about key variables such as electric vehicle adoption and economic growth rates.

Source: California Energy Commission. (2022). Final 2021 Integrated Energy Policy Report Volume IV Energy Demand Forecast.

Changing energy supplies

These additional demands on the grid coincide with a requirement for increasingly higher percentages of electricity generation to come from renewable resources which are predominantly **intermittent** (as per [SB 1078, Sher, 2022](#); [SB 350, de León 2015](#); [SB 100, de León, 2018](#); and [SB 1020, Laird, 2022](#)) and as current sources of **firm power** go offline. For example, [SB 100, de León, 2018](#) and [AB 1279 \(Muratsuchi, 2022\)](#), effectively require the elimination of any natural gas plants without CCS from the electricity sector.

Diablo Canyon Power Plant (DCPP)—California’s last operational nuclear facility which currently provides roughly 6% of California’s power¹²—is scheduled to close no later than 2030 (as per [SB 846, Dodd, 2022](#)).¹³

Fossil fuels and DCPP will need to be replaced by a combination of renewable resources like solar, wind, geothermal, **biomethane**, and hydroelectric power and complemented by additional energy storage.¹⁴ Modeling for [CARB’s 2022 Scoping Plan](#) suggests that renewable and zero-carbon power capacity will need to increase by 180 **gigawatts (GW)** by 2045. Annual build rates for solar power and battery storage will have

¹² Nyberg, M. (2022). 2022 Total System Electric Generation. *California Energy Commission*. Available at: <https://www.energy.ca.gov/data-reports/energy-almanac/california-electricity-data/2022-total-system-electric-generation>.

¹³ Dodd, B. (2022). SB 846. Diablo Canyon Powerplant: Extension of Operations. California State Legislature.

¹⁴ California Air Resources Board. (2022). 2022 Scoping Plan for Achieving Carbon Neutrality. Available at: <https://ww2.arb.ca.gov/sites/default/files/2022-11/2022-sp.pdf>.

to increase 60% and 700%, respectively (compared to historic maximums) to meet California's 2045 decarbonization targets.¹⁵ Some natural gas capacity will need to be replaced with other sources of clean, firm power (see **Section 3**).¹⁶ As these new energy resources come online, new and upgraded transmission infrastructure will be required to move the electricity from generation sites to consumers.

As of July 2023, 15 GW of rooftop solar had been installed in California.¹⁷ Rooftop solar generation has reduced demand on the electric grid by about 25% during periods of solar power production, i.e., when the sun is shining.¹⁸ While distributed energy resources may improve grid resilience if dispatched appropriately,¹⁹ they introduce new challenges related to grid interconnection and energy economics (see Section 4 for more details). For example, distribution networks can only accommodate a certain number of distributed energy resources before they require upgrading—this is known as the **hosting capacity**.

Reliability challenges

California's utilities have faced constraints on their ability to provide reliable power to consumers. For example, in August 2020, CAISO was

forced to institute rotating outages for the first time in nearly 20 years during an extreme heat wave when a combination of factors—including increased demand for air conditioning, decreased generation efficiency at natural gas power plants, and limited energy imports—created an energy shortfall.²⁰ These blackouts affected hundreds of thousands of residents.²¹

Climate change is predicted to increase the frequency of these extreme heat events. California came close to a repeat of this experience in early September 2022, when CAISO issued Flex Alerts for 10 straight days, urging consumers to conserve electricity between 4:00 p.m. to 9:00 p.m. during a record-breaking heat wave.²²

In early 2022, the CEC had predicted that the combination of extreme heat, drought, wildfires, and project delays could result in an energy shortfall of up to 7 GW that summer, growing to 10 GW by 2025.²³ To help address this, [SB 846 \(Dodd, 2022\)](#) provided a pathway to extend DCPD operations through 2030 (DCPD was initially slated to close in 2025).

[AB 205 \(Committee on Budget, 2022\)](#) created a Strategic Reliability Reserve Fund at the Department of Water Resources (DWR) to support the procurement of 5 GW of generation that

15 California Air Resources Board. (2022). 2022 Scoping Plan for Achieving Carbon Neutrality. Available at: <https://ww2.arb.ca.gov/sites/default/files/2022-11/2022-sp.pdf>.

16 Gill, L., Gutierrez, A., and Weeks, T. (2021). 2021 SB 100 Joint Agency Report, Achieving 100 Percent Clean Electricity in California: An Initial Assessment. *California Energy Commission, California Public Utilities Commission and California Air Resources Board*. Publication number: CEC-200-2021-00. Available at: <https://www.energy.ca.gov/publications/2021/2021-sb-100-joint-agency-report-achieving-100-percent-clean-electricity>.

17 California Solar Initiative. (2023). California Distributed Generation Statistics. Accessed on 10/10/2023 at: <https://www.californiadgstats.ca.gov/>.

18 California Public Utilities Commission. (ND). Modernizing California's Net Energy Metering Program to Meet Our Clean Energy Goals. Available at: <https://www.cpuc.ca.gov/industries-and-topics/electrical-energy/demand-side-management/net-energy-metering/nem-revisit/net-billing-tariff-fact-sheet>.

19 Rickerson, W. et al. (2019). The Value of Resilience for Distributed Energy Resources: An Overview of Current Analytical Practices. National Association of Regulatory Utility Commissioners. Available at: <https://pubs.naruc.org/pub/531AD059-9CC0-BAF6-127B-99BCB5F02198>.

20 California ISO, California Public Utilities Commission, and California Energy Commission. (2021). Root Cause Analysis: Mid-August 2020 Extreme Heat Wave. Available at: <http://www.caiso.com/Documents/Final-Root-Cause-Analysis-Mid-August-2020-Extreme-Heat-Wave.pdf>.

21 California ISO, California Public Utilities Commission, and California Energy Commission. (2021). Root Cause Analysis: Mid-August 2020 Extreme Heat Wave. Available at: <http://www.caiso.com/Documents/Final-Root-Cause-Analysis-Mid-August-2020-Extreme-Heat-Wave.pdf>.

22 California ISO. (2022). Flex Alert Extended to Sunday, Sept. 4 Due to High Heat. Available at: <http://www.caiso.com/Documents/flex-alert-extended-to-sunday-sept-4-due-to-high-heat.pdf>.

23 California Energy Commission. (2022). Draft 2022 Integrated Energy Policy Report Update. Available at: <https://www.energy.ca.gov/data-reports/reports/integrated-energy-policy-report/2022-integrated-energy-policy-report-update>.

can be called upon when the state is faced with a potential energy shortfall. [AB 1373 \(Garcia, 2023\)](#) grants DWR additional authority to act as a central procurement entity for eligible clean energy resources through 2035. This is significant as centralized procurement can better drive the significant investments necessary for developing large-scale clean energy projects.

The California Public Utilities Commission (CPUC) ordered utilities to procure an additional 4 GW of capacity by 2026 on top of the historic 11.5 GW procurement order for renewable and zero-carbon resources it had issued in 2021.²⁴

Congestion on the transmission grid can create pockets of imbalances where it is difficult to either export excess renewable generation out of an area or to import renewable energy into an area to meet demand. The reliable delivery of renewable energy resources requires the resolution of both types of constraints.

An increasing reliance on solar power introduces challenges of maintaining grid reliability and meeting demand after the sun has gone down—something currently largely accomplished with natural gas power plants. Energy storage can help by capturing excess renewable energy produced during the day and discharging it back to the grid in the evening. CAISO now has more than 5 GW of battery storage.²⁵ This new battery storage helped prevent rotating outages during the September 2022 heat wave.²⁶ See **Section 3** for more on energy storage and other solutions for improving grid reliability.

Relevant State Institutions

- California Air Resources Board (CARB)
- California Department of Water Resources (DWR)
- California Energy Commission (CEC)
- California Independent System Operator (CAISO)
- California Public Utilities Commission (CPUC)
- Assembly Budget Subcommittee 3 on Climate Crisis, Resources, Energy, and Transportation
- Assembly Utilities and Energy Committee
- Assembly Natural Resources Committee
- Senate Budget Subcommittee 2 on Resources, Environmental Protection and Energy
- Senate Energy, Utilities and Communications Committee
- Senate Natural Resources and Water Committee
- Joint Leg. Committee on Climate Change Policies

Scale, impacts, and challenges of necessary grid infrastructure development

CAISO estimates that the high-voltage bulk infrastructure necessary to transition to clean energy by 2040 will require a \$30.5 billion investment.²⁷

The construction of new generation and transmission infrastructure impacts both land use and biodiversity.²⁸

Potential transmission line sites are constrained by the size of site; the number of landowners (creating complications including reaching right-of-way agreements); public opposition to projects; environmental sensitivities or other land-use

24 California Public Utilities Commission. (2023). CPUC Augments Historic Clean Energy Procurement Goals to Ensure Electric Reliability. Accessed on 5/25/2023 at: <https://www.cpuc.ca.gov/news-and-updates/all-news/cpuc-augments-historic-clean-energy-procurement-goals-to-ensure-electric-reliability-2023>.

25 California ISO. (2023). Special Report on Battery Storage. Available at: <http://www.caiso.com/Documents/2022-Special-Report-on-Battery-Storage-Jul-7-2023.pdf>.

26 California ISO. (2022). Summer Market Performance Report. Available at: <http://www.caiso.com/Documents/SummerMarketPerformanceReportforSeptember2022.pdf>.

27 California ISO. (2022). 20-Year Transmission Outlook. Available at: <http://www.caiso.com/InitiativeDocuments/Draft20-YearTransmissionOutlook.pdf>.

28 Biasotto, L.D., and Kindel, A. (2018). Power Lines and Impacts on Biodiversity: A Systematic Review. *Environmental Impact Assessment Review*, 71, pp. 110-119.

restrictions; and the need for upgrades to sites that make construction prohibitively expensive.²⁹

Developing and upgrading transmission infrastructure requires complex coordination among agencies including CAISO, CARB, CEC, CPUC, and the Governor's Office, as well as counties, utilities, labor, project developers, communities, and more. State agencies already coordinate their various grid planning efforts to ensure needed transmission infrastructure is built.

More work is being done to incorporate other interested parties. For example, in 2021, the Energy Unit was created at the Governor's Office of Business and Economic Development ([AB 137, Committee on Budget, 2021](#)).

Transmission infrastructure projects require long lead times (CAISO estimates eight to 10 years for some projects) primarily due to right-of-way acquisition and environmental permitting requirements.³⁰ These planning horizons are in tension with the necessary build out pace. [SB 149 \(Cabrallero, 2023\)](#) helps to address this by requiring expedited judicial review for qualifying energy infrastructure projects that have been challenged through the California Environmental Quality Act (CEQA). [AB 205 \(Committee on Budget, 2022\)](#) grants the CEC authority to certify renewable facilities and associated transmission lines, providing developers an alternative pathway to going through local permitting processes.

Many distribution networks will also require upgrades in a high-electrification future. One model suggests that by 2030, ZEV charging will necessitate upgrades to roughly 20% of **feeder circuits** across the Pacific Gas & Electric service territory; only one-fifth of those are currently scheduled for

upgrades.³¹ These upgrades may create bottlenecks that slow the pace of electrification if not proactively addressed.³²

The process of either connecting new customers to the grid or upgrading the electrical panels of existing customers to support greater energy demands (e.g., because new electric vehicle chargers are installed) is known as "interconnection" or "energization." In April 2023, a coalition of more than 35 organizations (including nonprofits, cities, towns, counties, community choice aggregators, and business groups) wrote a letter urging the California Legislature to address interconnection delays in California. According to the coalition, these delays have imperiled clean energy projects across the state.³³

[SB 410 \(Becker, 2023\)](#)—known as the Powering up Californians Act—aims to help to address current and projected grid interconnection delays by requiring the CPUC to set reasonable target timelines for grid connections by September 2024. Utility providers will be required to report their performance at least annually and to take remedial actions to address unreasonable delays if necessary.

[AB 50 \(Wood, 2023\)](#) helps to address existing interconnection backlogs and requires electrical corporations to review and, if necessary, revise their distribution planning processes to better predict demand.

As per [AB 1373 \(Garcia, 2023\)](#), the CEC will assess barriers to interconnection as part of their 2025 Integrated Energy Policy Report.

Interconnection delays have recently received attention at the national level as well. In 2023, the

29 Colvin, M., and Prochnik, J.S. (2021). Building a Zero Carbon California Grid: Moving from Models to an Implementable Plan. *California Air Resources Board*. Available at: <https://ww2.arb.ca.gov/sites/default/files/2021-11/EDF-sp22-electricity-ws-11-02-21.pdf>.

30 California ISO. (2022). 20-Year Transmission Outlook. Available at: <http://www.caiso.com/InitiativeDocuments/Draft20-YearTransmissionOutlook.pdf>.

31 Jenn, A., and Highleyman, J. (2022). Distribution Grid Impacts of Electric Vehicles: A California Case Study. *Iscience*, 25(1), pp. 103686.

32 Brockway, A. et al. (2022). Can Distribution Grid Infrastructure Accommodate Residential Electrification and Electric Vehicle Adoption in Northern California? Energy Institute at Haas Working Paper 327. Available at: <https://haas.berkeley.edu/wp-content/uploads/WP327.pdf>.

33 The County of Humboldt et al. (2023). Over 35 Organizations Urge the California Legislature to Address the State's Interconnection Crisis and Ensure Timely and Equitable Access to the Electrical Grid. Available at: <https://efiling.energy.ca.gov/GetDocument.aspx?tn=250310&DocumentContentId=85042>.

U.S. Department of Energy initiated the Interconnection Innovation e-Xchange (i2X) to facilitate dialogue among diverse stakeholders across the U.S. in pursuit of solutions to interconnection issues.³⁴ In October 2023, the i2X released a draft roadmap for improving the interconnection process with 34 discrete recommendations.³⁵

Both distribution and transmission lines may pose wildfire risks. Undergrounding high-risk power lines is one of the most effective mitigation methods.³⁶ However, constructing underground lines costs significantly more than aboveground lines (\$3 to \$5 million per mile versus \$800,000 for distribution lines).³⁷

Environmental Justice and Equity Considerations

Grid failure disproportionately impacts low-income individuals and communities. For example, replacing spoiled food is more economically burdensome for low-income households than it is for wealthier households.

Grid failure and rotating outages are life-threatening for medically vulnerable individuals who live at home and rely on medical equipment for life support.

California, and the U.S. more broadly, has a history of redlining—a practice in which public and private institutions denied or severely restricted financial services to Black and other people of color.³⁸ Race, as well as environmental factors, were criteria used to assess creditworthiness of neighborhoods. The legacies of this practice continue in California whereby underinvestment in low-income neighborhoods and communities of color has resulted in less access to clean energy technologies.³⁹

The costs of building out this energy infrastructure are largely borne by energy utility customers via their monthly bills. Regulatory processes that address infrastructure decommissioning and rate structure modifications may help to provide an orderly transition away from fossil fuels and lessen negative impacts on low-income communities.⁴⁰

AB 205 (Committee on Budget, 2022) instructs the CPUC to establish an income-based rate structure for fixed charges (i.e., charges not based on power consumption). The CPUC has received proposals for new income-based rate structures from California's three largest **investor-owned utilities**.⁴¹ The CPUC will decide whether to adopt these proposed changes in July 2024.

34 Office of Energy Efficiency and Renewable Energy. (2023). Interconnection Innovation e-Xchange. U.S. Department of Energy. Accessed 10/24/2023 at: <https://www.energy.gov/eere/i2x/interconnection-innovation-e-xchange>.

35 Interconnection Innovation e-Xchange. (2023). Draft Report: Transforming Interconnection: Paving the Way to Reliably Achieve an Energy Transition on the U.S. Transmission System by 2035. Available at: <https://www.energy.gov/sites/default/files/2023-10/Draft%20i2X%20Transmission%20Roadmap.pdf>.

36 California Public Utilities Commission. (2021). CPUC Undergrounding Programs Description. Accessed on 11/29/2022 at: <https://www.cpuc.ca.gov/industries-and-topics/electrical-energy/infrastructure/electric-reliability/undergrounding-program-description>.

37 Pacific Gas & Electric. (ND). Facts about Undergrounding Electric Lines. Accessed on 11/15/2022 at: <https://www.pgecurrents.com/2017/10/31/facts-about-undergrounding-electric-lines/>.

38 California Environmental Protection Agency. (2021). Pollution and Prejudice Redlining and Environmental Injustice in California. Available at: <https://storymaps.arcgis.com/stories/f167b251809c43778a2f9f040f43d2f5>.

39 California Environmental Protection Agency. (2021). Pollution and Prejudice Redlining and Environmental Injustice in California. Available at: <https://storymaps.arcgis.com/stories/f167b251809c43778a2f9f040f43d2f5>.

40 Southern California Edison. (2019). Pathway 2045 Update to the Clean Power and Electrification Pathway. Available at: https://download.newsroom.edison.com/create_memory_file/?f_id=5dc0be0b2cfac24b300fe4ca&content_verified=True.

41 Southern California Edison, Pacific Gas and Electric, and San Diego Gas and Electric. (2023). Joint Testimony of Southern California Edison Company, Pacific Gas and Electric Company, and San Diego Gas and Electric Company (the Joint IOUs) Describing Income-Graduated Fixed Charge Proposals. Available at: <https://www.cpuc.ca.gov/-/media/cpuc-website/divisions/energy-division/documents/demand-response/demand-response-workshops/advanced-der---demand-flexibility-management/joint-iou-opening-testimony-exhibit-1.pdf>.

Relevant Policies

(Laws/Regulations)

Renewables Portfolio Standard (RPS) Program

SB 1078 (Sher, 2002)

The RPS Program mandated an initial 20% of electricity retail sales to come from renewable resources by 2017. SB 1078 defined eligible renewables to include small hydropower, solar, wind, and geothermal, among others. [SB 350 \(de León, 2015\)](#) introduced interim annual RPS targets with three-year compliance periods and requires 65% of RPS procurement to be derived from long-term contracts of 10 or more years. [SB 100 \(de León, 2018\)](#) increased the RPS target to 60% by 2030 and requires all the state's electricity to come from carbon-free resources by 2045.

Clean Energy and Pollution Reduction Act

SB 350 (de León, 2015)

SB 350 increases California's renewable electricity procurement goal from 33% by 2020 to 50% by 2030, thus supporting greater use of resources eligible for the Renewables Portfolio Standard.

SB 350 mandates doubling statewide energy efficiency savings for electricity and natural gas end uses by 2030.

SB 350 requires large utilities to submit integrated resource plans (IRPs) on how they will meet consumers' needs, reduce greenhouse gas emissions, and increase use of clean energy resources.

The 100 Percent Clean Energy Act of 2018

SB 100 (de León, 2018)

SB 100 establishes a goal that by 2045 all retail electricity sold in California and state agency

electricity needs will be powered by renewable and zero-carbon resources.

SB 100 updates the Renewables Portfolio Standard to ensure that by 2030 at least 60% of state's electricity is renewable.

SB 100 requires the California Energy Commission, California Public Utilities Commission and California Air Resources Board to use existing laws to achieve 100% clean electricity and issue joint policy on SB 100 by 2021 and every four years after that.

Clean Energy, Jobs, and Affordability Act of 2022

SB 1020 (Laird, 2022)

SB 1020 added interim targets for renewable energy and zero-carbon electricity retail sales as legislated in [SB 100 \(de León, 2018\)](#): 90% by 2035 and 95% by 2040. SB 1020 requires state agencies to use 100% renewable energy and zero-carbon resources by 2030 and establishes a Climate and Equity Trust fund to manage rising electricity rates that threaten affordability.

Energy Storage Systems

AB 2514 (Skinner, 2010)

AB 2514 encourages the incorporation of storage systems within the electric grid. The benefits to adding storage include integrating greater quantities of renewable energy into the grid, reducing need for fossil-fueled power plants and transmission, and reducing fossil fuel generation during peak load periods.

Energy

AB 205 (Committee on Budget, 2022)

AB 205 provides funding for the California Energy Commission to establish distributed energy resource investments and demand response programs.

AB 205 also established the Strategic Reliability Reserve Fund to be overseen by the California Department of Water Resources. The 2022 Budget allocated \$2.2 billion to the Reliability Reserve Fund to support the procurement of up to 5

GW of generation that can be called upon when the state is faced with a potential energy shortfall.

Energy

AB 1373 (Garcia, 2023)

This law allows the California Department of Water Resources to act as a central procurement entity for eligible clean energy resources through 2035.

AB 1373 requires the CEC to assess barriers to interconnection—and to propose solutions to address those barriers—as part of its 2025 Integrated Energy Policy Report.

AB 1373 provides the CPUC with additional authority to ensure that publicly owned utilities are procuring enough energy to maintain a reliable grid and to penalize them if they are not (the same requirements already apply to investor-owned utilities).

California Environmental Quality Act: Judicial Streamlining

SB 149 (Caballero, 2023)

SB 149 makes qualifying energy infrastructure projects eligible for judicial streamlining. Energy infrastructure projects that have been challenged through the California Environmental Quality Act that are certified by the Governor as eligible infrastructure must have their cases resolved (to the extent feasible) within 270 days.

Powering Up Californians Act

SB 410 (Becker, 2023)

SB 410 requires the CPUC to develop reasonable average and maximum interconnection timelines (i.e., the time it takes to either connect new customers to the grid or to provide upgraded service to an existing customer to meet new energy demands, such as electric vehicle chargers). Utility providers will be required to report their performance to the CPUC annually and to take remedial actions if necessary.

Read More

2022 Scoping plan for achieving carbon neutrality

California Air Resources Board (2022).

Integrated Energy Policy Report Volume IV: Energy Demand Forecast.

California Energy Commission. (2021).

20-Year Transmission Outlook

California ISO (2022).

Distribution grid impacts of electric vehicles: A California case study.

Jenn, A., and Highleyman, J. (2022). *iScience*, 25(1).

Electricity Grids and Secure Energy Transitions

International Energy Agency. (2023).

Clean firm power is the key to California's carbon-free energy future.

Long, J.C.S. et al. (2021). *Issues in Science and Technology*.

Public Utilities: Timely Service: Customer Energization

AB 50 (Wood, 2023)

This law requires electrical corporations to complete at least 80% of interconnection requests submitted before January 31, 2022 by December 1, 2024; this law applies only to electrical corporations that currently have less than a 35% success rate for interconnection requests submitted before January 31, 2022. AB 50 also requires electrical corporations to reevaluate their distribution planning processes to improve the accuracy of demand projections.

Electricity: Transmission Planning and Permitting

SB 319 (McGuire, 2023)

This law requires the CPUC, CEC, and CAISO to collaboratively develop a guidebook by July 2025 that describes the status of electrical transmission infrastructure development across the state. The CPUC is required to submit a report every two years on the progress of transmission infrastructure development.

Utility-Scale Solar and Wind Development

Dramatically scaling California’s capacity to produce renewable energy without compromising the State’s natural and working lands.

Overview

Approximately 28% of California’s energy is currently provided by utility-scale wind and solar facilities (as of 2022).⁴² SB 100 (de León, 2018) requires that by 2045, 100% of retail electricity will be provided by zero-carbon and renewable resources.

Many alternatives exist (e.g., geothermal, natural gas with **carbon capture and storage***, nuclear, hydro-, solar, and wind power). Due to low costs and high resource availability, solar and wind power will likely comprise the majority of California’s energy portfolio in a zero-carbon, renewable future.⁴³

Distributed solar resources (e.g., rooftop solar) are and will continue to be important. Expanding

this resource could avoid some of the impacts of utility-scale solar. However, these distributed resources will likely not meet all demand for renewable electricity. Further, utility-scale facilities are much more cost-effective than these small-scale applications.⁴⁴ To meet predicted demand, unprecedented construction of utility-scale solar and wind facilities will be required.⁴⁵

For example, California currently has 18 **gigawatts (GW)** of utility-scale solar;⁴⁶ the SB 100 Joint Agency Report projects that an additional 70 GW of utility-scale solar will be required by 2045. Each GW of solar currently requires between 2,900 and 4,200 acres of land on average.⁴⁷ The state is also committed to protecting and managing **natural and working lands** as a

42 Nyberg, M. (2023). 2022 Total System Electric Generation. *California Energy Commission*. Available at: <https://www.energy.ca.gov/data-reports/energy-almanac/california-electricity-data/2022-total-system-electric-generation>.

43 Gill, L., Gutierrez, A., and Weeks, T. (2021). 2021 SB 100 Joint Agency Report, Achieving 100 Percent Clean Electricity in California: An Initial Assessment. *California Energy Commission, California Public Utilities Commission and California Air Resources Board*. Publication number: CEC-200-2021-00. Available at: <https://www.energy.ca.gov/publications/2021/2021-sb-100-joint-agency-report-achieving-100-percent-clean-electricity>.

44 Ramasamy, V. et al. (2022). U.S. Solar Photovoltaic System and Energy Storage Cost Benchmarks, with Minimum Sustainable Price Analysis: Q1 2022 (No. NREL/TP-7A40-83586). *National Renewable Energy Lab*.

45 Gill, L., Gutierrez, A., and Weeks, T. (2021). 2021 SB 100 Joint Agency Report, Achieving 100 Percent Clean Electricity in California: An Initial Assessment. *California Energy Commission, California Public Utilities Commission and California Air Resources Board*. Publication number: CEC-200-2021-00. Available at: <https://www.energy.ca.gov/publications/2021/2021-sb-100-joint-agency-report-achieving-100-percent-clean-electricity>.

46 Nyberg, M. (2023). Electric Generation Capacity and Energy. Available at: <https://www.energy.ca.gov/data-reports/energy-almanac/california-electricity-data/electric-generation-capacity-and-energy>.

47 Bolinger, M., and Bolinger, G. (2022). Land Requirements for Utility-Scale PV: An Empirical Update on Power and Energy Density. *IEEE Journal of Photovoltaics*, 12(2), pp. 589-594.

* Find **bold** words in the Glossary (Appendix A).

strategy for meeting the state's goals for reducing greenhouse gas emissions (as per [SB 1386, Wolk, 2016](#)).

In siting utility-scale solar and wind, the state must consider clean energy needs, while also supporting other land use priorities such as agriculture, wildlife conservation, and recreation. New utility-scale solar often requires new transmission to deliver power to customers; this infrastructure presents its own siting challenges.

Wind and solar production

The attractiveness of wind and solar generation has increased with increasing energy efficiency. Improvements in technology have made them a cost-competitive part of California's plan for decarbonization.

Most of California's utility-scale solar farms are concentrated in the Central Valley.⁴⁸ Wind facilities tend to be co-located with cropland and rangeland.⁴⁹

In California, an average of 1 GW of utility-scale solar and 300 **megawatt (MW)** of wind have been built each year over the last 10 years. Modeling conducted for the [SB 100 Joint Agency Report](#) suggests that the average annual build rates will

need to be nearly tripled (2.8 GW and 900 MW per year for solar and wind, respectively) and sustained for the next 25 years.⁵⁰ Note that this model assumes roughly 28 GW of natural gas capacity is maintained as a source of **firm power**. More work is needed to estimate the maximum amount of solar and wind power possible by mid-century given all the factors that affect development.⁵¹

Sites for utility-scale facilities must first have adequate wind or solar resources. Land use regulations, site topology, and community acceptance further constrain options. These constraints often lead to new facility construction being situated away from communities in remote locations with adequate land.⁵² The delivery of energy produced at these new remote facilities to distant consumers requires expanding and upgrading California's transmission infrastructure.⁵³ California's transmission capacity may need to be expanded by as much as 20% to 60%, depending on the final energy resource portfolio.⁵⁴

Solar and wind facilities require large amounts of land. For example, the Solar Star project occupies 3,200 acres north of Los Angeles. On average and with current technology, between 2,900 to 4,200 acres are needed for every 1 GW of solar power.⁵⁵ Approximately 30,000 to 44,700 acres are needed per 1 GW of wind power,⁵⁶

48 California Energy Commission. (2022). Utility-Scale Solar Capacity and Electrical Generation by County. California State Geoport. Accessed on 11/28/2022 at: <https://gis.data.ca.gov/documents/CAEnergy::utility-scale-solar-capacity-and-electrical-generation-by-county/explore>.

49 Harrison-Atlas, D., Lopez, A., and Lantz, E. (2022). Dynamic Land Use Implications of Rapidly Expanding and Evolving Wind Power Deployment. *Environmental Research Letters*, 17(4), pp. 044064.

50 Gill, L., Gutierrez, A., and Weeks, T. (2021). 2021 SB 100 Joint Agency Report, Achieving 100 Percent Clean Electricity in California: An Initial Assessment. *California Energy Commission, California Public Utilities Commission and California Air Resources Board*. Publication number: CEC-200-2021-00. Available at: <https://www.energy.ca.gov/publications/2021/2021-sb-100-joint-agency-report-achieving-100-percent-clean-electricity>.

51 The Nature Conservancy. (2022). Power of Place – West: Executive Summary. Accessed 5/15/2023 at: https://www.nature.org/content/dam/tnc/nature/en/documents/TNC_Power-of-Place-WEST-Executive_Summary_WEB-9.2.22.pdf.

52 O'Shaughnessy, E. et al. (2022). Drivers and Energy Justice Implications of Renewable Energy Project Siting in the United States. *Lawrence Berkeley National Laboratory, Energy Analysis & Environmental Impacts Division*. Available at: <https://escholarship.org/content/qt68c4g1xr/qt68c4g1xr.pdf>.

53 California ISO. (2022). ISO 2021-2022 Transmission Plan. Available at: <http://www.caiso.com/InitiativeDocuments/ISOBoardApproved-2021-2022TransmissionPlan.pdf>.

54 Long, J.C.S. et al. (2021). California Needs Clean Firm Power, and So Does the Rest of the World: Three Detailed Models of the Future of California's Power System all show that California needs Carbon-Free Electricity Sources that don't Depend on the Weather. *Clean Air Task Force*.

55 Bolinger, M., and Bolinger, G. (2022). Land Requirements for Utility-Scale PV: An Empirical Update on Power and Energy Density. *IEEE Journal of Photovoltaics*, 12(2), pp. 589-594.

56 National Renewable Energy Laboratory. (ND). Energy Analysis. Land Use by System Technology. *National Renewable Energy Lab*. Accessed on 11/01/2022 at: <https://www.nrel.gov/analysis/tech-size.html>.



Photo: American Public Power Association

Modeling conducted for the SB 100 Joint Agency Report suggests that the average annual build rates [of utility-scale solar and wind] will need to be nearly tripled and sustained for the next 25 years.⁵⁷

though much of the area occupied by wind farms can still be used for other purposes.⁵⁷ The next SB 100 Joint Agency Report, planned for release in 2025, will evaluate the potential land-use impacts of its scenarios.⁵⁸

California's coast also has up to 112 GW of offshore wind potential.⁵⁹ The CEC set a planning goal of 25 GW of offshore wind by 2045.⁶⁰ The first auction for leases to construct offshore wind facilities off the coast of California was held in

early December 2022; final bids totaled \$757.1 million.⁶¹

Because offshore wind speeds tend to peak in the late afternoon and early evening when solar resources are declining, offshore wind complements land-based wind and solar generation and could help address some of the daily intermittency challenges of solar power (see **Section 3**).⁶²

57 Harrison-Atlas, D., Lopez, A., and Lantz, E. (2022). Dynamic Land Use Implications of Rapidly Expanding and Evolving Wind Power Deployment. *Environmental Research Letters*, 17(4), pp. 044064.

58 California Energy Commission. (2022). 2025 SB 100 Report: Scoping Phase: Tribal Listening Session. Accessed 5/16/2023 at: https://www.energy.ca.gov/sites/default/files/2023-03/2025_SB100_Report_Scoping_Tribal_Listening_Session_ADA.pdf

59 Sathe, A. et al. (2020). Research and Development Opportunities for Offshore Wind Energy in California. *California Energy Commission*. Publication Number: CEC-500-2020-053. Available at: <https://www.energy.ca.gov/sites/default/files/2021-05/CEC-500-2020-053.pdf>.

60 California Energy Commission. (2022). CEC Adopts Historic California Offshore Wind Goals, Enough to Power Upwards of 25 Million Homes. Available at: <https://www.energy.ca.gov/news/2022-08/cec-adopts-historic-california-offshore-wind-goals-enough-power-upwards-25>.

61 Lopez, N. (2022). First-ever California Offshore Wind Auction Nets \$757 Million. CalMatters. Available at: <https://calmatters.org/environment/2022/12/california-offshore-wind/>.

62 Speer, B., Keyser, D., and Tegen, S. (2016). Floating Offshore Wind in California: Gross Potential for Jobs and Economic Impacts from Two Future Scenarios (No. NREL/TP-5000-65352). *National Renewable Energy Laboratory*. Available at: <https://www.nrel.gov>.

Challenges to siting renewable facilities

Potential sites for utility-scale renewable energy include privately owned land, state and federal lands and waters, or a mix with multiple jurisdictions and oversight agencies, requiring the coordination of planning and management of land parcels. In California, county governments typically have planning control over related siting decisions.

To encourage private investment in solar facilities, the construction of qualifying solar facilities has been excluded from “ad valorem” property taxation in California since 1980, meaning that the construction of such facilities results in no new tax to the local government (which would otherwise receive a tax benefit with any new development). However, this exclusion—recently extended through 2026 by [SB 1340 \(Hertzberg, 2022\)](#)—disincentivizes counties to prioritize solar development when other development alternatives are available. Kern County—home to more than 60,000 acres of solar panels—has been vocal about their opposition to the solar tax exclusion, claiming that it has cost the county \$110 million in lost tax revenue over the last 10 years.⁶³

Some communities oppose utility-scale renewable power generation, citing concerns over changes to their communities’ characteristics and quality of life, that the energy produced would serve consumers outside the areas of planned developments rather than benefiting those who bear the burden, and that communities had not been sufficiently consulted during planning.^{64,65}

Relevant State Institutions

- California Energy Commission (CEC)
- California Department of Fish and Wildlife
- California Natural Resources Agency (CNRA)
- California State Lands Commission
- California Public Utilities Commission (CPUC)
- The Governor’s Office of Tribal Affairs
- Assembly Utilities & Energy Committee
- Assembly Natural Resources Committee
- Assembly Subcommittee No. 3 Climate Crisis, Resources, Energy, and Transportation
- Senate Energy, Utilities and Communications Committee
- Senate Governance and Finance
- Senate Natural Resources and Water Committee
- Senate Subcommittee No. 2 on Resources, Environmental Protection and Energy
- Senate Subcommittee on Clean Energy Future
- Joint Leg. Committee on Climate Change Policies

For example, in 2019, San Bernardino County—the largest county in California—banned construction of large solar and wind farms on 1 million acres of private land, citing opposition from local residents, despite claims from developers that the projects would bring jobs and tax revenue.⁶⁶

Other counties have banned wind turbine development within their borders due to complaints about aesthetics and noise.⁶⁷ Conflicts about renewable facilities may be caused by insufficient community engagement in advance of renewable facility development; poor coordination among

[gov/docs/fy16osti/65352.pdf](https://www.energy.ca.gov/docs/fy16osti/65352.pdf).

63 Grinnell, C. (2022). Senate Governance and Finance Committee. Senate Floor Analysis on SB-1340 (Hertzberg, 2022): Property Taxation: Active Solar Energy Systems: Extension. California State Legislature. Available at: https://leginfo.legislature.ca.gov/faces/billAnalysisClient.xhtml?bill_id=202120220SB1340#.

64 Cart, J. (2022). Wrangling Over Renewables: Counties Push Back on Newsom Administration Usurping Local Control. *CalMatters*. Accessed on 11/01/2022 at: <https://calmatters.org/environment/2022/08/renewable-energy-california-counties/>.

65 Wainwright, O. (2023). How Solar Farms took over the California Desert: ‘An Oasis has become a Dead Sea.’ *The Guardian*. Available at: <https://www.theguardian.com/us-news/2023/may/21/solar-farms-energy-power-california-mojave-desert>.

66 Cart, J. (2022). Wrangling Over Renewables: Counties Push Back on Newsom Administration Usurping Local Control. *CalMatters*. Accessed on 11/01/2022 at: <https://calmatters.org/environment/2022/08/renewable-energy-california-counties/>.

67 California Energy Commission. (2021). Electricity from Wind Energy Statistics and Data. *California Energy Commission: Data on Renewable Energy Markets and Resources: Energy Almanac*. Accessed on 11/01/2022 at: https://ww2.energy.ca.gov/almanac/renewables_data/wind/index cms.php.

utilities, regulators, and planners; limited data; and/or incommensurable values.⁶⁸

These challenges have impeded the construction of new renewable facilities. In response, in June 2022, California legislators passed [AB 205 \(Committee on Budget, 2022\)](#), which grants the California Energy Commission (CEC) authority to certify renewable facilities and associated transmission lines (that meet given criteria), providing developers an alternative pathway to local permitting processes.

Possible synergies among land uses

Though more expensive on a per watt basis, distributed solar has the advantage of requiring no new land conversion. California's rooftops—already supporting 15 GW of solar power as of July 2023⁶⁹—could potentially support an estimated 128.9 GW of solar power, with a generation potential equivalent to 71% of all energy needed in California in 2021.⁷⁰ In 2019, the CEC mandated that starting in 2020 all newly constructed low-rise residential, high-rise multifamily, and commercial buildings be equipped with solar panels.^{71,72} Parking lots also represent opportuni-

ties for solar panel installation.⁷³ See **Section 4** for more on **distributed energy resources**.

California has 4,000 miles of canals that convey water across the state. Modeling suggests that if these canals were covered by solar panels, the shading would prevent the evaporation of around 65 billion gallons of water a year and provide 13 GW of renewable power, enough to power 9.75 million homes.⁷⁴ In February 2022, California's Department of Water Resources awarded the Turlock Irrigation District \$20 million in funding for a pilot project, "Project Nexus," to be constructed in the Central Valley as a proof of concept.⁷⁵

Solar farms could be optimized for compatibility with certain crops that do well in shade or partial shade,⁷⁶ such as lettuce, alfalfa, sweet potatoes, and kale (this is known as "agrovoltatics"). By shading the soil, solar panels can significantly reduce water evaporation⁷⁷ and enhance resilience of dryland farms.⁷⁸

The Multibenefit Land Repurposing Program from the California Department of Conservation provides grants for the transition of agricultural lands to land uses that reduce reliance on groundwater and provide other benefits (including renewable energy) in drought-stricken areas.⁷⁹

68 Susskind, L. et al. (2022). Sources of Opposition to Renewable Energy Projects in the United States. *Energy Policy*, 165, pp. 112922.

69 California Solar Initiative. (2023). California Distributed Generation Statistics. Accessed on 10/10/2023 at: <https://www.californiadgstats.ca.gov/>.

70 Gagnon, P. et al. (2016). Rooftop Solar Photovoltaic Technical Potential in the United States. A detailed assessment (No. NREL/TP-6A20-65298). *National Renewable Energy Lab*.

71 California Energy Commission. (2018). Energy Commission Adopts Standards Requiring Solar Systems for New Homes, First in Nation. Available at: <https://www.energy.ca.gov/news/2018-05/energy-commission-adopts-standards-requiring-solar-systems-new-homes-first>.

72 California Energy Commission. (2021). 2022 Building Energy Efficiency Standards Summary. Available at: https://www.energy.ca.gov/sites/default/files/2021-08/CEC_2022_EnergyCodeUpdateSummary_ADA.pdf.

73 Hernandez-Jason, S. (2021). Solar Parking Canopy Goes Online, Providing UCSC with 2 Megawatts of Renewable Energy. *UC Santa Cruz Newscenter*. Accessed on 11/28/2022 at: <https://news.ucsc.edu/2021/09/solar-array-parking.html>.

74 McKuin, B. et al. (2021). Energy and Water Co-Benefits from Covering Canals with Solar Panels. *Nature Sustainability*, 4(7), pp. 609-617.

75 California Department of Water Resources. (2022). Innovative Solar Project Awarded State Funds: DWR Funds Turlock Irrigation District to Install Solar Panels Over Canals. Available at: <https://water.ca.gov/News/News-Releases/2022/Feb-22/DWR-Funds-Turlock-Irrigation-District-to-Install-Solar-Panels-Over-Canals>.

76 Miskin, C. et al. (2019). Sustainable Co-Production of Food and Solar Power to Relax Land-Use Constraints. *Nature Sustainability*, 2(10), pp. 972-980.

77 Omer, A.A.A. et al. (2022). Water Evaporation Reduction by the Agrivoltaic Systems Development. *Solar Energy*, 247, pp. 13-23.

78 Barron-Gafford, G.A. et al. (2019). Agrivoltaics Provide Mutual Benefits Across the Food-Energy-Water Nexus in Drylands. *Nature Sustainability*, 2(9), pp. 848-855.

79 California Department of Conservation. (2022). Solicitation Notice and Application for: Multibenefit Land Repurposing

Lands adjacent to the state highway system are owned by the California Department of Transportation (Caltrans) and largely underdeveloped. [SB 49 \(Becker, 2023\)](#) directs Caltrans to coordinate with the CPUC and the CEC to evaluate what barriers exist to Caltrans leasing its right-of-way for renewable energy infrastructure development.

Environmental impacts of renewable energy installation

While less harmful than oil and gas developments, utility-scale wind and solar facilities still have negative environmental impacts.

Wind and solar facilities are known to impact wildlife where they are located, particularly birds and bats.⁸⁰ For example, every year in Southern California, an estimated 19,000 to 38,000 birds are killed by wind turbines and an estimated 16,000 to 60,000 birds are killed at utility-scale solar facilities.⁸¹ If these impacts are not mitigated, additional renewable development will likely lead to population declines for some species.⁸²

Other impacts on wildlife include habitat loss and impeded migration corridors. Careful siting to avoid sensitive habitats can help mitigate these impacts. Sensors, acoustic deterrents, and adjustments to operation times can reduce wildlife

deaths at wind farms.⁸³ Offshore wind facilities may negatively impact marine life, including fisheries, encouraging careful siting.⁸⁴

Solar farms sited in deserts are detrimental to native plant species (many of which are of cultural value to Native American tribes) and facilitate the spread of invasive grasses.⁸⁵ As with other forms of development, land disturbance due to utility-scale wind, solar, and transmission installations can release greenhouse gases from soil and damage grasslands and rangelands that naturally sequester carbon and control erosion.⁸⁶

Environmental Justice and Equity Considerations

While scaling California's production of renewable energy has the potential to benefit disadvantaged communities—by providing cleaner and safer energy, as well as jobs and other economic benefits—these benefits are not always realized, and net impacts at the local level may be negative.⁸⁷ For example, some residents near large solar developments in the Mojave Desert “feel like [they’ve] been sacrificed.”⁸⁸ Communities may be under-represented in decision-mak-

Program. *Division of Land Resource Protection*. Accessed on 11/28/2022 at: https://www.conservation.ca.gov/dlrp/grant-programs/Documents/grant/00_Land%20Repurposing%20Program%20Guidelines_FINAL.pdf.

80 California Energy Commission and California Department of Fish and Game. (2007). California Guidelines for Reducing Impacts to Birds and Bats from Wind Energy Development. Commission Final Report. *California Energy Commission, Renewables Committee, and Energy Facilities Siting Division, and California Department of Fish and Game, Resources Management and Policy Division*. Publication number: CEC-700-2007-008-CMF. Available at: <https://nrm.dfg.ca.gov/FileHandler.ashx?DocumentID=9832>.

81 Walston Jr., L.J. et al. (2016). A Preliminary Assessment of Avian Mortality at Utility-Scale Solar Energy Facilities in the United States. *Renewable Energy*, 92, pp. 405-414.

82 Conkling, T.J. et al. (2022). Vulnerability of Avian Populations to Renewable Energy Production. *Royal Society Open Science*, 9(3), pp. 211558.

83 Agha, M. et al. (2020). Wind, Sun, and Wildlife: Do Wind and Solar Energy Development ‘Short-Circuit’ Conservation in the Western United States? *Environmental Research Letters*, 15(7), pp. 075004.

84 Gill, A.B. et al. (2020). Setting the Context for Offshore Wind Development Effects on Fish and Fisheries. *Oceanography*, 33(4), pp. 118-127.

85 Grodsky, S.M., and Hernandez, R.R. (2020). Reduced Ecosystem Services of Desert Plants from Ground-Mounted Solar Energy Development. *Nature Sustainability*, 3(12), pp. 1036-1043.

86 Van de Ven, D.J. et al. (2021). The Potential Land Requirements and Related Land Use Change Emissions of Solar Energy. *Scientific Reports*, 11(1), pp. 1-12.

87 O’Shaughnessy, E. et al. (2022). Drivers and Energy Justice Implications of Renewable Energy Project Siting in the United States. *Lawrence Berkeley National Laboratory, Energy Analysis & Environmental Impacts Division*. Available at: <https://escholarship.org/content/qt68c4g1xr/qt68c4g1xr.pdf>.

88 Wainwright, O. (2023). How Solar Farms took over the California Desert: ‘An Oasis has become a Dead Sea.’ *The Guardian*. Available at: <https://www.theguardian.com/us-news/2023/may/21/solar-farms-energy-power-california-mojave-desert>.

ing or lack full information on impacts and risks.⁸⁹ Early and ongoing community engagement can help alleviate concerns⁹⁰ and ensure projects maximize local benefits.⁹¹ The process should be as transparent as possible to cultivate trust.⁹²

The development of distributed energy resources such as **microgrids** by and with communities can also enhance energy resilience during energy disruptions while also providing cost savings and grid services during normal operations (see **Section 4**).

Rural communities and Tribes may not have their preferences and input adequately addressed. For example, in 2015, the Colorado River Indian Tribes filed a lawsuit against Riverside County for approving a 3,660-acre solar project that impacted Tribal resources.⁹³ In addition to state laws and policies related to land use with impacts on Tribal lands and sovereignty, national environmental laws with impact on renewable energy development include the National Environmental Protection Act (NEPA), the National Historic Preservation Act (NHPA), and the Federal Land Policy and Management Act (FLPMA), with each stipulating participation requirements for the general public and consultation with Tribal nations.⁹⁴

Relevant Policies

(Laws/Regulations)

Desert Renewable Energy Conservation Plan (DRECP)

The plan focuses on 10.8 million acres of public lands in desert areas within seven California counties. The plan identifies potential sites for renewable energy development and access to transmission networks on public lands while also protecting desert habitat, species, cultural heritage, and current recreational use in the Mojave, Colorado, and Sonoran Deserts. The California Energy Commission, U.S. Bureau of Land Management, California Department of Fish and Wildlife, and the U.S. Fish and Wildlife Service collaborated to develop the DRECP across jurisdictional boundaries.⁹⁵

California Environmental Quality Act (CEQA) SB 275 (1970)

CEQA requires that environmental impacts of development projects or major land use decisions be conducted.

California Endangered Species Act (CESA)

The act aims to protect endangered native species and their habitats from threats including those related to land use change or developments, including renewable energy projects, with potential to “jeopardize the

89 Ross, E. et al. (2022). Intersections of Disadvantaged Communities and Renewable Energy Potential: Data Set and Analysis to Inform Equitable Investment Prioritization in the United States. *Renewable Energy Focus*, 41, pp. 1-14.

90 Susskind, L. et al. (2022). Sources of Opposition to Renewable Energy Projects in the United States. *Energy Policy*, 165, pp. 112922.

91 O’Shaughnessy, E. et al. (2022). Drivers and Energy Justice Implications of Renewable Energy Project Siting in the United States. *Lawrence Berkeley National Laboratory, Energy Analysis & Environmental Impacts Division*. Available at: <https://escholarship.org/content/qt68c4g1xr/qt68c4g1xr.pdf>.

92 O’Shaughnessy, E. et al. (2022). Drivers and Energy Justice Implications of Renewable Energy Project Siting in the United States. *Lawrence Berkeley National Laboratory, Energy Analysis & Environmental Impacts Division*. Available at: <https://escholarship.org/content/qt68c4g1xr/qt68c4g1xr.pdf>.

93 Wright, J. (2015). CRIT Sues Riverside County Over Solar Project. *ParkerLive*. Accessed 11/28/2022 at: <https://parkerliveonline.com/2015/06/24/crit-sues-riverside-county-over-solar-project/>.

94 Susskind, L. et al. (2022). Sources of Opposition to Renewable Energy Projects in the United States. *Energy Policy*, 165, pp. 112922.

95 U.S. Department of the Interior: Bureau of Land Management. Desert Renewable Energy Conservation Plan. Accessed on 11/03/22 at: <https://www.blm.gov/programs/planning-and-nepa/plans-in-development/california/desert-renewable-energy-conservation-plan>.

continued existence of any endangered species or threatened species or result in the destruction or adverse modification of habitat essential to the continued existence of those species.”

Natural Community Conservation Planning Act (NCCP)

The act aims to protect plants, animals, and habitats at the regional level while allowing for compatible economic development. The NCCP encourages coordination among landowners, state agencies, and developers in the identification of potential environmental and other impacts. Plans are cooperative, voluntary, and provide a framework to identify potential impacts to wildlife or habitat early in the process of siting a project within a community.

Energy: Land Exchange for Renewable Energy-related Projects

AB 982 (Skinner, 2011)

This law requires the State Lands Commission to enter into an agreement with the U.S. Secretary of the Interior to facilitate land exchanges that consolidate school land parcels into contiguous holdings suitable for renewable energy-related projects.

Native Americans: California Environmental Quality Act

AB 52 (Gatto, 2014)

This law requires consultation with Native American Tribes that are culturally or traditionally connected to the geographic area of a proposed project. The purpose is to identify and prevent or minimize impacts on Native American prehistoric, historic, archaeological, cultural, and sacred places.

Resource Conservation: Working and Natural Lands

SB 1386 (Wolk, 2016)

SB 1386 declares it the policy of the state to consider the protection and management of natural and working lands as part of its approach to meeting greenhouse gas reduction goals.

Energy

AB 205 (Committee on Budget, 2022)

Among other things, AB 205 grants the California Energy Commission the authority to certify renewable facilities and associated transmission lines (that meet given criteria), providing developers with an alternative pathway to local processes.

California Global Warming Solutions Act of 2006: Climate Goal: Natural and Working Lands

AB 1757 (Garcia, 2022)

AB 1757 requires the California Natural Resources Agency to determine an ambitious range of targets for natural carbon sequestration and nature-based climate solutions that reduce greenhouse gas emissions in support of the state’s goal of carbon neutrality by 2045.

Property Taxation: Active Solar Energy Systems: Extension

SB 1340 (Hertzberg, 2022)

SB 1340 extends the exclusion of the construction of active solar energy systems from ad valorem taxation through the 2025-2026 fiscal year. Energy systems that qualify for exclusion prior to the repeal date (January 1, 2027) will continue to receive the exclusion until there is a subsequent change in ownership.

Renewable Energy: Department of Transportation: Evaluation

SB 49 (Becker, 2023)

This law requires the California Department of Transportation (Caltrans) to evaluate what barriers currently prevent the development of renewable energy infrastructure along department-owned rights-of-way (i.e., the lands adjacent to state highways). Caltrans must also develop a process for entities interested in developing such infrastructure to lease these lands from the department.

Read More

[A New Solar Landscape: Improving Landscape Planning for Utility-Scale Solar Planning.](#)

Elkind, E.N., and Lamm, T. (2018). UCLA and UC Berkeley Schools of Law.

[Renewables, Land Use, and Local Opposition in the United States.](#)

Gross, S. (2020). Brookings Institute.

[Identifying Least-Conflict Solar PV Development in California's San Joaquin Valley.](#)

Pearce, D., Strittholt, J., Watt, T., and Elkind, E.N. (2016). UC Berkeley.

[Assessing the Techno-Economics and Environmental Attributes of Utility-Scale PV with Battery Energy Storage Systems \(PVS\) Compared to Conventional Gas Peakers for Providing Firm Capacity in California.](#)

Roy, S., Shah, S.I., and Sinha, P. (2020). Energies,13, pp. 488.

[Utility-Scale Renewable Energy Generation Roadmap.](#)

Energies,13, pp. 488. Schwartz, H., and Brueske, S. (2020). California Energy Commission. Publication number: CEC-500-2020-062.

[Sources of Opposition to Renewable Energy Projects in the United States.](#)

Susskind, L. et al. (2022). Energy Policy, 165.

Reliability and the Need for Clean, Firm Power

Managing the intermittency of renewable resources.

Overview

Wind and solar resources are integral to California's path to decarbonization, but these weather- and season-dependent resources introduce reliability challenges. To cost-effectively resolve these challenges and still meet **net-zero*** by 2045 (as per [AB 1279, Muratsuchi, 2022](#)), the state will need clean, **firm power**—carbon-neutral power that can be delivered for as long as needed in the amount needed.

Utility-scale wind and solar currently comprise the majority (74%) of California's portfolio of renewable energy.⁹⁶ In 2022, 26.8% of the total electricity generated in-state came from these intermittent renewable resources (19.9% and 6.9% from solar and wind, respectively).⁹⁷ Moreover, de-

mand for electricity is expected to increase 76% (relative to demand in 2022) by 2045 as a result of population growth and electrification efforts.⁹⁸

Energy storage, **demand response**, and grid regionalization can alleviate some—but not all—of the challenges associated with **intermittent** renewable resources. A diverse portfolio that also includes clean, firm power—be it geothermal, nuclear, renewable hydrogen, natural gas with **carbon capture and storage**, or something else—would address seasonal fluctuations and extreme weather events and is predicted to result in significantly reduced system costs and therefore lower electricity rates.

96 Nyberg, M. (2023). 2022 Total System Electric Generation. *California Energy Commission*. Available at: <https://www.energy.ca.gov/data-reports/energy-almanac/california-electricity-data/2022-total-system-electric-generation>.

97 Nyberg, M. (2023). 2022 Total System Electric Generation. *California Energy Commission*. Available at: <https://www.energy.ca.gov/data-reports/energy-almanac/california-electricity-data/2022-total-system-electric-generation>.

98 California Air Resources Board. (2022). 2022 Scoping Plan for Achieving Carbon Neutrality. Available at: <https://ww2.arb.ca.gov/sites/default/files/2022-11/2022-sp.pdf>.

* Find **bold** words in the Glossary (Appendix A).

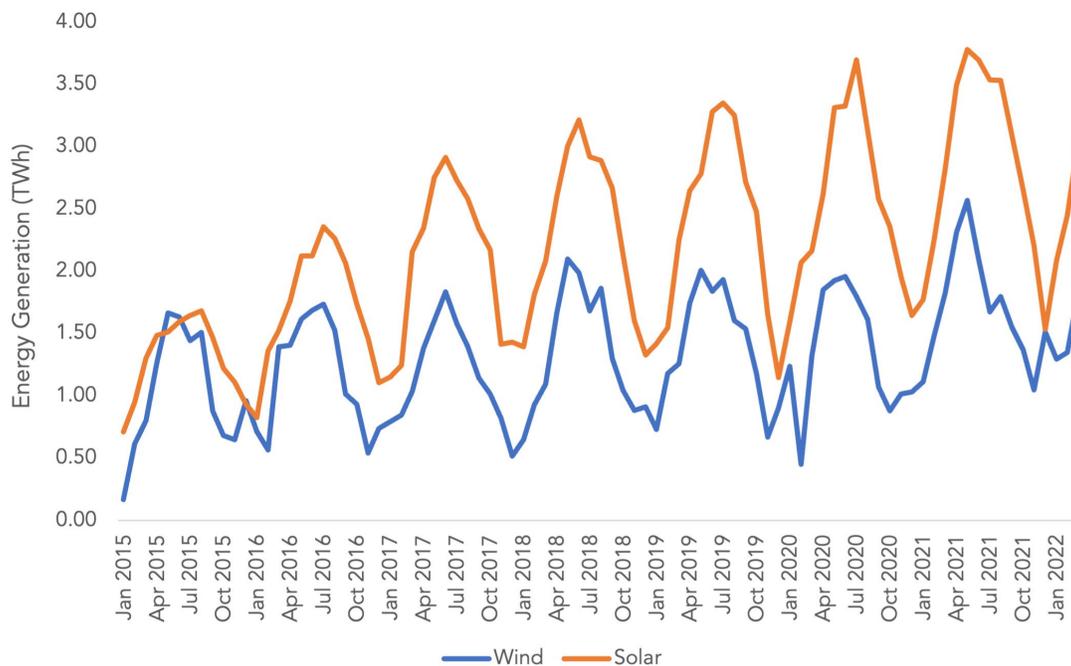


Figure 3.1. Utility-scale wind and solar generation over time in the CAISO service territory. Units are in terawatt hours (TWh).

Data from California Independent System Operator (CAISO) [Monthly Metered Renewable Generation](#). Accessed on 11/16/2022.

The nature of renewable intermittency

Wind and solar generation are variable or “intermittent”: they depend on weather conditions, season, and time of day. Seasonal mismatch between supply and demand presents the most challenging issue to resolve. Average daily output from current wind and solar developments in winter is just 30% to 40% of maximum summer output (see **Figure 3.1**).

This is significant as the electrification of space heating will increase demand in the winter.⁹⁹

Winter—rather than summer—may become the more challenging season for California’s electric grid.¹⁰⁰ Occasional weather patterns covering 1,000 kilometers (620 miles) or more can cause reduced solar production that can last for weeks or, in extreme cases, months.

Current battery technology is not suited for cost-effectively resolving these seasonal differences in energy generation or addressing shortfalls created by atypical weather events (see more on energy storage below).¹⁰¹

Other challenges are associated with balancing the daily supply of renewable energy with con-

⁹⁹ Buonocore, J. J. et al. (2022). Inefficient Building Electrification Will Require Massive Buildout of Renewable Energy and Seasonal Energy Storage. *Scientific Reports*, 12, pp. 11931.

¹⁰⁰ Abido, M.Y. et al. (2022). Seasonal Challenges for a California Renewable-Energy-Driven Grid. *Iscience*, 25(1), pp. 103577.

¹⁰¹ Long, J.C.S. et al. (2021). California Needs Clean Firm Power, and So Does the Rest of the World: Three Detailed Models of the Future of California’s Power System all show that California needs Carbon-Free Electricity Sources that don’t Depend on the Weather. *Clean Air Task Force*.

sumer demand. Solar production peaks midday, while demand for energy usually peaks around 4 p.m. to 6 p.m.,¹⁰² just as solar resources are starting to go offline. This creates the need to quickly ramp other sources of energy generation to compensate. During the middle of the day, renewable generation may exceed demand and needs to be exported to other parts of the West, stored for use at other times, or **curtailed**.¹⁰³ These challenges are illustrated in a chart of **net demand** (total energy demand minus renewable energy generation) known as the “**duck curve**” (Figure 3.2).

The state presently relies on 39.5 **gigawatts (GW)** of in-state, unmitigated (i.e., without carbon capture and storage) natural gas to meet demand when solar and wind generation are insufficient (as of 2022).¹⁰⁴ However, SB 100 (de León, 2018) and AB 1279 (Muratsuchi, 2022), effectively require the elimination of unmitigated natural gas from the electricity sector.

Due to intermittency issues and fluctuations in available power, a zero-carbon system based primarily on wind and solar would require building excess capacity or generation potential and associated storage so that when solar or wind output is low, there is still sufficient electricity to meet demand.¹⁰⁵ This excess build-out would likely increase cost as this infrastructure would be idle for significant periods of time; further, this would require more land use conversion and transmission infrastructure, both of which generate challenges of siting and permitting.

Batteries and other energy storage

Energy storage systems could include electrochemical, mechanical, or thermal technologies. All can be leveraged to improve the reliability of the grid and reduce the need for fossil fuel generation. By absorbing excess renewable energy and discharging it back to the grid later when demand is high but renewable production is limited, energy storage systems can both alleviate the need for renewable energy curtailment during the day and soften the need for ramping other sources of generation in the evening.

Modeling conducted for the SB 100 Joint Agency Report projects that 49,000 **megawatts (MW)** (i.e., 49 GW) of short-duration battery storage will be needed to meet clean energy targets by 2045.¹⁰⁶ For context, California Independent System Operator (CAISO) estimated the grid contained around 5,000 MW of battery storage in May 2023 (up from 250 MW in 2020).¹⁰⁷ Most of this storage is in the form of lithium-ion batteries that can only discharge energy for up to four hours.

Long duration energy storage systems can address some of the challenges associated with seasonal deficiencies and extreme weather. AB 205 (Committee on Budget, 2022) created a Long-Duration Energy Storage Program at the California Energy Commission (CEC) with a \$330 million budget to support innovative systems capable of continuously discharging energy for eight or more hours. The two largest awards to

102 California ISO. (2022). California ISO Peak Load History 1998 through 2022. Accessed on 11/29/2022 at: <https://www.caiso.com/documents/californiaisopeakloadhistory.pdf>.

103 California ISO. (2022). Managing Oversupply. Accessed on 11/29/2022 at: <http://www.caiso.com/informed/Pages/ManagingOversupply.aspx>.

104 Nyberg, M. (2023). Electric Generation Capacity and Energy. *California Energy Commission*. Accessed on 5/18/2023 at: <https://www.energy.ca.gov/data-reports/energy-almanac/california-electricity-data/electric-generation-capacity-and-energy>.

105 Gill, L., Gutierrez, A., and Weeks, T. (2021). 2021 SB 100 Joint Agency Report, Achieving 100 Percent Clean Electricity in California: An Initial Assessment. *California Energy Commission, California Public Utilities Commission and California Air Resources Board*. Publication number: CEC-200-2021-00. Available at: <https://www.energy.ca.gov/publications/2021/2021-sb-100-joint-agency-report-achieving-100-percent-clean-electricity>.

106 Gill, L., Gutierrez, A., and Weeks, T. (2021). 2021 SB 100 Joint Agency Report, Achieving 100 Percent Clean Electricity in California: An Initial Assessment. *California Energy Commission, California Public Utilities Commission and California Air Resources Board*. Publication number: CEC-200-2021-00. Available at: <https://www.energy.ca.gov/publications/2021/2021-sb-100-joint-agency-report-achieving-100-percent-clean-electricity>.

107 California ISO. (2023). Special Report on Battery Storage. Available at: <http://www.caiso.com/Documents/2022-Special-Report-on-Battery-Storage-Jul-7-2023.pdf>.

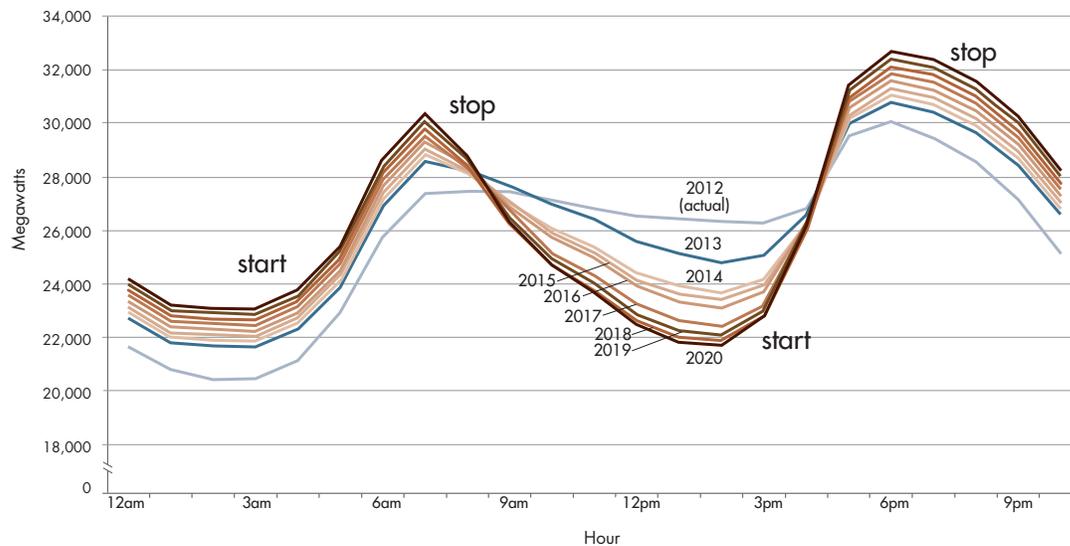


Figure 3.2. This “duck curve” shows net demand (total energy demand minus renewable energy generation) over time on a specific day, January 11. The duck curve illustrates the steep ramps necessary when other sources of energy generation must be quickly shut down or brought online to either make room or compensate for renewable energy generation. Licensed with permission from the California ISO.

date have gone to the Viejas Tribe of Kumeyaay Indians (\$31 million) and the Paskenta Band of Nomlaki Indians (\$32.75 million); both projects will use non-lithium technologies.

Pumped storage hydropower (PSH) has long been the most common utility-scale energy storage system in California and the United States. PSH comprises two reservoirs at different elevations. Power is generated when water is released from the upper reservoir and passes through a turbine on its way to the lower. The system is recharged (like a battery) by pumping the water back into the upper reservoir. California currently has about 4,500 MW of PSH.

Demand response

One tool for mitigating intermittency is through demand response—a method of grid management where consumers are signaled to adjust their energy use (*Decision 17-12-003*).¹⁰⁸

To date, most demand response tools in California are signals for consumers to reduce or “shed” demand (e.g., *CAISO Flex Alerts*). However, consumers could also be signaled to shift their demand from one time of day to another (“**load shifting**”).

Like energy storage (above), load shifting could avert curtailment of renewable generation during the day and soften the generation ramps necessary in the evening, providing up to \$700 million worth of system benefits in California annually.¹⁰⁹ Newly electrified technologies (like **heat pumps** and electric vehicles) could automate load shifting and represent significant load shift

108 California Public Utilities Commission. (2021). Demand Response (DR). Accessed on 11/29/2022 at: <https://www.cpuc.ca.gov/industries-and-topics/electrical-energy/electric-costs/demand-response-dr>.

109 Alstone, P. et al. (2017). 2025 California Demand Response Potential Study — Charting California’s Demand Response Future: Final Report on Phase 2 Results. Lawrence Berkeley National Laboratory. Available at: <https://eta-publications.lbl.gov/sites/default/files/lbnl-2001113.pdf>.

resources.¹¹⁰ In April 2022, the California Public Utilities Commission (CPUC) expanded incentives in the [Self-Generation Incentive Program \(SGIP\)](#) to include heat pump water heaters designed to load shift.¹¹¹

[SB 846 \(Dodd, 2022\)](#) directs the CEC, CPUC, and CAISO to develop and regularly update load shifting targets to reduce peak net demand. In May 2023, the first report was released by the CEC which described pathways towards “an aspirational but achievable” goal of load-shifting 7,000 MW by 2030.¹¹²

See Section 4 for more on the potential role of demand response and other **distributed energy resources**.

Coordination across states

The Western Energy Imbalance Market (WEIM)—which launched in 2014—allows for utilities and balancing authorities (like CAISO) across the Western United States to transfer energy between and among their jurisdictions in real time.

Multistate coordination eases some of the challenges associated with intermittent renewable energy.¹¹³ Increasing the geographic diversity of wind and solar resources smooths variability in generation.¹¹⁴ Expanding connections of California's grid to other states in the West could help increase the utilization of renewable generation when it exceeds demand. In response to [ACR](#)

Relevant State Institutions

- California Air Resources Board (CARB)
- California Department of Water Resources (DWR)
- California Energy Commission (CEC)
- California Independent System Operator (CAISO)
- California Public Utilities Commission (CPUC)
- The Governor's Office of Emergency Services
- The Governor's Office of Tribal Affairs
- Assembly Budget Subcommittee no 3 on Climate Crisis, Resources, Energy, and Transportation
- Asm. Environmental Safety and Toxic Materials Cmte.
- Assembly Natural Resources Committee
- Assembly Utilities and Energy Committee
- Senate Energy, Utilities and Communications Committee
- Senate Budget Subcommittee 2 on Resources, Environmental Protection and Energy

[188 \(Holden, 2022\)](#), CAISO contracted the National Renewable Energy Laboratory to produce a report on the impacts of expanded regional energy coordination.¹¹⁵

In August 2023, CAISO submitted an application to the Federal Energy Regulatory Commission (FERC) to initiate a voluntary Extended Day-Ahead Market (EDAM) across the footprint of the WEIM. EDAM would enable participants to proactively buy and sell energy based on supply and demand forecasts, thereby enabling enhanced coordination. EDAM could reduce carbon dioxide emissions by nearly 3 million metric tons per year,

110 Gerke, B. F. et al. (2020). The California Demand Response Potential Study, Phase 3: Final Report on the Shift Resource through 2030. Lawrence Berkeley National Laboratory. Available at: https://eta-publications.lbl.gov/sites/default/files/ca_dr_potential_study_-_phase_3_-_shift_-_final_report.pdf

111 California Public Utilities Commission. (2022). CPUC Provides Additional Incentives and Framework for Electric Heat Pump Water Heater Program. Available at: <https://www.cpuc.ca.gov/news-and-updates/all-news/cpuc-provides-additional-incentives-and-framework-for-electric-heat-pump-water-heater-program>.

112 Neumann, I., and Lyon, E. (2023). Senate Bill 846 Load-Shift Goal Report. California Energy Commission. Available at: <https://www.energy.ca.gov/publications/2023/senate-bill-846-load-shift-goal-report>.

113 Gill, L., Gutierrez, A., and Weeks, T. (2021). 2021 SB 100 Joint Agency Report, Achieving 100 Percent Clean Electricity in California: An Initial Assessment. *California Energy Commission, California Public Utilities Commission and California Air Resources Board*. Publication number: CEC-200-2021-00. Available at: <https://www.energy.ca.gov/publications/2021/2021-sb-100-joint-agency-report-achieving-100-percent-clean-electricity>.

114 GE Energy. (2010). Western Wind and Solar Integration Study: Executive Summary. *National Renewable Energy Laboratory*. Available at: <https://www.nrel.gov/docs/fy10osti/47781.pdf>.

115 Hurlbut, D., Greenfogel, M., and Speetles, B. (2023). The Impacts on California of Expanded Regional Cooperation to Operate the Western Grid (Final Report). *National Renewable Energy Laboratory*. Available at: <http://www.caiso.com/Documents/Expanded-Regional-Cooperation-ACR-188-Final-Report-Feb2023.pdf>.

if implemented West-wide.¹¹⁶ FERC unanimously approved the proposal in December 2023.¹¹⁷

Clean firm power options

SB 423 (Stern, 2022) requires the California Energy Commission (CEC) to consider the role of firm zero-carbon resources that can address atypical weather events and support a clean, reliable, and resilient grid. There are currently few options for clean, firm power. While this may change, the most compelling choices that would enable California to achieve a net-zero economy by 2045 are geothermal energy, nuclear power, hydropower, natural gas with carbon capture and storage (CCS), and renewable hydrogen. See below for discussions of each. There are benefits and costs to all choices, but each of these resources could help to ensure reliability of a grid primarily powered by intermittent renewable resources. Further, each of these options would help stabilize the cost of electricity.

Research suggests that a greater diversity of options will result in a more resilient grid and lower costs for consumers.¹¹⁸ Although clean, firm power may be more expensive than solar and wind per **kilowatt (kW)**, the critical role these

resources will play in addressing intermittency and reliability issues will facilitate lower overall costs to the consumer.^{119,120,121} An optimal energy portfolio would be best informed by considering the impacts of each resource on cumulative system costs rather than the specific costs per kW of each technology.

Geothermal energy

California is the U.S.'s largest producer of geothermal energy, with sites including the Geysers—the world's largest complex of geothermal plants—in northern California and the Salton Sea in southern California. California's 40 geothermal plants currently produce more geothermal energy than any other state and account for about 5.5% of the state's total energy.¹²² As of 2022, California had 2,693 MW of geothermal capacity.¹²³ While geothermal represents a smaller fraction of California's energy supply than wind and solar, there is potential to expand development. The geothermal resources in the Salton Sea alone represent an estimated 2,200 MW of untapped generation capacity;¹²⁴ across California, the potential could be as high as 15,000 MW.¹²⁵ Geothermal energy requires less land than solar or wind, and once established, is a source of clean,

116 California Independent Systems Operator. (2023). Extended Day-Ahead Market. Available at: <http://www.caiso.com/Documents/extended-day-ahead-market-edam-fact-sheet.pdf>.

117 Federal Energy Regulatory Commission. (2023). Chairman Phillips Concurrence Regarding CAISO Day-Ahead Market Enhancements (DAME) and Extended Day-Ahead Market (EDAM) Proposal (ER23-2686-000). Accessed on 3/4/2024 at: <https://www.ferc.gov/news-events/news/chairman-phillips-concurrence-regarding-caiso-day-ahead-market-enhancements-dame>.

118 Long, J.C.S. et al. (2021). California Needs Clean Firm Power, and So Does the Rest of the World: Three Detailed Models of the Future of California's Power System all show that California needs Carbon-Free Electricity Sources that don't Depend on the Weather. *Clean Air Task Force*.

119 Gill, L., Gutierrez, A., and Weeks, T. (2021). 2021 SB 100 Joint Agency Report, Achieving 100 Percent Clean Electricity in California: An Initial Assessment. *California Energy Commission, California Public Utilities Commission and California Air Resources Board*. Publication number: CEC-200-2021-00. Available at: <https://www.energy.ca.gov/publications/2021/2021-sb-100-joint-agency-report-achieving-100-percent-clean-electricity>.

120 Breckel, A. et al. (2022). Growing the Grid: A Plan to Accelerate California's Clean Energy Transition. *Environmental Defense Fund, Clean Air Task Force*.

121 Long, J.C.S. et al. (2021). California Needs Clean Firm Power, and So Does the Rest of the World: Three Detailed Models of the Future of California's Power System all show that California needs Carbon-Free Electricity Sources that don't Depend on the Weather. *Clean Air Task Force*.

122 Nyberg, M. (2023). 2022 Total System Electric Generation. *California Energy Commission*. Available at: <https://www.energy.ca.gov/data-reports/energy-almanac/california-electricity-data/2022-total-system-electric-generation>.

123 Nyberg, M. (2023). Electric Generation Capacity and Energy. *California Energy Commission*. Accessed on 5/18/2023 at: <https://www.energy.ca.gov/data-reports/energy-almanac/california-electricity-data/electric-generation-capacity-and-energy>.

124 Goodman, D., Mirick, P., and Wilson, K. (2022). Salton Sea Geothermal Development: Nontechnical Barriers to Entry—Analysis and Perspectives. *Pacific Northwest National Laboratory*. Available at: https://www.pnnl.gov/main/publications/external/technical_reports/PNNL-32717.pdf.

125 U.S. Geological Survey. (2008). Assessment of Moderate- and High-Temperature Geothermal Resources of the United States. Available at: <https://pubs.usgs.gov/fs/2008/3082/pdf/fs2008-3082.pdf>.

firm power. The expansion of geothermal is challenged by high costs for exploratory drilling, though research for technical innovations and to reduce costs is ongoing.¹²⁶

Geothermal brine waters contain low concentrations of lithium—a highly valuable mineral used in most rechargeable batteries that is considered to be “essential to the economic and national security of the United States.”¹²⁷ The CEC is supporting demonstration projects that seek to effectively separate lithium from geothermal brine as one avenue for improving the economics of geothermal energy.¹²⁸ The CEC estimates that the Salton Sea has the potential to produce more than 600,000 tons of lithium carbonate per year, which is equivalent to \$7.2 billion per year under current market conditions.¹²⁹

Geothermal energy can operate as a **base load** resource (i.e., operating continuously to meet baseline demand) and be ramped to meet peak demand if necessary.

Nuclear power

Zero-carbon nuclear energy has long played an important role in California’s power generation, although the percent of the grid powered by nuclear energy has declined as plants have been decommissioned. Roughly 6% of California’s energy comes from Diablo Canyon Power Plant

(DCPP),¹³⁰ California’s last operational nuclear facility. Another 3.3% of California’s energy is from imported nuclear power.

DCPP has long been contentious as the facility is located near seismic fault lines, creating community concerns about safety in addition to radioactive waste management.¹³¹ Furthermore, people of color—and particularly Native American communities—are disproportionately impacted by uranium mining and nuclear waste disposal in the United States.¹³²

Pacific Gas & Electric (PG&E) originally petitioned for decommissioning DCPP in 2025, citing the high costs of running the plant, burdensome regulatory requirements, and a potential lack of need.¹³³ However, a joint study by Stanford University and Massachusetts Institute of Technology researchers concluded that keeping Diablo Canyon open past 2025 would help California meet its climate goals and reduce emissions.¹³⁴ According to another model, retaining Diablo Canyon until 2045 would reduce emissions from the electricity sector by 40 million metric tons (MMT) and generate more than \$4 billion in savings.¹³⁵

To improve reliability over the short-term, SB 846 (Dodd, 2022) provided a pathway to extend DCPP operations through 2030 (pending approval from the Nuclear Regulatory Commission, the U.S. Department of Energy, and state regulatory agencies) and provides PG&E a loan of up to

126 Kolker, A. (ND). Exploration and Targeting. Geothermal Research. *National Renewable Energy Laboratory*. Accessed 11/29/2022 at: <https://www.nrel.gov/geothermal/exploration-targeting.html>.

127 The US Department of Commerce. (2020). A Federal Strategy to Ensure Secure and Reliable Supplies of Critical Minerals. Available at: https://www.commerce.gov/sites/default/files/2020-01/Critical_Minerals_Strategy_Final.pdf.

128 California Energy Commission. (2020). Geothermal, Lithium Recovery Projects get Boost from California Energy Commission. Available at: <https://www.energy.ca.gov/news/2020-05/geothermal-lithium-recovery-projects-get-boost-california-energy-commission>.

129 Ventura, S. et al. (2020). Selective Recovery of Lithium from Geothermal Brines. *California Energy Commission*. Available at: <https://www.energy.ca.gov/sites/default/files/2021-05/CEC-500-2020-020.pdf>.

130 Nyberg, M. (2023). 2022 Total System Electric Generation. *California Energy Commission*. Available at: <https://www.energy.ca.gov/data-reports/energy-almanac/california-electricity-data/2022-total-system-electric-generation>.

131 Van Niekerken, B. (2016). Diablo Canyon Nuclear Plant: A Legacy of Powerful Protests. *San Francisco Chronicle*. Accessed 11/03/2022 at: https://www.sfchronicle.com/chronicle_vault/article/Diablo-Canyon-nuclear-plant-A-legacy-of-powerful-8344582.php.

132 Jantz, E. (2018). Environmental Racism with a Faint Green Glow. *Natural Resources Journal*, 58, pp. 247.

133 California Public Utilities Commission. (2018). Decision Approving Retirement of Diablo Canyon Nuclear Power Plant. Available at: <https://docs.cpuc.ca.gov/PublishedDocs/Published/G000/M205/K090/205090240.PDF>.

134 Aborn, J. et al. (2021). An Assessment of the Diablo Canyon Nuclear Plant for Zero Carbon Electricity, Desalination, and Hydrogen Production. *Stanford Energy*.

135 Newell, S. et al. (2022). Retaining Diablo Canyon: Economic, Carbon, and Reliability Implications. The Brattle Group. Accessed on 5/17/2023 at: https://carbonfreeca.org/wp-content/uploads/2022/06/2022-06-09_Brattle-Report-on-Impacts-of-Diablo-Extension.pdf.

\$1.4 billion to do so. The Nuclear Regulatory Commission has granted PG&E permission to continue operating DCPD while its license renewal application is being considered. If granted, DCPD would have authorization from the Nuclear Regulatory Commission to operate for another 20 years.¹³⁶

The San Onofre Nuclear Generating Station (SONGS) had a similar maximum capacity as DCPD. Its unexpected closure in 2012 caused an immediate rise in electricity prices, natural gas usage, electricity imports, and greenhouse gas (GHG) emissions.¹³⁷ California is proactively developing regulations to ensure that when DCPD is decommissioned, similar effects can be avoided. For example, [SB 1090 \(Monning, 2018\)](#) and [SB 846 \(Dodd, 2022\)](#) require the CPUC's integrated resource plans to be designed to avoid any increases in greenhouse gas emissions due to the eventual closure of DCPD.

Compared to other energy resources, nuclear power tends to be relatively inflexible—meaning that it can't easily (or economically) be ramped up or down in response to demand (with some exceptions). Consequently, nuclear power runs best as a base load resource.

Next generation nuclear technologies are on the horizon. Some of these feature enhanced safety mechanisms, the potential for small-scale or modular designs, and dramatic reductions in nuclear waste.¹³⁸ Current California law prohibits the construction of any new nuclear facilities until the federal government identifies a viable option for nuclear waste disposal ([Warren-Alquist Act, 2022, §25524.1](#)). The nation is currently in

violation of the [Nuclear Waste Policy Act](#) and will need to revisit this issue to make a new plan for waste disposal. A licensed waste repository will not likely be in place before mid-century. Consequently, any new nuclear power in California would require reversal of this provision.

Over the long term, nuclear fusion technology—which does not produce any nuclear waste—may hold promise as a clean energy solution for California.¹³⁹ However, nuclear fusion is at least a decade away from commercial deployment for electricity generation. It is therefore unlikely to play a large role in achieving a net-zero economy by 2045. This could be an important resource later in the century. [AB 1172 \(Calderon, 2023\)](#) requires the CEC to consider fusion energy in its 2027 Integrated Energy Policy Report.

Hydropower

Established hydropower is a zero-carbon flexible resource that is strategically deployed to ensure grid reliability. Over the last decade, hydroelectric production has varied significantly. During “wet” years like 2017 and 2019, California's large and small hydroelectric resources provided roughly 14-15% of total energy consumed in the state. During dry years, like 2015 and 2021, they accounted for only 4-5%.¹⁴⁰ Reduced hydropower has historically increased California's reliance on natural gas and energy imports, leading to increased GHG emissions.¹⁴¹ Hydropower can be used as a base load or peaking resource. During dry years, hydropower tends to be reserved for meeting net demand on summer evenings.¹⁴²

136 Nuclear Regulatory Commission. (2023). NRC Grants “Timely Renewal” Exemption to Allow Continued Operation of Diablo Canyon Nuclear Power Plant. NRC News. Available at: <https://www.nrc.gov/cdn/doc-collection-news/2023/23-015.pdf>.

137 U.S. Energy Information Administration. (2012). San Onofre Nuclear Outage Contributes To Southern California's Changing Generation Profile. Accessed on 11/03/2022 at: <https://www.eia.gov/todayinenergy/detail.php?id=8770>.

138 National Academy of Sciences, Engineering, and Medicine. (2023). Laying the Foundation for New and Advanced Nuclear Reactors in the United States. *The National Academies Press*. Available at: <https://nap.nationalacademies.org/catalog/26630/laying-the-foundation-for-new-and-advanced-nuclear-reactors-in-the-united-states>.

139 Bishop, B. (2022). Lawrence Livermore National Laboratory Achieves Fusion Ignition. Accessed on 5/18/2023 at: <https://www.llnl.gov/news/lawrence-livermore-national-laboratory-achieves-fusion-ignition>.

140 California Energy Commission. (2022). Total System Electric Generation 2009-2021. Accessed on 11/29/2022 at: <https://www.energy.ca.gov/media/7311>.

141 Nyberg, M. (2022). In-State Electric Generation by Fuel Type (GWh). Accessed on 11/29/2022 at: <https://www.energy.ca.gov/data-reports/energy-almanac/california-electricity-data/electric-generation-capacity-and-energy>.

142 Erne, D. (2022). Final 2021 Integrated Energy Policy Report. Volume II: Ensuring Reliability in a Changing Climate. *California Energy Commission*. Publication Number: CEC-100-2021-001-V2. Available at: <https://efiling.energy.ca.gov/GetDocument.aspx?tn=241583>.

Reservoirs are dependent upon spring and summer snowmelt, but because of climate change, more precipitation is predicted to fall as rain rather than snow,¹⁴³ leading to uncertainty about the long-term reliability of this resource for meeting net demand in summer.¹⁴⁴ Further, demands for hydroelectric power compete with other objectives including a secure water supply, flood control, and supporting fish populations.

New hydropower would be difficult to site and permit, and the state does not currently plan to construct any new large (greater than 30 MW) hydropower facilities. New hydropower may be inadvisable given that flooded vegetation leads to the production of **methane**, a strong greenhouse gas.¹⁴⁵

Natural gas with carbon capture and storage

As mentioned previously, California currently relies on natural gas to ensure grid reliability. The State could continue to use natural gas in this capacity and leverage much of the current natural gas infrastructure if these facilities implemented CCS, so long as sufficient capture rates can be achieved. Natural gas with CCS could be reserved to meet peak demand or provide power at night when solar resources are offline.

CCS is often dismissed or opposed in part because previous facilities have demonstrated lower-than-expected capture efficiencies. New technologies are being developed that, if successful, could capture all or nearly all of the carbon dioxide from the flue stream. For example, a 300 MW natural gas power plant is being constructed in Odessa, Texas which will demonstrate a new approach to carbon capture that is expected to achieve 100% capture efficiency.¹⁴⁶ However, even with 100% capture efficiency, CCS

would still not address all emissions associated with the facility, nor would it account for methane leakage from the pipelines supplying the plant.

To date, CCS has not presented a compelling financial case for the electricity sector. Separating the carbon dioxide from the emission stream is an additional costly and energy-intensive process. While costs for CCS are expected to decline over time, the pace of decline is highly uncertain. The successful build out of CCS facilities in California would require support from climate policies. The expanded tax credits for CCS provided by the [Inflation Reduction Act](#) are helping to address this financial barrier.

California has a geology well-suited to carbon sequestration, given its extensive depleted oil and gas reservoirs and deep saline reservoirs in the Central Valley. Long-term retention rates at storage facilities and the potential for leaks from pipelines and storage reservoirs would need attention. The state and federal government have been developing regulatory frameworks to conduct CCS safely.

Please see **Section 5** for a more complete discussion of CCS.

Hydrogen

Hydrogen rarely exists in a usable state in nature; pure hydrogen must be created in a process that requires energy. Thus, hydrogen is more accurately understood as an energy storage solution rather than a source of energy itself. Hydrogen can be either combusted (burned) or used in a **fuel cell**; when burned, hydrogen produces nitrogen oxides.

Zero-carbon hydrogen can be produced by using renewable energy to split water into its constituent hydrogen and oxygen components (a process

143 Pierce, D. W. et al. (2018). Climate, Drought, and Sea Level Rise Scenarios for California's Fourth Climate Change Assessment. California Energy Commission. Available at: https://www.energy.ca.gov/sites/default/files/2019-11/Projections_CCCA4-CEC-2018-006_ADA.pdf.

144 Tarroja, B. et al. (2019). Implications of Hydropower Variability from Climate Change for a Future, Highly Renewable Electric Grid in California. *Applied Energy*, 237(1), pp. 353-366.

145 Deemer, B. R. et al. (2016). Greenhouse Gas Emissions from Reservoir Water Surfaces: A New Global Synthesis. *Bioscience*, 66(11), pp. 949-964.

146 Patal, S. (2022). NET Power's First Allam Cycle 300-MW Gas-Fired Project will be Built in Texas. *POWER*. Accessed on 5/17/2023 at: <https://www.powermag.com/net-powers-first-allam-cycle-300-mw-gas-fired-project-will-be-built-in-texas/>.

known as electrolysis).¹⁴⁷ Electrolytic hydrogen is often referred to as “green” hydrogen but there are disagreements about this terminology.

Alternatively, hydrogen can be produced from methane in a process called steam methane reformation. Most hydrogen (95%) produced today is produced through steam methane reformation.¹⁴⁸ This method of hydrogen production emits carbon dioxide, and thus would need to be accompanied by CCS to be considered a low-carbon resource. Hydrogen produced through steam methane reformation with CCS is often called “**blue hydrogen**.”

In 2023, scientists seeking underground natural gas deposits in France found a large amount of naturally occurring hydrogen (known as “white hydrogen”) spurring many conversations about the potential for other large hydrogen deposits. More research is needed to understand how much white hydrogen may exist, where such deposits are likely to occur, and how it could best be extracted to minimize leakage.

Once created, hydrogen can be stored for long periods of time before being used as an energy resource. Electrolytic hydrogen is thus an attractive solution for converting excess solar and wind capacity for long-duration energy storage, thereby improving grid resilience.

Electrolytic hydrogen—as well as hydrogen produced by other pathways—also has potential applications in hard-to-electrify sectors including long-haul transportation (see **Section 7**), steel and cement production, industrial operations, and agriculture. *SB 1075 (Skinner, 2022)* requires the

CPUC and CEC to consider the role of hydrogen in their respective decarbonization strategies.

In October 2023, the U.S. Department of Energy announced that California would receive up to \$1.2 billion for a [regional clean hydrogen hub](#). California’s hub will primarily focus on electrolytic hydrogen production to be used in hard-to-decarbonize sectors including heavy duty transportation and port operations, as well as for back-up power generation.¹⁴⁹

Hydrogen is known to be an indirect GHG—this means that while it is not a GHG itself, hydrogen interacts with other molecules in the atmosphere in a process that ultimately causes methane and sometimes **ozone** to remain in the atmosphere longer than they would otherwise.¹⁵⁰ One model suggests that hydrogen has a **global warming potential** that is nearly 12 times greater than that of carbon dioxide.¹⁵¹ Thus, hydrogen leakage must be strictly controlled, which is challenging given the incredibly small size of the hydrogen molecule. This is an active area of research at several public and private research institutions.

Other clean fuels are possible but limited. For example, ammonia may be an attractive solution but has not been fully evaluated. **Biomethane** will be one critical clean fuel in the portfolio, but supplies are limited.¹⁵² These limited clean fuel supplies should be allocated only to the most recalcitrant decarbonization challenges.

147 Maiden, T.O., and Schmoll, E. (2022). California Clean Hydrogen Bill Targets Alternative Energy Sources for Expansion. *EHS Law Insights: Reed Smith*. Available at: <https://www.ehslawinsights.com/2022/02/california-clean-hydrogen-bill-targets-alternative-energy-sources-for-expansion/>.

148 U.S. Department of Energy. (ND). Hydrogen Production: Natural Gas Reforming. Accessed 5/30/2023 at: <https://www.energy.gov/eere/fuelcells/hydrogen-production-natural-gas-reforming>.

149 U.S. Department of Energy. (2023). Regional Clean Hydrogen Hubs Selected for Award Negotiations. Accessed 10/19/2023 at: <https://www.energy.gov/oced/regional-clean-hydrogen-hubs-selections-award-negotiations>.

150 Warwick, N. et al. (2022). Atmospheric Implications of Increased Hydrogen Use. *Crown*. Available at: https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/1067144/atmospheric-implications-of-increased-hydrogen-use.pdf.

151 Sand, M. et al. (2023). A Multi-Model Assessment of the Global Warming Potential of Hydrogen. *Communications Earth & Environment*, 4, pp. 203.

152 Jaffe, A. M. et al. (2016). The Feasibility of Renewable Natural Gas as a Large-Scale, Low Carbon Substitute. *California Air Resources Board*. Available at: <https://ww2.arb.ca.gov/sites/default/files/classic/research/apr/past/13-307.pdf>.

Environmental Justice and Equity Considerations

Natural gas facilities—which currently provide 75% of the flexibility the California grid requires to accommodate renewable resources¹⁵³—are disproportionately located near disadvantaged communities.¹⁵⁴ Until cost-effective, clean, firm power alternatives are found, these communities will continue to be burdened by pollution generated by natural gas plants.

Each of the clean, firm power options presented here have the potential to negatively impact nearby communities. Inclusive decision-making will be essential to ensure a more equitable transition to a net-zero economy.

Relevant Policies

(Laws/Regulations)

Self-Generation Incentive Program (SGIP)

Provides incentives to support distributed energy systems including wind turbines, waste heat-to-power technologies, pressure reduction turbines, internal combustion engines, microturbines, gas turbines, fuel cells, and advanced energy storage systems.

Renewables Portfolio Standard (RPS) Program

SB 1078 (Sher, 2002)

The RPS Program mandated an initial 20% of electricity retail sales to come from renewable resources by 2017. In 2018, [SB 100 \(de León, 2018\)](#) was signed into law, which increases RPS to 60% by 2030 and requires all the state's electricity to come from carbon-free resources by 2045.

SB 1078 defined eligible renewables to include small hydropower, solar, wind, and geothermal among others. SB 350 introduced interim annual RPS targets with three-year compliance periods and requires 65% of RPS procurement to be derived from long-term contracts of 10 or more years.

Clean Energy Pollution Reduction Act

SB 350 (de León, 2015)

SB 350 increases California's renewable electricity procurement goal from 33% by 2020 to 50% by 2030, thus supporting greater use of resources eligible for the Renewables Portfolio Standard.

SB 350 mandates doubling statewide energy efficiency savings for electricity and natural gas end uses by 2030. SB 350 requires large utilities to submit integrated resource plans on how they will meet consumers' needs, reduce greenhouse gas emissions, and increase use of clean energy resources.

The 100 Percent Clean Energy Act of 2018

SB 100 (de León, 2018)

SB 100 establishes a goal that by 2045 all retail electricity sold in California and state agency electricity needs will be powered by renewable and zero-carbon resources.

SB 100 updates the Renewables Portfolio Standard to ensure that by 2030 at least 60% of state's electricity is renewable.

SB 100 requires the CEC, CPUC, and CARB to use existing laws to achieve 100% clean electricity and issue joint policy on SB 100 by 2021 and every four years after that.

Clean Energy, Jobs, and Affordability Act of 2022

SB 1020 (Laird, 2022)

SB 1020 added interim targets for renewable energy and zero-carbon electricity retail sales as legislated in [SB 100 \(de León, 2018\)](#): 90% by

153 California Air Resources Board. (2022). 2022 Scoping Plan for Achieving Carbon Neutrality. Available at: <https://ww2.arb.ca.gov/sites/default/files/2022-11/2022-sp.pdf>.

154 PSE Healthy Energy. (2017). Natural Gas Power Plants in California's Disadvantaged Communities. Available at: https://www.psehealthyenergy.org/wp-content/uploads/2017/04/CA.EJ_Gas_Plants.pdf.

2035 and 95% by 2040. SB 1020 requires state agencies to use 100% renewable energy and zero-carbon resources by 2030 and establishes a Climate and Equity Trust fund to manage rising electricity rates that threaten affordability.

California Global Warming Solutions Act

AB 32 (Nunez, 2006)

AB 32 required California to reduce greenhouse gas emissions to 1990 levels by 2020 and is designed to mitigate risks of climate change, improve energy efficiency, expand renewable energy, support cleaner transportation, and reduce waste. AB 32 requires CARB to develop a Scoping Plan (e.g., the [2022 Scoping Plan](#)) that delineates strategies for achieving emission reduction goals.

AB 32 also requires convening an Environmental Justice Advisory Committee to advise on Scoping Plans and climate programs. [SB 32 \(Pavley, 2016\)](#) expanded emissions targets to reflect a 40% reduction from 1990 levels by 2030.

California Climate Crisis Act

AB 1279 (Muratsuchi, 2022)

AB 1279 declares the policy of the state to achieve net-zero greenhouse gas emissions as soon as possible, but no later than 2045, and to achieve and maintain net negative emissions thereafter. Further, this law mandates that emissions by 2045 are reduced by 85% below 1990 levels (this is to ensure that direct emission reductions are favored over the broad deployment of carbon removal technologies).

This law requires CARB to work with relevant agencies to 1) ensure scoping plan updates include measures to achieve these policy goals; and 2) identify and implement strategies to enable carbon dioxide removal solutions and carbon capture, utilization, and storage technologies.

Diablo Canyon Nuclear Power Plant

SB 1090 (Monning, 2018)

SSB 1090 requires the CPUC to ensure that integrated resource plans avoid increases in greenhouse gas emissions resulting from the closure of Diablo Canyon Nuclear Power Plant.

Diablo Canyon Powerplant: Extension of Operations

SB 846 (Dodd, 2022)

SB 846 invalidates the CPUC's approval of the PG&E request to decommission Diablo Canyon Powerplant (DCPP). SB 846 provides a pathway to extend the life of Diablo Canyon Powerplant through 2030 and provides PG&E a loan of up to \$1.4 billion to do so. Relicensing through 2030 will first require PG&E to receive approval from the Nuclear Regulatory Commission, the U.S. Department of Energy, and several state regulatory agencies.

SB 846 directs the CEC, CPUC, and CAISO to develop load shifting targets to reduce peak net demand. These targets are to be updated for each Integrated Energy Policy Report. Further, the CEC, in consultation with the CPUC and CAISO, is to recommend policies that would increase load shifting and other forms of demand response that would not inadvertently lead to increased greenhouse gas emissions.

Green Hydrogen: Emissions of Greenhouse Gases

SB 1075 (Skinner, 2022)

SB 1075 requires the CPUC and CEC to consider the role of green hydrogen in their respective decarbonization strategies. SB 1075 affirms the intent of the Legislature to develop a leading green hydrogen industry in the state. SB 1075 supports the evaluation of other forms of hydrogen as possible decarbonization solutions.

Energy: Firm Zero-carbon Resources

SB 423 (Stern, 2022)

SB 423 requires the CEC to consider and incorporate firm zero-carbon resources into its integrated energy policy reports. By 2023, the CEC must submit to the Legislature an assessment of such resources that support a "clean, reliable, and resilient electrical grid in California" and achieve goals set by [SB 100 \(de León, 2018\)](#).

Integrated Energy Policy Report: Fusion Energy

AB 1172 (Calderon, 2023)

This law requires the CEC to consider the possible role of fusion energy in California's clean energy future as part of their 2027 Integrated Energy Policy Report.

Read More

[Seasonal Challenges for a California Renewable-Energy-Driven Grid.](#) Abido, M.Y. et al. (2022). iScience, 25(1), 103577.

[An assessment of the Diablo Canyon Nuclear Plant for zero-carbon electricity, desalination, and hydrogen production.](#) Aborn, J. et al. (2021). Stanford Energy.

[2025 Calif. Demand Response Potential Study — Charting California's Demand Response Future: Final Report on Phase 2 Results.](#)

Alstone, P. et al. (2017). Lawrence Berkeley National Laboratory.

[California's Electricity of the Future.](#)

CARB, CEC, CAISO, CPUC, and Office of Planning and Research. (2021).

[Modeling California Policy Impacts on Greenhouse Gas Emissions.](#) Greenblat, J. B. (2015). Energy Policy, 78, 158-172.

[California Needs Clean Firm Power, and so does the Rest of the World: Three Detailed Models of the Future of California's Power System all show that California Needs Carbon-Free Electricity Sources that don't Depend on the Weather.](#)

Long, J.C.S. et al. (2021).

[Clean Firm Power is the Key to California's Carbon-Free Energy Future.](#) Long, J.C.S. et al. (2021). Issues In Sci. and Tech.

[Low-Income Barriers Study, Part A: Overcoming Barriers to Energy Efficiency and Renewables for Low-Income Customers and Small Business Contracting Opportunities in Disadvantaged Communities.](#) Scavo, J. et al. (2016). Calif. Energy Commission. Pub. Number: CEC-300-2016-009-CMF.

Decentralizing the Grid

Deploying, integrating, and coordinating distributed energy resources to improve energy resilience.

Overview

California’s power grid—which is more than a century old in some places—is challenged by the growth in energy demand, addition of renewable resources, and increasingly common extreme heat and wildfires.

If effectively leveraged, **distributed energy resources (DERs)*** can help enhance energy resilience for consumers and the grid at large. This umbrella term includes small-scale energy resources—like rooftop solar panels, back-up generators, and batteries—that either store or generate energy and that are usually **behind-the-meter** (as opposed to utility-scale energy resources like power plants). DERs also include technologies that help reduce or shift energy demand (i.e., **demand response** and energy efficiency).

California is embarking on plans to modernize the electric grid by further integrating and coordinating these distributed resources.¹⁵⁵ However, California’s grid operators and electric utilities have numerous hurdles to overcome if they are to fully realize the benefits of DERs.

For example, transitioning from California’s historically centralized grid—whereby power is generated by a small number of large power plants and then transmitted across long distances to consumers across the state—to a more decentralized grid that also draws power from innumerable DERs will take a fundamental shift in grid management and introduces numerous challenges.

155 California Public Utilities Commission. (2021). Order Instituting Rulemaking to Modernize the Electric Grid for a High Distributed Energy Resources Future. Available at: <https://docs.cpuc.ca.gov/PublishedDocs/Published/G000/M382/K451/382451995.PDF>.

* Find **bold** words in the Glossary (Appendix A).

DERs defined

DERs are small-scale energy resources that are connected to lower-voltage distribution networks (as opposed to the high-voltage transmission system). They include technologies that store energy, generate electricity, or affect electricity use at the local level. They are often—but not always—located behind-the-meter.

The term “DER” does not necessarily imply a renewable or zero-carbon resource: diesel generators are technically DERs. However, most policy discussions about the role of DERs in California’s clean energy future will explicitly exclude non-renewable resources. Likewise, from this point forward, this section will only speak to DERs that could assist with decarbonizing the grid.

DERs can provide numerous benefits to the consumers who own them, including more affordable electricity and greater energy resilience. DERs could also be leveraged to provide valuable services to the grid, but it is usually the consumers—rather than utility providers or grid operators—who decide when and how they’re operated. Thus, the full potential of DERs can only be realized if these interests can be aligned, typically through financial incentives and compensation for their grid services. “Aggregators” help facilitate this alignment by virtually bundling DERs whose coordinated services are then sold on the wholesale market.

The three largest electrical utility providers in California are required to annually identify, review, and select opportunities where DERs could defer or avoid distribution infrastructure investments (known as the “Distribution Investment Deferral Framework”).¹⁵⁶

Distributed solar power

California already has significant DER capacity, primarily in the form of solar: 15 **gigawatts (GW)** of distributed solar has been installed as of July 2023.¹⁵⁷

Distributed generation may reduce the need for investment in utility-scale generation as well as transmission infrastructure. However, interconnecting high volumes of distributed solar in California has not been without challenges. For example, passing clouds can result in rapid and problematic fluctuations to the voltage on a distribution network.¹⁵⁸ These fluctuations become even more pronounced as more distributed solar is connected. As of 2017, California requires that all new rooftop installations include advanced inverters—which regulate the flow of power from the solar panels to the grid—that help counteract this issue.¹⁵⁹

Rooftop solar markets have been supported through a variety of policies and programs, including the Net Energy Metering Program (NEM). Under the program, customers who produce excess energy can receive financial credit on their electric bills for the surplus energy fed back into the grid. NEM makes the installation of solar panels more economical. The California Public Utilities Commission (CPUC) recently approved changes to NEM (see more later in the section).

156 California Public Utilities Commission. (2021). Distribution Planning. Accessed 12/3/2023 at: <https://www.cpuc.ca.gov/industries-and-topics/electrical-energy/infrastructure/distribution-planning>.

157 California Solar Initiative. (2023). California Distributed Generation Statistics. Accessed on 10/10/2023 at: <https://www.californiadgstats.ca.gov/>.

158 Visser, L.R. et al. (2022). Regulation Strategies for Mitigating Voltage Fluctuations Induced by Photovoltaic Solar Systems in an Urban Low Voltage Grid. *International Journal of Electrical Power & Energy Systems*, 137, pp. 107695.

159 California Public Utilities Commission. (2014). Interim Decision Adopting Revisions to Electric Tariff Rule 21 for Pacific Gas and Electric Company, Southern California Edison Company, and San Diego Gas & Electric Company to Require “Smart” Inverters. Available at: <https://docs.cpuc.ca.gov/PublishedDocs/Published/G000/M143/K827/143827879.PDF>.



Distributed battery storage

Distributed batteries are typically either 2-hour or 4-hour lithium-ion batteries. As of September 2022, there were approximately 81,000 distributed batteries connected to California's grid, capable of discharging almost 9 GW of power.¹⁶⁰

Distributed energy storage—if effectively deployed—could ease some of the challenges associated with **intermittent** renewable resources and reduce the need for fossil fuel generation (see **Section 3**).

By absorbing excess renewable energy produced during periods of low demand and then delivering that energy back to the grid during **net demand** peak, storage could reduce stress on the grid, improve flexibility during net demand peak, and allow for greater penetration of intermittent renewable resources. This potential role for distributed storage has not yet been fully realized as **price signals** have been ineffective at encouraging this behavior.¹⁶¹ See Section 3 for a longer discussion of intermittency and net demand.

When used in tandem, solar power and storage can enhance energy resilience for consumers. For example, during **public safety power shutoffs** or other outages, these systems allow consumers continued access to solar-generated electricity.

Demand response

The CPUC defines demand response as “reductions, increases, or shifts in electricity consumption by customers in response to either economic signals [e.g., time-of-use pricing] or reliability signals [e.g., **CAISO Flex Alerts**].” Reducing or shifting energy use in response to such signals

is known as “load shedding” or **load shifting**, respectively.

Demand response can help align energy demand with the supply of abundant renewable energy. By shifting energy use away from evening hours (when renewable electricity production is declining but electricity demand is often still high), demand response can alleviate the need for new energy generation.

As of 2022, all residential customers in California have been transitioned to time-of-use rate plans wherein energy consumption is more costly during the evening (i.e., during the net demand peak) than any other time of the day. These rate structures are meant to encourage consumers to conserve energy during peak net demand and/or shift their energy use to another time.

Electric utility providers also offer direct incentives to customers willing to participate in demand response programs. For example, Southern California Edison (SCE) offers up to \$180 in credit for customers with smart thermostats that allow SCE to remotely turn off or cycle their air conditioners during heat events that stress the grid.¹⁶²

“Smart” technologies can be programmed to automate load-shifting with little to no impact on consumer experience and with numerous grid and decarbonization benefits. For example, **heat pump** water heaters can be programmed to proactively heat water midday when renewable resources are abundant, helping to avert the **curtailment** of renewable generation and lessening net peak demand.

The California Energy Commission (CEC) has set a goal of achieving 7 GW of load shift resources by 2030.¹⁶³

¹⁶⁰ California Solar + Storage Association. (2022). Distributed Sun-charged Batteries Helped Grid During California Heat Wave, Again. Accessed on 12/2/2023 at: <https://calssa.org/press-releases/2022/9/8/distributed-sun-charged-batteries-helped-grid-during-california-heat-wave-again>.

¹⁶¹ California Public Utilities Commission. (2022). Advanced Strategies for Demand Flexibility Management and Customer DER Compensation. Energy Division White Paper and Staff Proposal. Available at: <https://www.cpuc.ca.gov/-/media/cpuc-website/divisions/energy-division/documents/demand-response/demand-response-workshops/advanced-der---demand-flexibility-management/ed-white-paper---advanced-strategies-for-demand-flexibility-management.pdf>.

¹⁶² Southern California Edison. (2023). Summer Discount Plan. Accessed 12/2/2023 at: <https://www.sce.com/residential/rebates-savings/summer-discount-plan>.

¹⁶³ Neumann, I., and Lyon, E. (2023). Senate Bill 846 Load-Shift Goal Report. *California Energy Commission*. Available at: <https://www.energy.ca.gov/publications/2023/senate-bill-846-load-shift-goal-report>.

Battery electric vehicles

California has over one million battery electric and plug-in hybrid vehicles.¹⁶⁴ In 2023, more than 25% of total vehicle sales in California were zero-emission vehicles.¹⁶⁵ Executive Order N-79-20 (2020) mandates that 100% of new vehicle sales be zero-emission vehicles by 2035, the majority of which are expected to be battery electric vehicles (BEVs). The CEC projects that by 2035, BEVs will account for 22% of the total electricity consumed annually in California.¹⁶⁶

While this new demand could strain the grid if unmanaged, BEVs also present new opportunities as DERs. For one, they represent significant load shift resources.¹⁶⁷ Vehicles are idle most of the time, indicating flexibility in when they could be charged.¹⁶⁸ Smart chargers could provide consumers with the option to avoid charging during net demand peak, reducing costs to the consumer, averting the curtailment of renewable energy generation (if charged midday),¹⁶⁹ and mitigating the need for distribution system upgrades and new electricity generation. According to one estimate, these load shift services could provide an estimated \$119 worth of benefits and avoided costs to the grid per vehicle per year.¹⁷⁰

With bidirectional charging (i.e., batteries that can discharge stored energy), battery electric vehicles could additionally provide very similar services to the grid and consumers as distributed battery storage. Bidirectional charging is sometimes referred to as vehicle-to-home, vehicle-to-grid, or vehicle-to-everything, depending on how the charging equipment is configured. At

Relevant State Institutions

- California Energy Commission (CEC)
- California Independent System Operator (CAISO)
- California Public Utilities Commission (CPUC)
- Calif. Dept. of Forestry and Fire Protection (CalFire)
- The Governor's Office of Tribal Affairs
- Assembly Budget Subcommittee No. 3 Climate Crisis, Resources, Energy, and Transportation
- Assembly Natural Resources
- Assembly Utilities & Energy Committee
- Senate Budget Subcommittee No. 2 on Resources, Environmental Protection and Energy
- Senate Energy, Utilities and Communications Committee
- Senate Environmental Quality Committee
- Senate Natural Resources and Water Committee
- Joint Leg. Committee on Climate Change Policies
- Joint Leg. Committee on Emergency Management

present, few BEV models allow for bidirectional charging. SB 233 (Skinner, 2023)—now a 2-year bill—would require bidirectional charging capabilities for all new BEVs and BEV charging equipment sold in California by 2030.

SB 676 (Bradford, 2019) required the CPUC to establish strategies for adjusting the time, intensity, and location of BEV charging (and discharging) with the goal of optimizing BEV integration with the grid. Determining and supporting the optimal integration of BEVs with the grid ("vehicle-grid integration") is an active area of effort at the CPUC.¹⁷¹

164 California Energy Commission. (2023). Light-duty Vehicle Population in California. Accessed on 12/3/2023 at: <https://www.energy.ca.gov/data-reports/energy-almanac/zero-emission-vehicle-and-infrastructure-statistics/light-duty-vehicle>.

165 California Energy Commission. (2023). New ZEV sales in California. Accessed on 12/3/2023 at: <https://www.energy.ca.gov/data-reports/energy-almanac/zero-emission-vehicle-and-infrastructure-statistics/light-duty-vehicle>.

166 California Energy Commission. (2023). Additional Transportation Electrification Scenario. Available at: <https://efiling.energy.ca.gov/Lists/DocketLog.aspx?doctetnumber=21-IEPR-03>.

167 Lipman, T., Harrington, A., and Langton, A. (2021). Total Charge Management of Electric Vehicles. *California Energy Commission*. Available at: <https://www.energy.ca.gov/sites/default/files/2021-12/CEC-500-2021-055.pdf>.

168 Kim, W., V. Añorve, and Tefft, B.C. 2019. American Driving Survey, 2014 – 2017. AA Foundation for Traffic Safety.

169 Sheppard, C. et al. (2019). Grid Impacts of Electric Vehicles and Managed Charging in California: Linking Agent-Based Electric Vehicle Charging with Power System Dispatch Models. *Lawrence Berkeley National Laboratory*. Available at: https://eta-publications.lbl.gov/sites/default/files/sheppard_-_grid_impacts.pdf.

170 Lipman, T., Harrington, A., and Langton, A. (2021). Total Charge Management of Electric Vehicles. *California Energy Commission*. Available at: <https://www.energy.ca.gov/sites/default/files/2021-12/CEC-500-2021-055.pdf>.

171 California Public Utilities Commission. (2021). VGI Policy, Pilots, and Technology Enablement. Accessed 12/15/2023 at:

Energy efficiency

Energy efficiency—the use of less energy to achieve the same result—has been a pillar of California’s decarbonization efforts for decades. The CEC has set energy efficiency standards for home appliances and buildings since the 1970s. Since 2003, regulations have required that energy efficiency and conservation measures be adopted before any new generation can be considered as a means to meet increasing demand.¹⁷²

Energy efficiency contributes to grid resilience by decreasing total demand (i.e., load shedding), which is particularly important for mitigating net demand peaks. In June 2023, the CPUC approved \$4.3 billion in investments for energy efficiency programs for 2024 – 2027.¹⁷³

Challenges

Historically, there were few DERs, and they were insignificant to grid operations. However, advancements in technology, rising electricity rates, and decarbonization policies and programs—like net energy metering, SB 100 (de Leon, 2018), and more recently the Advanced Clean Cars II Regulations—have been driving the adoption of DERs in California.

The 2022 Integrated Energy Policy Report Update predicts that by 2035, distributed generation and storage will be providing 68,256 giga-

watt-hours of electricity per year.¹⁷⁴ For context, California consumed 287,220 gigawatt-hours of utility-scale electricity in 2022.¹⁷⁵

A highly decentralized grid characterized by multidirectional energy flows (with many customers both drawing energy from the grid and producing energy that feeds the grid) requires transforming transmission and distribution systems—reshaping traditional roles and responsibilities of utility providers and energy markets and requiring new engineering standards.^{176,177} The CPUC is evaluating how best to address these challenges of a “high DER future.”¹⁷⁸

Because they are usually behind-the-meter, DERs are often not “visible” to grid operators. As millions of these resources are integrated into the distribution system, energy demand becomes significantly less predictable. This unpredictably creates challenges for grid operators who must ensure that power supplied to the grid closely matches the demand for energy, resulting in a consistent electrical frequency on the grid.

This unpredictably could be resolved by reinforcing distribution networks to better withstand voltage fluctuations. However, this approach is costly. More cost-effective approaches include financially incentivizing consumers to align their DER operations with grid requirements and improving the visibility operators have over DERs on their networks.¹⁷⁹

<https://www.cpuc.ca.gov/industries-and-topics/electrical-energy/infrastructure/transportation-electrification/vehicle-grid-integration-activities>.

172 Consumer Power and Conservation Financing Authority, Energy Resources Conservation and Development Commission, Public Utilities Commission. (2003). Energy Action Plan. Available at: https://docs.cpuc.ca.gov/word_pdf/REPORT/28715.pdf.

173 California Public Utilities Commission. (2023). Decision Authorizing Energy Efficiency Portfolio for 2024-2027. Available at: <https://docs.cpuc.ca.gov/PublishedDocs/Published/G000/M512/K638/512638943.PDF>.

174 California Energy Commission. (2023). Final 2022 Integrated Energy Policy Report Update. Available at: <https://www.energy.ca.gov/data-reports/reports/integrated-energy-policy-report/2022-integrated-energy-policy-report-update>.

175 Nyberg, M. (2023). 2022 Total System Electric Generation. *California Energy Commission*. Available at: <https://www.energy.ca.gov/data-reports/energy-almanac/california-electricity-data/2022-total-system-electric-generation>.

176 Gridworks. (2022). Evaluating Alternative Distribution System Operator Models for California. Available at: <https://gridworks.org/wp-content/uploads/2022/03/Evaluating-Alternative-DSO-Models-for-California.docx.pdf>.

177 De Martini, P., Kristov, L., and Schwartz, L. (2015). Distribution Systems in a High Distributed Energy Resources Future. *Lawrence Berkeley National Lab*, No. LBNL-1003797.

178 California Public Utilities Commission. (2021). Order Institute Rulemaking to Modernize the Electric Grid for a High Distributed Energy Resources Future. Available at: <https://docs.cpuc.ca.gov/PublishedDocs/Published/G000/M382/K451/382451995.PDF>.

179 International Energy Agency. (2022). Unlocking the Potential of Distributed Energy Resources: Power System Opportunities and Best Practices. Available at: <https://iea.blob.core.windows.net/assets/3520710c-c828-4001-911c->

Distributed energy resources

Small-scale energy resources that are connected to lower voltage distribution networks (as opposed to the high-voltage transmission system).

EXAMPLES	DESCRIPTION	POSSIBLE BENEFITS TO GRID	CHALLENGES TO IMPLEMENTATION AND INTEGRATION
Distributed Solar	Solar photovoltaic (PV) systems, typically sited on rooftops, that generate less than 1 MW	<ul style="list-style-type: none"> • An additional source of renewable generation that does not require new land conversion 	<ul style="list-style-type: none"> • Long queues for new interconnections • Variable generation that is hard for grid operators to forecast with precision
Distributed Batteries	Typically lithium-ion batteries that can be deployed in tandem with rooftop solar systems	<ul style="list-style-type: none"> • Additional generation during net demand peak • Capturing excess renewable generation, averting curtailment • If aggregated, voltage regulation on the distribution network/load balancing 	<ul style="list-style-type: none"> • Expensive for consumers to install
Demand Response	Adjustments to energy use by customers in response to economic or reliability signals. Could be automated with smart technologies (e.g., heat pump water heaters).	<ul style="list-style-type: none"> • Reducing energy use during net demand peak, lessening need for additional generation • Increasing use when there is abundant renewable energy, averting curtailment 	<ul style="list-style-type: none"> • Consumer responses to economic and reliability signals poorly understood • Lack of consumer awareness about demand response programs
Battery Electric Vehicles	Zero-emission vehicles that are charged by electricity	<ul style="list-style-type: none"> • Load shifting from net demand peak to other times of day • If capable of bidirectional charging, the same services could be provided by BEVs as other distributed battery storage (additional generation during net demand peak, voltage regulation) 	<ul style="list-style-type: none"> • If unmanaged, charging demands could strain the grid, necessitating new generation
Energy Efficiency	The use of less energy to achieve the same result (e.g., energy efficient light bulbs, dryers)	<ul style="list-style-type: none"> • Reduces demand, particularly beneficial for net demand peak 	<ul style="list-style-type: none"> • High up-front costs for energy-efficient technology • Rebound effect—consumers use more energy after acquiring energy efficient technologies, partially or fully counteracting energy reductions achieved

an upfront payment of \$750 and a free smart thermostat.

All three of California's largest investor-owned utilities are piloting programs for coordinating DERs on distribution networks.^{187,188,189} If successful, these programs could defer or substitute for further investment in generation, transmission, and distribution infrastructure,¹⁹⁰ alleviating some of the challenges discussed in Sections 1, 2, and 3.

Supporting distributed energy resources in California

As part of California's Strategic Reliability Reserve—created by AB 205 (Committee on Budget, 2022)—the CEC created the Demand Side Grid Support Program to help incentivize the participation of DERs as emergency resources during extreme events.

The CEC's Electric Program Investment Charge (EPIC) provides over \$130 million in research funding annually to accelerate the transformation of the electricity sector. One of the strategic objectives guiding EPIC investments through 2025 is "to increase the value proposition of distributed energy resources to customers and the grid."¹⁹¹

The CPUC's Self-Generation Incentive Program (SGIP) provides rebates to drive the adoption of qualifying behind-the-meter DERs that achieve reductions in greenhouse gas emissions (as per SB 700, Wiener, 2018).

The Solar on Multifamily Affordable Housing (SOMAH) Program, also administered by the CPUC, incentivizes solar panel installations for low-income tenants and property owners in disadvantaged communities.

Net energy metering

The rates at which customers should be paid for the energy they feed into the grid is a contentious debate. For example, the former net energy metering rate structure in California (NEM 2.0) paid consumers **retail rates** for the excess energy they exported to the grid as opposed to paying for the value of the energy alone.

Retail rates are what utilities charge consumers for every unit of power they use, and they reflect the bundled costs of energy generation, transmission, and distribution, as well as the costs of wildfire mitigation and investments in renewable and zero-carbon energy. Retail rates are roughly two to three times greater than the value of the energy.¹⁹²

This rate structure effectively subsidized power for consumers with rooftop solar and shifted the costs of infrastructure maintenance and other fixed costs (that are normally included in utility fees) to those without solar power.¹⁹³ This rate structure exacerbated inequalities given that low-income consumers face more barriers to installing rooftop solar.¹⁹⁴

187 Pacific Gas & Electric. (2022). Distributed Energy Resources Partnership Pilot. Accessed on 11/29/2022 at: https://www.pge.com/en_US/residential/save-energy-money/savings-programs/savings-programs-overview/partnership-pilot.page.

188 Southern California Edison. (2022). Integrated Distributed Energy Resources Partnership Pilot. Accessed on 11/29/2022 at: <https://www.sce.com/business/savings-incentives/integrated-distributed-energy-resources-partnership-pilot>.

189 San Diego Gas & Electric. (2022). Partnership Pilot. Accessed on 11/29/2022 at: <https://www.sdge.com/partnership-pilot>.

190 San Diego Gas & Electric. (2022). Partnership Pilot. Accessed on 11/29/2022 at: <https://www.sdge.com/partnership-pilot>.

191 Lew, V. et al. (2023). The Electric Program Investment Charge 2021—2025 Investment Plan. *California Energy Commission*. Available at: <https://www.energy.ca.gov/publications/2021/electric-program-investment-charge-proposed-2021-2025-investment-plan-epic-4>.

192 Borenstein, S., Fowlie, M., and Sallee, J. (2021). Designing Electricity Rates for an Equitable Energy Transition. *Energy Institute at Haas*, 314.

193 California Public Utilities Commission. (2021). Decision Revising Net Energy Metering Tariff and Subtariffs. Available at: <https://docs.cpuc.ca.gov/PublishedDocs/Efile/G000/M430/K903/430903088.PDF>.

194 Barbose, G. et al. (2022). Residential Solar-Adopter Income and Demographic Trends: 2022 Update. Lawrence Berkeley

In response, in December 2022, the CPUC unanimously approved the Net Billing Tariff (NBT) which reduced the rates paid for exported energy by about 75% compared to NEM 2.0; this new rate structure is applicable to any systems installed after the date the NBT took effect (April 15, 2023). These new rate structures are based on an “Avoided Cost Calculator” that estimates the relative value provided by DERs, which is dependent on time of day and stress on the grid (among other things).

Because exported energy will fetch a higher price in the evening than it would midday, the NBT is meant to help incentivize homeowners to install energy storage systems. However, the reduced rates decrease the economic incentive to install rooftop solar—something that has been criticized by solar advocates and some environmental nonprofits. Data collected by the California Solar and Storage Association show that applications for new rooftop solar installations across PG&E and Southern California Edison service territories have declined by 66 – 83% since NBT took effect.¹⁹⁵

Environmental Justice and Equity Considerations

Energy storage systems and demand response technologies can alleviate the energy burden borne by low-income households (i.e., the proportion of household income spent on energy costs), as long as there are resources available to help cover the costs of installation and maintenance. The Self-Generation Incentive Program (SGIP) earmarks \$100 million for low-income communities, stating that rebates will “lower the cost of energy storage technology to almost, if not completely, free of cost” for qualifying customers.¹⁹⁶

Only so many DERs can be supported on a distribution network before upgrades to the circuit are required—this is known as the **hosting capacity**. Research shows that patterns of hosting capacity in California result in inequitable access to DERs for disadvantaged communities and Black-identifying households.¹⁹⁷ Centering equity as one objective in prioritizing grid upgrades could help address these inequities.

National Laboratory. Available at: https://eta-publications.lbl.gov/sites/default/files/solar-adopter_income_trends_final_0.pdf.

195 St. John, J. (2023). California’s Rooftop Solar Policy is Killing its Rooftop Solar Industry. *Canary Media*. Accessed on 12/4/2023 at: <https://www.canarymedia.com/articles/solar/californias-rooftop-solar-policy-is-killing-its-rooftop-solar-industry>.

196 California Public Utilities Commission. (ND) Participating in Self-Generation Incentive Program (SGIP). Available at: <https://www.cpuc.ca.gov/industries-and-topics/electrical-energy/demand-side-management/self-generation-incentive-program/participating-in-self-generation-incentive-program-sgip>.

197 Brockway, A.M., Conde, J., and Callaway, D. (2021). Inequitable Access to Distributed Energy Resources due to Grid Infrastructure Limits in California. *Nature Energy*, 6(9), pp. 892-903.

Relevant Policies

(Laws/Regulations)

Public Utilities: Energy Metering

SB 656 (Alquist, 1995)

SB 656 required electric utilities to establish compensation schemes for customers who generate electricity in excess of their own needs and export said energy to the grid. This scheme requires measuring the difference between the electricity supplied by a utility to the customer and the electricity exported by the customer to the grid—known as net energy metering. AB 327 (Perea, 2013) required large investor-owned utilities to switch over to the standard tariff structure known as NEM 2.0. In December 2022, the CPUC approved the Net Billing Tariff.¹⁹⁸

Electricity: Natural Gas: Rates: Net Energy Metering: California Renewables Portfolio Standard

AB 327 (Perea, 2013)

Among other things, AB 327 included several provisions that affected DER planning and implementation in California. In addition to requiring utilities to switch to NEM 2.0, this law also required utilities to submit distribution resource plans to the CPUC and thereby initiated the CPUC's Distribution Resource Plans proceeding. Utilities were charged with calculating the locational benefits and costs of DERs, to identify mechanisms for their cost-effective deployment, and to propose methods that would maximize locational benefits.

Budget Act of 2013: Public Resources

SB 96 (Cmte. on Budget and Fiscal Review, 2013)

SB 96 created the Electric Program Investment Charge (EPIC) Program. Overseen by the CEC, EPIC invests more than \$130 million annually in research on expanding renewable energy, building safe/resilient electricity systems; advancing electric technologies; enabling a more decentralized electric grid; improving affordability, health, and comfort in communities; and supporting local economies.

Clean Energy and Pollution Reduction Act of 2015

SB 350 (de León, 2015)

SB 350 mandated that the CEC study barriers to solar energy generation and other renewable energy technologies confronted by low-income and disadvantaged communities.

Self-Generation Incentive Program

SB 700 (Wiener, 2018)

SB 700 extended the administration of the Self-Generation Incentive Program through 2025 and established the requirement that qualifying DERs must contribute to a reduction in greenhouse gas emissions.

The 100 Percent Clean Energy Act of 2018

SB 100 (de León, 2018)

Establishes goal that by 2045 all retail electricity sold in California and state agency electricity needs will be powered by renewable and zero-carbon resources.

Updates Renewables Portfolio Standard to ensure that by 2030 at least 60% of the state's electricity is renewable.

Requires CEC, CPUC and CARB to use existing laws to achieve 100% clean electricity and issue joint policy on SB 100 by 2021 and every four years after that.

198 California Public Utilities Commission. (2022). CPUC Issues Solar Tariff Modernization Proposal to Support Reliability and Decarbonization. Accessed 11/29/2022 at: <https://www.cpuc.ca.gov/news-and-updates/all-news/cpuc-issues-solar-tariff-modernization-proposal-to-support-reliability-and-decarbonization>.

Energy

AB 205 (Committee on Budget, 2022)

Among other things, AB 205 required the CEC to establish the Distributed Electricity Backup Assets Program to incentivize the use of distributed energy resources during emergencies and extreme events. This law also required the CEC to create the Demand Side Grid Support Program to help incentivize the participation of customer-sited DERs as emergency resources during extreme events.

Energy

AB 1373 (Garcia, 2023)

Among other things, AB 1373 requires the CEC to assess barriers to interconnection—and to propose solutions to address those barriers—as part of its 2025 Integrated Energy Policy Report.

Read More**[The Role of Net Metering in the Evolving Electricity System.](#)**

Besser, J.B. et al. (2023). National Academy of Sciences.

[Inequitable Access to Distributed Energy Resources Due to Grid Infrastructure Limits in California.](#)

Brockway, A.M. et al. (2021). Nature Energy, 6(9), pp. 892-903.

[Distributed Energy Resources Action Plan: Aligning Vision and Action.](#)

California Public Utilities Commission. (2022).

[Locational Value of Distributed Energy Resources.](#)

Frick, N.M. et al. (2021). Lawrence Berkeley National Laboratory.

[Evaluating Alternative Distribution System Operator Models for California.](#)

Gridworks. (2022).

[Unlocking the Potential of Distributed Energy Resources.](#)

International Energy Agency. (2022).

Carbon Capture & Storage

Capturing difficult-to-mitigate emissions.

Overview

Carbon capture and storage* (CCS) is the process of capturing, compressing, transporting, and sequestering carbon dioxide (CO₂). Most proposed applications for CCS involve capturing CO₂ that would have otherwise been released into the atmosphere during industrial processes, particularly fuel combustion. However, new applications are emerging that remove CO₂ from ambient air (known as “**direct air capture**” or DAC). The captured carbon can then be sequestered in geologic formations (see **Figure 5.1**). A small fraction could also be used for other industrial applications (like concrete, fuels, or plastic). Much of the cost and complexity of CCS relates to separating CO₂ from other gases, especially oxygen and nitrogen.¹⁹⁹ Where CO₂ is present in higher concentrations, this separation is typically easier and less expensive.

In its proposed scenario for reaching a **net-zero** economy by 2045 (as per AB 1279, Muratsuchi,

2022, 2022), the California Air Resources Board (CARB) includes CCS—and DAC—to limit emissions and minimize leakage from hard-to-decarbonize sectors.²⁰⁰ This aligns with the findings of multiple studies on climate change that have found few, if any, feasible trajectories to climate stabilization without significant amounts of CCS.²⁰¹

CCS deployment has historically been slow, but the pace is quickening. Globally, just over 40 commercial CCS facilities are operational, but 142 are either being constructed or at an advanced stage of development.²⁰² Early CCS projects have produced mixed results: many have been in continuous operation for several years, but others have closed or been cancelled due to both technical and economic challenges.

The extent to which California should rely on CCS to achieve its emissions reduction goals has

199 Congressional Research Service. (2022). Carbon Capture and Sequestration in the United States. Available at: <https://sgp.fas.org/crs/misc/R44902.pdf>.

200 California Air Resources Board. (2022). 2022 Scoping Plan for Achieving Carbon Neutrality. Available at: <https://ww2.arb.ca.gov/sites/default/files/2022-11/2022-sp.pdf>.

201 Intergovernmental Panel on Climate Change. (2022). Summary of the 56th Session of the Intergovernmental Panel on Climate Change and the 14th Session of Working Group III: 21 March - 4 April 2022. *Earth Negotiations Bulletin*, 12(795), pp. 1-32.

202 International Energy Agency. (2023). Carbon Capture, Utilisation and Storage. Accessed on 10/19/2023 at: <https://www.iea.org/energy-system/carbon-capture-utilisation-and-storage>.

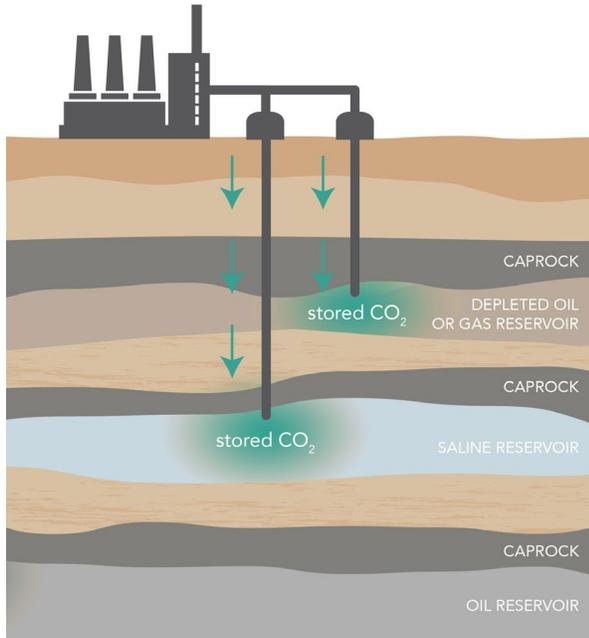


Figure 5.1. Captured CO₂ may be injected into depleted oil and gas reservoirs or saline reservoirs. Adapted from California Air Resources Board. (2022). Carbon Capture and Sequestration.

Available at: <https://ww2.arb.ca.gov/our-work/programs/carbon-capture-sequestration/about>.

generated much debate. Opponents argue that CCS does not achieve the emissions reductions promised, prolongs the life of polluting industries that are often located in disadvantaged communities, and distracts from opportunities for direct emissions reductions.

CCS in California

CCS has the potential to reduce carbon emissions by millions of metric tons and may be key to meeting California's climate targets.^{203,204,205} In *CARB's 2022 Scoping Plan*, modeling assumes

CCS will capture 25 million metric tons of CO₂ in 2045 from petroleum refineries, cement factories, and the electricity sector. This will require considerable capital investment for the construction and implementation of CCS facilities.²⁰⁶

Broad deployment of CCS could reduce emissions associated with hard-to-decarbonize sectors, including the production of ethanol, stone, clay, glass, and cement, and petroleum refining. Without access to CCS, these industries may close or, if demand persists, relocate to other states where they can continue to emit GHGs (known as **leakage**).²⁰⁷

203 California Air Resources Board. (2022). 2022 Scoping Plan for Achieving Carbon Neutrality. Available at: <https://ww2.arb.ca.gov/sites/default/files/2022-11/2022-sp.pdf>.

204 California Council on Science and Technology (CCST). (2015). California's Energy Future: The View to 2050 Summary Report. Available at: <https://www.ccst.us/wp-content/uploads/2011energy.pdf>. ISBN-13: 978-1-930117-44-0.

205 Baker, S.E. et al. (2020). Getting to Neutral: Options for Negative Carbon Emissions in California. *Lawrence Livermore National Laboratory*, LLNL-TR-796100.

206 National Energy Technology Laboratory. (2019). Cost and Performance Baseline for Fossil Energy Plants Volume 1: Bituminous Coal and Natural Gas to Electricity. Available at: https://netl.doe.gov/projects/files/CostAndPerformanceBaselineForFossilEnergyPlantsVol1BitumCoalAndNGtoElectBBRRev4-1_092419.pdf.

207 California Air Resources Board. (2022). 2022 Scoping Plan for Achieving Carbon Neutrality. Available at: <https://ww2.arb.ca.gov/sites/default/files/2022-11/2022-sp.pdf>.

More dilute CO₂ streams—like from cement and steel manufacturing—are more expensive to capture,²⁰⁸ hence the slow deployment of CCS in these industries. Conversely, some processes—like ethanol production or hydrogen production via steam methane reformation—generate relatively pure streams of CO₂ and represent opportunities for relatively cost-effective CCS deployment.

In most cases, CCS generates no economic value unless one is created through policy. The lack of sufficient financial incentives has long been viewed as a barrier to large-scale deployment of CCS.²⁰⁹ The [Infrastructure Investment and Jobs Act](#) allocated \$3.5 billion for carbon capture demonstrations and large pilots, while the [Inflation Reduction Act](#) (IRA) significantly expanded tax credits for carbon sequestration. The expanded tax credits are believed to make CCS more economically viable for electricity generation and a greater number of industrial applications.²¹⁰

Indeed, since the IRA was passed, more than 50 new CCS projects have been announced in the U.S. CCS projects announced since the IRA represent a greater diversity of industrial applications than those preceding the IRA.²¹¹

Several projects in California could benefit (and have already benefitted) from these and other federal investments. For example, in July 2023, Calpine launched a carbon capture pilot at its

natural gas power plant in the Eastbay city of Pittsburg which benefitted from a \$5.8 million grant from the U.S. Department of Energy (DOE).²¹² A coalition of organizations—led by Carbon TerraVault Holdings, LLC (a subsidiary of California Resources Corporation), Kern Community College District, and the Electric Power Research Institute—received close to \$12 million from the DOE to design and plan a network of direct air capture hubs, the first of which will be in Kern County.²¹³

California's [Low Carbon Fuel Standard](#)—designed to reduce the **carbon intensity** of transportation fuels in the state—created a pathway for relevant CCS and DAC projects to receive credits starting in 2019.²¹⁴ To date, no projects have been approved—or even advanced to public review—under this program.

CCS—either used with hydrogen production or at natural gas plants—could facilitate the production of the clean, **firm power** necessary to manage the intermittency of renewable resources (see **Section 3**), so long as sufficient capture rates can be achieved.

CCS technologies can leverage the existing workforce in refinery operations and oil and gas production. CCS may also support the economic development of other emerging industries like DAC.²¹⁵

208 International Energy Agency. (2022). Levelised Cost of CO₂ Capture by Sector and Initial CO₂ Concentration. Accessed on 11/29/2022 at: <https://www.iea.org/data-and-statistics/charts/levelised-cost-of-co2-capture-by-sector-and-initial-co2-concentration-2019>.

209 U.S. Department of Energy. (2010). Report of the Interagency Task Force on Carbon Capture and Storage. *Office of Fossil Energy and Carbon Management*. Available at: https://www.energy.gov/sites/prod/files/2013/04/f0/CCSTaskForceReport2010_0.pdf.

210 Bright, M. (2022). The Inflation Reduction Act Creates a Whole New Market for Carbon Capture. *Clean Air Task Force*. Accessed on 11/28/2022 at: <https://www.catf.us/2022/08/the-inflation-reduction-act-creates-a-whole-new-market-for-carbon-capture/>.

211 Sheff, E, and Ulama, D. (2023). From Act to Action: How the Inflation Reduction Act is Accelerating Decarbonization in the United States with Carbon Capture and Storage. Accessed on 10/16/2023 at: <https://www.catf.us/2023/08/from-act-action-inflation-reduction-act-accelerating-decarbonization-united-states-carbon-capture-storage/>.

212 U.S. Department of Energy. (2021). DOE Invests \$45 million to Decarbonize the Natural Gas Power and Industrial Sectors Using Carbon Capture and Storage. Accessed 10/29/2023 at: <https://www.energy.gov/articles/doe-invests-45-million-decarbonize-natural-gas-power-and-industrial-sectors-using-carbon>.

213 California Resources Corporation. (2023). California DAC Hub. Accessed 10/19/2023 at: <https://www.crc.com/carbon-terravault/projects/california-dac-hub/default.aspx>.

214 California Air Resources Board. (2023). Carbon Capture and Sequestration Protocol Under the Low Carbon Fuel Standard. Accessed on 5/24/2023 at: <https://ww2.arb.ca.gov/resources/documents/carbon-capture-and-sequestration-protocol-under-low-carbon-fuel-standard>.

215 Glenwright, K. (2020). Roadmap for Carbon Capture and Storage in California. *Stanford Earth Matters Magazine*. Accessed on 11/03/2022 at: <https://earth.stanford.edu/news/roadmap-carbon-capture-and-storage-california#gs.8754ku>.

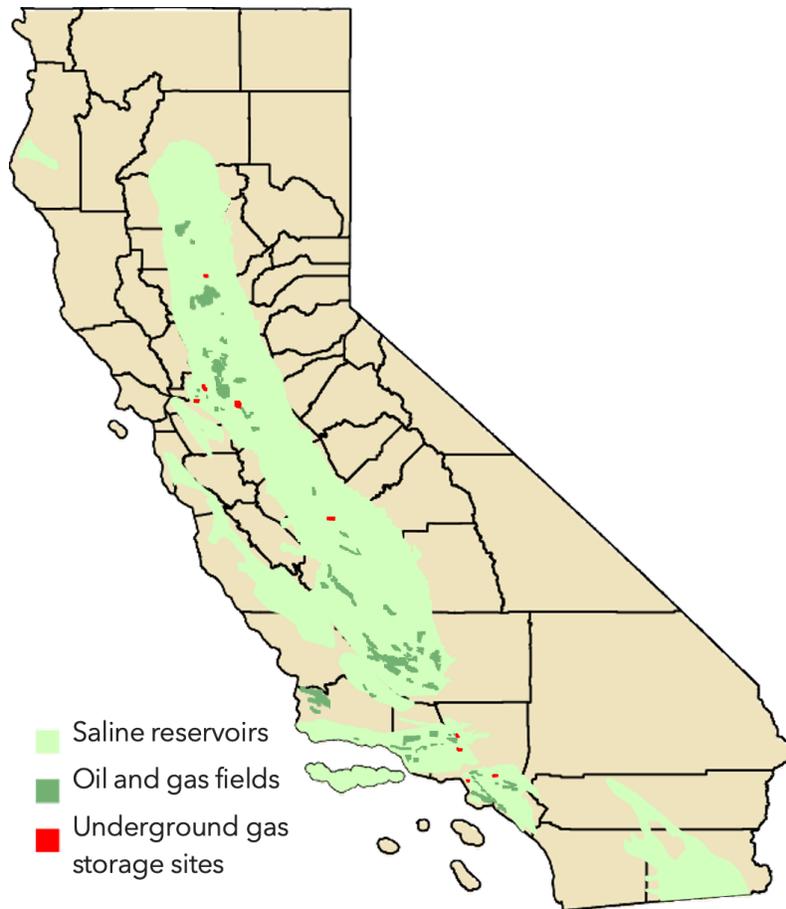


Figure 5.2. Potential storage sites for CO₂ in California include saline reservoirs, oil and gas fields, and underground gas storage sites. Note that current legislation prohibits the use of carbon captured from CCS projects for enhanced oil recovery (SB 905, Caballero, 2022 and SB 1315, Limón, 2022). Adapted from Energy Futures Initiative and Stanford University. (2020). An Action Plan for Carbon Capture and Storage in California: Opportunities, Challenges, and Solutions.

Available at: https://sccs.stanford.edu/sites/g/files/sbi-ybj17761/files/media/file/EFI-Stanford-CA-CCS-FULL-rev2-12.11.20_0.pdf.

California has a geology well-suited to permanently storing large amounts of carbon given the presence of large saline reservoirs and depleted oil and gas reservoirs, which are considered among the best storage sites for carbon (see **Figure 5.2**).²¹⁶ The sedimentary rock formations in the Central Valley alone have an estimated storage capacity of at least 17 billion tons of CO₂.²¹⁷ Estimates for California's total CO₂ storage capacity exceed that necessary to store 1,000 times the CO₂ emitted from California's electricity sector in 2020.²¹⁸ Close proximity to storage sites greatly reduces the need for costly pipeline infrastructure.

The extent to which California should rely on CCS to achieve its emissions reduction goals has generated much debate. Opponents argue that CCS does not achieve the emissions reductions promised, prolongs the life of polluting industries that are often located in disadvantaged communities, and distracts from opportunities for direct emissions reductions. Proponents argue that CCS can be an effective tool for eliminating emissions, that the enormity of the task at hand will require every tool available, and that the slow deployment to date has been due to overly complicated regulations and insufficient and uncertain incentives for CCS. They also argue that there are some applications—such as production of cement, liquid shipping and aviation fuels, and perhaps clean firm power—that have no cost-effective, scalable zero-emission alternatives.

Public opposition to CCS presents a significant challenge to its deployment. For example, proposed carbon pipelines in the U.S. Midwest have been met with fierce opposition.²¹⁹ The inclusion of CCS in CARB's 2022 Scoping Plan was vehemently opposed by more than 150 environmental justice, climate equity, faith-based, and environmental groups that called CCS an

Relevant State Institutions

- California Air Resources Board (CARB)
- California Energy Commission (CEC)
- California Environmental Protection Agency (CalEPA)
- California Natural Resources Agency (CNRA)
- California Geological Survey
- California Geologic Energy Mgmt. Division (CalGEM)
- California Public Utilities Commission (CPUC)
- California State Lands Commission
- California State Water Resources Board
- The Governor's Office of Tribal Affairs
- Assembly Budget Subcommittee No. 3 Climate Crisis, Resources, Energy, and Transportation
- Assembly Natural Resources Committee
- Assembly Utilities & Energy Committee
- Assembly Committee on Water, Parks, and Wildlife
- Senate Budget Subcommittee No. 2 on Resources, Environmental Protection and Energy
- Senate Energy, Utilities and Communications Committee
- Senate Environmental Quality Committee
- Senate Natural Resources and Water Committee
- Joint Legislative Committee on Climate Change Policies

Permitting at the state level will require approvals from many or all of the following:

- California State Water Resources Board
- California Department of Fish and Game
- California Department of Transportation
- California Public Utilities Commission
- California Energy Commission
- Local Air Districts
- Regional Water Quality Control Boards
- Numerous Federal Agencies

216 Raza, A. et al. (2019). Significant Aspects of Carbon Capture and Storage—A Review. *Petroleum*, 5(4), pp. 335-340.

217 Baker, S.E. et al. (2020). Getting to Neutral: Options for Negative Carbon Emissions in California. *Lawrence Livermore National Laboratory*, LLNL-TR-796100.

218 California Air Resources Board. (2020). 2020 GHG Emissions by Main Economic Sector. *GHG Emission Inventory Graphs*. Accessed 11/28/2022 at: <https://ww2.arb.ca.gov/ghg-inventory-graphs>.

219 Douglas, L. (2022). U.S. Carbon Pipeline Proposals Trigger Backlash over Potential Land Seizures. *Reuters*. Accessed on 11/28/2022 at: <https://www.reuters.com/business/environment/us-carbon-pipeline-proposals-trigger-backlash-over-potential-land-seizures-2022-02-07/>.

“industry scam” and “a cynical attempt at green-washing.”^{220,221}

Capture rates and emission reductions

Current CCS technologies are typically designed to capture an estimated 90% of the carbon produced in targeted emission streams when operating at full capacity (the other 10% is released into the atmosphere).²²² Capture rates are not meant to indicate that a facility's total onsite emissions will be reduced by 90%, rather that up to 90% of the CO₂ from a given emission stream can be captured and removed. Capture rates do not account for total lifecycle emissions, which vary across industrial applications. For example, capture rates do not account for **upstream emissions** associated with the production and distribution of the fossil fuels, which can be substantial. Some facilities have many emission sources. This makes it difficult, if not impossible, to capture all associated emissions, especially when considering retrofits to existing infrastructure.

Additional energy (10–29% more than standard operation requirements^{223,224}) is required to power the CCS equipment. As with electrification efforts, the source of the energy matters and will influence net emission reductions achieved. At power plants, this energy demand may be satisfied by the output of the plant on which it's installed, but this reduces the amount of power delivered to the grid. As for any mitigation technology, the life-cycle emissions and environmental impacts must be considered in comparing options.

When the captured carbon is used for **enhanced oil recovery** (i.e., injected into oil reserves to improve extraction of residual oil), the GHG benefits of CCS are likely to be reduced in comparison to CCS projects without enhanced oil recovery.²²⁵ Most older petroleum wells in California currently use steam injection to extend production. Enhanced oil recovery with CO₂ may use comparatively less natural gas while providing the added benefit of carbon sequestration. Current legislation (SB 905, Caballero, 2022 and SB 1314, Limón, 2022) prohibits the injection of captured carbon from CCS projects for enhanced oil recovery in California.

Accurate carbon accounting is critical for all CCS projects. For example, carbon captured from power plant exhaust could be used in concrete manufacturing. Both the power plant and concrete producer played a role in capturing the CO₂, but GHG accounting rules should establish how credits would be produced and allocated in a way that avoids double counting. In addition, if a CCS project receives funding to support some or all of its construction costs, further policy incentives may not actually provide any additional GHG reductions. Most incentives implicitly assume that emission reductions would not have occurred if that incentive were not present (i.e., that any GHG reductions generated are additional to a hypothetical business-as-usual scenario), but that may not always be the case. That is not to say that a single project cannot or should not receive support from multiple programs, but crediting the project's full GHG benefits under each program may overstate the total impact of both programs, together. Policymakers may need to critically examine claims of GHG reductions to ensure

220 California-Based Groups and National Organizations with Members in California. (2022). A Call for a Climate Change Scoping Plan that Addresses the Needs of the Climate, the People and the Environment. Available at: <https://www.foodandwaterwatch.org/wp-content/uploads/2022/06/Group-Letter-Fix-CAs-Climate-Plan-6.21.2292.pdf>.

221 Physicians for Social Responsibility Los Angeles and Allies. (2021). Oppose AB 1395—California Climate Crisis Act Opposition Letter. Available at: <https://www.deltacouncil.ca.gov/pdf/council-meeting/meeting-materials/2021-11-18-item-9-attachment-1-ab-1395-opposition-letter.pdf>.

222 International Energy Agency. (2021). Zero-emission Carbon Capture and Storage In Power Plants Using Higher Capture Rates. Available at: <https://www.iea.org/articles/zero-emission-carbon-capture-and-storage-in-power-plants-using-higher-capture-rates>.

223 Vasudevan, S. et al. (2016). Energy Penalty Estimates for CO₂ Capture: Comparison Between Fuel Types and Capture-Combustion Modes. *Energy*, 103, pp. 709-714.

224 Sgouridis, S. et al. (2019). Comparative Net Energy Analysis of Renewable Electricity and Carbon Capture and Storage. *Nature Energy*, 4(6), pp. 456-465.

225 Farajzadeh, R. et al. (2020). On the Sustainability of CO₂ through CO₂ – Enhanced Oil Recovery. *Applied Energy*, 261, pp. 114467.

benefits are not double counted, as well as claims of additionality to ensure efficient use of policy incentives.

Potential risks

Permanent geologic carbon storage may cause induced seismicity—minor earthquakes due to pressure changes that cause repositioning or cracking of stressed rocks.²²⁶ “Microseismicity” (small earthquakes not felt at the surface) are common for geologic carbon storage sites.²²⁷ Whether carbon storage could induce larger earthquakes is debated.²²⁸ Even small seismic events negatively impact public perception and could damage nearby infrastructure.²²⁹ Research suggests that prior oil and gas production at carbon injection sites reduces the risk of induced seismicity.²³⁰

Though long-term carbon retention rates are expected to be quite high in well-regulated environments (98% over 10,000 years),²³¹ there is still a risk that geological storage sites may gradually leak CO₂, with ramifications for overall efficacy as a mitigation technique, as well as human health and safety.^{232,233} Concentrated CO₂ can cause asphyxiation. Leaked CO₂ can also contaminate groundwater because CO₂ causes water to be more acidic and leads to the release of harmful

metals.²³⁴ However, most potential CCS reservoirs are in non-potable saline aquifers that are far deeper and geologically isolated from drinkable aquifers. Appropriate site selection, rigorous monitoring, and regulatory oversight will be critical to mitigating these risks.²³⁵

Pipeline failures also pose safety risks. For example, in 2020, a CO₂ pipeline ruptured outside of Satartia, Mississippi, requiring the evacuation of close to 200 people and causing 45 people to seek medical attention. In response, in May 2022 the U.S. Department of Transportation’s Pipeline and Hazardous Materials Safety Administration (PHMSA) announced it will be updating safety requirements for CO₂ pipelines.²³⁶ A notice of proposed rulemaking is expected from PHMSA in June 2024.²³⁷ SB 905 (Caballero, 2022) prohibits the transport of CO₂ via pipeline until these new measures take effect.

Environmental Justice and Equity Considerations

The implementation of CCS alone does not necessarily address other harmful pollutants emitted by industrial facilities—including some that are

226 Cesca, S. et al. (2014). The 2013 September–October Seismic Sequence Offshore Spain: A Case of Seismicity Triggered by Gas Injection? *Geophysical Journal International*, 198(2), pp. 941-953.

227 Vilarrasa, V. et al. (2019). Induced Seismicity in Geologic Carbon Storage. *Solid Earth*, 10(3), pp. 871-892.

228 Vilarrasa, V., and Carrera, J. (2015). Geologic Carbon Storage is Unlikely to Trigger Large Earthquakes and Reactivate Faults Through Which CO₂ Could Leak. *Proceedings of the National Academy of Sciences*, 112(19), pp. 5938-5943.

229 Vilarrasa, V. et al. (2019). Induced Seismicity in Geologic Carbon Storage. *Solid Earth*, 10(3), pp. 871-892.

230 Dvory, N. Z., and Zoback, M. D. (2021). Prior Oil and Gas Production can Limit the Occurrence of Injection-Induced Seismicity: A Case Study in the Delaware Basin of Western Texas and Southeastern New Mexico, USA. *Geology*, 49(10), pp. 1198-1203.

231 Alcalde, J. et al. (2018). Estimating Geological CO₂ Storage Security to Deliver on Climate Mitigation. *Nature Communications*, 9(1), pp. 1-13.

232 Bielicki, J.M., Peters, C.A., Fitts, J.P., and Wilson, E.J. (2015). An Examination of Geologic Carbon Sequestration Policies in the Context of Leakage Potential. *International Journal of Greenhouse Gas Control*, 37, pp. 61-75.

233 Vinca, A., Emmerling, J., and Tavoni, M. (2018). Bearing the Cost of Stored Carbon Leakage. *Frontiers in Energy Research*, 6, pp. 40.

234 Little, M.G., and Jackson, R.B. (2010). Potential Impacts of Leakage from Deep CO₂ Geosequestration on Overlying Freshwater Aquifers. *Environmental Science & Technology*, 44(23), pp. 9225-9232.

235 Anderson, J. et al. (2005). *Underground Geological Storage*. Cambridge University Press, pp. 195-275.

236 U.S. Department of Transportation. (2022). PHMSA Announces New Safety Measures to Protect Americans from Carbon Dioxide Pipeline Failures After Satartia, MS Leak. Pipeline and Hazardous Materials Safety Administration. Accessed on 11/28/2022 at: <https://www.phmsa.dot.gov/news/phmsa-announces-new-safety-measures-protect-americans-carbon-dioxide-pipeline-failures>.

237 Parfomak, P.W. (2023). Carbon Dioxide (CO₂) Pipeline Development: Federal Initiatives. Congressional Research Service. Available at: <https://crsreports.congress.gov/product/pdf/IN/IN12169>.

known or suspected to cause cancer and birth defects. Completely eliminating harmful co-pollutants from these facilities would be challenging and would require other technologies including electrification and advanced control technologies.

Some CCS technologies operate more efficiently if some of these pollutants are removed beforehand. For example, amine solvents (used in some CCS projects) are degraded by the presence of sulfur dioxide, particulate matter, and certain nitrogen oxides in flue streams.^{238,239} Because Section 45Q of the U.S. Tax Code—which provides a tax credit for carbon sequestration—is proportional to the amount of CO₂ captured and stored, this provides an incentive for facilities to address these co-pollutants.

The U.S. Environmental Protection Agency (U.S. EPA) has proposed new standards for fossil fuel power plants that would necessitate CCS on many of these facilities.²⁴⁰ Flue streams at coal fired power plants (of which California has only one) contain significant amounts of co-pollutants known to degrade amine solvents often used for CCS. Thus, the U.S. EPA estimates that these regulations would indirectly lead to the reduction of tens of thousands of tons of these air pollutants through 2042, resulting in \$5.4 to \$5.9 billion annually in net health benefits.²⁴¹ Flue streams

at natural gas power plants already contain suitably low levels of these co-pollutants from an amine-degradation perspective and will not require pretreatment for CCS.²⁴²

More than 80 environmental justice and conservation nonprofits urged the U.S. Environmental Protection Agency to deny applications for CCS facilities in California's Central Valley, contending that proposed projects would "resurrect or prolong the life of polluting industrial facilities in predominantly low-income neighborhoods of color that already experience some of the worst air quality in the country."²⁴³

CARB's Environmental Justice Advisory Committee (EJAC) has raised concerns about CCS, including potential impacts to human health and safety presented by leaks and due to increased industrial activity at carbon capture sites. Instead, EJAC recommends that CARB prioritize direct emission reductions and natural approaches to carbon sequestration.²⁴⁴

In a study of sites identified as potential pilots for carbon sequestration, researchers found that communities expressed the desire to understand the range of technological options and potential risks to be mitigated and to be empowered in the decision-making process to ensure justice

238 International CCS Knowledge Centre. (2021). Lehigh Cement Edmonton CCUS Feasibility Project. Available at: <https://www.eralberta.ca/wp-content/uploads/2022/04/Lehigh-Edmonton-CCS-Feasibility-ERA-Project-Outcomes-Non-Confidential.pdf>.

239 U.S. Environmental Protection Agency. (2023). Proposed Rule: New Source Performance Standards for Greenhouse Gas Emissions from New, Modified, and Reconstructed Fossil Fuel-Fired Electric Generating Units; Emission Guidelines for Greenhouse Gas Emissions from Existing Fossil Fuel-Fired Electric Generating Units; and Repeal of the Affordable Clean Energy Rule. National Archives. Available at: <https://www.federalregister.gov/documents/2023/05/23/2023-10141/new-source-performance-standards-for-greenhouse-gas-emissions-from-new-modified-and-reconstructed#citation-366-p33302>.

240 U.S. Environmental Protection Agency. (2023). Proposed Rule: New Source Performance Standards for Greenhouse Gas Emissions from New, Modified, and Reconstructed Fossil Fuel-Fired Electric Generating Units; Emission Guidelines for Greenhouse Gas Emissions from Existing Fossil Fuel-Fired Electric Generating Units; and Repeal of the Affordable Clean Energy Rule. National Archives. Available at: <https://www.federalregister.gov/documents/2023/05/23/2023-10141/new-source-performance-standards-for-greenhouse-gas-emissions-from-new-modified-and-reconstructed#citation-366-p33302>.

241 U.S. Environmental Protection Agency. (2023). Fact Sheet for Communities with Environmental Justice Concerns: Greenhouse Gas Standards and Guidelines for Fossil Fuel-Fired Power Plants Proposed Rule. Available at: <https://www.epa.gov/system/files/documents/2023-05/FS-EJ-GHG-for%20Power%20Plants%20-%20FINAL%205-10-23.pdf>.

242 U.S. Environmental Protection Agency. (2023). Proposed Rule: New Source Performance Standards for Greenhouse Gas Emissions from New, Modified, and Reconstructed Fossil Fuel-Fired Electric Generating Units; Emission Guidelines for Greenhouse Gas Emissions from Existing Fossil Fuel-Fired Electric Generating Units; and Repeal of the Affordable Clean Energy Rule. National Archives. Available at: <https://www.federalregister.gov/documents/2023/05/23/2023-10141/new-source-performance-standards-for-greenhouse-gas-emissions-from-new-modified-and-reconstructed#citation-366-p33302>.

243 Center for Biological Diversity. (2022). EPA Urged to Reject Carbon Capture Projects in Central California. Accessed 11/02/2022 at: <https://biologicaldiversity.org/w/news/press-releases/epa-urged-to-reject-carbon-capture-projects-in-central-california-2022-06-29/>.

244 California Air Resources Board. (2022). Preliminary Draft of EJAC Scoping Plan Recommendations. Available at: <https://ww2.arb.ca.gov/sites/default/files/barcu/board/books/2022/031022/ejacrecs.pdf>.

or fairness in decisions.²⁴⁵ Empowerment in the decision-making process is critical as disadvantaged communities may be neglected by local leadership.²⁴⁶

Relevant Policies

(Laws/Regulations)

Low Carbon Fuel Standard

Executive Order S-01-07, 2007

The Low Carbon Fuel Standard (LCFS) is administered by CARB. LCFS was launched in 2011 after being formally established by Executive Order S-01-07 and identified by CARB's 2008 Scoping Plan as an early action to reduce greenhouse gas emissions.

LCFS assesses a carbon-intensity (CI) value for transportation fuels based on lifetime GHG emissions associated with the production, transportation, and use of those fuels. All fuels are compared to a declining CI target. Fuels with increasingly lower CIs than the target generate more credits, while fuels with CIs that exceed the target generate deficits.

In 2019, CARB created a pathway for projects that implement CCS or DAC to reduce the CI of transportation fuels to receive credits.

Carbon Sequestration: Carbon Capture, Removal, Utilization, and Storage Program

SB 905 (Caballero, 2022)

SB 905 established a program to evaluate the efficacy, safety, and viability of carbon capture, utilization, or storage technologies and carbon dioxide removal technologies, and to facilitate the capture and sequestration of carbon dioxide from those technologies. The law also requires certain monitoring and reporting activities to ensure public environmental health and safety.

SB 905 prohibits injection of concentrated carbon dioxide fluid produced through capture, removal, or sequestration into Class II injection wells to enhance recovery of oil resources. SB 905 prohibits the transfer of CO₂ pipelines until the Federal Pipeline and Hazardous Materials Safety Administration has updated the minimum federal safety standards for carbon dioxide pipelines.

Oil and Gas: Class II Injection Wells: Enhanced Oil Recovery

SB 1314 (Limón, 2022)

SB 1314 prohibits the injection of concentrated carbon dioxide fluid produced by a carbon dioxide capture and/or sequestration project into Class II injection wells with the intent of increasing recovery of oil resources, including the enabling of enhanced oil recovery from another well.

California Climate Crisis Act

AB 1279 (Muratsuchi, 2022)

AB 1279 declares the policy of the state to achieve net zero greenhouse gas emissions as soon as possible—but no later than 2045—and to achieve and maintain net negative emissions thereafter.

Further, this law mandates that emissions by 2045 are reduced by 85% below 1990 levels (this is to ensure that direct emission reductions are favored over the broad deployment of carbon removal technologies).

This law requires CARB to work with relevant agencies to 1) ensure scoping plan updates include measures to achieve these policy goals; and 2) identify and implement strategies to enable carbon dioxide removal solutions and carbon capture, utilization, and storage technologies.

245 Wong-Parodi, G., and Ray, I. (2009). Community Perceptions of Carbon Sequestration: Insights from California. *Environmental Research Letters*, 4(3), pp. 034002.

246 Flores-Landeros, H. et al. (2021). Community Perspectives and Environmental Justice in California's San Joaquin Valley. *Environmental Justice* 15(6), pp. 337-345.

Read More

[Sharing the Benefits: How the Economics of Carbon Capture and Storage Projects in California Can Serve Communities, the Economy, and the Climate.](#)

Grove, B., and Peridas, G. (2023). Lawrence Livermore National Laboratory.

[Getting to Neutral: Options for Negative Carbon Emissions in California.](#)

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[2022 Scoping Plan for Achieving Carbon Neutrality](#)

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[Accounting and Permanence Protocol for Carbon Capture and Geologic Sequestration under Low Carbon Fuel Standard](#)

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[Pathways to Carbon Neutrality in California: Clean Energy Solutions that Work for Everyone](#)

Surles, T., Grossman, T., and Saltzer, S.D. (2021). Stanford Center for Carbon Storage and Stanford Carbon Removal Initiative.

[An Action Plan for Carbon Capture and Storage in California: Opportunities, Challenges, and Solutions](#)

Energy Futures Initiative and Stanford University. (2020).

[Recommendations for Geologic Carbon Sequestration in California: I. Siting Criteria and Monitoring Approaches, and II. Example Application Case Study](#)

Oldenburg, C.M., Jordan, P.D., and Burton, E. (2017). Lawrence Berkeley National Laboratory.

[Permitting Carbon Capture & Storage Projects in California](#)

Peridas, G. (2021). Lawrence Livermore National Laboratory.

The Future of the Natural Gas System

Reducing natural gas consumption to meet climate and air quality laws while ensuring a reliable energy supply.

Overview

More natural gas is consumed in California than in any other state except Texas. Of all natural gas consumed in state, approximately 32% is used to generate electricity; 33% is used in industry; 22% is used for residential purposes (e.g., heating and cooking); 12% is used for commercial applications; and 1% is used for vehicle fuel (**Figure 6.1**).²⁴⁷ Approximately 36% of California's power is derived from natural gas (as of 2022).²⁴⁸ However, meeting the State's climate and air quality laws requires nearly eliminating consumption of natural gas—other than at facilities with **carbon capture and storage*** (CCS)—by 2045.

Policies are being implemented that reduce California's dependence on natural gas due to

its impacts on climate and health (via **electrification**, increasing energy efficiency, building more renewable resources, etc.). Between 2001 and 2022, in-state natural gas use declined by 15%²⁴⁹ despite a 14% increase in population over the same period.²⁵⁰ The California Energy Commission (CEC) predicts close to another 12% reduction by 2035 (relative to 2020 levels).²⁵¹

Currently, natural gas is most commonly used as an **energy carrier** for heat production. Renewable electricity can replace natural gas in most of these applications. However, some current uses of natural gas—particularly for **firm power** (i.e., power that can be delivered for as long as needed in the amount needed) and as a

247 U.S. Energy Information Administration. (2022). California Natural Gas Consumption by End Use. Independent Statistics & Analysis. Accessed on 10/16/2023 at: https://www.eia.gov/dnav/ng/ng_cons_sum_dcu_SCA_a.htm.

248 California Energy Commission. (2023). 2022 Total System Electric Generation. *California Energy Commission*. Available at: <https://www.energy.ca.gov/data-reports/energy-almanac/california-electricity-data/2022-total-system-electric-generation>.

249 U.S. Energy Information Administration. (2022). Natural Gas Delivered to Consumers in California (Including Vehicle Fuel). Accessed on 11/22/2022 at: <https://www.eia.gov/dnav/ng/hist/n3060ca2m.htm>.

250 USA Facts. (2022). Our Changing Population: California. Accessed on 12/15/2022 at: <https://usafacts.org/data/topics/people-society/population-and-demographics/our-changing-population/state/california?endDate=2021-01-01&startDate=2001-01-01>.

251 Javanbakht, H. et al. (2022). Final 2021 Integrated Energy Policy Report, Volume IV: California Energy Demand Forecast. *California Energy Commission*. Publication Number: CEC-100-2021-001-V4. Available at: <https://efiling.energy.ca.gov/GetDocument.aspx?tn=241581>

* Find **bold** words in the Glossary (Appendix A).

feedstock for chemical industries—may not be feasible to replace with renewable electricity. The key challenges for policymakers will be to transition most natural gas uses to lower-carbon alternatives while preserving the capacity to supply the hard-to-replace sectors and reducing the environmental impacts of natural gas extraction, distribution, and use, particularly **methane** leaks and air pollution caused by natural gas combustion.

Climate, health, and safety impacts

Natural gas is primarily composed of methane—a greenhouse gas with nearly 30 times the **global warming potential** of carbon dioxide (over a 100-year time period)²⁵²—and also contains ethane, propane, carbon dioxide, water vapor, as well as toxic pollutants like benzene.

California imports more than 90% of the natural gas it consumes through a network of interstate pipelines that leak.^{253,254} Approximately 12% of California's methane emissions are attributed to pipeline leaks.²⁵⁵ Other natural gas infrastructure is also susceptible to large leaks, as in 2015-2016 when Aliso Canyon—a natural gas

storage facility outside Los Angeles—leaked approximately 100,000 metric tons of methane over four months,²⁵⁶ the largest methane leak in the United States to date. Aliso Canyon is still in operation at reduced capacity, though attempts have been made to shut it down (e.g., [SB 1486, Stern, 2022](#)). In August 2023, the California Public Utilities Commission (CPUC) unanimously voted to expand capacity at Aliso Canyon by 67% from the previously allowable limit to better protect consumers from volatile gas prices.²⁵⁷ Research suggests that the risks of underground gas storage can be managed with appropriate regulations and careful monitoring.²⁵⁸

While less carbon intensive than oil or coal, the combustion of natural gas generates carbon dioxide (along with other pollutants). Natural gas combustion contributed 38% of carbon dioxide emissions in California in 2019.²⁵⁹ Combustion also produces nitrogen oxides and volatile organic compounds which react in the atmosphere to form **ozone**—a toxic air pollutant, greenhouse gas, and precursor to smog.

Natural gas and oil production facilities are known to emit **hazardous air pollutants**—pollutants known or suspected to cause cancer or other serious health problems.^{260,261} For this reason, [SB](#)

252 Forster, P. et al. (2021). The Earth's Energy Budget, Climate Feedbacks, and Climate Sensitivity. *Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change*, pp. 923-1054. Available at: <https://www.ipcc.ch/report/ar6/wg1/chapter/chapter-7/>.

253 Duren, R.M. et al. (2019). California's methane super-emitters. *Nature*, 575(7781), pp. 180-184.

254 Ersoy D. et al. (2019). Quantifying Methane Emissions from Distribution Pipelines in California. *Gas Technology Institute, California Air Resources Board*. Available at: https://ww2.arb.ca.gov/sites/default/files/2021-01/Final_CARB_Pipeline%20Study_1-14-21.pdf.

255 Jones, M. et al. (2022). Final 2021 Integrated Energy Policy Report, Volume III: Decarbonizing the State's Gas System. *California Energy Commission*. Publication Number: CEC-100-2021-001-V3. Available at: <https://efiling.energy.ca.gov/GetDocument.aspx?tn=242233>.

256 California Air Resources Board. (2016). Determination of Total Methane Emissions from the Aliso Canyon Natural Gas Leak Incident. Available at: https://ww2.arb.ca.gov/sites/default/files/2020-07/aliso_canyon_methane_emissions-arb_final.pdf.

257 California Public Utilities Commission. (2023). CPUC Takes Action to Enhance Energy Affordability for Ratepayers in Southern California. Accessed 10/16/2023 at: <https://www.cpuc.ca.gov/news-and-updates/all-news/cpuc-takes-action-to-enhance-energy-affordability-for-ratepayers-in-southern-california-2023>.

258 California Council on Science and Technology. (2018). Long-Term Viability of Underground Natural Gas Storage in California. Available at: https://ccst.us/wp-content/uploads/Full-Technical-Report-v2_max.pdf.

259 Jones, M. et al. (2022). Final 2021 Integrated Energy Policy Report, Volume III: Decarbonizing the State's Gas System. *California Energy Commission*. Publication Number: CEC-100-2021-001-V3. Available at: <https://efiling.energy.ca.gov/GetDocument.aspx?tn=242233>.

260 Garcia-Gonzales, D.A. et al. (2019). Hazardous Air Pollutants Associated with Upstream Oil and Natural Gas Development: A Critical Synthesis of Current Peer-Reviewed Literature. *Annual Review of Public Health*, 40, pp. 283-304.

261 U.S. Environmental Protection Agency. (ND). Oil and Natural Gas Production Facilities: National Emission Standards for Hazardous Air Pollutants (NESHAP). Accessed on 11/01/22 at: <https://www.epa.gov/stationary-sources-air-pollution/oil-and-natural-gas-production-facilities-national-emission>.

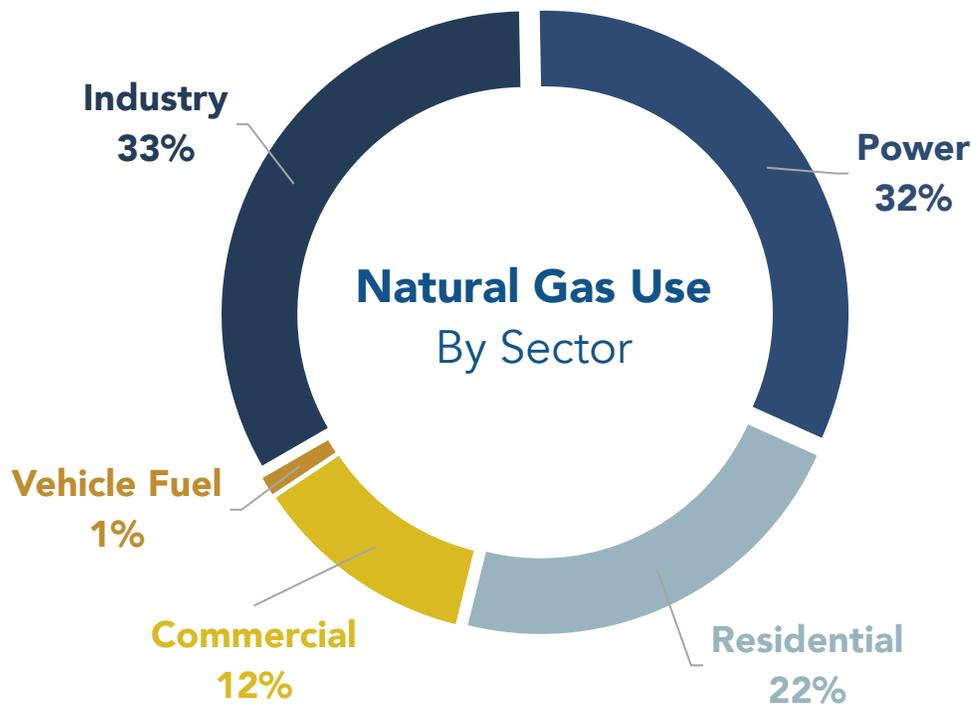


Figure 6.1. Natural gas use across sectors in California in 2022. Data are from the U.S. Energy Information Administration. (2023). Natural Gas Consumption by End Use.

Available at: https://www.eia.gov/dnav/ng/ng_cons_sum_dcu_SCA_a.htm.

1137 (Gonzalez, 2022) would prohibit the construction of new oil and gas production facilities within 3,200 feet of homes, daycare centers, schools, hospitals, or other sensitive zones, and requires oil and gas well operators to implement a leak detection and response plan by 2027. This law would have taken effect in January 2023 but was qualified for a veto referendum. It will appear on the ballot in November 2024.

Approximately 70% of Californian households currently cook with natural gas (compared to 38% nationwide).²⁶² Without proper ventilation,²⁶³ cooking with natural gas introduces hazardous air pollutants—including particulate matter, nitrogen dioxide, carbon monoxide, and formaldehyde—into the home. Studies have linked natural gas stoves to higher rates of asthma and other respiratory illnesses in children.^{264,265} The use of a natural gas stove without proper ventilation can elevate nitrogen dioxide concentrations

262 U.S. Energy Information Agency. (2022). In 2020, Most U.S. Households Prepared at least one Hot Meal a Day at Home. Accessed on 5/30/2023 at: <https://www.eia.gov/todayinenergy/detail.php?id=53439>.

263 Singer, B.C. et al. (2021). Effective Kitchen Ventilation for Healthy Zero Net Energy Homes with Natural Gas. *California Energy Commission*. Publication Number: CEC-500-2021-005. Available at: <https://www.energy.ca.gov/sites/default/files/2021-05/CEC-500-2021-005.pdf>.

264 Lin, W., Brunekreef, B., and Gehring, U. (2013). Meta-Analysis of the Effects of Indoor Nitrogen Dioxide and Gas Cooking on Asthma and Wheeze in Children. *International Journal of Epidemiology*, 42(6), pp. 1724-1737.

265 Zhu, Y. et al. (2020). Effects of Residential Gas Appliances on Indoor and Outdoor Air Quality and Public Health in California. *UCLA Fielding School of Public Health, Department of Environmental Health Sciences*. Available at: <https://ucla.app.box.com/s/xyzt8jc1ixnetiv0269qe704wu0ihif7>.



within households to levels considered by the U.S. Environmental Protection Agency²⁶⁶ to be “unhealthy for sensitive groups” in a matter of minutes.²⁶⁷ Furthermore, a small amount of natural gas is continuously leaked into the home even when appliances are turned off.²⁶⁸ Thus, even when proper ventilation is used while cooking, the presence of natural gas stoves in homes still poses certain health risks.²⁶⁹

Decarbonizing buildings

The building decarbonization strategy in California calls for enhancing energy efficiency, electrifying end uses, increasing demand flexibility, and supplying more renewable energy²⁷⁰—all of which will reduce natural gas consumption in the commercial and residential sectors.

Natural gas-powered space and water heating represent the bulk of greenhouse gas emissions produced on-site,²⁷¹ but there are efficient electric alternatives available. The Technology and Equipment for Clean Heating (TECH) Initiative—established as part of SB 1477 (Stern, 2018)—incentivizes the adoption of low-emission electric **heat pump** technologies for space heating, air conditioning, and water heating in existing single and multifamily homes in California.

The Equitable Building Decarbonization Program, established by AB 209 (Committee on Budget, 2022), will invest close to \$1 billion by June 2027 to support building decarbonization efforts, including support for the direct installation of electric appliances for low-income residents.

The Inflation Reduction Act also established two energy rebate programs: the Homeowner Managing Energy Savings (HOMES) Rebate Program

266 Office of Air and Radiation. (2011). Air Quality Guide for Nitrogen Dioxide. U.S. Environmental Protection Agency. Available at: <https://www.airnow.gov/sites/default/files/2018-06/no2.pdf>.

267 Lebel, E.D. et al. (2022). Methane and NOx Emissions from Natural Gas Stoves, Cooktops, and Ovens in Residential Homes. *Environmental Science & Technology*, 56(4), pp. 2529-2539.

268 Lebel, E.D. et al. (2022). Methane and NOx Emissions from Natural Gas Stoves, Cooktops, and Ovens in Residential Homes. *Environmental science & technology*, 56(4), pp. 2529-2539.

269 Lebel, E.D. et al. (2022). Composition, Emissions, and Air Quality Impacts of Hazardous Air Pollutants in Unburned Natural Gas from Residential Stoves in California. *Environmental Science & Technology*, 56(22), pp. 15828-15838.

270 Kenney, M. et al. (2022). Final 2021 Integrated Energy Policy Report, Volume I: Building Decarbonization. *California Energy Commission*. Publication Number: CEC-100-2021-001- V1. Available at: <https://efiling.energy.ca.gov/GetDocument.aspx?tn=241599>.

271 Kenney, M. et al. (2022). Final 2021 Integrated Energy Policy Report, Volume I: Building Decarbonization. *California Energy Commission*. Publication Number: CEC-100-2021-001- V1. Available at: <https://efiling.energy.ca.gov/GetDocument.aspx?tn=241599>.

and the High-Efficiency Electric Home (HEEH-RA) Rebate Program. HOMES will provide up to \$8,000 for whole-house efficiency upgrades (or up to \$400,000 for multifamily buildings) while HEEHRA will provide point-of-sale rebates of up to \$14,000 for the purchase and installation of qualified appliances including heat pump technologies and electric stoves.²⁷² HEEHRA is only available for low- or moderate-income households. These rebates are expected to be available in 2024.

The 2022 Energy Code encourages heat pump technologies for newly constructed single-family homes, multifamily buildings, and select commercial buildings.²⁷³

The California Air Resources Board (CARB) 2022 Scoping Plan recommends that a) 100% of new residential and 100% of new commercial buildings be outfitted for electrical appliances by 2026 and 2029, respectively; and b) new appliance sales be 80% electric by 2030 and 100% electric by 2045. As per the 2022 Energy Code, all new homes built in California are required to be electric-ready (effective January 2023).

As of October 2023, more than 76 cities and counties in California have adopted regulations that restrict or discourage natural gas in new construction.²⁷⁴ Berkeley, California, was the first U.S. city to ban natural gas hookups for new developments. While Berkeley's ban was overturned by a federal appeals court in April 2023, regulations in other jurisdictions that differ in their structure may not be similarly impacted.²⁷⁵ In September 2022, the CPUC voted to eliminate subsidies for natural gas hookups for new buildings (effective July 2023).²⁷⁶

Relevant State Institutions

- California Air Resources Board (CARB)
- California Energy Commission (CEC)
- California Geologic Energy Mgmt. Division (CalGEM)
- California Independent System Operator (CAISO)
- California Public Utilities Commission (CPUC)
- Assembly Budget Subcommittee 3 on Climate Crisis, Resources, Energy, and Transportation
- Assembly Natural Resources Committee
- Assembly Utilities and Energy Committee
- Senate Budget Subcommittee 2 on Resources, Environmental Protection and Energy
- Senate Energy, Utilities and Communications Committee
- Senate Environmental Quality Committee
- Senate Natural Resources and Water Committee
- Joint Legislative Cmte. on Climate Change Policies

Natural gas infrastructure

One challenge introduced by electrification is determining how best to manage existing natural gas infrastructure even as demand for natural gas declines. One approach, known as **pruning**, is to strategically retire parts of the gas system as buildings served by each segment are fully electrified. Pruning would minimize costs borne by ratepayers and mitigate inequitable outcomes (see Environmental Justice and Equity Considerations, below). For example, rather than replacing an aging gas line, pruning the line can avert this cost. Savings can be used to upgrade the electric distribution system or to support incentives that mitigate electrification costs for consumers (such as those introduced by the early retirement of natural gas heaters).

272 California Energy Commission. (2023). Inflation Reduction Act Residential Energy Rebate Programs in California. Accessed 10/16/2023 at: <https://www.energy.ca.gov/programs-and-topics/programs/inflation-reduction-act-residential-energy-rebate-programs-california>.

273 California Energy Commission. (2021). 2022 Building Energy Efficiency Standards Summary. Available at: https://www.energy.ca.gov/sites/default/files/2021-08/CEC_2022_EnergyCodeUpdateSummary_ADA.pdf.

274 Kushen, S. (2023). California's Cities Lead the Way on Pollution-Free Homes and Buildings. *Sierra Club*. Accessed on 10/16/23 at: <https://www.sierraclub.org/articles/2021/07/californias-cities-lead-way-pollution-free-homes-and-buildings>.

275 Har, J. (2023). Court Tosses Berkeley Gas Ban, but Wider Impact is Unclear. *Associated Press*. Accessed on 5/23/2023 at: <https://apnews.com/article/berkeley-california-natural-gas-ban-overturned-court-3546acbaec5db011c89a610baa42cebc>.

276 California Public Utilities Commission. (2022). CPUC Decision Makes California First State in Country to Eliminate Natural Gas Subsidies to Accelerate Building Decarbonization. Available at: <https://docs.cpuc.ca.gov/PublishedDocs/Published/G000/M496/K979/496979465.PDF>.

The CEC has awarded grants for two pilot projects on gas system decommissioning in the Pacific Gas & Electric²⁷⁷ and Southern California Gas service areas.²⁷⁸ These pilots will inform data-driven tools that could help optimize gas system decommissioning.²⁷⁹

The Pacific Gas & Electric project team released [an interim report](#) in June 2023 that highlights several structural and policy changes they believe would be necessary before gas system decommissioning could be achieved at scale.²⁸⁰ Examples of recommended actions include legislation that identifies electricity as an acceptable fuel substitute that would fulfill the “obligation to serve” and guidelines for ratepayer funding of gas decommissioning projects.

The production of plastic, hydrogen, and ammonia (as well as a few other chemical industries) require the methane molecules themselves rather than the energy they carry. These industries will continue to need a safe, reliable, and cost-effective supply of methane. The uses that are likely to require methane for the foreseeable future tend to occur at larger, industrial scales. They can likely be satisfied even as California extensively prunes its natural gas distribution network.

Meeting electricity demand

Demand for natural gas in the electricity sector is predicted to decline due to SB 100 (de León, 2018), which requires 100% of retail electricity sold in the state to be obtained from renewable or zero-carbon resources by 2045.²⁸¹

California needs clean, firm power that can meet demand when renewable resources are insufficient. Natural gas currently provides much of the firm power necessary to balance the state’s energy load during peak demand periods and during the winter when wind and solar capacities decline significantly. Energy storage, **demand response**, and grid regionalization can alleviate some, but likely not all, of the needs for firm power.

Peaker plants—natural gas plants that only operate when needed to meet periods of high demand—have grown more numerous in California over the last two decades, from 29 plants in 2001 to 74 in 2020.²⁸² Peaker plants can be quickly deployed when there is need for additional power, but they emit more greenhouse gases than typical natural gas plants.²⁸³ The majority of these plants are in **disadvantaged communities**.²⁸⁴ [SB 338 \(Skinner, 2017\)](#) requires energy providers to identify clean, low-cost alternatives to meeting peak demand, though [CARB’s 2022 Scoping Plan](#) acknowledges that “fossil gas generation will continue to play a critical role in grid reliability

277 Energy and Environmental Economics, Inc. (2022). E3 Undertakes Analysis of Targeted Decommissioning of Natural Gas Infrastructure in California. Accessed on 12/02/22 at: <https://www.ethree.com/e3-undertakes-analysis-of-targeted-decommissioning-of-natural-gas-infrastructure-in-california/>.

278 California Energy Commission. (2021). Strategic Pathways and Analytics for Tactical Decommissioning of Portions of Natural Gas Infrastructure in Southern California. Accessed 10/17/2023 at: <https://www.energizeinnovation.fund/projects/strategic-pathways-and-analytics-tactical-decommissioning-portions-natural-gas-0>.

279 California Energy Commission. (2023). Development of a Data-Driven Tool to Support Strategic and Equitable Decommissioning of Gas Infrastructure. Accessed on 11/01/2022 at: <https://www.energy.ca.gov/solicitations/2021-11/gfo-21-504-development-data-driven-tool-support-strategic-and-equitable>.

280 Energy & Environmental Economics, Inc. (2023). Strategic Pathways and Analytics for Tactical Decommissioning of Portions of Gas Infrastructure in Northern California. Available at: <https://gridworks.org/wp-content/uploads/2023/06/Evaluation-Frame-work-for-Strategic-Gas-Decommissioning-in-Northern-California-Interim-Report-for-CEC-PIR-20-009.pdf>.

281 California ISO. (2022). 20-Year Transmission Outlook. Available at: <http://www.caiso.com/InitiativeDocuments/Draft20-YearTransmissionOutlook.pdf>.

282 Roy, S., Sinha, P., and Ismat Shah, S. (2020). Assessing the Techno-Economics and Environmental Attributes of Utility-Scale PV with Battery Energy Storage Systems (PVS) Compared to Conventional Gas Peakers for Providing Firm Capacity in California. *Energies*, 13(2), pp. 488.

283 McNamara, W. (2020). Issue Brief - Energy Storage to Replace Peaker Plants. *Sandia National Laboratories*. Available at: <https://www.sandia.gov/app/uploads/sites/163/2022/04/Issue-Brief-2020-11-Peaker-Plants.pdf>.

284 Krieger, E.M., Casey, J.A., and Shonkoff, S.B. (2016). A framework for Siting and Dispatch of Emerging Energy Resources to Realize Environmental and Health Benefits: Case Study on Peaker Power Plant Displacement. *Energy Policy*, 96, pp. 302-313.

As Californians transition away from natural gas, those who remain on the natural gas system risk being burdened with an increasingly larger share of the “fixed costs” associated with infrastructure maintenance through their energy bills.⁴⁰

until other clean, dispatchable alternatives are available and can be deployed at scale.²⁸⁵

Modeling conducted for the 2021 SB 100 Joint Agency Report suggests that maintaining “significant gas capacity” in the power sector is the most economical path to ensuring adequate resources are available to meet demand. One possible solution is to deploy CCS at natural gas plants to facilitate the production of firm, low-carbon electricity. Please see **Section 3** for a discussion of firm power alternatives.

Reducing carbon intensity

Some demand for natural gas or other gaseous energy carriers in industry, transportation, and the

building sector will likely remain, even in a highly decarbonized future.²⁸⁶ The substitution of natural gas with renewable gas alternatives—like renewable hydrogen or **biomethane**—would reduce the lifecycle emissions associated with hard-to-electrify applications. However, there are challenges with these alternatives.

For example, like fossil gas, hydrogen and biomethane produce nitrogen oxides when burned. Because biomethane is chemically identical to methane, it is also a potent greenhouse gas though it has a lower lifecycle **carbon intensity** (see more below). Hydrogen is known to be an indirect greenhouse gas—this means that while it is not a greenhouse gas itself, hydrogen interacts with other molecules in the atmosphere

285 California Air Resources Board. (2022). 2022 Scoping Plan for Achieving Carbon Neutrality. Available at: <https://ww2.arb.ca.gov/sites/default/files/2022-11/2022-sp.pdf>.

286 Jones, M. et al. (2022). Final 2021 Integrated Energy Policy Report, Volume III: Decarbonizing the State’s Gas System. California Energy Commission. Publication Number: CEC-100-2021-001-V3. Available at: <https://efiling.energy.ca.gov/GetDocument.aspx?tn=242233>.

in a process that ultimately causes methane and sometimes ozone to remain in the atmosphere longer than they would otherwise.²⁸⁷ For biomethane or renewable hydrogen to provide the envisioned greenhouse gas reduction benefits, infrastructure leaks must be strictly controlled. The demand for these alternatives is likely to be much less than current natural gas demand and concentrated in fewer high-volume customers.

As per [SB 1440 \(Hueso, 2018\)](#), the CPUC has set procurement requirements for biomethane for the large **investor-owned utilities** providing gas service in California—Southern California Gas, Pacific Gas & Electric, San Diego Gas & Electric, and Southwest Gas—as a means for reducing methane emissions in the state.²⁸⁸ [AB 678 \(Alvarez, 2023\)](#) extends the CPUC's authority to also set procurement targets for third-party natural gas providers who were previously exempt. These procurement targets may not be sufficient to spur the development of projects necessary to support long-term biomethane demand in the state nor the deployment of anaerobic digesters necessary to meet California's methane emission reduction targets.

Biomethane qualifies for Low-Carbon Fuel Standard (LCFS) credits when used to replace natural gas for transportation. Biomethane produced from anaerobic digesters at livestock operations has been assigned an extremely low, typically negative, carbon intensity, which results in large financial incentives for dairy farmers to participate. This low carbon intensity rating assumes manure would otherwise generate methane that gets released into the atmosphere (known as "avoided methane crediting"). In 2022, biomethane represented only around 1%

of transportation fuel in California yet generated the third largest number of LCFS credits out of all transportation fuels.²⁸⁹

A petition has been filed against the inclusion of biomethane derived from dairy and swine farms in the LCFS. The petition argues that these facilities negatively impact nearby communities and that—because other manure management alternatives exist that could reduce methane emissions from livestock operations—LCFS inflates the emissions reductions achieved through this biomethane production pathway.²⁹⁰ CARB has proposed phasing out avoided methane crediting for dairy and swine biomethane pathways by 2040. CARB has also proposed amending the pipeline deliverability requirements in such a way that new biomethane producers in the eastern U.S. would be ineligible to participate in LCFS.²⁹¹

As electric vehicle technology has improved over the last decade, the consensus among energy system experts is that biomethane is no longer needed as part of the transportation fuel portfolio. See **Section 7** for more on decarbonizing transportation.

Blending hydrogen into existing natural gas pipelines and infrastructure is being explored as a potential solution that could reduce the carbon intensity of gas systems and expedite the production, storage, and use of renewable hydrogen. However, preliminary results suggest that hydrogen blending—especially at concentrations greater than 5%—creates a range of challenges that must be addressed before implementation.²⁹² In mid-December 2022, the

287 Warwick, N. et al. (2022). Atmospheric Implications of Increased Hydrogen Use. *Crown*. Available at: https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/1067144/atmospheric-implications-of-increased-hydrogen-use.pdf.

288 California Public Utilities Commission. (2022). Decision Implementing Senate Bill 1440 Biomethane Procurement Program. Available at: <https://docs.cpuc.ca.gov/PublishedDocs/Published/G000/M454/K335/454335009.PDF>.

289 California Air Resources Board. (2023). 2022 LCFS Reporting Tool (LRT) Quarterly Data Summary: Report No. 4. Available at: https://ww2.arb.ca.gov/sites/default/files/2023-04/Q4%202022%20Data%20Summary_042823.pdf.

290 California Air Resources Board. (2021). Petition for Reconsideration of the Denial of the Petition for Rulemaking to Exclude all Fuels Derived from Biomethane from Dairy and Swine Manure from the Low Carbon Fuel Standard Program. Available at: <https://ww2.arb.ca.gov/sites/default/files/2022-04/2022-03-28%20-%20Petition%20for%20Reconsideration%20%28TOC%20Updated%29.pdf>.

291 California Air Resources Board. (2023). Low Carbon Fuel Standard 2023 Amendments: Standardized Regulatory Impact Assessment. Available at: https://ww2.arb.ca.gov/sites/default/files/2023-09/lcfs_sria_2023_0.pdf.

292 Miroslav, P. et al. (2022). Hydrogen Blending Impacts Study Final Report. *California Public Utilities Commission*. Available at: <https://docs.cpuc.ca.gov/PublishedDocs/Efile/G000/M493/K760/493760600.PDF>.

CPUC called for more pilot projects to inform possible standards for hydrogen blending in natural gas pipelines.²⁹³

Alternatively, hard-to-electrify sectors might be able to implement carbon capture and storage (see **Section 5**) to reduce the carbon impacts of their operations while continuing to use natural gas.

For those applications that require methane as a chemical feedstock, biomethane—produced from the anaerobic digestion of organic waste or the gasification of agricultural or woody biomass—presents a compelling low-carbon alternative. Biomethane production pathways can differ greatly in the carbon intensities of their respective lifecycles.²⁹⁴ Most biomethane pathways have lower life cycle carbon intensities than fossil natural gas. However, as with most renewable fuels, the greenhouse gas impact is seldom zero. The carbon intensities of each pathway will need to be factored carefully into California’s plans to reach net-zero. More research is needed to better understand how biomethane supplies compare to projected demand.

Environmental Justice and Equity Considerations

More than half of California’s natural gas power plants are in communities ranked among the 25% most disadvantaged (according to CalEnviroScreen—an online mapping tool used by the California Environmental Protection Agency to identify communities in California most vulnerable to pollution).²⁹⁵

Low-income households tend to have worse indoor pollution created by natural gas stoves because they are smaller, have a higher occupant density, and are more likely to have substandard ventilation equipment.²⁹⁶

As Californians transition away from natural gas, those who remain on the natural gas system risk being burdened with an increasingly larger share of the “fixed costs” associated with infrastructure maintenance through their energy bills.²⁹⁷ If such a transition occurs without pruning, a shrinking pool of consumers using the gas system must pay to maintain it. Often, those that remain on the gas system do so not as a choice but as a matter of circumstance, such as renters or low-income consumers.

Electrification may lead to long-term savings, but there are often higher upfront costs that may be infeasible for socioeconomically disadvantaged groups. Programs have been developed to help address barriers to electrification. For example, the TECH Initiative directs 40% of program benefits to low-income and disadvantaged communities.

293 California Public Utilities Commission. (2022). Decision Directing Biomethane Reporting and Directing Pilot Projects to Further Evaluate and Establish Pipeline Injection Standards for Clean Renewable Hydrogen. Available at: <https://docs.cpuc.ca.gov/PublishedDocs/Published/G000/M500/K055/500055657.PDF>.

294 Rai, S. et al. (2022). Comparative Life Cycle Evaluation of the Global Warming Potential (GWP) Impacts of Renewable Natural Gas Production Pathways. *Environmental Science & Technology*, 56(12), pp. 8581-8589.

295 PSE Healthy Energy. (2017). Natural Gas Power Plants in California’s Disadvantaged Communities. Available at: https://www.psehealthyenergy.org/wp-content/uploads/2017/04/CA.EJ_Gas_Plants.pdf.

296 Zhao, H. et al. (2021). Indoor Air Quality in New and Renovated Low-Income Apartments with Mechanical Ventilation and Natural Gas Cooking in California. *Indoor Air*, 31(3), pp. 717-729.

297 Aas, D. et al. (2020). The Challenge of Retail Gas in California’s Low-Carbon Future: Technology Options, Customer Costs and Public Health Benefits of Reducing Natural Gas Use. *California Energy Commission*. Publication Number: CEC-500-2019-055-F. Available at <https://www.energy.ca.gov/sites/default/files/2021-06/CEC-500-2019-055-F.pdf>.

Relevant Policies

(Laws/Regulations)

Building Energy Efficient Standards

(Energy Code) – Title 24

Standards to lower carbon emissions of new and renovated buildings to a) encourage heat pump technology; b) establish electric-ready requirements; c) expand solar photovoltaic and battery storage; and d) strengthen ventilation standards.

Renewables Portfolio Standard (RPS) Program

SB 1078 (Sher, 2002)

The RPS Program mandated an initial 20% of electricity retail sales to come from renewable resources by 2017. SB 1078 defined eligible renewables to include small hydropower, solar, wind, and geothermal, among others. SB 350 (de León, 2015) introduced interim annual RPS targets with three-year compliance periods and requires 65% of RPS procurement to be derived from long-term contracts of 10 or more years.

SB 100 (de León, 2018) increased the RPS target to 60% by 2030 and requires that 100% of electricity retail sales come from renewable and carbon-free resources by 2045.

Clean Energy and Pollution Reduction Act

SB 350 (de León, 2015)

SB 350 increases California's renewable electricity procurement goal from 33% by 2020 to 50% by 2030, thus supporting greater use of resources eligible for the Renewables Portfolio Standard. SB 350 mandates doubling statewide energy efficiency savings for electricity and natural gas end uses by 2030.

SB 350 requires large utilities to submit integrated resource plans on how they will meet consumers' needs, reduce greenhouse gas emissions, and increase use of clean energy resources.

The 100 Percent Clean Energy Act of 2018

SB 100 (de León, 2018)

SB 100 establishes a goal that by 2045 all retail electricity sold in California and procured to meet state agency electricity needs will be powered by renewable and zero-carbon resources. SB 1020 (Laird, 2022) added interim targets for renewable electricity retail sales.

SB 100 updated the Renewables Portfolio Standard to ensure that by 2030 at least 60% of the state's electricity is from RPS eligible resources.

SB 100 requires the CEC, CPUC, and CARB to use existing laws to achieve 100% clean electricity and issue a joint policy report on SB 100 by 2021 and every four years after that.

Clean Energy, Jobs, and Affordability Act of 2022

SB 1020 (Laird, 2022)

SB 1020 added interim targets for renewable energy and zero-carbon electricity retail sales as legislated in SB 100 (de León, 2018) (90% by 2035 and 95% by 2040). SB 1020 requires state agencies to use 100% renewable energy and zero-carbon resources by 2030 and establishes a Climate and Equity Trust fund to manage rising electricity rates that threaten affordability.

California Global Warming Solutions Act

AB 32 (Nunez, 2006)

AB 32 requires California to reduce greenhouse gas emissions to 1990 levels by 2020 and is designed to mitigate risks of climate change, improve energy efficiency, expand renewable energy, support cleaner transportation, and reduce waste. AB 32 requires CARB to develop a Scoping Plan (e.g., the 2022 Scoping Plan) that delineates strategies for achieving this goal. The Act also requires convening an Environmental Justice Advisory Committee to advise on Scoping Plans and climate programs. SB 32 (Pavley, 2016) expanded emissions targets to reflect a 40% reduction from 1990 levels by 2030.

Low Carbon Fuel Standard (LCFS)

Executive Order S-01-07, 2007

The Low Carbon Fuel Standard (LCFS) is administered by CARB. LCFS was established following Executive Order S-01-07 and was identified by CARB's 2008 Scoping Plan as an early action to reduce greenhouse gas emissions.

LCFS assesses a carbon-intensity (CI) value for transportation fuels based on lifetime greenhouse gas emissions associated with the production, transportation, and use of those fuels. All fuels are compared to a declining CI target. Fuels with increasingly lower CIs than the target generate more credits, while fuels with CIs that exceed the target generate deficits. This incentivizes fuel providers to procure low-carbon fuels to sell credits to fuel providers generating deficits. The LCFS requires the average carbon intensity of all transportation fuels to decline over time, beginning with a quarter of a percent in 2011 and targeting a 20% reduction by 2030.²⁹⁸ CARB is currently considering increasing the 2030 CI reduction target from 20% to 25%, 30%, or 35%.²⁹⁹

Integrated Resource Plan: Peak Demand

SB 338 (Skinner, 2017)

This law requires utilities to consider the role of existing clean energy resources (e.g., energy efficiency, energy storage, demand response) in helping to ensure that energy and reliability needs can be met during peak demand period, reducing the need for new generation and transmission infrastructure.

Zero-Emissions Buildings and Sources of Heat**Energy**

AB 3232 (Friedman, 2018)

AB 3232 requires the CEC to analyze the potential for reducing greenhouse gas emissions from the state's residential and commercial building stock by at least 40% below 1990 levels by 2030. The law further requires the CEC to include data on

the emissions of greenhouse gases associated with energy supplied to these buildings in all Integrated Energy Policy Reports starting in 2021.

Energy: Biomethane: Biomethane Procurement

SB 1440 (Hueso, 2018)

SB 1440 requires the CEC, in consultation with CARB, to consider adopting biomethane procurement requirements for gas corporations.

Oil and Gas Operations Location Restrictions

SB 1137 (Gonzalez, 2022)

This law would prohibit new oil and gas developments within 3,200 feet (1 kilometer) of schools, hospitals, homes, or other sensitive establishments and includes restrictions on noise as well as release of toxic gases from storage tanks. SB 1137 was qualified for a veto referendum and will be on the ballot in November 2024. It is on hold until that time.

California Climate Crisis Act

AB 1279 (Muratsuchi, 2022)

AB 1279 declares the policy of the state to achieve net-zero greenhouse gas emissions as soon as possible—but no later than 2045—and to achieve and maintain net negative emissions thereafter. Further, this law mandates that emissions by 2045 are reduced by 85% below 1990 levels (this is to ensure that direct emission reductions are favored over the broad deployment of carbon removal technologies). This law requires CARB to work with relevant agencies to 1) ensure scoping plan updates include measures to achieve these policy goals; and 2) identify and implement strategies to enable carbon dioxide removal solutions and carbon capture, utilization, and storage technologies.

²⁹⁸ California Air Resources Board. (2022). Low Carbon Fuel Standard. Accessed on 11/30/2022 at: <https://ww2.arb.ca.gov/our-work/programs/low-carbon-fuel-standard>.

²⁹⁹ California Air Resources Board. (2022). Low Carbon Fuel Standard—Public Workshop: Concepts and Tools for Compliance Target Modeling. Accessed on 11/30/2022 at: <https://ww2.arb.ca.gov/sites/default/files/2022-11/LCFSPresentation.pdf>.

Read More

[2022 Scoping Plan for Achieving Carbon Neutrality.](#)

California Air Resources Board (2022)

[Biomethane in California Common Carrier Pipelines: Assessing Heating Value and Maximum Siloxane Specifications.](#)

California Council on Science and Technology. (2018).

[Long Term Viability of Underground Natural Gas Storage in California.](#)

California Council on Science and Technology. (2018).

[20-year Transmission Outlook.](#)

California ISO (2022)

[California Integrated Energy Policy Report Volume I Building Decarbonization.](#)

California Energy Commission (2022)

[Integrated Energy Policy Report Volume III Decarbonizing the State's Gas System.](#)

California Energy Commission (2022)

[Methane and NOx Emissions from Natural Gas Stoves, Cooktops, and Ovens in Residential Homes.](#)

Lebel, E.D., Finnegan, C.J., Ouyang, Z., and Jackson, R.B. (2022). Environmental Science & Technology, 56(4), pp. 2529-2539.

[The Challenge of Retail Gas in California's Low-Carbon Future.](#)

California Energy Commission (2020)

Decarbonizing Transportation

Transitioning to zero-emission vehicles and reducing vehicle miles traveled.

Overview

The transportation sector accounts for about 38%³⁰⁰ of California's greenhouse gas (GHG) emissions (50% if including emissions from fuel production), 80% of smog-forming nitrogen oxide emissions, and 95% of diesel particulate matter emissions.³⁰¹

Achieving **net-zero*** GHG emissions by 2045 (as per [AB 1279, Muratsuchi, 2022](#)) requires the vast majority of the transportation sector to transition to vehicles that can be powered by zero, or near-zero carbon energy. Zero-emission vehicles (ZEVs) probably cannot satisfy every transportation demand, so California has adopted a portfolio approach to decarbonizing the transportation sector.

Critical complementary strategies include supporting markets for low- and carbon-free fuels, improving access to active transportation through safe pedestrian and bicycle pathways, optimizing city planning, and mitigating barriers to public transportation and decarbonization technologies in lower income and rural communities.

The transition to carbon-neutral transportation is likely to provide significant co-benefits, including improvements to air pollution, public health, environmental equity, and economic development.

300 California Air Resources Board. (2022). Current California GHG Emission Inventory Data. Accessed on 10/17/2023 at: <https://ww2.arb.ca.gov/ghg-inventory-data>.

301 California Air Resources Board. (2021). Advanced Clean Trucks: Accelerating Zero-Emission Truck Markets. Accessed on 12/01/2022 at: https://ww2.arb.ca.gov/sites/default/files/2021-08/200625factsheet_ADA.pdf.



Decarbonizing vehicles and fuels

In support of [Executive Order \(EO\) N-79-20 \(2020\)](#), the California Air Resources Board's (CARB) [Advanced Clean Cars II Regulations \(ACC2\)](#) require that all new passenger cars, trucks, and SUVs sold in California be zero-emission by 2035. Passenger vehicles currently account for 70% of transportation-related emissions.³⁰² This mandate is predicted to cut GHG emissions from the passenger vehicle sector by 35% and nitrogen oxide (NOx) emissions by 80%.³⁰³

EO N-79-20 further requires that medium- and heavy-duty trucks be 100% zero-emission (where feasible) by 2045. CARB's [Advanced Clean Trucks](#) regulation requires truck manufacturers to sell an

increasing percentage of medium- and heavy-duty ZEVs between 2024 and 2045. In July 2023, leading truck manufacturers and CARB formed a "Clean Truck Partnership" whereby the manufacturers agreed to meet these standards regardless of any future challenges to CARB's authority to implement them. In exchange CARB would work more collaboratively with manufacturers to allow for sufficient lead time and provide greater support for the necessary ZEV infrastructure.³⁰⁴

CARB's [Advanced Clean Fleets \(ACF\)](#) regulation requires large fleets to transition to ZEV vehicles. In mid-October 2023, the California Trucking Association [filed a lawsuit](#) against CARB's ACF rule, stating that CARB has overstepped its jurisdictional authority.³⁰⁵ The ACF took effect January 1, 2024. CARB will delay the enforcement of certain ACF regulatory provisions until the U.S. EPA

302 California Air Resources Board. (2022). 1 Clean Miles Standard. Accessed 10/17/2023 at: <https://ww2.arb.ca.gov/our-work/programs/clean-miles-standard/about>.

303 Office of Governor Gavin Newsom. (2020). Governor Newsom Announces California will Phase Out Powered Cars and Drastically Reduce Demand for Fossil Fuel in California's Fight Against Climate Change. Available at: <https://www.gov.ca.gov/2020/09/23/governor-newsom-announces-california-will-phase-out-gasoline-powered-cars-dramatically-reduce-demand-for-fossil-fuel-in-californias-fight-against-climate-change/>.

304 California Air Resources Board. (2023). CARB and Truck and Engine Manufacturers Announce Unprecedented Partnership to Meet Clean Air Goals. Accessed 11/15/2023 at: <https://ww2.arb.ca.gov/news/carb-and-truck-and-engine-manufacturers-announce-unprecedented-partnership-meet-clean-air>.

305 Complaint for Declaratory Judgement and Injunctive Relief, California Trucking Association vs. California Air Resources Board, (Eastern District of California 2023). Available at: <https://californiatruckingassoc.growthzoneapp.com/ap/CloudFile/Download/LxO5Y-M1P>.

Passenger vehicles currently account for 70% of transportation-related emissions.²³⁷

issues a preemption waiver (or determines that a waiver is unnecessary).³⁰⁶

The Innovative Clean Transit regulation requires all transit authorities to purchase only zero-emission buses by 2029, to fully transition to 100% zero-emission fleets by 2040, and to submit Zero-Emission Bus Rollout Plans detailing how they intend to comply.³⁰⁷ Rollout plans reflect a diversity of approaches ranging from 100% battery electric buses to 100% hydrogen fuel cell buses, with many proposed mixed fleets in between (more on these technologies below).

The Clean Miles Standard and Incentive Program, established by SB 1014 (Skinner, 2018), requires that rideshare companies (like Uber and Lyft) begin to electrify their fleets and meet annual GHG

emission targets. SB 500 (Min, 2021) prohibits the operation of emission-producing autonomous vehicles starting in 2030.

The Low-Carbon Fuel Standard (LCFS), launched in 2011, uses a **carbon-intensity** (CI) standard coupled with credit trading to incentivize the use of low-carbon transportation fuels, thereby reducing GHG emissions associated with transportation. The LCFS requires the average CI of all transportation fuels to decline over time, currently targeting a 20% reduction (from a 2010 baseline) by 2030.³⁰⁸ Since its implementation, LCFS has reduced the CI of fuel in California by 12.63% (as of 2022).³⁰⁹

CARB staff have proposed amendments to the LCFS which would increase the stringency of

306 California Air Resources Board. (2023). Advanced Clean Fleets Regulation: Enforcement Notice. Available at: https://ww2.arb.ca.gov/sites/default/files/2023-12/231228acfnote_ADA.pdf?utm_medium=email&utm_source=govdelivery.

307 California Air Resources Board. (2022). ICT-Rollout Plans. Accessed on 12/01/2022 at: <https://ww2.arb.ca.gov/our-work/programs/innovative-clean-transit/ict-rollout-plans>.

308 California Air Resources Board. (2022). Low Carbon Fuel Standard. Accessed 12/01/2022 at: <https://ww2.arb.ca.gov/our-work/programs/low-carbon-fuel-standard>.

309 California Air Resources Board. (ND). LCFS Data Dashboard. Accessed on 5/30/2023 at: <https://ww2.arb.ca.gov/resources/documents/lcfs-data-dashboard>.

the 2030 CI reduction target from 20% to 30% and extend CI reduction targets to achieve a 90% CI reduction by 2045.³¹⁰ These and other amendments to the LCFS will be considered by the board for implementation in early 2024 though the program targets would not change until 2025. If implemented, these changes should help strengthen the LCFS credit price and enable the LCFS to more effectively support markets for alternative fuels in the future.³¹¹

Zero-emission vehicles (ZEVs)

Battery electric vehicles (BEVs) are powered by batteries alone and are recharged when plugged into a source of electricity. **Plug-in hybrid electric vehicles (PHEVs)** are powered by a blend of fuel and electric power. Typically, PHEVs drive on electric power until their battery is depleted, then run the engine using liquid fuels (like gasoline or diesel) to provide additional range.

In addition to providing zero-emission transportation, batteries used in electric vehicles have the potential to provide energy resilience to consumers by providing extra mobile energy storage during power outages.³¹² BEV charging can be optimized to **load shift** and draw power from the grid only during times of low demand or high renewable energy production. Vehicle-to-grid integration allows ZEVs to discharge stored power back to the grid, thereby improving grid resilience to energy shortfalls. See **Section 3** for further discussion of load shifting.

Fuel cell electric vehicles (FCEVs) are powered by hydrogen fuel cells, which combine hydrogen fuel (pure H₂) with oxygen pulled from the air and generate electricity in the process. FCEVs are refueled at hydrogen stations rather than recharged. FCEVs can be refueled much more quickly than current BEVs can be recharged and produce only water vapor at the tailpipe.³¹³ Hydrogen fuel can be produced by renewable energy resources, such as electrolysis of water using renewable electricity or from **biomethane**.

CARB's Advanced Clean Cars II Regulations (ACC2) clarify that full battery electric vehicles, fuel cell electric vehicles, and plug-in hybrid electric vehicles (with an all-electric range of at least 50 miles) will count towards zero-emission passenger vehicle requirements for automakers.³¹⁴ No more than 20% of an automakers' ZEV requirements can be met by plug-in hybrids. Plug-in hybrids with longer electric ranges, like those that qualify as ZEVs under ACC2, typically rely on electricity for about 60-65% of their total travel range, though this number may increase as more charging options become available and drivers become accustomed to ZEVs.³¹⁵

When measuring lifecycle emissions (also known as **well-to-wheel emissions**)—i.e., the total emissions related to fuel production, processing, distribution, and use—the source of electricity is important for BEVs and PHEVs because charging from fossil-fueled sources results in higher emissions than charging from renewable energy.³¹⁶ For FCEVs, the pathway by which the hydrogen was produced and how the hydrogen was transported impact lifecycle emissions.

310 California Air Resources Board. (2023). Low Carbon Fuel Standard 2023 Amendments: Standardized Regulatory Impact Assessment. Available at: https://ww2.arb.ca.gov/sites/default/files/2023-09/lcfs_sria_2023_0.pdf.

311 Brown, A.L. et al. (2021). Chapter 9: Fuel Technology and Policy to Support a Carbon-Neutral Transportation System in Driving California's Transportation Emissions to Zero. *UC Institute of Transportation Studies*. Available at: <https://escholarship.org/uc/item/3np3p2t0>.

312 Office of Energy Efficiency and Renewable Energy. Bidirectional Charging and Electric Vehicles for Mobile Storage. (ND). *US Department of Energy*. Accessed on 12/01/2022 at: <https://www.energy.gov/eere/femp/bidirectional-charging-and-electric-vehicles-mobile-storage>.

313 California Energy Commission. (2022). Hydrogen Vehicles and Refueling Infrastructure. Available at: <https://www.energy.ca.gov/programs-and-topics/programs/clean-transportation-program/clean-transportation-funding-areas-1>.

314 California Air Resources Board. (2022). California Moves to Accelerate to 100% New Zero-Emission Vehicle Sales by 2035. Accessed on 12/01/2022 at: <https://ww2.arb.ca.gov/news/california-moves-accelerate-100-new-zero-emission-vehicle-sales-2035>.

315 Raghavan, S.S. and Tal, G. (2020). Plug-in Hybrid Electric Vehicle Observed Utility Factor: Why the Observed Electrification Performance Differ from Expectations. *International Journal of Transportation*, 16(2), pp. 105-136.

316 Office of Energy Efficiency and Renewable Energy. Emissions from Electric Vehicles. (ND). Accessed on 12/01/2022 at: https://afdc.energy.gov/vehicles/electric_emissions.html.

The roles of BEVs versus FCEVs in the clean energy transition can be a divisive topic. The market for BEVs is inarguably more advanced, leading some to assert that California need not support the nascent FCEV market. Others argue that FCEVs can fill niches not yet successfully electrified by BEVs—including long haul transport, maritime, rail, and aviation. Further, having some portion of passenger vehicles be FCEVs could alleviate some of the predicted strain on the grid from vehicle electrification (see **Section 1**).

With current technology, hydrogen fuel is inefficient to produce and there are significant challenges associated with distributing hydrogen to fueling stations. Hydrogen can be compressed and transported via pipelines with relatively high efficiency, but this would likely require extensive upgrades to natural gas infrastructure. Further, hydrogen is known to be an indirect greenhouse gas; a recent study estimated that hydrogen has a **global warming potential** that is nearly 12 times greater than carbon dioxide.³¹⁷ Therefore, any leaks from these pipelines would need to be strictly monitored and controlled.³¹⁸ Alternatively, hydrogen can be liquified and transported to stations by truck, though cooling to the temperatures required for liquefaction consumes energy equal to about 30% of that contained in the hydrogen.³¹⁹

Supporting the electric vehicle transition

California's transition to ZEVs necessitates significant investment in electric vehicle charging and

Relevant State Institutions

- California Air Resources Board (CARB)
- California Energy Commission (CEC)
- California Strategic Growth Council
- California Transportation Commission
- Metropolitan Planning Organizations & Regional Transportation Planning Agencies
- Assembly Budget Subcommittee No. 3 Climate Crisis, Resources, Energy, and Transportation
- Assembly Natural Resources Committee
- Assembly Transportation Committee
- Senate Budget Subcommittee No. 2 on Resources, Environmental Protection and Energy
- Senate Budget Subcommittee No. 5 on Corrections, Public Safety, Judiciary, Labor, and Transportation
- Senate Environmental Quality Committee
- Senate Governance and Finance
- Senate Transportation Committee
- Joint Leg. Committee on Climate Change Policies

hydrogen fueling infrastructure. [Executive Order B-48-18 \(2018\)](#) called for the installation of 200 hydrogen fueling stations by 2025. An estimated 1.2 million public passenger vehicle chargers and 157,000 medium- and heavy-duty vehicle chargers will be required by 2030.³²⁰ For context, California currently has 71 hydrogen refueling stations³²¹ and 41,384 public electric vehicle chargers³²² (as of October 2023).

The [Clean Transportation Program](#)—established by [AB 8 \(Perea, 2013\)](#) and managed by the CEC—invests about \$100 million annually for infrastructure to support electric vehicles, hydrogen

317 Sand, M. et al. (2023). A Multi-Model Assessment of the Global Warming Potential of Hydrogen. *Communications Earth & Environment*, 4, pp. 203.

318 Warwick, N., et al. (2022). Atmospheric Implications of Increased Hydrogen Use. *Crown*. Available at: https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/1067144/atmospheric-implications-of-increased-hydrogen-use.pdf.

319 Department of Energy. (2009). Energy Requirements for Hydrogen Gas Compression and Liquefaction as Related to Vehicle Storage Needs. Available at: https://www.hydrogen.energy.gov/pdfs/9013_energy_requirements_for_hydrogen_gas_compression.pdf.

320 Fauble B. et al. (2022). California's Deployment Plan for the National Electric Vehicle Infrastructure Program. California Department of Transportation, California Energy Commission. Available at: <https://dot.ca.gov/-/media/dot-media/programs/sustainability/documents/nevi/2022-ca-nevi-deployment-plan-a11y.pdf>.

321 California Energy Commission. (2023). Hydrogen Refueling Stations in California. Available at: <https://www.energy.ca.gov/data-reports/energy-almanac/zero-emission-vehicle-and-infrastructure-statistics/hydrogen-refueling>.

322 California Energy Commission. (2023). Electric Vehicle Chargers in California. Available at: <https://www.energy.ca.gov/data-reports/energy-almanac/zero-emission-vehicle-and-infrastructure-statistics/electric-vehicle>.

refueling, low-carbon fuels, advanced technology for medium- and heavy-duty vehicles, and economic development related to clean technologies.³²³ AB 126 (Reyes, 2023) reauthorized the fees that support this program through 2035 and revised the program to focus more exclusively on zero-emission technologies. AB 126 requires that at least 15% of expenditures be directed towards hydrogen refueling infrastructure through 2030. Currently, about 35% of the investments target underserved, low-income, or disadvantaged communities, as these communities are disproportionately impacted by emissions from fossil-fuel transportation.³²⁴ Starting in 2025, AB 126 will require the CEC to increase this percentage to at least 50%.

The California Electric Vehicle Infrastructure Project (CALeVIP) coordinates charging infrastructure investments and streamlines charger installations with a \$164 million grant from the Clean Transportation Program.

California will receive an estimated \$384 million over five years from the National Electric Vehicle Infrastructure Program, funded by the federal Infrastructure Investment and Jobs Act.³²⁵

CARB administers several ZEV incentive programs, including the Clean Vehicle Rebate Project (CVRP), the Clean Cars 4 All (CC4A) Program, the Clean Vehicle Assistance Program (CVAP), and the Hybrid and Zero-Emission Truck and Bus Voucher Incentive Project (HVIP). These incentive programs are all supported by Cap-and-Trade revenue (see **Section 8**). Owners of non-residential chargers receive LCFS credit for charging ZEVs, as do utilities that supply homes where ZEVs are charged. Revenue from LCFS credits

from ZEV charging must be spent to support vehicle electrification. These funds are commonly used to reduce the cost of ZEV charging, provide incentives for charger installation, conduct public education campaigns, and support rebates for ZEV purchase.

The 2021-2023 budget cycles were marked by historic investments in clean transportation funding. A cumulative \$10 billion has been earmarked for ZEV-related investments over the next three to five years.

During the 2022-2023 fiscal year, CARB invested \$2.6 billion for clean transportation incentives—CARB's largest clean transportation investment to date.³²⁶ A \$623.6 million investment is proposed for the 2023-2024 fiscal year.³²⁷ The CPUC will invest \$1 billion over five years to support a transportation electrification program, with 70% earmarked for charging infrastructure for medium- and heavy-duty vehicles.³²⁸

Low-carbon fuels

While ZEVs are likely to provide the largest share of GHG emission reductions from the transportation sector, other technologies will need to play a complementary role. The rate of ZEV deployment is effectively capped by the number of new vehicle sales and the retirement of conventional vehicles out of the fleet.

Even if Advanced Clean Cars II is successful, in 2035, California's vehicle fleet is still likely to include almost 5 million light-duty and 500,000 medium- and heavy-duty conventional vehicles. Collectively, these vehicles will require rough-

323 California Energy Commission. (2022). Transforming Transportation. Accessed on 12/01/2022 at: <https://www.energy.ca.gov/about/core-responsibility-fact-sheets/transforming-transportation>.

324 California Energy Commission. (2022). Transforming Transportation. Accessed on 12/01/2022 at: <https://www.energy.ca.gov/about/core-responsibility-fact-sheets/transforming-transportation>.

325 Fauble B. et al. (2022). California's Deployment Plan for the National Electric Vehicle Infrastructure Program. California Department of Transportation, California Energy Commission. Available at: <https://dot.ca.gov/-/media/dot-media/programs/sustainability/documents/nevi/2022-ca-nevi-deployment-plan-a11y.pdf>.

326 California Air Resources Board. (2022). Fiscal Year 2022-23 Funding Plan for Clean Transportation Incentives. Accessed on 12/01/2022 at: https://ww2.arb.ca.gov/sites/default/files/2022-11/funding_plan_key_proposals_final.pdf.

327 California Air Resources Board. (2023). Fiscal Year 2023-24 Funding Plan for Clean Transportation Incentives. Accessed on 10/23/2023 at: https://ww2.arb.ca.gov/sites/default/files/2023-10/fy2023_24_funding_plan_summary_final.pdf.

328 California Public Utilities Commission. (2022). CPUC Adopts Transportation Electrification Program to Help Accelerate Electric Vehicle Adoption. Accessed on 12/01/2022 at: <https://docs.cpuc.ca.gov/PublishedDocs/Published/G000/M498/K953/498953325.PDF>.

While ZEVs are likely to provide the largest share of GHG emission reductions from the transportation sector, other technologies will need to play a complementary role.

ly 2.5 billion gallons per year of liquid fuels.³²⁹ Achieving carbon neutrality would be impossible if this demand were met by petroleum gasoline and diesel. Similarly, achieving or significantly exceeding California’s current target of 5 million ZEVs by 2030 may not generate sufficient emission reductions from the transportation sector to reach targets established by SB 32 (Pavley, 2016).

California will also need to deploy a significant amount of low-carbon alternative fuels capable of reducing emissions from conventional gasoline and diesel engines (known as “drop-in” fuels). At present, only biofuels have demonstrated the capacity to reach market at commercial scale. However, a significant fraction of such fuels at present (and likely through the next decade) use crop-based feedstocks, which provide only modest GHG benefits compared to petroleum. Several technologies— including cellulosic fuels, e-fuels synthesized using renewable electricity,

and fuels made from algae—have emerged as candidates to supply large volumes of liquid fuels that reduce GHG emissions by 60% or more compared to petroleum. However, these technologies have yet to demonstrate successful operation at commercial scale and will need continued policy support if they are to fulfill this role in California’s fuel portfolio.

Some applications—such as aviation, marine, long-distance freight rail, and emergency backup power—are not well-suited for electrification and will likely need other technologies. Long-distance aviation in particular is likely to need liquid fuels due to energy density and operational safety requirements.

In recent years, alternative jet fuel made from “hydrotreated” fats, oils, and greases has started to enter the California market. Almost 12 million gallons of these fuels were consumed in Califor-

329 Brown, A.L. et al. (2021). Chapter 9: Fuel Technology and Policy to Support a Carbon-Neutral Transportation System in *Driving California’s Transportation Emissions to Zero. UC Institute of Transportation Studies*. Available at: <https://escholarship.org/uc/item/3np3p2t0>.

nia in 2022.³³⁰ These alternative aviation fuels use the same feedstocks as renewable diesel and are often produced at the same refinery, suggesting there is likely to be some competition between the two.

To date, most renewable diesel and hydrotreated aviation fuel consumed in California has been made from waste oils (e.g., used cooking oil and tallow from food processing). Supplies of these waste products are, for the most part, already fully exploited in North America. Thus, any future growth in renewable diesel or hydrotreated aviation fuel would need to come from other resources, like agricultural residue, forest residue, and crop oils. Attempts to produce fuels using agricultural and forest residues as feedstock at commercial scale have not yet been successful.

Waste- and residue-based fuels offer substantial GHG benefits, while using crops for feedstock may cause inadvertent harm to food markets or cause emissions from expansion of agricultural land. As the shift to ZEVs continues, the amount of liquid fuel needed for on-road transportation will decline, offering an opportunity to shift some of the fuel supply from that market to aviation.

Reducing vehicle miles traveled

SB 375 (Steinberg, 2008) directed California's 18 regional metropolitan planning organizations to develop plans to reduce per capita **vehicle miles traveled (VMT)**, or how much the average Californian drives.

These plans—Sustainable Communities Strategies—consider the interactions between transportation, land use, and housing decisions that impact driving patterns (e.g., proximity of hous-

ing to key destinations like parks, schools, and jobs). However, according to CARB's Progress Report, per capita VMT have increased rather than decreased.

This is in part because of the challenge involved in changing personal travel behavior in relatively fixed urban environments, and partly because local planning agencies have been unwilling or unable to overcome objections to higher-density, more sustainable land use plans. Improved implementation will require more concerted funding mechanisms and greater alignment across state, regional, and local actions.³³¹

AB 1633 (Ting, 2023) prohibits local agencies from withholding or delaying valid CEQA clearances for housing developments in densely populated urban areas.

As per AB 285 (Friedman, 2020), the California Department of Transportation is required to develop transportation plans that will achieve maximum feasible emission reductions. However, state transportation spending has historically not been well-aligned with California's goals of reducing greenhouse gas emissions and VMT.³³² Of \$22.4 billion in transportation funding that has been invested or committed between 2019 and 2027, only 19% (\$4.2 billion) went towards projects that will reduce greenhouse gas emissions, while close to 10% (\$2.2 billion) will likely lead to more driving.³³³

To increase transparency of transportation funding allocations at the state level, SB 695 (Gonzalez, 2023) requires the California Department of Transportation (Caltrans) to publish and annually update information and data regarding projects on the state highway system, including estimates of how these projects have and will impact greenhouse gas emissions and VMT.

330 California Air Resources Board. (2023). Low Carbon Fuel Standard Reporting Tool Quarterly Summaries. Accessed on 05/29/2023 at: <https://ww2.arb.ca.gov/resources/documents/low-carbon-fuel-standard-reporting-tool-quarterly-summaries>.

331 California Air Resources Board. (2023). 2022 Progress Report: California's Sustainable Communities and Climate Protection Act. Accessed on 10/25/2023 at: <https://ww2.arb.ca.gov/sites/default/files/2023-05/2022-SB150-MainReport-FINAL-ADA.pdf>.

332 Deakin, E. et al. (2021). Evaluation of California State and Regional Transportation Plans and their Prospects for Attaining State Goals. Available at: <https://escholarship.org/uc/item/50j4b4r8>.

333 Rubin, C., Abonour, R., and Gahbauer, J. (2023). Closing the Climate Investment Gap: California Must Prioritize Climate-Smart Transportation Projects. National Resource Defense Council. Available at: <https://www.nrdc.org/sites/default/files/2023-09/ca-transportation-investment-report.pdf>.

In an effort to minimize sprawl and encourage development conducive to walking and biking, [SB 743 \(Steinberg, 2013\)](#) updated [CEQA](#) to use a VMT metric—rather than congestion—to assess the transportation impacts of projects (effective 2020). This shift alleviates a potential hurdle to more compact development which will reduce the amount of driving overall but affect local congestion.

[SB 99 \(Committee on Budget and Fiscal Review, 2013\)](#) established the [Active Transportation Program](#) to encourage active modes of mobility by developing safe pathways. In addition to supporting decarbonization, this program provides health benefits and is targeted at diverse users, including those in **disadvantaged communities**. The program has been “incredibly oversubscribed”³³⁴ since its inception.³³⁵ In response, the [State Budget Act of 2022 \(SB 154, Skinner\)](#) allocated an additional \$1.05 billion to the program. The Electric Bicycle Incentive Project, launching early 2023, will leverage \$10 million in funding to help low-income Californians purchase e-bikes.³³⁶

Environmental Justice and Equity Considerations

Non-white and low-income communities are more likely to be located near highways³³⁷ and experience disproportionate exposure to vehicle-related pollution.³³⁸ For example, a study in Los Angeles found that low-income communities have twice the road density as the wealthiest neighborhoods.³³⁹

Areas with lower household incomes and Black and Hispanic majority populations are less likely to have access to public chargers in California.³⁴⁰ Further, disadvantaged communities and Black-identifying households are more likely to confront grid infrastructure limits that complicate the grid interconnection necessary to install home chargers.³⁴¹

Despite the numerous incentive programs available in California, low-income consumers may still experience financial barriers to purchasing new or even used ZEVs.³⁴² Research demonstrates that rebates like the Clean Vehicle Rebate Project have been disproportionately allocated to higher income, more educated consumers living in less-polluted areas.³⁴³ Equity-focused provisions, like tiered rebate structures (implemented for the Clean Vehicle Rebate Project in 2016)

334 Waters, L. et al. (2022). Active Transportation Program. *California Transportation Commission*. Accessed on 12/01/2022 at: <https://catc.ca.gov/programs/active-transportation-program>.

335 Waters, L. et al. (2022). Active Transportation Program. *California Transportation Commission*. Accessed on 12/01/2022 at: <https://catc.ca.gov/programs/active-transportation-program>.

336 California Air Resources Board. (2022). Nonprofit Administrator Selected to Implement New Statewide, Income-Based Electric Bicycle Incentive Project. Accessed on 12/01/2022 at: <https://ww2.arb.ca.gov/news/nonprofit-administrator-selected-implement-new-statewide-income-based-electric-bicycle>.

337 US Department of Transportation. (2013). Health and Equity. Accessed on 12/01/2022 at: <https://www.transportation.gov/mission/health/health-equity>.

338 Boeing, G. et al. (2021). Race, Class, and the Production of and Exposure to Vehicular Pollution in Los Angeles. *Pacific Southwest Region University Transportation Center*. Available at: <https://rosap.nrl.bts.gov/view/dot/59264>.

339 Houston, D. et al. (2004). Structural Disparities of Urban Traffic in Southern California: Implications for Vehicle-Related Air Pollution Exposure in Minority and High-Poverty Neighborhoods. *Journal of Urban Affairs*, 26(5), pp 565-592.

340 Hsu, C. W., and Fingerman, K. (2020). Public Electric Vehicle Charger Access Disparities Across Race and Income in California. *Transport Policy*, 100, pp 59-67.

341 Brockway, A.M., Conde, J., and Callaway, D. (2021). Inequitable Access to Distributed Energy Resources due to Grid Infrastructure Limits in California. *Nature Energy*, 6(9), pp. 892-903.

342 Hardman, S. et al. (2021). A Perspective on Equity in the Transition to Electric Vehicles. MIT Science Policy Review. Available at: <https://sciencepolicyreview.org/2021/08/equity-transition-electric-vehicles/>.

343 Ju, Y. et al. (2020). An Equity Analysis of Clean Vehicle Rebate Programs in California. *Climate Change*, 162(4), pp 2087-2105.

helped address, but did not eliminate, these disparities.³⁴⁴ Implementing additional equity-focused design elements could further improve equitable allocation of ZEV incentives. Point-of-sale discounts or grants (like that provided by the Clean Vehicle Assistance Program) may be more helpful as they don't require low-income consumers to front the capital for a ZEV before receiving a rebate. A limited number of low-interest loans are also available through the Clean Vehicle Assistance Program. Ultimately, since lower-income Californians almost exclusively buy used vehicles, deployment of ZEVs in lower-income communities may be contingent upon there being enough ZEVs entering the used vehicle market.

Other barriers to decarbonized transportation options include concerns for personal safety, including fear of crime and injury during shared or active transportation; exposure to infectious diseases like COVID-19 on public transit; poor access to alternative transportation modes within communities, including limited hours or inconvenient routes of transport options; unaffordability; lack of access to funding for clean transportation and mobility projects; limited awareness of clean transportation options; and a lack of permanent long-term funding for transportation.³⁴⁵

While disadvantaged communities clearly face challenges that complicate efforts to address environmental justice problems, California's progress toward carbon neutrality is likely to help. Many air quality problems facing disadvantaged communities are due to the combustion of fossil fuels; emissions from diesel-fueled vehicles are a significant source of their pollution burden.

The LCFS has led to over 40% of California's diesel fuel being replaced by renewable diesel, which offers some air quality advantages compared to petroleum. The transition to ZEVs across the transportation sector will yield even bigger improvements in air quality for communities near roads. Modeling studies have

indicated that broad adoption of renewable fuels and clean energy is likely to improve air quality and reduce the size of racial and income-based disparities in air pollutant exposure.³⁴⁶

Relevant Policies

(Laws/Regulations)

California Global Warming Solutions Act

AB 32 (Nunez, 2006)

AB 32 requires California to reduce greenhouse gas emissions to 1990 levels by 2020 and is designed to mitigate risks of climate change, improve energy efficiency, expand renewable energy, support cleaner transportation, and reduce waste. SB 32 (Pavley, 2016) expanded emissions targets to reflect a 40% reduction from 1990 levels by 2030.

Alternative Fuel and Vehicle Technologies

AB 118 (Núñez, 2007)

AB 118 established the Clean Transportation Program (formerly the Alternative and Renewable Fuel and Vehicle Technology Program). The program supports innovation and development of advanced transportation and fuel technologies. AB 8 (Perea, 2013) restructured and extended the program through January 1, 2024, with a provision to allocate funds from the Clean Transportation Program to create public hydrogen refueling stations.

The program supports fueling and charging stations for low- and zero-emission vehicles; development and implementation of alternative fuel and advanced technology vehicles; production of low-carbon renewable fuels; and relevant workforce training in the manufacturing sector.

344 Ju, Y. et al. (2020). An Equity Analysis of Clean Vehicle Rebate Programs in California. *Climate Change*, 162(4), pp 2087-2105.

345 California Air Resources Board. (2018). Low-Income Barriers Study, Part B: Overcoming Barriers to Clean Transportation Access for Low-Income Residents. Available at: https://ww2.arb.ca.gov/sites/default/files/2018-08/sb350_final_guidance_document_022118.pdf.

346 Li, Y. et al. (2022). Future Emissions for Particles and Gases that Cause Regional Air Pollution in California under Different Greenhouse Gas Mitigation Strategies. *Atmospheric Environment*, 273, pp. 118960.

Low Carbon Fuel Standard

Executive Order S-01-07, 2007

The Low Carbon Fuel Standard (LCFS) is administered by CARB. LCFS was launched in 2011 after being formally established by Executive Order S-01-07 and identified by CARB's 2008 Scoping Plan as an early action to reduce greenhouse gas emissions.

LCFS assesses a carbon-intensity (CI) value for transportation fuels based on lifetime GHG emissions associated with the production, transportation, and use of those fuels. All fuels are compared to a declining CI target. Fuels with increasingly lower CIs than the target generate more credits, while fuels with CIs that exceed the target generate deficits. This incentivizes fuel providers to procure low-carbon fuels to sell credits to fuel providers generating deficits. The LCFS requires the average CI of all transportation fuels to decline over time, beginning with a quarter of a percent in 2011 and targeting a 20% reduction by 2030.³⁴⁷ CARB is currently considering increasing the 2030 CI reduction target from 20% to 30%.³⁴⁸

Transportation Planning: Travel Demand Models: Sustainable Communities Strategy

SB 375 (Steinberg, 2008)

SB 375 requires metropolitan planning organizations to develop strategies for reducing greenhouse gas emissions associated with passenger vehicles as part of their regional transportation plans. Greenhouse gas emission reduction targets would be provided by CARB. These plans—Sustainable Communities Strategies—outline strategies to reduce vehicle miles traveled by considering the interactions between transportation, land use, and housing decisions that impact driving patterns (e.g., proximity of housing to key destinations like parks, schools, and jobs).

Active Transportation Program (ATP)

SB 99 (Cmte. on Budget and Fiscal Review, 2013)

ATP encourages active modes of transportation (such as walking and biking) by increasing safety and mobility options. The program provides a range of projects to benefit diverse users including disadvantaged communities.

Environmental Quality: Transit Oriented Infill Projects

SB 743 (Steinberg, 2013)

Among other things, SB 743 updated the California Environmental Quality Act guidelines to consider the impacts of development on vehicle-miles traveled. This was enacted with the intent to better balance the state's goal of reducing vehicle miles traveled with that of reducing traffic congestion.

Electric Vehicle Charging

AB 1236 (Chiu, 2015)

AB 1236 requires local governments to develop streamlined ordinances for electric vehicle charging infrastructure.

Clean Energy Pollution Reduction Act

SB 350 (de León, 2015)

SB 350 mandated that the CEC study barriers to clean energy technologies confronted by low-income and disadvantaged communities. The Low-Income Barriers Study, Part B analyzed barriers to clean transportation access.

The Road Repair and Accountability Act

SB 1 (Beall, 2017)

SB 1 provides funding for transportation development, including at the local level, to provide more transportation choices and preserve and enhance communities. The act significantly augments funding provided when the Active Transportation Program was established in 2013.

347 California Air Resources Board. (2022). Low Carbon Fuel Standard. Accessed on 12/01/2022 at: <https://ww2.arb.ca.gov/our-work/programs/low-carbon-fuel-standard>.

348 California Air Resources Board. (2023). Low Carbon Fuel Standard 2023 Amendments: Standardized Regulatory Impact Assessment. Available at: https://ww2.arb.ca.gov/sites/default/files/2023-09/lcfs_sria_2023_0.pdf.

California Clean Miles Standard and Incentive Program: Zero-emission Vehicles

SB 1014 (Skinner, 2018)

SB 1014 establishes the California Clean Miles Standard and Incentive Program. This law requires CARB to establish annual per-passenger-mile emission reduction targets for transportation network companies.

California Transportation Plan

AB 285 (Friedman, 2020)

This law requires the California Department of Transportation (Caltrans) to develop a transportation plan that will achieve the maximum feasible emission reductions consistent with California's goal to reduce greenhouse gas emissions to 40% below 1990 levels by 2030. AB 285 also required the Strategic Growth Council to prepare a report on how to better align funding and programs to achieve the state's climate commitments.

Autonomous Vehicles: Zero Emissions

SB 500 (Min, 2021)

SB 500 prohibits the operation of emission-producing autonomous vehicles starting in 2030.

Advanced Clean Cars II (ACCII)

ACCII requires that 100% of in-state sales of new passenger cars, trucks, and SUVs be zero-emission vehicles by 2035. Full battery electric vehicles, hydrogen fuel cell electric vehicles, and plug-in hybrid electric vehicles (with an all-electric range of at least 50 miles) will count towards zero-emission requirements for automakers.³⁴⁹ No more than 20% of an automakers' zero-emission vehicle requirements can be met by plug-in electric hybrids.

Vehicular Air Pollution: Clean Transportation Program: Extension

AB 126 (Reyes, 2023)

AB 126 extends funding for the Clean Transportation Program through 2035. In addition, this law refocuses the Clean Transportation Program to focus more exclusively on the development and deployment of zero-emission technologies and fuels where feasible. At least 15% of expenditures will be required to go towards hydrogen refueling infrastructure until 2030. Starting on January 1, 2025, AB 126 will require the CEC to spend at least 50% of funds on projects that will benefit or serve residents of disadvantaged and low-income Californians.

Department of Transportation: Internet Website: State Highway System Data and Information

SB 695 (Gonzalez, 2023)

This law requires the California Department of Transportation (Caltrans) to publish information and data on state highway projects implemented since July 2018, including all those currently planned. Caltrans has until January 2025 to do so. Starting in 2026, Caltrans will be required to update this list at least annually with projects implemented the year prior. Caltrans must include in this dataset estimates for how the projects have or will impact greenhouse gas emissions and vehicle miles traveled.

Housing Accountability Act: Disapprovals: California Environmental Quality Act

AB 1633 (Ting, 2023)

The Housing Accountability Act prohibits local agencies from disapproving housing development projects unless there is a "preponderance of evidence" that the project should be denied. This law strengthens the HAA by including a prohibition on withholding or delaying valid CEQA clearances for housing developments in densely populated urban areas.

³⁴⁹ California Air Resources Board. (2022). California Moves to Accelerate to 100% New Zero-Emission Vehicle Sales by 2035. Accessed on 12/01/2022 at: <https://ww2.arb.ca.gov/news/california-moves-accelerate-100-new-zero-emission-vehicle-sales-2035>.

Read More

[Driving California's Transportation Emissions to Zero](#)

Brown et al. (2021). UC Inst. of Transp. Studies.

[Distribution Grid Impacts of Electric Vehicles: A California Case Study](#)

Jenn, A., and Highleyman, J. (2022). iScience, 25(1).

[Enhancing Equity while Eliminating Emissions in California's Supply of Transportation Fuels](#)

Deschenes, O. et al. (2021). UC Santa Barbara.

[Factors Affecting Plug-in EV Sales in California](#)

University of California Los Angeles. (2017).

[Emissions Associated with EV Charging: Impact of Electricity Generation Mix, Charging Infrastructure Availability, and Vehicle Type](#)

McLaren, J. et al. (2016). National Renewable Energy Lab. Tech. Report: NREL/TP-6A20-6485-2.

Cap-and-Trade

Leveraging market mechanisms to incentivize decarbonization through 2030 (and beyond?).

Overview

As part of its implementation of [AB 32 \(Nunez, 2006\)](#), the California Air Resources Board (CARB) launched the statewide Cap-and-Trade Program in late 2012. The program initially covered greenhouse gases (GHGs)—including carbon dioxide (CO₂), methane (CH₄), and nitrous oxide (N₂O)—produced by the industrial and electricity sectors. Emissions associated with transportation fuels and natural gas distributors were added to the program in 2015.

Currently about 80% of statewide emissions are covered by the cap, including emissions from electricity imports and fuel imported and consumed in the state.³⁵⁰ As a result of implementation decisions, the direct contributions of Cap-and-Trade to emission reductions achieved in California are suspected to be modest in comparison with other programs.³⁵¹ Proceeds from the Cap-and-Trade auction are deposited into the Greenhouse Gas Reduction Fund (GGRF). The GGRF supports programs that contribute to additional emission reductions (see [Figure 8.1](#)).³⁵² The future role of Cap-and-Trade in driving emission reductions through 2030 (when the program is currently set to expire) is uncertain depending

in part on the performance of complementary programs. Analysts have cautioned that excessive **banked allowances*** jeopardize California’s ability to reach 2030 emission reduction targets.^{353,354}

Compared to the [2017 Scoping Plan](#), [CARB’s 2022 Scoping Plan](#) predicts a much more modest role for Cap-and-Trade in driving future reductions in GHG emissions. However, the Independent Emissions Market Advisory Committee—established by [AB 398 \(Eduardo Garcia, 2017\)](#) to analyze the performance of Cap-and-Trade—has recommended several reforms that could make the program play a larger role in driving emission reductions.

Facilities regulated by Cap-and-Trade are disproportionately located in communities with greater numbers of residents of color and residents living in poverty. Environmental justice advocates argue the program inadequately addresses pollution in these communities because it does not require these facilities to directly reduce emissions if the operating firms satisfy their compliance obligations in other ways.

350 California Air Resources Board. (2022). Mandatory Greenhouse Gas Reporting, 2021 Emissions Year Frequently Asked Questions. Available at: <https://ww2.arb.ca.gov/sites/default/files/classic/cc/reporting/ghg-rep/reported-data/2021mrrfaqs.pdf>.

351 Legislative Analyst’s Office. (2019). Assessing California’s Climate Policies. Available at: <https://lao.ca.gov/handouts/resources/2019/Assessing-California-Climate-Policies-022019.pdf>.

352 California Climate Investments. (2023). 2023 Annual Report: Cap-and-Trade Auction Proceeds. Available at: https://ww2.arb.ca.gov/sites/default/files/auction-proceeds/ci_annual_report_2023.pdf.

353 Legislative Analyst’s Office. (2017). Cap-and-Trade Extension: Issues for Legislative Oversight. Available at: <https://lao.ca.gov/Publications/Report/3719>.

354 Burtraw, D. et al. (2022). 2021 Annual Report of the Independent Emissions Market Advisory Committee. Available at: <https://calepa.ca.gov/wp-content/uploads/sites/6/2022/01/2021-IEMAC-Annual-Report.a.pdf>.

* Find **bold** words in the Glossary (Appendix A).

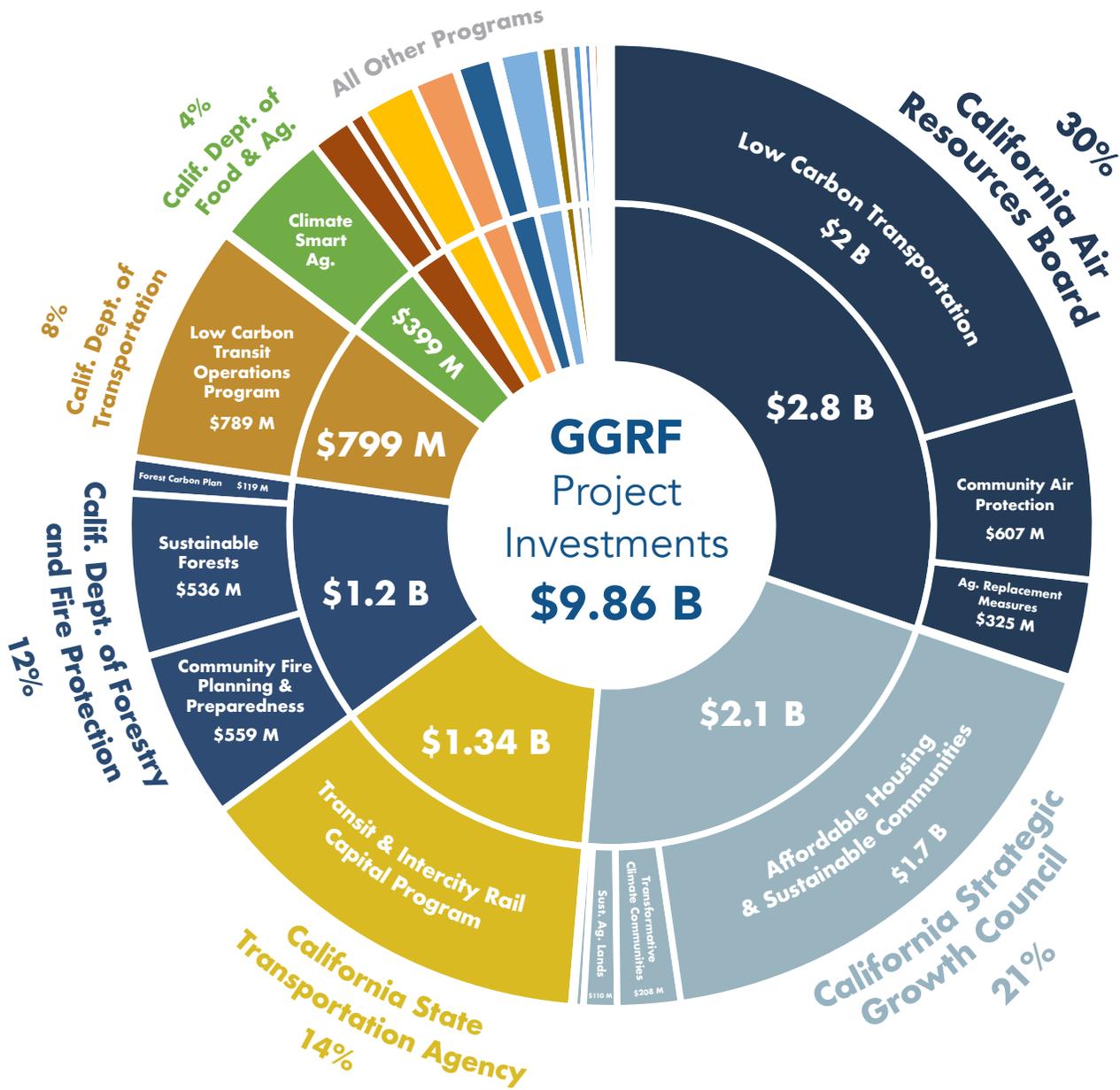


Figure 8.1. Greenhouse Gas Reduction Fund project investments by agency and program, all-time (as of May 31, 2023). Data are for “implemented” projects, notably not including the in-process High Speed Rail Project. Data are from the California Climate Investments Data Dashboard by CARB. (2023). Smaller categories may not be visible here. View online for full data.

Available at: <https://public.tableau.com/app/profile/california.air.resources.board/viz/CaliforniaClimateInvestmentsDataDashboard/AppropriatedFunds>.

Cap-and-Trade Fundamentals

Under California's Cap-and-Trade Program, a soft cap or limit is set on emissions, which grows more stringent over time. For every metric ton of GHGs allowed, CARB makes available an equivalent number of **allowances**. Some allowances are given directly to facilities ("free allowances") while others are auctioned on the open carbon market to covered GHG emitters and other market participants. As per [AB 398 \(Eduardo Garcia, 2017\)](#), CARB holds some allowances across two tiers of a price containment reserve and at the price ceiling. To be in compliance with the program, covered entities—which include electric power plants, importers of electricity, large industrial plants, and fuel distributors—must surrender one permit for every metric ton of GHGs they emit. In the event that cumulative emissions exceed the total supply of allowances—i.e., both tiers of the price containment reserve have been exhausted and there are no more allowances at the price ceiling—covered entities must buy additional price ceiling units (this has not happened to date). California's Cap-and-Trade Program is linked with a program in Quebec for carbon trading.

Entities may also buy or trade for compliance **offset credits** (i.e., credits generated by projects that reduce GHG emissions from sectors not covered by the Cap-and-Trade Program) to meet compliance obligations. As of 2021, 4% of an entity's total emissions can be accounted for with offset credits; this will increase to 6% in the period 2026-2030.³⁵⁵ As per [AB 398 \(Eduardo Garcia, 2017\)](#), at least 50% of an entity's offset credits must be generated by projects with direct environmental benefits for California.

Relevant State Institutions

- California Air Resources Board (CARB)
- California Environmental Protection Agency (CalEPA)
- Independent Emissions Market Advisory Committee (IEMAC)
- Governor's Office of Business and Economic Development
- Assembly Budget Subcommittee No. 3 Climate Crisis, Resources, Energy, and Transportation
- Assembly Natural Resources
- Senate Budget Subcommittee No. 2 on Resources, Environmental Protection and Energy
- Senate Environmental Quality Committee
- Senate Natural Resources and Water Committee
- Joint Leg. Committee on Climate Change Policies

Whether California's Cap-and-Trade Program should include offset credits has generated much debate. The impact on climate change remains the same whether emissions reductions occur in California or elsewhere. Offsets may play an important role in global climate policy by supporting GHG reduction projects elsewhere that may not have otherwise occurred due to political opposition, market failures, or lack of resources. Furthermore, offset credits can reduce the cost of compliance with the Cap-and-Trade Program. However, ensuring that offset credits produce emission reductions that are permanent (lasting at least 100 years) and additional (resulting in more GHG reduction benefits than would have occurred otherwise) remains a challenge.^{356,357,358} Further, direct emissions reductions often generate other co-benefits (e.g., reductions in harmful air pollution) that some argue should accrue to **disadvantaged communities** in "California First."³⁵⁹

355 Garcia, E. (2017). AB 398. California Global Warming Solutions Act of 2006: Market-Based Compliance Mechanisms. *California State Legislature*. Available at: https://leginfo.legislature.ca.gov/faces/billNavClient.xhtml?bill_id=201720180AB398.

356 Burtraw, D. et al. (2022). 2021 Annual Report of the Independent Emissions Market Advisory Committee. Available at: <https://calepa.ca.gov/wp-content/uploads/sites/6/2022/01/2021-IEMAC-Annual-Report.a.pdf>.

357 Badgley, G. et al. (2021). Systematic Over-Crediting in California's Forest Carbon Offsets Program. *Global Change Biology*, 28(4), pp 1433-1445.

358 Stapp, J. et al. (2023). Little Evidence of Management Change in California's Forest Offset Program. *Communications Earth & Environment*, 4, pp. 331.

359 Lueders, J. et al. (2014). The California REDD+ Experience: The Ongoing Political History of California's Initiative to Include

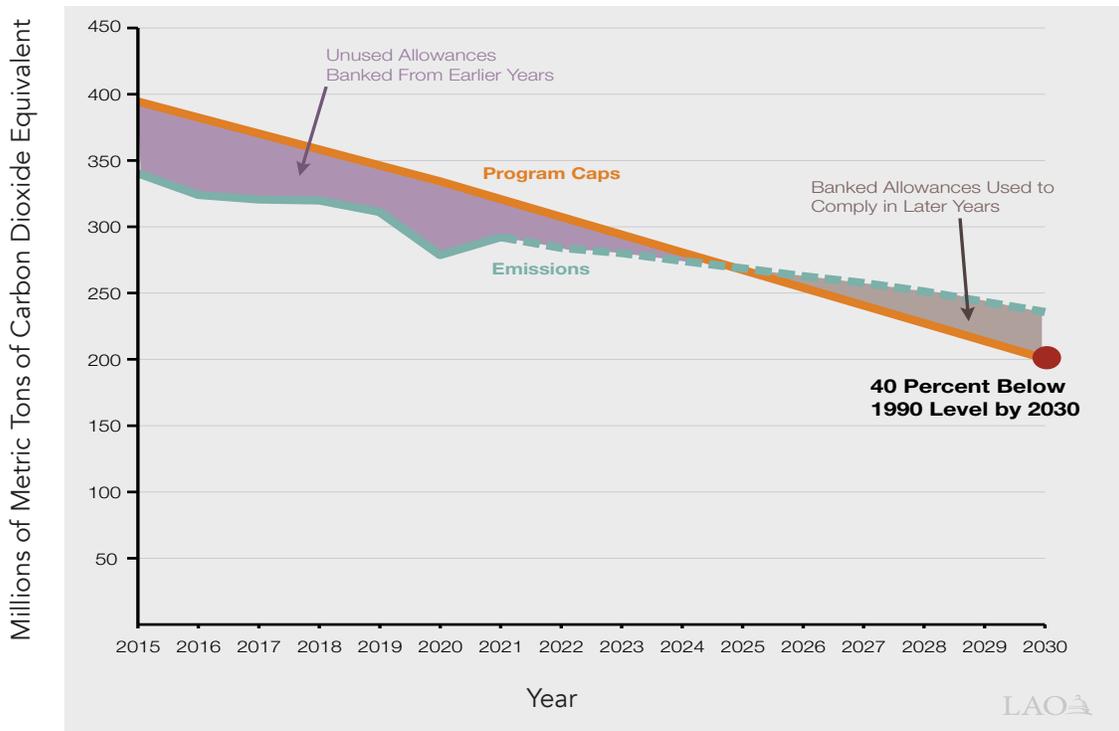


Figure 8.2. Scenario illustrating how the accumulation of banked allowances increases risk of exceeding GHG target.

Source: Legislative Analyst’s Office. (2024). The Cap-and-Trade Program: Issues for Legislative Consideration. Available at: <https://lao.ca.gov/handouts/resources/2024/Cap-and-Trade-Issues-021324.pdf>.

Cap-and-Trade is designed to provide a steadily increasing **price signal** that will encourage entities to make long-term investments to reduce their GHG emissions. This is accomplished through the combination of an established minimum auction price (or “price floor”) that increases each year and a declining emissions cap. The program has a mechanism to remove unsold allowances from circulation under certain market conditions, but this mechanism has predominantly served to temporarily remove unsold allowances that have later been reintroduced in the market.

Cap-and-Trade lets the market determine carbon prices (within the bounds of price floors and ceil-

ings set by CARB) and provides covered entities flexibility in identifying the cheapest options for reducing emissions, but a surplus of allowances (relative to emissions) has kept prices in the market at or near the price floor through much of the program’s lifetime (see Challenges below).^{360,361}

State proceeds from Cap-and-Trade auctions are deposited into the Greenhouse Gas Reduction Fund, which support projects funded by a range of programs included in the California Climate Investments Program. AB 1550 (Gomez, 2016) requires that at least 35% of the revenue from the auctions is directed towards projects that are located in or near, or provide benefits to,

Jurisdictional REDD+ Offsets within its Cap-and-Trade System. *Center for Global Development*. Available at: <https://www.cgdev.org/sites/default/files/CGD-Climate-Forest-Paper-Series-13-Lueders-Horowitz-et-al-California-REDD.pdf>.

360 Taylor, M. (2017). The 2017-18 Budget: Cap-and-Trade. The Legislative Analyst’s Office. Available at: <https://lao.ca.gov/reports/2017/3553/cap-and-trade-021317.pdf>.

361 California Air Resources Board. (2023). Cap-and-Trade Program Data Dashboard: Carbon Allowance Prices. Accessed on 5/24/2023 at: <https://ww2.arb.ca.gov/our-work/programs/cap-and-trade-program/program-data/cap-and-trade-program-data-dashboard#Figure7>.

low-income and disadvantaged communities (defined in [SB 535, de León, 2012](#)).³⁶² Since the program began, \$9.8 billion dollars of revenue has been implemented, with at least \$7.2 billion benefitting communities as defined in AB 1550 (as of May 2023).³⁶³ The Climate Investment Program has resulted in an estimated 98 million metric tons (MMT) of emission reductions.³⁶⁴

Challenges

Other regulatory programs—as well as the Great Recession³⁶⁵—led to emissions reductions greater than what was anticipated when Cap-and-Trade was introduced. For example, emissions from the electricity sector have been reduced by 36% (from 94 MMT in 2013 to 59.5 MMT of CO₂ in 2020),³⁶⁶ largely due to the [Renewables Portfolio Standard Program](#) and other cross-sectoral policies.³⁶⁷ This effectively led to a surplus of emission allowances, which has kept prices at or near the price floor (up until around August 2021) and weakened the ability of the market to drive any further emission reductions.³⁶⁸

Entities can bank a predetermined number of unused allowances to meet emissions requirements in later years. The relatively low cost of allowances, combined with predicted cost increases in the

future (that would be driven by the increasingly stringent emission reduction requirements) created an incentive to purchase excess allowances to be banked for future use. By the end of 2020, banked allowances exceeded the cumulative emissions reductions Cap-and-Trade was meant to deliver through 2030.³⁶⁹ Thus, if these banked allowances are used for compliance for the next seven years, entities could still be in technical compliance with the program while collectively emitting above program caps (see **Figure 8.2**).³⁷⁰

Thus far, CARB has not taken action to address the issue of banked allowances. In 2021, CARB prepared a report for the California legislature that details their justification for not having acted on the matter.³⁷¹ However, CARB is currently evaluating potential changes to Cap-and-Trade that would better align the program with the increased stringency necessary to achieve the new emissions reductions mandated by [AB 1279 \(Muratsuchi, 2022\)](#). They will be considering in this evaluation the potential impact of banked allowances.³⁷²

Due to the nature of the interconnected western electricity grid and markets, California imports much of its electricity (approximately 30% as of 2022).³⁷³ This imported electricity makes the

362 California Environmental Protection Agency. (2022). California Climate Investments to Benefit Disadvantaged Communities. Accessed on 12/01/2022 at: <https://calepa.ca.gov/envjustice/ghginvest/>.

363 California Air Resources Board. (2023). California Climate Investments 2023 Mid-Year Data Update. Available at: https://ww2.arb.ca.gov/sites/default/files/auction-proceeds/cci_2023mydu_cumulative_statistics.pdf.

364 California Air Resources Board. (2023). California Climate Investments 2023 Mid-Year Data Update. Available at: https://ww2.arb.ca.gov/sites/default/files/auction-proceeds/cci_2023mydu_cumulative_statistics.pdf.

365 Mastrandrea, M. D. et al. (2020) Assessing California's Progress Toward its 2020 Greenhouse Gas Emissions Limit. *Energy Policy*, 138, 111219.

366 California Air Resources Board. (2023). California Greenhouse Gas Emission Inventory (2023 Edition). Available at: <https://ww2.arb.ca.gov/ghg-inventory-data>.

367 Petek, G. (2020). Assessing California's Climate Policies – Electricity Generation. *Legislative Analyst's Office*. Available at: <https://lao.ca.gov/reports/2020/4131/climate-policies-electricity-010320.pdf>.

368 Burtraw, D. et al. (2022). 2021 Annual Report of the Independent Emissions Market Advisory Committee. Available at: <https://calepa.ca.gov/wp-content/uploads/sites/6/2022/01/2021-IEMAC-Annual-Report.a.pdf>.

369 Burtraw, D. et al. (2022). 2021 Annual Report of the Independent Emissions Market Advisory Committee. Available at: <https://calepa.ca.gov/wp-content/uploads/sites/6/2022/01/2021-IEMAC-Annual-Report.a.pdf>.

370 Legislative Analyst's Office. (2017). Cap-and-Trade Extension: Issues for Legislative Oversight. <https://lao.ca.gov/Publications/Report/3719>.

371 California Air Resources Board. (2021). BR 18-51 Cap-and-Trade Allowance Report. Available at: https://ww2.arb.ca.gov/sites/default/files/cap-and-trade/Allowance%20Report_Reso18_51.pdf

372 California Air Resources Board. (2023). Important Process Information Regarding Cap-and-Trade Regulatory Updates. Available at: https://ww2.arb.ca.gov/sites/default/files/2023-02/nc-CT_Notice_Feb_2023.pdf.

373 Nyberg, M. (2022). 2022 Total System Electric Generation. California Energy Commission. Available at: <https://www.energy.ca.gov/data-reports/energy-almanac/california-electricity-data/2022-total-system-electric-generation>.

Cap-and-Trade system susceptible to resource shuffling—a type of “leakage” where apparent reduced in-state emissions correspond with increased out-of-state emissions (where the Cap does not apply), and thus no net reduction in emissions actually occurs.³⁷⁴ For example, resource shuffling would occur if a California utility purchases power from a less-carbon intensive power generator to meet emissions standards, but the carbon-intensive generator with whom they were previously contracted continues to provide power to another utility outside of California not covered by the program. CARB has taken steps to reduce the potential for resource shuffling,³⁷⁵ though some assert resource shuffling likely remains a problem.³⁷⁶ Expanding the scope of climate policies (either by direct linkage with programs in other jurisdictions or by other jurisdictions adopting policies of comparable stringency) is another way to reduce leakage risk.

Environmental Justice and Equity Considerations

Harmful co-pollutants are emitted in conjunction with carbon emissions from industrial facilities.

This means that carbon emission reductions tend to also generate some air quality co-benefits for nearby communities.³⁷⁷ Due to complex and interacting factors including income inequality³⁷⁸ and historical redlining,³⁷⁹ facilities regulated by Cap-and-Trade are disproportionately located in communities with greater numbers of residents of color and residents living in poverty.³⁸⁰ Evidence is mixed whether such communities have benefited from or been harmed by Cap-and-Trade. For example, one study found that Cap-and-Trade benefits have disproportionately accumulated in wealthier neighborhoods, while disadvantaged communities and communities with greater percentages of people of color have experienced fewer air quality improvements, and in some cases, worsened air quality.³⁸¹

However, other research—including an analysis by the Office of Environmental Health Hazard Assessment—has found that Cap-and-Trade has been correlated with greater air quality improvements for disadvantaged communities and a narrowing of the “pollution gap” though inequities persist.^{382,383}

CARB has been working to address pollution inequities through a variety of other programs, including the Community Air Protection Program (established by AB 617, Garcia, 2017) and

374 Pauer, S. U. (2018). Including Electricity Imports in California’s Cap-And-Trade Program: A Case Study of a Border Carbon Adjustment in Practice. *The Electricity Journal*, 31(10), pp 39-45.

375 California Air Resources Board. (2020). Review of Potential for Resource Shuffling in the Electricity Sector. Available at: https://ww2.arb.ca.gov/sites/default/files/cap-and-trade/guidance/resource_shuffling_faq.pdf.

376 Burtraw, D. et al. (2022). 2021 Annual Report of the Independent Emissions Market Advisory Committee. Available at: <https://calepa.ca.gov/wp-content/uploads/sites/6/2022/01/2021-EMAC-Annual-Report.a.pdf>.

377 Zwickl, K., Stum, S., and Boyce, J. K. (2023). Effects of Carbon Mitigation on Co-Pollutants at Industrial Facilities in Europe. *The Energy Journal*, 42(5), pp. 1-26.

378 Banzhaf, H. S., Ma, L., and Timmins, C. (2019). Environmental Justice: Establishing Causal Relationships. *Annual Review of Resource Economics*. 11, pp. 377-398.

379 California Environmental Protection Agency. (2021). Pollution and Prejudice Redlining and Environmental Injustice in California. Available at: <https://storymaps.arcgis.com/stories/f167b251809c43778a2f9f040f43d2f5>.

380 Cushing, L. J. et al. (2016). A Preliminary Environmental Equity Assessment of California’s Cap-and-Trade Program. Available at: https://dornsife.usc.edu/assets/sites/242/docs/Climate_Equity_Brief_CA_Cap_and_Trade_Sept2016_FINAL2.pdf.

381 Pastor, M. et al. (2022). Up in the Air: Revisiting Equity Dimensions of California’s Cap-and-Trade System. Available at: https://dornsife.usc.edu/assets/sites/1411/docs/CAP_and_TRADE_Updated_2020_v02152022_FINAL.pdf.

382 Plummer, L. et al. (2022). Impacts of Greenhouse Gas Emissions Limits within Disadvantaged Communities: Progress Toward Reducing Inequities. *Office of Environmental Health Hazard Assessment*. Available at: <https://oehha.ca.gov/media/downloads/environmental-justice/impactsofghgpoliciesreport020322.pdf>.

383 Hernandez-Cortes, D., and Meng, K. C. (2022). Do Environmental Markets Cause Environmental Injustice? Evidence from California’s Carbon Market. *National Bureau of Economic Research Working Paper Series*. Available at: https://www.nber.org/system/files/working_papers/w27205/w27205.pdf.

the California Climate Investment Program.³⁸⁴ The Environmental Justice Advisory Committee (EJAC)—which advises CARB on the scoping plan—recommends that “no-trade zones” be established in pollution hotspots. Facilities in no-trade zones would be required to demonstrate direct emission reductions rather than being able to meet compliance with purchased allowances.³⁸⁵ In their 2022 Annual Report, the Independent Emissions Market Advisory Committee explores this recommendation and offers some suggestions on how it might be implemented by CARB.³⁸⁶

EJAC has suggested that CARB eliminate the allocation of free allowances (currently required by [AB 398, Eduardo Garcia, 2017](#)) and the option to meet emissions targets with carbon offsets. Should carbon offsets continue, EJAC recommends that offset-generating projects should be restricted to the same vicinity where the emissions occur.

Relevant Policies

(Laws/Regulations)

California Global Warming Solutions Act

AB 32 (Nunez, 2006)

AB 32 established the State Air Resources Board (now the California Air Resources Board, or CARB) with the authority to monitor and regulate sources of greenhouse gas emissions. AB 32 required CARB to limit the statewide greenhouse gas emissions to 1990 levels by 2020. AB 32 authorized CARB to include the use of market-based compliance mechanisms to meet these aims. [SB 32 \(Pavley, 2016\)](#) expanded emissions targets to reflect a 40% reduction from 1990 levels by 2030.

In response to AB 32, CARB adopted Cap-

and-Trade regulations in 2011 for an emissions trading scheme launched in 2012. Compliance obligations for electricity generators and large industrial facilities began in 2013.

California Global Warming Solutions Act of 2006: Greenhouse Gas Reduction Fund

SB 535 (de León, 2012)

SB 535 mandated that proceeds of Cap-and-Trade auctions be directed towards funding investments in disadvantaged communities (DACs). Recognizing that low-income communities suffer disproportionate levels of pollution, SB 535 also charged the California Environmental Protection Agency (CalEPA) to designate DACs, using “geographic, socioeconomic, public health, and environmental hazard criteria,” but with broad discretion. In May 2022, CalEPA finalized its [Designation of Disadvantaged Communities](#).

Public Resources

SB 1018 (Cmte. on Budget and Fiscal Review, 2012)

SB 1018 established the Greenhouse Gas Reduction Fund within the State Treasury, where Cap-and-Trade auction proceeds are deposited for the California Climate Investments Program.

Greenhouse Gases: Investment Plan: Disadvantaged Communities

AB 1550 (Gomez, 2016)

AB 1550 updated investment targets set in [SB 535 \(de León, 2012\)](#) for funds generated from Cap-and-Trade auctions. AB 1550 requires that 1) at least 25% of the revenue to go to projects located in and that benefit disadvantaged communities (defined in SB 535, de León, 2012); 2) 5% be directed to projects located in or that benefit low-income communities; and 3) 5% be directed to projects located within or that benefit

384 California Air Resources Board. (2022). Environmental Justice and Local Air Pollution. Accessed on 12/01/2022 at: <https://ww2.arb.ca.gov/resources/documents/faq-cap-and-trade-program#ftn4>.

385 Environmental Justice Advisory Committee. (2022). Preliminary Draft of EJAC Scoping Plan Recommendations. Available at: <https://ww2.arb.ca.gov/sites/default/files/barcu/board/books/2022/031022/ejacrecs.pdf>.

386 Burtraw, D. et al. (2023). 2022 Annual Report of the Independent Emissions Market Advisory Committee. Available at: <https://calepa.ca.gov/wp-content/uploads/sites/6/2023/02/2022-annual-report-of-the-independent-emissions-market-advisory-committee-2.pdf>.

households within 0.5 miles of a disadvantaged communities.

California Global Warming Solutions Act of 2006: Emissions Limit

SB 32 (Pavley, 2016)

SB 32 mandated that CARB reduce greenhouse gas emissions to 40% of 1990 levels by 2030.

California Global Warming Solutions Act of 2006: Market-based Compliance Mechanisms: Fire Prevention Fees

AB 398 (Eduardo Garcia, 2017)

AB 398 extended Cap-and-Trade to 2030, added a price ceiling for compliance, restricted the number of offset credits that could be met by projects without direct environmental benefits to California to less than 50%, and added preemption of location regulation of CO₂ for facilities under the Cap. AB 398 also established the Independent Emissions Market Advisory Committee which meets at least once a year to analyze the performance of Cap-and-Trade and delivers its findings to CARB and the Joint Legislative Committee on Climate Change Policies.

CARB amended Cap-and-Trade in 2018 to address cost containment, offsets, allocation, phase-out of exemptions, administrative issues, and the delinked program with the Canadian province of Ontario.

Community Air Protection Program

AB 617 (Garcia, 2017)

AB 617 reduces pollution exposure in communities based on environmental, health, and socioeconomic information. This inaugural statewide effort requires community air monitoring, community emission reduction plans, and incentive funding to deploy the cleanest technologies in the most impacted areas.

California Climate Crisis Act

AB 1279 (Muratsuchi, 2022)

AB 1279 declares the policy of the state to achieve net-zero greenhouse gas emissions as soon as possible, but no later than 2045,

Read More

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Wang, A., Carpenter-Gold, D., and So, A. (2022). UCLA School of Law and California-China Climate Institute.

and to achieve and maintain net negative emissions thereafter. Further, this law mandates that emissions by 2045 are reduced by 85% below 1990 levels (this is to ensure that direct emission reductions are favored over the broad deployment of carbon removal technologies).

This law requires CARB to work with relevant agencies to 1) ensure scoping plan updates include measures to achieve these policy goals; and 2) identify and implement strategies to enable carbon dioxide removal solutions and carbon capture, utilization, and storage technologies.

Glossary

Allowances: Each allowance in California's Cap-and-Trade Program is a permit to emit one metric ton of carbon dioxide equivalent. The California Air Resources Board sets the total emissions cap for each year and introduces a corresponding number of allowances. Some allowances are provided directly to entities while the remainder of allowances are sold at quarterly auctions.

Banked allowances: An allowance that has been purchased but not used in the current year can be banked for future use. California's Cap-and-Trade program allows participants to save allowances for future emissions to alleviate price volatility in the market.

Base load: The minimum amount of power that must be supplied to grid over a given time frame is referred to as the "base load." Base load resources supply the grid with a consistent amount of power.

Battery electric vehicles (BEVs): Vehicles powered solely by the chemical energy stored in rechargeable battery packs with no other source of propulsion.

Behind-the-meter (BTM): Behind-the-meter refers to the position of energy resources in relation to the energy user's electric meter. BTM resources are located onsite and do not require transmission or distribution infrastructure to reach the consumer (as opposed to front-of-meter energy resources supplied by the power grid).

Biomethane: Biomethane (or renewable natural gas) is produced from decaying organic matter

through anaerobic digestion by microorganisms. When biomethane is created from organic matter that would have otherwise released methane into the atmosphere (such as from landfills or wastewater treatment facilities), it is often considered to be carbon neutral or carbon negative. Biomethane is chemically identical to natural gas and can be readily substituted for all natural gas applications.

Blue hydrogen: Because of the high reactivity of hydrogen atoms, pure hydrogen (H_2) rarely exists in nature and instead must be produced. There are a variety of different methods for generating pure hydrogen. Blue hydrogen is created from natural gas in a process that includes carbon capture and storage.

Carbon capture and storage (CCS): CCS is the process of capturing, compressing, transporting, and sequestering carbon dioxide (CO_2). Most proposed applications for CCS involve capturing CO_2 that would have otherwise been released into the atmosphere during industrial processes, particularly fuel combustion.

Carbon intensity: Carbon intensity is a measure of how much carbon dioxide (or equivalent greenhouse gas) was emitted during the production of a given unit of electricity, transportation fuel, or some other good. For example, carbon intensities of different energy resources may be provided as kg of CO_2 per megawatt-hour (MWh) of electricity.

Curtail: To curtail is to reduce power generation to balance supply and demand on the grid. Curtailment is necessary when power generators are producing more power than is required by customers or can be absorbed by energy storage systems.

Demand response: Demand response is a method of grid management where consumers are signaled to adjust their energy use in response to grid conditions. Flex Alerts issued by the California Independent System Operator (CAISO) are an example of demand response where consumers are signaled to reduce their energy use (by adjusting their thermostat, avoiding the use of their ovens, etc.).

Disadvantaged communities (DACs): Disadvantaged communities are legally defined by the California Environmental Protection Agency as per SB 535 (de León, 2012). They are identified as those communities throughout California that suffer the most from a combination of economic, health, and environmental burdens, including poverty, high unemployment, air and water pollution, hazardous waste, and high incidence of asthma and heart disease.

Distributed energy resources (DERs): Distributed energy resources are small-scale assets that either generate electricity (e.g., rooftop solar panels), store energy (e.g., 4-hour lithium batteries), or influence energy use (e.g., demand response technologies and energy efficiency). DERs are typically behind-the-meter but may be aggregated and coordinated to provide benefits to the grid.

Duck curve: Coined by the California Independent System Operator (CAISO), the term “duck curve” refers to a chart that displays the difference between energy demand and available renewable energy (known as net demand) over the course of a single day, which roughly resembles the shape of a duck.

Electrification: Electrification refers to the process of replacing fossil fuel-powered technologies or systems with ones powered by electricity. For example, cooking can be electrified by replacing natural gas stoves with electric ovens.

Energy burden: Energy burden refers to the proportion of household income spent on energy costs. Low-income households generally have higher energy burdens.

Energy carrier: Energy carriers allow energy to be moved between systems or places. The energy they carry is then used to generate heat or mechanical work.

Enhanced oil recovery (EOR): EOR involves the injection of gas, heat, or chemicals into reservoirs to extract oil that would otherwise be unrecoverable.

Feeder circuits: Feeder circuits are composed of the main distribution lines that carry electricity from distribution substations to be delivered to large groups of consumers within a given area (e.g., multiple city blocks).

Firm power: Firm power refers to sources of energy that can be delivered reliably and for a long duration (as opposed to intermittent resources that are not consistently available).

Fuel cell electric vehicles (FCEVs): Also known as hydrogen fuel cell vehicles, FCEVs use oxygen pulled from the air and compressed hydrogen to generate electricity via a fuel cell to power the engine.

Gigawatt (GW): Gigawatts are a unit of electric power equal to 1,000 megawatts or 1 million kilowatts. For context, during the September 2022 heat wave, the total demand for electricity in California peaked at roughly 52 GW (setting an all-time record).

Global warming potential (GWP): Global warming potential is a unit of measurement that was created to allow the comparison of global warming effects from different greenhouse gases. GWP is the amount of energy (or heat) that 1 ton of an emitted gas would absorb in the atmosphere over a given period of time compared to 1 ton of carbon dioxide.

Hazardous air pollutants: Hazardous air pollutants are designated by the U.S. Environmental Protection Agency as substances known or suspected to cause cancer or other serious health problems, including reproductive or birth defects and adverse environmental effects. Hazardous air pollutants are designated as toxic air contaminants in the state of California.

Heat pump: Heat pumps are highly efficient electric appliances that provide air conditioning, space heating, or water heating. Heat pumps operate by using electricity to transfer heat from one material to another. For example, heat pump water heaters capture heat from ambient air and transfer that heat to water in the tank (rather than using electricity to heat the water directly).

Hosting capacity: Hosting capacity indicates the number of distributed energy resources that can be reliably supported on a local distribution network before upgrades to the circuit are required.

Intermittency: Intermittency refers to irregularity or inconsistency. In energy, intermittent resources are those that are not continuously available such as solar and wind power.

Investor-owned utilities (IOUs): IOUs are privately held companies that provide public utility services. California has six electric IOUs: Bear Valley Electric Service, Liberty Utilities, PacifiCorp, Pacific Gas and Electric (PG&E), San Diego Gas and Electric (SDG&E), and Southern California Edison (SCE). The latter three—PG&E, SDG&E, and SCE—are the largest in the state and participate in the California Independent System Operator (CAISO) service territory. PG&E, SDG&E, Southwest Gas, and Southern California Gas (SoCalGas) are the four largest IOUs providing natural gas service in the state.

Leakage (Carbon leakage): Leakage occurs when market share moves from one geographic area (with more strict climate policies) to another area. Emissions appear to decrease in the geographic area with strict policies, but increase elsewhere, resulting in no net change in emissions to the atmosphere.

Load balancing: Load balancing is the act of ensuring energy supplied to the grid matches that required to meet energy demand, resulting in a consistent electric frequency.

Load shifting: Load shifting is a form of demand response where electricity consumption is shifted from one time period to another. For example, some electric water heaters can be configured to proactively heat water during the day when electricity is cheapest and renewable energy generation greatest, rather than heating water in the evening during peak net demand.

Kilowatt (kW): This unit of electric power is equal to 1,000 watts. Electric bills are usually expressed in kilowatt hours, or the amount of electricity equivalent to 1 kilowatt delivered for 1 hour. For reference, the average household in California consumes a little more than 6,000 kWh per year.

Megawatt (MW): This unit of electric power is equal to 1 million watts. According to the California Independent System Operator (CAISO), 1 MW is roughly equivalent to the amount of electricity needed to meet the simultaneous demand of 750 homes.

Methane: Methane (CH₄) is a short-lived greenhouse gas and the second most abundant human-generated greenhouse gas after carbon dioxide (CO₂). Methane is emitted from a variety of anthropological sources including landfills, dairy farms, and oil and gas operations. Methane is the primary component of natural gas. According to the International Panel on Climate Change, methane has a global warming potential 80 times and 29.8 times higher than CO₂ over a 20-year and 100-year time span, respectively.

Microgrids: Microgrids are collections of distributed energy resources that can supply energy to consumers independent from the main power grid. They typically include a local source of energy generation, a means of storing energy, electrical cables to connect end-users, and a control system to manage energy.

Natural lands: SB 1386 (Wolk, 2016) defines natural lands as forests, grasslands, deserts, freshwater and riparian systems, wetlands, coastal and estuarine areas, watersheds, wildlands, wildlife habitat. Also included are in this definition are lands used for recreation like parks, urban and community forests, trails, greenbelts, etc.

Net demand: Net demand is a measure of total energy demand minus renewable energy generation. In California, net demand tends to be highest during the evening (from about 4:00 - 6:00 pm) as solar resources go offline.

Net-zero: Net-zero greenhouse gas emissions indicates that any emission of greenhouse gases is balanced by the removal of equivalent greenhouse gases from the atmosphere. Though similar in meaning, the term "net-zero greenhouse gas emissions" is typically considered broader in scope than "carbon neutrality," which technically only refers to a balance in carbon emissions and removals. Achieving net-zero greenhouse gas emissions by 2045 was declared the policy of the state by AB 1279 (Muratsuchi, 2022).

Offset credits: California compliance offset credits are an alternative to allowances purchased from the Cap-and-Trade market. Offset credits are generated by projects that either prevent greenhouse gas emissions from being released or that capture emissions from ambient air. Each offset credit represents the reduction of one ton of CO₂ or other equivalent greenhouse gas. Offset credits are only generated from sectors that are not covered by the Cap-and-Trade Program. California law (AB 32, Nunez, 2006) requires that offset credits must represent real, permanent, quantifiable, verifiable and enforceable greenhouse gas emission reductions that are additional to any GHG reduction that would have otherwise occurred.

Ozone: Ozone is a greenhouse gas and toxic air pollutant, as well as the primary component of smog. Ozone is created when nitrogen oxides (NOx) and volatile organic compounds (which are emitted by vehicles, industrial plants, and consumer products) interact in the presence of sunlight and heat.

Peak demand: Peak demand refers to the largest amount of power (in MW or GW) required to meet customer demand within a specified time period.

Plug-in hybrid electric vehicles (PHEVs): PHEVs are powered by both a battery-powered electric motor and a gasoline- or diesel-powered internal combustion engine. The engine will draw on battery power for shorter trips. For longer trips, the PHEV will use on-board fuel to achieve similar driving ranges to conventional internal combustion engines.

Pollution gap: Pollution gap refers to the difference in pollution exposure experienced by different communities (for example, between disadvantaged communities in California and the general population).

Price signal: Price signals convey information to either consumers or producers (via cost adjustments) that results in adjustments to behavior. For example, if electricity rates are more expensive during peak net demand, consumers may decide to use less electricity during those windows of time.

Pruning: With respect to the natural gas system, pruning is the strategic decommissioning or retirement of parts of the natural gas distribution network after households have been fully electrified. Pruning may be more cost effective than paying to maintain natural gas pipelines that are underutilized.

Public safety power shutoff (PSPS): Utilities may intentionally cut power to specific parts of the electric grid to mitigate the risk of wildfire ignitions caused by electric infrastructure. These intentional outages are called public safety power shutoffs or “de-energization.”

Retail rates: Retail rates are state-regulated prices for the sale of electricity to consumers by utilities. Retail rates reflect the bundled costs of generating, transmitting, and distributing electricity to consumers. These costs include things like new infrastructure construction, wildfire mitigation, personnel wages, and other overhead costs.

Upstream emissions: Upstream emissions reflect greenhouse gas emissions that occur prior to the combustion or use of a fuel. For example, upstream emissions of oil include the emissions generated during the extraction, refining, and transportation of that oil before it reaches its final destination.

Vehicle miles traveled (VMT): Vehicle miles traveled (VMT) is a cumulative measure of how much people in a given area drive. Per capita VMT is how much the average person drives. Reducing VMT—by encouraging mass transit or walking, for example—is one method for reducing greenhouse gas emissions from the transportation sector.

Well-to-wheel emissions: Well-to-wheel is an estimate of the total cumulative emissions produced during the lifetime of a transportation fuel, from its production to use by the final consumer.

Working lands: [SB 1386 \(Wolk, 2016\)](#) defines working lands as those used for farming, grazing, or the production of forest products.

Expert Oversight & Review



Steering Committee

The Steering Committee approved the scope of the Energy Primer, deliberated over and reached consensus on content within the eight sections, and authored the Overview of California's Energy Transition.

Jane Long, Chair

Independent Consultant, CCST Distinguished Expert

Michael Mastrandrea

Stanford University

Louise Bedsworth

University of California, Berkeley

Colin Murphy

University of California, Davis

Arun Raju

University of California, Riverside

Expert Reviewers

Expert Reviewers provided anonymous peer review of the 8 sections.

Catherine Garoupa White

Central Valley Air Quality Coalition

Michael Jarred

Regenerative Strategies Consulting

Elena Krieger

PSE Healthy Energy

Achintya Madduri

California Public Utilities Commission

Daniel Sperling

University of California, Davis

CCST Board Oversight Subcommittee*

The CCST Board Oversight Subcommittee reviewed and granted formal approval for the provisional Steering Committee members, ensuring that the final composition of the Steering Committee achieved a reasonable balance of perspectives and experiences.

Andrew McIlroy

Sandia National Laboratories

Elizabeth Hadly

Stanford University

Pramod Khargonekar

University of California, Irvine

Report Monitor

The Report Monitor assessed the adequacy of the authors' responses to peer review comments.

Jane Park

California State Assembly

Additional Oversight

Amber Mace

CCST CEO*

*During initial project development and launch.

*Subcommittee of the Board of Directors Program Committee

KEY CHALLENGES FOR
CALIFORNIA'S ENERGY FUTURE

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CCST
1017 L St, #438
Sacramento, California 95814
(916) 492-0996 • ccst@ccst.us • ccst.us • @CCSTorg

