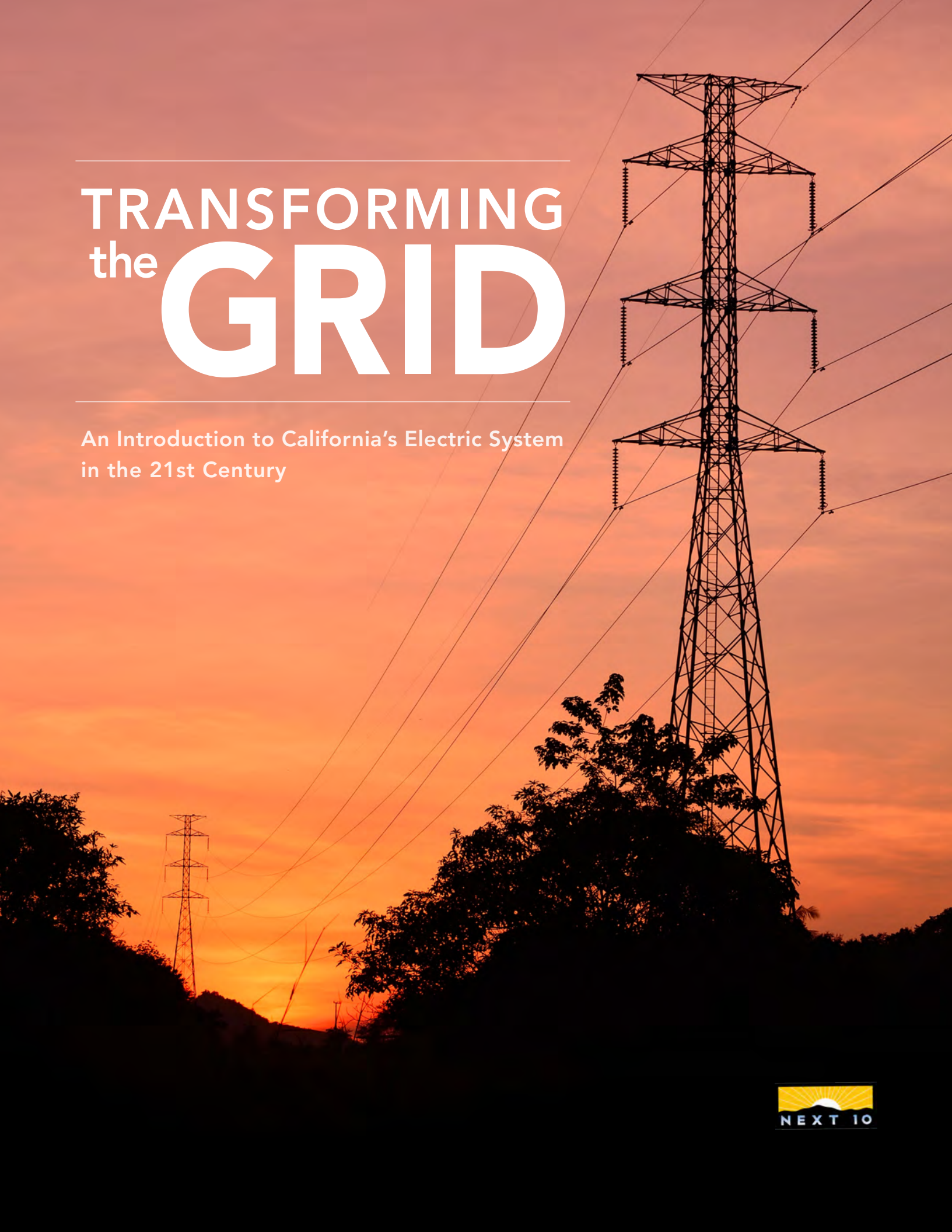

TRANSFORMING the GRID

An Introduction to California's Electric System in the 21st Century

NEXT 10

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I.

Introduction

CLIMATE change is the key challenge of the 21st century and California has been at the global forefront of the development of strategies to reduce greenhouse gas emissions while maintaining economic growth. With California's electricity sector serving as one of the largest sources of greenhouse gas emissions in the state, lawmakers and regulators face critical questions about how the sector can maintain affordability and reliability as it decarbonizes. An increasingly clean power system is also key to decarbonizing other parts of the economy, including transportation – the largest source of statewide emissions – and heat.

Given this challenge, California's energy system is undergoing a radical transformation driven by disruptive technologies, consumer preferences, and aggressive clean energy policies. The old paradigm of central suppliers serving passive customers is giving way to a more decentralized and digitized system, with modular and smart technologies generating and controlling energy with greater efficiency and higher value.

As the state looks to transform its power system and deliver an increasing amount of renewable energy reliably and affordably, this paper sets out to provide an overview of the current features of, and challenges facing, California's electric grid. Key takeaways from this analysis include:

California's resource diversity, combined with a willingness to innovate, is creating opportunities for industry and policy leadership, environmental improvement, and economic growth.

California's significant investment in energy efficiency has kept energy demand flat, even as the economy has boomed. Though the state has among the highest electricity prices in the country, it has among the lowest expenditure per capita.

California's renewable energy sectors such as wind and solar are mature. The state's Investor Owned Utilities (IOUs) are meeting Renewable Portfolio Standard (RPS) goals well ahead of schedule.[1] While renewable energy in the state is affordable and abundant, the addition of these resources requires a new approach to managing the grid. Fortunately, there are a growing set of options for managing the variability of renewable energy, and the state is currently weighing the prospect of expanding its regional energy market to balance demand and cost concerns.

There is growing consensus that electrification of transportation and heat are critical to deep decarbonization, while also helping integrate more renewables. However, building electrification and broader adoption of electric vehicles will increase electricity demand in the state, creating new challenges for how the state manages a rapidly evolving power system.

New distributed energy technologies are expanding the role of customers, saving energy, lowering costs for consumers, reducing emissions, and providing more reliable service. But distributed energy, community choice aggregation programs (CCAs) and competitive electricity service providers are causing significant changes to traditional business models, and policies and business practices are still evolving.

The need to cut emissions across the economy, combined with increasingly common distributed energy resources, will create a new paradigm. Instead of forecasting demand and meeting it with controllable supply (fossil fueled generators), we are moving to an era of forecasted supply (such as wind and solar) and controllable demand.

As California's energy system grows to accommodate new energy demands and a shift to more renewable resources, the grid and associated regulatory bodies and energy markets face critical challenges to help balance competing concerns: reliability, affordability, and environmental and social issues. This paper aims to provide background on the state's power system and these associated concerns as state lawmakers look to develop policies that will shape the future of California's clean energy economy.

1 The three IOUs include San Diego Gas & Electric (SDG&E), Pacific Gas & Electric (PG&E), and Southern California Edison (SCE).

FEATURES OF CALIFORNIA'S POWER SYSTEM

California's electric power system, and the western U.S. electrical grid of which it is an integral part, is an engineering marvel.

Like all power systems, it has to balance supply and demand in every instant, be reliable, resilient, and affordable. But what makes California's grid stand apart from other regions of America and the world is its tremendous diversity.

Electricity supply in many states is dominated by only one or two fuel sources. California gets energy from natural gas, large hydro, nuclear, solar photovoltaic (PV), wind, geothermal, biomass, small hydro, solar thermal, coal, petroleum coke, waste heat, and oil – in that order.

California is also unique for its leadership on clean energy. California is the birthplace of the global wind energy industry; the leading state in the country for solar, geothermal, and biomass energy; the most energy efficient state per capita and per GDP; and one of the cleanest in terms of emissions per megawatt-hour (MWh).[2] The state is even home to the world's largest solar rooftop at the new Apple Headquarters in Cupertino, with panels from SunPower, based in San Jose.[3]

California is full of business and technology innovators in the energy space, from start-up tech firms to Silicon Valley giants who are jumping in to energy issues. Apple and Google now power their global operations entirely with renewable energy.[4] Tesla, based in Fremont, is a global leader in electric vehicles and energy storage, as well as the leading US distributed solar company.

California's diverse and innovative power system is due in part to the state's varied natural resources, including mountains, forests, deserts, oil and gas deposits, active geology, and the Pacific Ocean. It is also due to historical factors and decisions to innovate in both policy and technology. But most of all it reflects the will of the people – citizens, voters, entrepreneurs, activists, policymakers, and customers – to reduce greenhouse gas emissions from the power sector. Polls have shown consistent strong support for climate action. In the most recent poll by the Public Policy Institute of California, 81 percent of residents view global warming as a very serious or somewhat serious threat to the state's future economy and quality of life. Two-thirds support state efforts to cut carbon emissions, independent of the federal government.[5]

This issue brief is intended to provide an introduction to the California power system that is accessible to the lay reader, enabling Californians and key decision makers in the state to understand the issues facing California's power system. It is part of a series of briefs designed to provide an overview of key policy and technology considerations facing the future of California's energy grid.

To provide an overview of California's power system, this brief will first walk readers through the basics of how the power system works, including the technical, regulatory, and financial aspects. A discussion of various important environmental and social issues that are impacted by energy use will then be provided. Lastly, the authors will look at some visions of the future, and how the state might address the biggest energy problem of this generation—climate change—while maintaining a reliable and affordable power supply.

2 See Next10's 2017 California Green Innovation Index, for example, at http://next10.org/2017-gii.

3 Kyle Graycar, "Apple's New Campus Hosts the Country's Largest Solar Commercial Project," Pick My Solar, May 3, 2017, https://blog.pickmysolar.com/apples-new-campus-country-largest-solar-commercial-project

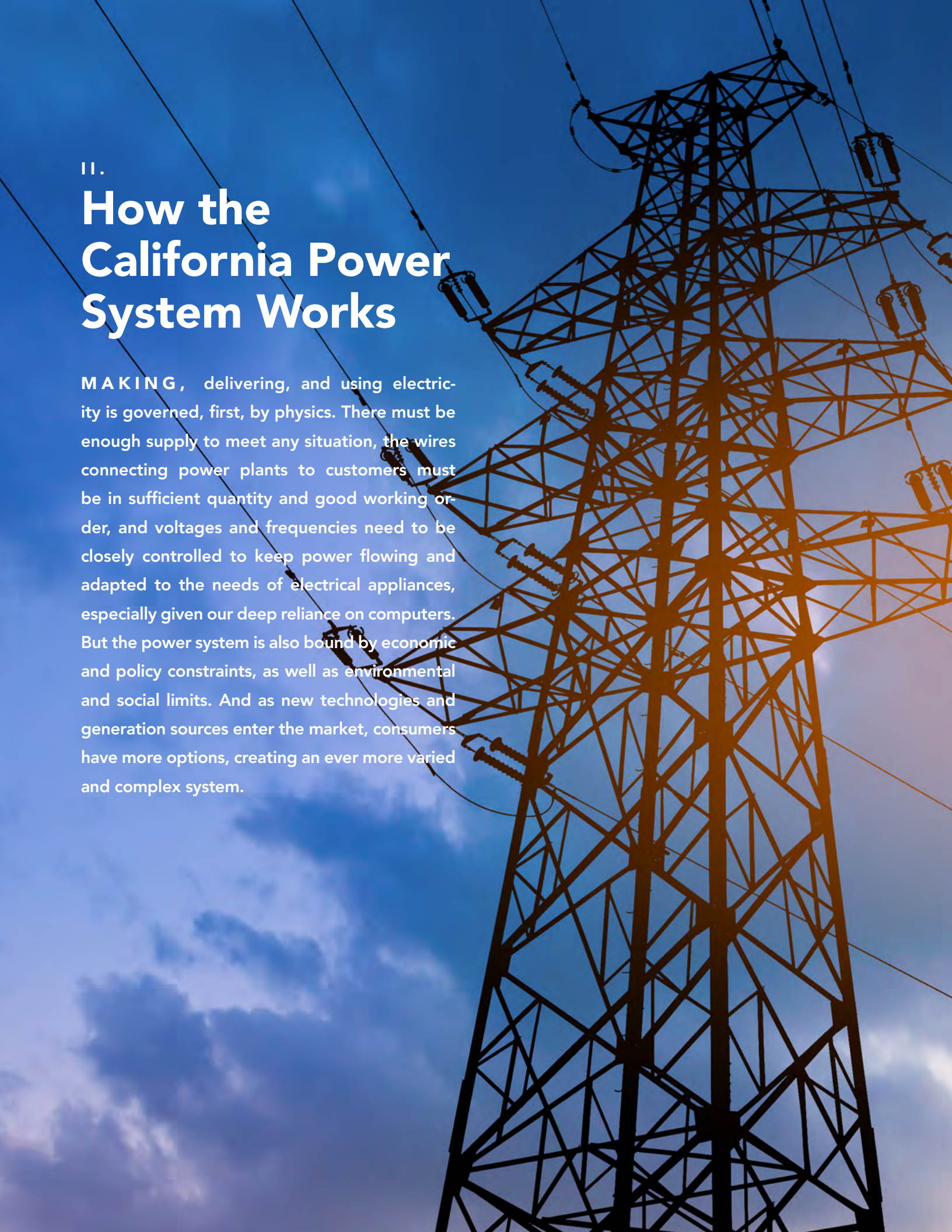
4 Apple, "Apple now globally powered by 100 percent renewable energy," press release, April 9, 2018, https://www.apple.com/newsroom/2018/04/apple-now-globally-powered-by-100-percent-renewable-energy/. Google, "100% renewable is just the beginning," undated, https://environment.google/projects/announcement-100/

5 Public Policy Institute of California, "Californians' Views on Climate Change," January 2017, http://www.ppic.org/publication/californians-views-on-climate-change/

II.

How the California Power System Works

MAKING, delivering, and using electricity is governed, first, by physics. There must be enough supply to meet any situation, the wires connecting power plants to customers must be in sufficient quantity and good working order, and voltages and frequencies need to be closely controlled to keep power flowing and adapted to the needs of electrical appliances, especially given our deep reliance on computers. But the power system is also bound by economic and policy constraints, as well as environmental and social limits. And as new technologies and generation sources enter the market, consumers have more options, creating an ever more varied and complex system.



The Grid is a Network

The power system is made up of many parts that work together as a seamless whole—most of the time.

Though the power system is often described as linear – from the generator through the power line to the customer – it is really better understood as a network. Every generator is connected to every electric appliance through a vast network of copper wires.

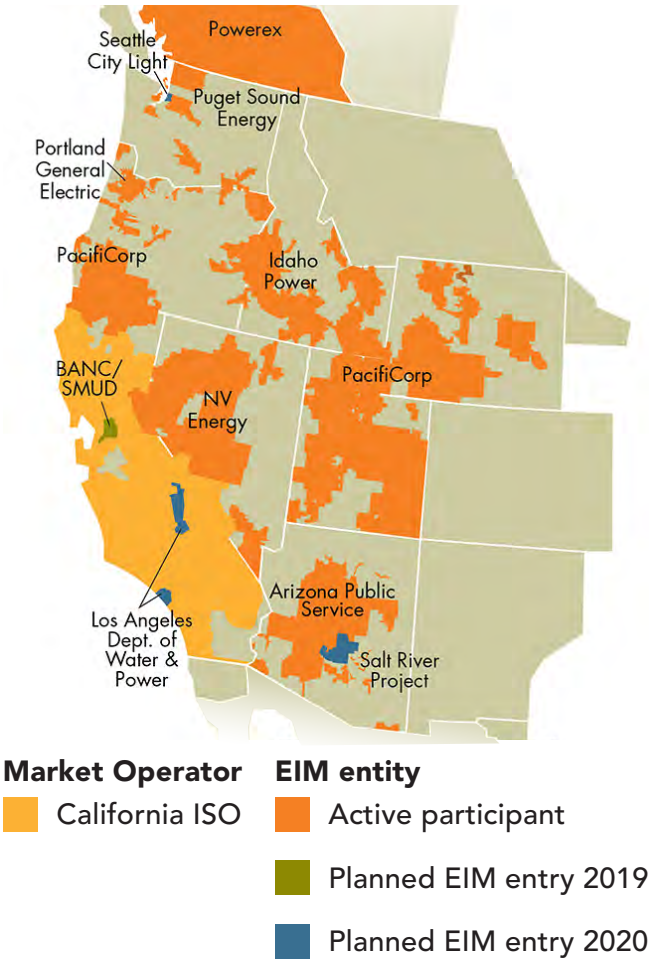
By interconnecting everything, the grid taps into the awesome power of aggregation to smooth out operations, thus reducing costs and improving reliability.

When you flip your light switch you cause a small increase in demand across a much larger pool. Generators don't respond to your light switch but to the demand of all customers, aggregated as a whole. A single household with central air conditioning may have demand that jumps from nothing to five kilowatts and back in a matter of minutes. But if the electrical use of thousands of homes and businesses are combined, aggregated demand moves up and down more gradually. If large regions are aggregated, the supply-demand balance becomes a predictable curve, moving with the patterns of work, recreation, sleep, and the weather.

The predictability of a large power system makes it much easier for operators to respond to changes, and to make sure supply and demand are matched in the most cost effective and efficient way.

Grid operators are like air traffic controllers – they don't own the power plants or the transmission lines, nor do they set prices. They do run a market that facilitates bidding by power plant owners, they track and share power prices and grid conditions, and issue orders to turn plants up or down as needed. The California Independent System Operator (CAISO) is the grid and market operator for much of the state, covering 80 percent of demand.

FIG 1 The Western Energy Imbalance Market



Source: The Western Energy Imbalance, California Independent System Operator.[6]

CAISO, also known as a regional transmission operator (RTO), facilitates wholesale competition, coordinates on planning and building transmission, and reduces the costs and inefficiencies that come from having many small operating areas. CAISO operates the daily market for electricity where power is bought and sold between generators, utilities, and competitive electricity marketers. Prices are set based on the bids of wholesale generators, which vary by time and location.

6 The Western Energy Imbalance, CAISO. See https://www.westerneim.com/Pages/About/default.aspx.

Publicly-owned utilities, including cities with utilities like Los Angeles, Sacramento, and Palo Alto, plus irrigation districts and electric cooperatives, tend to operate their own systems. As a result, there are eight balancing areas in the state, including CAISO.

CAISO is the largest of 38 balancing areas in the west, serving 35 percent of demand in the region. Despite over 20 years of debate, states and utilities in the Western Interconnection, which covers 11 states and parts of Canada and Mexico, have not adopted the RTO structures that dominate in the East.[7]

In lieu of a Western RTO, CAISO has led in the creation of what some call an "RTO-lite" – the Energy Imbalance Market (EIM). Balancing supply and demand is one of the most important functions of an RTO. By balancing at a larger scale, fewer power plants are needed to be on standby, the market chooses the least cost option, variability is lessened, and renewable energy that might have been curtailed can be used instead, reducing costs for all parties.

The EIM was launched in 2014 and has grown to include eight balancing authorities so far, with four more scheduled to join by 2020. CAISO estimates that the EIM has delivered $330 million in savings since it was launched.[8]

But an EIM only provides short term balancing services, and CAISO believes that greater integration of operations across the region will deliver bigger benefits, especially as California and other states across the West add greater amounts of wind and solar power.

California state legislators are currently considering Assembly Bill (AB) 813, a bill that would set conditions for membership in a regional transmission organization.[9]

The issue of regionalization is discussed further in *A Regional Power Market for the West: Risks and Benefits,* a companion report from Next10.

Market Structure

Until the 1990s, U.S. electricity markets were simple: investor-owned utilities were given a monopoly to serve captive customers in a given territory, in exchange for being closely regulated by state utility commissions. Government-owned utilities were overseen by elected officials, while cooperatives were managed by members. Each utility was vertically integrated, owning power plants, transmission and distribution lines, and other infrastructure. Customers could not choose another supplier, but could generate their own power, within limits.

A wave of deregulation in airlines, trucking, and telecommunications in the 1980s and 1990s led some policymakers to believe that electricity could also become a competitive industry. California was one of the first states to step in that direction, when the California Public Utilities Commission (CPUC) issued a concept paper in 1993 known as the "yellow book" and a decision in 1995 known as the "blue book."[10]

Legislation in 1996 (AB 1890) codified the move, opening up the markets of the three investor-owned utilities—Pacific Gas & Electric (PG&E), Southern California Edison, and San Diego Gas & Electric—to competition, creating an independent system operator (CAISO) to run the grid and a competitive wholesale power pool known as the Power Exchange. The market opened in 1998 and worked well—initially.

In the summer of 2000, however, things fell apart, due to a variety of factors.

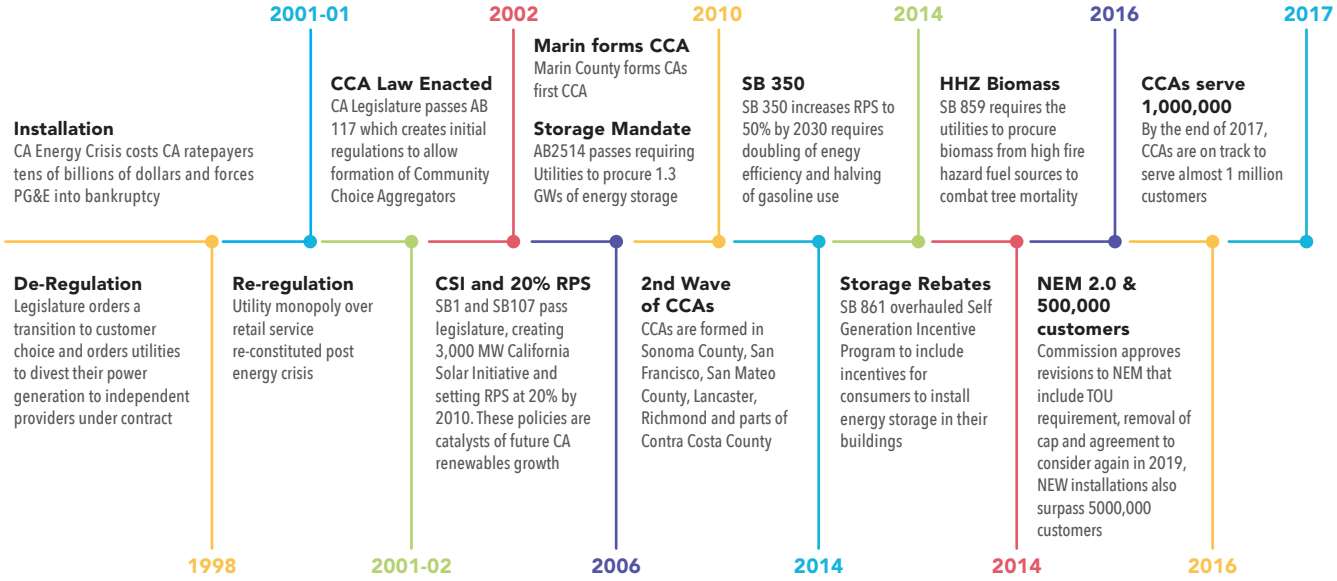
7 For more about CAISO see http://caiso.com. For more about the Western Interconnection see the Western Electricity Coordinating Council (WECC) at https://www.wecc.biz.

8 Western Energy Imbalance Market, accessed April 2018, https://www.westerneim.com/Pages/About/QuarterlyBenefits.aspx.

9 Assembly Bill No. 813, Introduced by Assembly Member Holden, Coauthor: Senator Wieckowski, February 15, 2017, https://leginfo.legislature.ca.gov/faces/billTextClient.xhtml?bill_id=201720180AB813

10 California Public Utilities Commission, California Customer Choice: An Evaluation of Regulatory Framework Options for an Evolving Electricity Market (Draft Green Book), May 2018, http://www.cpuc.ca.gov/uploadedFiles/CPUC_Public_Website/Content/Utilities_and_Industries/Energy_-_Electricity_and_Natural_Gas/CCC%20Paper.pdf

FIG 2 Timeline of California Electricity Market Issues



Source: California Public Utilities Commission (CPUC).[11]

A hot summer followed by a cold winter drove up energy demand, while a drought reduced hydropower generation. Flaws in the market design, including limits on the ability of utilities to sign long-term contracts and caps on retail rates that allowed consumers to ignore price signals, contributed to the crisis.[13] And, as was discovered later, competitive companies like Enron were able to manipulate the market by creating artificial congestion on power lines, withholding power and natural gas from the market, and "laundering" power by sending it out of state and buying it back at higher prices.[14]

In all, the crisis is estimated to have cost California consumers well over $40 billion in higher electricity costs.[15] It resulted in the bankruptcy of PG&E, led to multiple fines and convictions of energy traders, and spurred a successful recall election against Governor Gray Davis in the fall of 2003. It brought the move toward competitive retail markets to an end in California, as well as in many states around the country. Altogether, about half of states moved toward competitive markets, though only 13 have active retail choice now.[16]

While the energy crisis put retail competition on hold, the wholesale power market in California became highly competitive. It remains so today, with independent companies bidding to supply power in five-minute and fifteen-minute increments, and selling power through long-term contracts to utilities, community choice aggregators, and some large customers. The three investor-owned utilities own only a few power plants.

11 Consumer and Retail Choice, the Role of the Utility, and an Evolving Regulatory Framework, CPUC. See http://www.cpuc.ca.gov/uploadedFiles/CPUC_Public_Website/Content/News_Room/News_and_Updates/Retail%20Choice%20White%20Paper%205%208%2017.pdf

12 Update on Customer Choice in California and Portfolio Allocation Proposal, CPUC. See http://docs.cpuc.ca.gov/PublishedDocs/Efile/G000/M183/K388/183388329.PDF. Data from CEC at http://www.energy.ca.gov/2016_energypolicy/.

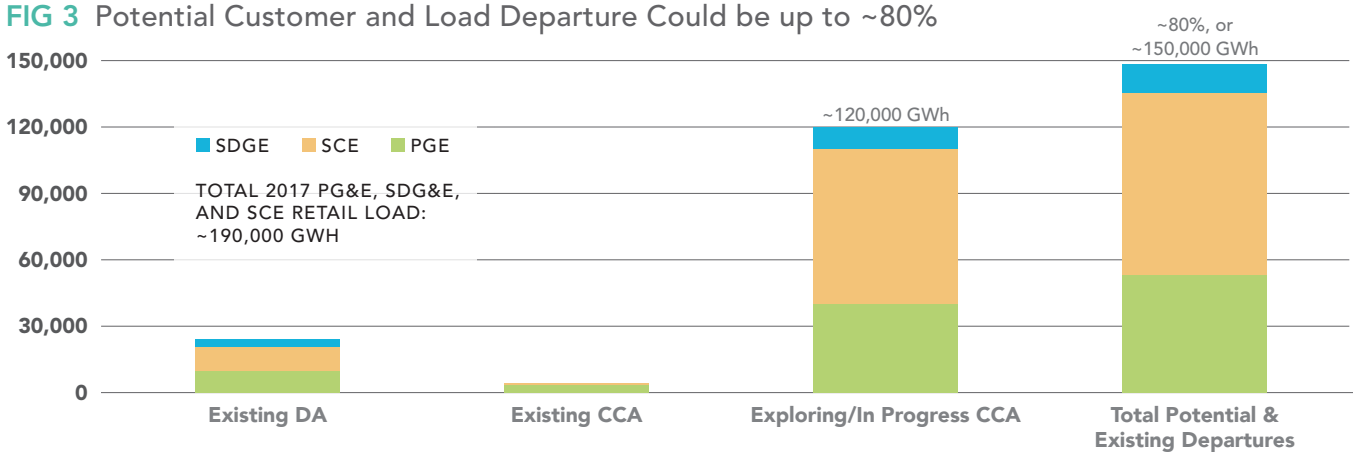
13 James L. Sweeney, *The California Electricity Crisis*, Hoover Institution Press, 2002.

14 Bethany McLean and Peter Elkind, *The Smartest Guys in the Room: The Amazing Rise and Scandalous Fall of Enron*, Penguin Group, revised edition 2004.

15 Christopher Weare, *The California Electricity Crisis: Causes and Policy Options*, Public Policy Institute Of California, 2003, http://www.ppic.org/content/pubs/report/R_103CWR.pdf

16 *21st Century Power Partnership, An Introduction To Retail Electricity Choice In The United States*, August 2017, https://www.nrel.gov/docs/fy18osti/68993.pdf

FIG 3 Potential Customer and Load Departure Could be up to ~80%



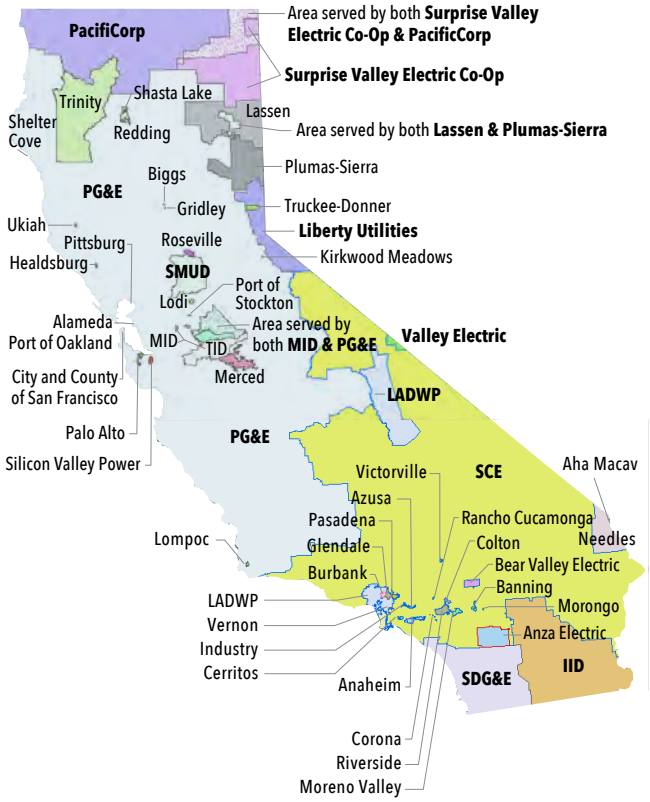
Source: California Energy Commission; California Public Utilities Commission[17]

The California power market is now served by three large and three small investor-owned utilities (IOUs), 46 publicly-owned utilities, four cooperatives, and 21 competitive power suppliers (called Electric Service Providers, or ESPs). As of 2016, IOUs served 66 percent of state demand, municipal and other public utilities served 21 percent, and ESPs served 8 percent.[18]

Competition is now taking shape in different forms. Community choice aggregation (CCA) was authorized in 2002, but is only now growing to be a significant force. CCA allows local governments to purchase power on behalf of their residents and businesses, with customers able to opt out and stay with their utility provider.

Marin Clean Energy was the pioneer in CCA, starting in 2010, but there are now 12 CCAs in operation, and larger cities have begun to follow suit. San Francisco and East Bay are phasing in service to customers, while San Jose and four others are launching in 2018. San Diego and Los Angeles County (outside of the city), among others, are discussing CCA. Aggregators accounted for only 1.8 percent of sales in 2016, but the Center for Climate Protection estimates that currently operational or under-development CCAs could serve 17.7 million of the 29 million people currently served by IOUs.[20]

FIG 4 California Electric Utility Service Areas



Source: California Energy Commission.[19]

17 Update on Customer Choice in California and Portfolio Allocation Proposal, CPUC. See http://docs.cpuc.ca.gov/PublishedDocs/Efile/G000/M183/K388/183388329.PDF. Data from CEC at http://www.energy.ca.gov/2016_energypolicy/.

18 US Energy Information Administration, Electric power sales, revenue, and energy efficiency, Form EIA-861 detailed data files, 2016 data, https://www.eia.gov/electricity/data/eia861.

19 California Energy Maps, CEC. See http://www.energy.ca.gov/maps/serviceareas/electric_service_areas.html.

20 Clean Power Exchange, from the Center for Climate Protection, accessed April 2018, https://cleanpowerexchange.org/california-community-choice/.

Competition is also emerging from customers themselves, who are adopting distributed energy technologies like solar, batteries, and energy controls. There are currently over 800,000 customers with rooftop solar systems, with 100,000 being added annually in recent years.[21] In May 2018, the California Energy Commission added rooftop solar as a building code requirement, which could lead to an additional 75,000 installations per year, depending on home-building trends.[22]

Between CCA, competitive electricity service providers, and distributed energy resources, investor-owned utilities could lose about 80 percent of their sales by the mid-2020s and become primarily grid management companies (see Figure 3).[23]

These consumer-driven changes are causing a reassessment of policies at the CPUC. "California may well be on the path towards a competitive market for consumer electric services," according to a CPUC staff white paper.[24] But the state is "moving in that direction without a coherent plan to deal with all the associated challenges that competition poses, ranging from renewable procurement rules to reliability requirements and consumer protection."

Generation

Like a set of golf clubs, electric generators have different operating capabilities and purposes with implications for cost and environmental performance. Nuclear, coal, and geothermal plants often run full-out, partly to take advantage of lower costs and economies of scale, and partly due to technical constraints that limit adjusting their output. More flexible natural gas and hydroelectric plants are often used to follow the ups and downs of demand.

Wind and solar power have capabilities and characteristics that do not fit easily into a system designed around fossil fuels. Because they are driven by the weather and the passage of the sun, they are somewhat less controllable by grid managers. In this sense, they are like electricity demand, which is also significantly affected by weather and time of day. Wind and solar are gaining more capabilities, using power electronics to provide voltage and frequency support to the grid. Grid operators are beginning to control them like any other plant, ramping them down and up—to their available capacity at that moment—to follow load.

In the CAISO market, the decision of which plants are used when is determined by competitive bidding. (At some municipal utilities and coops, operations are set mainly by direct contracts between generators and customers.) As mentioned above, plant owners or their brokers bid a day in advance or in real time, with bids accepted or rejected according to price. Power plant schedules are created every 15 minutes and orders are given to generate (plants are "dispatched") every five minutes.

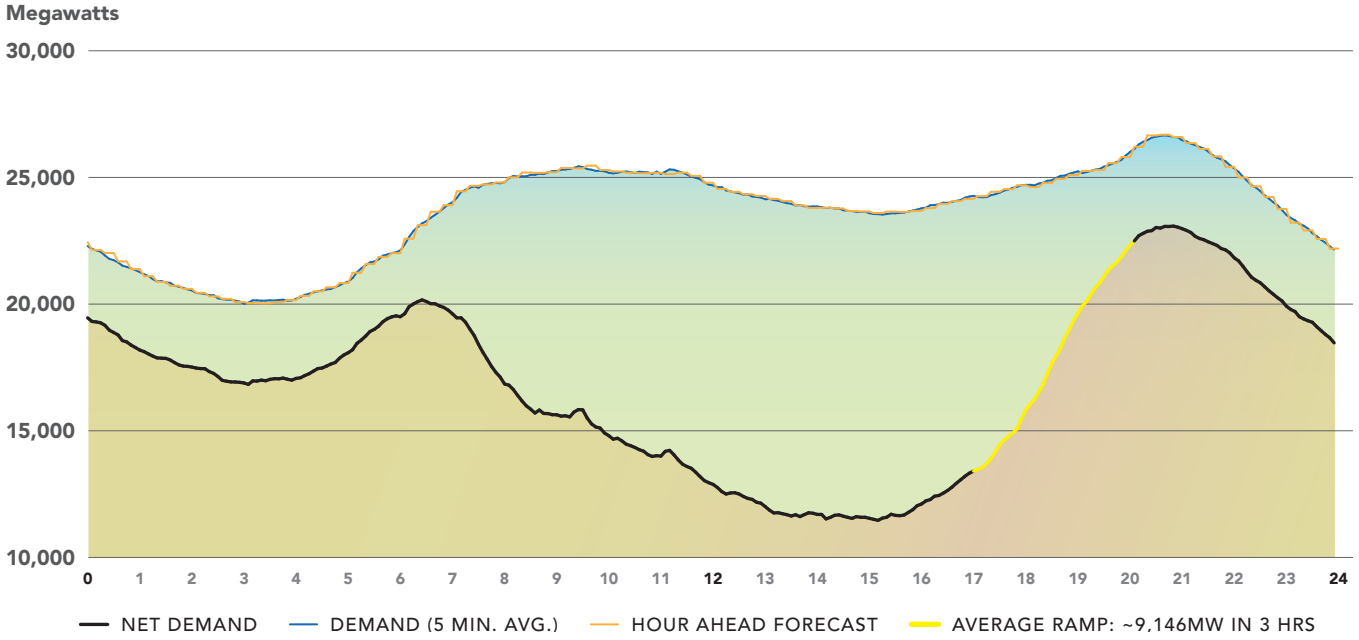
21 California DG Statistics, accessed April 2018, https://www.californiadgstats.ca.gov/charts/.

22 Christian Roselund, PV Magazine, "California's solar mandate: Questions and answers," May 10, 2018, https://pv-magazine-usa.com/2018/05/10/californias-solar-mandate-questions-and-answers/

23 CPUC's Staff White Paper: Consumer and Retail Choice, the Role of the Utility, and an Evolving Regulatory Framework, May 2017, http://www.cpuc.ca.gov/uploadedFiles/CPUC_Public_Website/Content/News_Room/News_and_Updates/Retail Choice White Paper 5 8 17.pdf

24 California Public Utilities Commission, California Customer Choice: An Evaluation of Regulatory Framework Options for an Evolving Electricity Market (Draft Green Book), May 2018, http://www.cpuc.ca.gov/uploadedFiles/CPUC_Public_Website/Content/Utilities_and_Industries/Energy_-_Electricity_and_Natural_Gas/CCC%20Paper.pdf

FIG 5 California Net Demand for One Day in May



Source: California Independent System Operator.[25]

The CAISO market dispatches resources based on their marginal cost, which is almost entirely a function of fuel cost. Because wind, solar and hydro have no fuel cost (and geothermal very low "fuel" cost), they are dispatched first, before nuclear or fossil fuel generators.

CAISO's market calculates the local price of power at more than 4,000 locations ("nodes") around the state. CAISO software combines the bid prices at given locations with the conditions on the transmission system to calculate the least-cost way to meet power needs in every area of the state—every five minutes. Dispatch instructions are then sent to every successful bidder. Winning bidders all receive the highest price that clears the market in each fifteen-minute period.

IMPACT OF WIND AND SOLAR

As wind and solar become dominant suppliers in California, they pose some fundamental challenges to this paradigm of economic dispatch and locational pricing. Since their fuels are free, wind and solar have essentially zero marginal costs. If they are bidding their marginal cost and meet all demand for a period, prices will be near zero. Meanwhile, dispatchable generators like gas turbines will be operating in fewer hours, making them increasingly unable to be profitable if they are paid mostly for selling megawatt-hours.

The need to cut emissions across the economy, combined with increasingly common distributed energy resources, will create a new paradigm. Instead of forecasting demand and meeting it with controllable supply (fossil fueled generators), we are moving to an era of forecasted supply (such as wind and solar) and controllable demand.

Market operations are discussed in more detail in the companion Next10 report on regionalization *A Regional Power Market for the West: Risks and Benefits.*

25 Net Demand for May 25, 2018, CAISO. See http://www.caiso.com/TodaysOutlook/Pages/default.aspx

FIG 6 Options for Integrating Renewables

STORAGE: increase the effective participation by energy storage resources

DEMAND RESPONSE: response enable adjustments in consumer demand, both up and down, when warranted by grid conditions.

TIME-OF-USE RATES: implement time-of-use rates that match consumption with efficient use of clean energy supplies.

RENEWABLE PORTFOLIO DIVERSITY: explore procurement strategies to achieve a more diverse renewable portfolio.

WESTERN EIM EXPANSION: expand the western Energy Imbalance Market.

REGIONAL COORDINATION: offers more diversified set of clean energy resources through a cost effective and reliable regional market.

ELECTRIC VEHICLES: incorporate electric vehicle charging systems that are responsive to changing grid conditions.

FLEXIBLE RESOURCES: invest in fast-responding resources that can follow sudden increases and decreases in demand.

Source: California Independent System Operator.[26]

Wind and solar power are already affecting daily grid operations. In the past, demand was a given, and grid operators controlled generators to meet gross demand. But now grid operators strive to meet net demand, treating wind and solar production as a subtraction from gross demand.[27] The resulting net demand is what must be met by other dispatchable generators—or by controlled changes to demand itself.

Solar, especially, is leading to operational challenges. Because solar power output is concentrated in the daytime, it is driving down net demand to levels that are forcing other types of power plants that may be needed to help support the grid to turn off, that may be needed to help support the grid, or that operate under rigid contracts that allow them to run regardless.

When the sun sets and evening demand rises as people return home, the net demand rises substantially to the day's peak demand, which is typically around 7pm. This "ramp" is not new, but it is getting much larger and happening more quickly than in the past, due to large amounts of mid-day solar power.

This shape of net demand has been dubbed "the duck curve" since it looks like a swimming duck in profile. Mark Rothleder, VP for Renewable Integration and Market Quality for CAISO, recently told a legislative committee that the impacts of the duck curve have manifested four years sooner than CAISO projected, due to the rapid growth of solar.[28] He laid out a suite of solutions that can help integrate renewables into the power system, as shown in Figure 5.

26 Regional Energy Markets & California's Green Goals, CAISO. See https://www.caiso.com/Documents/RegionalEnergyMarkets_CaliforniasGreenGoals.pdf.

27 Real time data on CAISO operations can be seen at http://www.caiso.com/TodaysOutlook/Pages/default.aspx

28 Mark Rothleder, VP for Renewable Integration and Market Quality, CAISO, "Regional Energy Markets & California's Green Goals," presentation to the Assembly Utilities & Energy Committee, March 14, 2018, https://www.caiso.com/Documents/RegionalEnergyMarkets_CaliforniasGreenGoals.pdf

California has over 1,500 power plants, ranging from the huge 2,240 megawatt Diablo Canyon nuclear plant down to small heat-and-power cogenerators in factories. It also has 800,000 individual rooftop solar systems, the number of which is continuing to grow rapidly.[29]

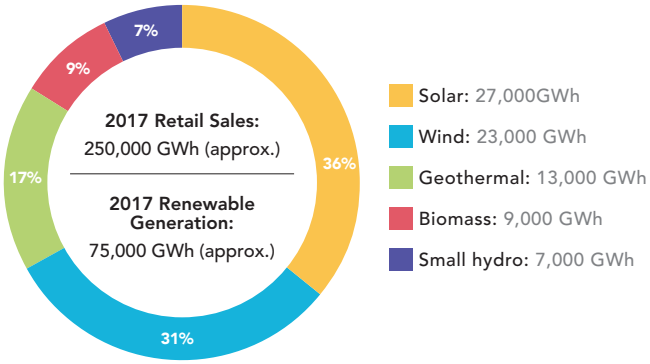
These plants make up 79,644 megawatts of in-state generating capacity (counting only systems over one megawatt in size) as of 2016.[30] Small-scale and rooftop solar adds another 6,500 megawatts.

RECENT TRENDS

A key feature of the California power system is the symbiotic relationship between natural gas and hydropower. Generation from hydroelectric dams varies widely based on rain and snowfall in the winter. California's in-state hydro generation doubled from 13,992 GWh in 2015 to 28,977 GWh in 2016, as a five-year drought ended in a year of heavy precipitation. Natural gas power is used to complement hydropower, with more gas used in dry years and less in wet years.

Wind and solar, growing rapidly in recent years, are beginning to change that relationship. In-state solar generation increased 31.5 percent from 2015 to 2016, while wind rose 10.8 percent. Renewables (not counting large hydropower) accounted for 30 percent of supply in 2017.[32] Other renewable sources, like geothermal, biomass, and small hydropower, have seen little growth, as utilities opt for lower cost wind and solar. The state renewable portfolio standard (RPS) requires power companies to obtain at least 50 percent of their electricity from renewable sources by 2030.

FIG 7 Renewable Electricity Sources, 2017



Source: California Energy Commission.[31]

California trades a large amount of electricity with neighbors in the West, both importing and exporting power. In 2016, California was a net importer of about one-third of its power from generators in the Southwest and Northwest, as shown in Figure 8. A significant portion of imports are from "unspecified sources," made when there is surplus generation on the spot market that is less expensive than from California plants. While these sources are not tracked, the California Energy Commission (CEC) says that much of the Pacific Northwest unspecified power comes from surplus hydro and newer gas-fired power plants. The Southwest spot market purchases are typically comprised of new combined cycle natural gas and some coal.

All power grids require some power plants held in reserve to ensure adequate supply at all times, in case of transmission line outages, generator failures and other unexpected events. California requires a "reserve margin" of 15-17 percent more than peak demand. Over-procurement has driven California's reserve margin above 19 percent in recent years. Margins in other parts of the West have been even higher.[33] Having too much capacity available raises costs without adding reliability.

29 California DG Statistics, https://www.californiadgstats.ca.gov/

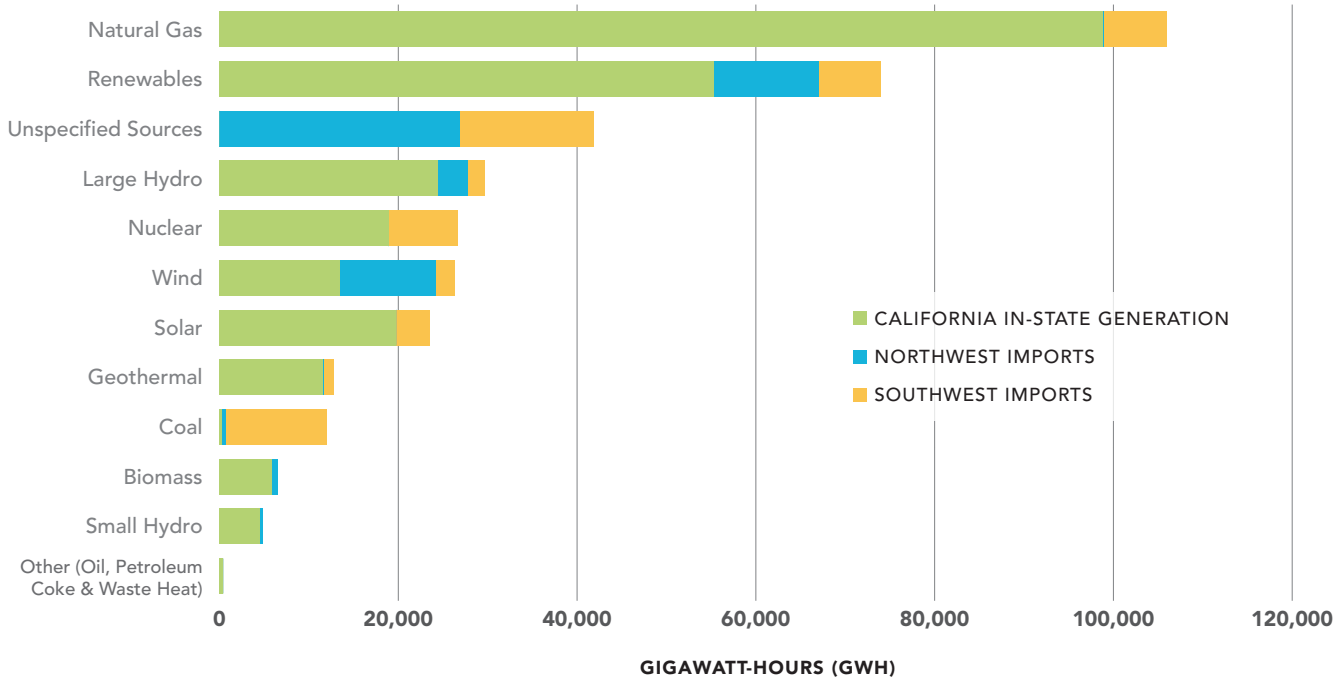
30 California Energy Commission, Electric Generation Capacity & Energy, accessed May 2018, http://www.energy.ca.gov/almanac/electricity_data/electric_generation_capacity.html

31 Renewable Energy Tracking Progress Report, CEC. See http://www.energy.ca.gov/renewables/tracking_progress/documents/renewable.pdf.

32 California Energy Commission, Tracking Progress: Renewable Energy, December 2017, http://energy.ca.gov/renewables/tracking_progress/documents/renewable.pdf

33 North American Electric Reliability Corporation (NERC), 2017 Long-Term Reliability Assessment, https://www.nerc.com/pa/RAPA/ra/Reliability%20Assessments%20DL/NERC_LTRA_12132017_Final.pdf

FIG 8 Generation Sources from California, Northwest and Southwest, 2016



Source: California Energy Commission.[34]

While some regions pay power plants to be available in future years through a "capacity market," California does not. It instead requires electricity sellers to maintain adequate future supply through "resource adequacy" or RA requirements. The RA requirements cover system-level, local, and operational flexibility needs. RA requirements now look only one year ahead. Because this does not provide adequate certainty about resource availability for either generators or the grid operator, the RA program is being reconsidered by the CPUC.

From a seller's perspective, too much capacity is bad for business. In an ideal competitive market, plant owners that can't compete will shut down their plants and exit the market. In California's complicated hybrid market, with both regulated and competitive power plants, whether a plant can shut down is often a regulatory decision.

Thirteen large gas-fired plants along the California coast are in the process of being retired as a result of the State Water Resources Control Board's decision in 2010 to phase out the use of ocean water for power plant cooling (called "once through cooling") due to the impact of waste heat on coastal marine habitats. Altogether 27 power plants are either retiring or switching to air-cooled systems before 2029.[35]

Nuclear plants are also phasing out. Mechanical problems with the San Onofre nuclear plant led to the permanent retirement of that 2,246 MW plant in 2013. PG&E has announced plans to close Diablo Canyon in 2025, to avoid the cost of upgrades and license renewal, in response to losing load to CCAs, and other reasons.[36] PG&E found it was less expensive to retire the plant and replace the power with renewables than to upgrade and relicense it, especially when earthquake-fault uncertainty was factored in. Retirement

34 Total System Electric Generation, CEC. See http://www.energy.ca.gov/almanac/electricity_data/total_system_power.html

35 California Energy Commission, Tracking Progress: Once-Through Cooling Phase-Out, updated March 8, 2017, http://www.energy.ca.gov/renewables/tracking_progress/documents/once_through_cooling.pdf

36 M.J. Bradley & Associates, Joint Proposal for the Orderly Replacement of Diablo Canyon Power Plant with Energy Efficiency and Renewables, June 21, 2016, https://www.pge.com/includes/docs/pdfs/safety/dcpp/MJBA_Report.pdf

is estimated to save PG&E customers more than one billion dollars compared to the cost of operating the plant for an additional 30 years.

Other plants are closing for market reasons. In 2016 two large natural gas plants declared bankruptcy—the 578 MW Sutter Energy Center and the 1,200 MW La Paloma plant—because they could not make sufficient revenues in the very competitive CAISO wholesale markets.[37]

Forecasters expect reserve margins to be above 20 percent through 2024 at least, when Diablo Canyon closes.

The Wires: Transmission and Distribution

All of the generators in California are connected to everything that uses electricity through a vast network of high voltage transmission lines and low voltage distribution lines, called T&D for short. The transmission lines are much like interstate highways, carrying large volumes, while distribution lines are like city streets, coming right up to homes and businesses.

California has 25,000 miles of transmission lines and more than 100,000 miles of distribution lines. Transformers step down the voltage from one to the other, so a home outlet has a relatively safe 110 volts, rather than the extremely dangerous 200,000 volts and up in the transmission grid.

There is very little energy storage in the system, so electricity is produced at the time it is consumed. The wires provide vital flexibility, mixing and moving the power around.

Just like highways, a significant problem in the T&D network is congestion. Because prices are set by location as well as by time, congestion can prevent cheaper power from getting into high-cost areas, driving up costs for consumers.

New transmission is expensive, more than $1 million per mile in some cases, but transmission currently accounts for only about 10 percent of customers' electricity bills. New transmission lines can also save money by reducing congestion, allowing access to cheaper power. New transmission is sometimes needed to connect resource areas to customers, such as the high-wind areas near Tehachapi Pass in Kern County. Thanks to transmission upgrades, Tehachapi is now home to the largest wind farm in the United States.

37 Utility Dive, "As gas plants struggle, California seeks new flexible capacity strategies," June 27, 2017, https://www.utilitydive.com/news/as-gas-plants-struggle-california-seeks-new-flexible-capacity-strategies/445760/

Reliability is another key issue with T&D lines. Wires strung on steel transmission towers or wooden pole distribution lines are vulnerable to many threats, including high winds, ice, and wildfires. Wires can also cause wildfires, as high winds blow tree branches into wires, causing sparks that ignite dry grass. Birds and squirrels, even aluminum-coated party balloons, can take out wires

Putting wires underground is the surest way to improve safety, and is one reason European power grids have such high reliability compared to the U.S. But underground transmission is also expensive, especially in cities with many existing impediments, like roads and sidewalks. PG&E estimates that undergrounding all of their 134,000 miles of wires would cost $100 billion.[38]

Building new transmission lines can be very difficult due to siting conflicts, aesthetic complaints, and fears of health impacts. While this is true everywhere, California has had its share of conflict over new lines, such as the Sunrise Powerlink near Anza Borrego State Park. The line was first proposed by San Diego Gas & Electric in 2005, and took five years to be approved, due to strong community opposition. Finally built in 2012, the $1.9 billion project has helped SDG&E increase their renewables portfolio to 43 percent as of 2016, the highest of the three investor-owned utilities.[39] It also helped make up for the loss of generation when the San Onofre nuclear plant closed in 2012.

The need for wires can also be challenged by the growth of distributed energy resources (DERs). Rooftop solar, battery storage, controllable demand, targeted energy efficiency, and electric vehicles (when plugged in) can serve as "non-wire alternatives" to reducing congestion or providing grid services. DERs are discussed more below, and in the forthcoming companion paper from Next 10.

The Customers: What Goes On Behind the Meter

Until recently, the grid ended at the meter, where the power was delivered. Customers were largely passive consumers of electricity, expected to simply pay their bills on time each month. Before the energy crises of the 1970s, there was little attention paid to energy efficiency, and an assumption that energy demand would continue to rise indefinitely.

Now, customer-focused technologies and policies dominate debates about the future of electricity.

Distributed Energy

The advent of modular generation, microchips, wireless communications, and the Internet are upending the traditional relationship between producers and consumers, enabling "prosumers" to be an active part of the power system. Distributed energy resources (DERs) are often compared to smart phones in their potential to disrupt traditional business models and operations, just as distributed computing displaced centralized mainframe computers and tailored streaming media is replacing broadcast media. While their effect so far is modest, it is growing rapidly and spells out a completely different vision of the energy future.

Homes and businesses with solar panels are the most visible manifestation of distributed energy. But customers can now choose from a variety of sophisticated monitoring and control products to change demand in response to price signals. These software-driven systems can be automated, like "learning thermostats" from Nest (based in Palo Alto) or controlled by third parties, in "energy as a service" arrangements. While much of the focus has been on commercial and industrial customers, the residential market is increasingly active.

38 David R. Baker, "Underground power lines don't cause wildfires. But they're really expensive," San Francisco Chronicle, October 22, 2017, https://www.sfchronicle.com/bayarea/article/Underground-power-lines-don-t-cause-wildfires-12295031.php

39 CPUC, California's Renewables Portfolio Standard Annual Report, November 2017, http://www.cpuc.ca.gov/uploadedFiles/CPUC_Website/Content/Utilities_and_Industries/Energy/Reports_and_White_Papers/Nov%202017%20-%20RPS%20Annual%20Report.pdf

Energy Storage

Energy can be captured and stored in large-scale batteries, a technology that has become increasingly anticipated for its ability to help smooth out energy supply and demand. As batteries become cost effective, they are beginning to offer grid services that can benefit both the customer and the utility. Batteries can shift demand and supply between peak and off-peak periods, cut demand charges for commercial customers, and offer technical services like voltage support and frequency regulation. Conceivably they could enable households to become energy independent, allowing customers to cut connections with the grid altogether and operate on solar power and batteries.

A 2013 law, AB 2514, requires utilities to procure 1,325 MW of storage, including 200 MW owned by customers. A second law in 2016, AB 2868, adds 500 MW of behind-the-meter energy storage to the mandate. An additional bill is pending in 2018, SB 1347, which would mandate 2000 MW of procurement.[40] California's long-running Self Generation Incentive Program (SGIP) has evolved to be primarily an incentive program for distributed batteries. SGIP is scheduled to pay out $448 million in incentives for distributed storage systems between 2017 and 2019.[41]

These policies have made California the national leader in behind-the-meter storage. As of the end of 2017, 123 MW of residential and non-residential storage has been deployed, including 51 MW in 2017, more than all other states combined.[42]

Electric Vehicles

Electric vehicles can also offer grid services when they are parked, which according to research by the CPUC, is 96 percent of the time.[43] From a grid perspective EVs look like both large appliances and storage devices. As appliances, their charging can be controlled to reduce or increase demand when needed. As storage devices, they can be charged and discharged as needed, such as absorbing plentiful solar power at mid-day and discharging it back to the grid during evening peak periods. EV chargers would need additional controls to allow for two-way electricity flows.

California currently has about 400,000 battery-powered vehicles on the road, and is adding an additional 10,000 every month. Governor Brown has set a goal of putting five million zero emission vehicles on California roads by 2030, up from the previous goal of 1.5 million by 2025.

The state's Advanced Clean Cars law, known as ZEV-LEV, requires car makers to get at least 16 percent of their sales from zero-emission vehicles by 2025. A budget of $100 million per year to support ZEV projects (under AB118) has been supplemented by $800 million over ten years from Volkswagen's "dieselgate" settlement fund, created when California regulators caught the car company cheating on emissions tests for their diesel vehicles.[44] On May 31, utility regulators approved another $768 million for investments in charging infrastructure and rebates for heavy-duty electric vehicles.[45]

40 Sen. Stern, SB-1347 Energy storage systems: procurement, https://leginfo.legislature.ca.gov/faces/billAnalysisClient.xhtml?bill_id=201720180SB1347#

41 Utility Dive, "California SGIP re-opens Monday with greater funding for energy storage," April 28, 2017, https://www.utilitydive.com/news/california-sgip-re-opens-monday-with-greater-funding-for-energy-storage/441479/

42 GTM Research, U.S. Energy Storage Monitor: 2017 Year In Review, March 2018, https://www.greentechmedia.com/research/subscription/u-s-energy-storage-monitor#gs.YdF9QjY.

43 Adam Langton and Noel Crisostomo, Energy Division, California Public Utilities Commission, Vehicle - Grid Integration: A Vision for Zero-Emission Transportation Interconnected throughout California's Electricity System, March 2014, http://docs.cpuc.ca.gov/PublishedDocs/Published/G000/M080/K775/80775679.pdf

44 Air Resources Board, Volkswagen Settlement - California ZEV Investments, https://www.arb.ca.gov/msprog/vw_info/vsi/vw-zevinvest/vw-zevinvest.htm

45 Emma Foehringer Merchant, "California Regulators Approve Landmark Utility EV-Charging Proposals," Greentech Media, May 31, 2018, https://www.greentechmedia.com/articles/read/california-cpuc-approves-landmark-ev-charging-proposals#gs.nf7zojQ

Recent research by Lawrence Berkeley National Laboratory and others looked at the potential for 1.5 million electric vehicles to provide grid services, both as appliances and storage devices. As two-way storage devices, they could provide grid services equal to about 5,000 MW of stationary storage, saving between $12.8 to $15.4 billion of investment compared to stationary batteries. "In other words, the California Storage Mandate can be accomplished through the ZEV Mandate, provided that controlled charging is also widely deployed," the study concluded.[46]

The effect of EVs on the grid is explored further in the forthcoming companion report from Next10.

Microgrids

Some customers are bundling these distributed technologies together into "microgrids." While definitions are not precise, a microgrid is typically a system of generation, storage, and controls that either interacts with the broader power grid or is capable of operating while disconnected from the grid in "island" mode.

The UC San Diego campus is one of the largest microgrids in the country, producing 85 percent of campus electricity needs from natural gas, fuel cells, solar panels, and a host of distributed energy technologies. It interacts with the San Diego regional grid, providing extra capacity as needed, but it is not capable of operating while disconnected from the grid.[47]

Microgrids that can operate independently of the grid are becoming more common. The microgrid at Stone Edge Farm in Sonoma was able to operate through a week of outages caused by the Santa Rosa fires in October 2017. The project was awarded the Governor's Environmental and Economic Leadership Award (GEELA) in January 2018.[48] Microgrids are also being installed to provide emergency power for critical facilities. Three fire stations in Fremont are now able to operate off-grid, thanks in part to grants from the state Energy Commission.[49] Even Governor Jerry Brown has a solar and storage microgrid serving his new home, a ranch north of Sacramento.[50]

New distributed technologies are pushing regulators to adapt policies to accommodate what is essentially a new form of competition. One of the most contentious issues is known as "net metering" for customer-owned generation. Old analog meters with spinning dials couldn't tell when or how power was consumed; they only counted total kilowatt-hours flowing through the meter. For customers with solar panels, the power could flow back through the meter onto the grid at times, making the meter literally spin backward. At the end of the month the utility read the meter to find the net consumption. As a result, customer-generated power was simply subtracted from the bill, giving it full retail value.

Now digital meters can keep track of when and how much solar power is generated. Utilities have argued that if solar customers don't pay for the upkeep of the grid, the costs will be borne by customers who either don't or can't afford to go solar. This will raise these customers' costs, thus encouraging them to go solar too—creating a financial death spiral that would undermine grid reliability, according to utilities. Proponents counter that distributed solar creates benefits to the grid and to society that outweigh the costs.

A few states have suspended net metering or have moved to accounting systems that separate the cost components of utility service and attribute a specific (usually lower) value to customer-owned solar generation. California regulators adopted "net metering 2.0"

46 Jonathan Coignard, et al., Clean vehicles as an enabler for a clean electricity grid, Environmental Research Letters, May 16, 2018, http://iopscience.iop.org/article/10.1088/1748-9326/aabe97/pdf

47 UC San Diego News Center, "UC San Diego's Path to Carbon Neutrality," October 13, 2016, http://ucsdnews.ucsd.edu/feature/uc_san_diegos_path_to_carbon_neutrality

48 California EPA, 2017 Governor's Environmental and Economic Leadership Award Winners Honored, January 17, 2018, https://calepa.ca.gov/2018/01/17/2017-governors-environmental-and-economic-leadership-award-winners-honored/

49 ICLEI, Case Study: Microgrid Demonstration Project at City of Fremont Fire Stations, December 2017, https://s3-us-west-2.amazonaws.com/memberresource/ICLEI+Member+Case+Study+Fremont+CA+Microgrid.pdf

50 Microgrid Knowledge, "Microgrid Dreaming: California Gov. Brown Makes it Real at his Ranch," April 18, 2018, https://microgridknowledge.com/microgrids-california-gov-brown/

in 2016, which shifted some costs to solar customers, but largely maintained the previous system.[51]

Other issues have yet to be resolved. Customer-owned energy storage battery systems are not allowed to use net metering, such as charging during off-peak periods and discharging to the grid during high-priced peak periods. They are also unable to sell voltage and frequency support services to the grid, like generators can. Until such policies are established, customers can only play a limited role in grid operations.

Distributed energy resources are discussed in greater detail in the forthcoming Next10 report.

Energy Efficiency

California has long prioritized energy efficiency, helping make the state a global leader in efficiency while saving customers money and reducing pollution.

Utilities have been offering ratepayer-funded energy efficiency programs, such as incentives and technical assistance programs, to California customers since the 1970s. In 2016, spending on electricity efficiency programs totaled $1.3 billion, or 3.5 percent of total utility revenues. Natural gas programs added another $294 million. These programs produced incremental savings of over 4 million MWh of electricity and 49 million therms of natural gas in that year.[52]

The Energy Commission sets and continually updates energy standards for buildings and appliances. Over the years, California has adopted standards on more than 50 products, many of which have subsequently become federal standards. For the past decade California has collaborated with other countries to set harmonized standards for products that have a worldwide market. These codes are considered the policies with the greatest impact on long-term energy savings.

The Title 24 energy code for buildings, first set in 1978, is considered to be one of the most aggressive and best enforced energy codes in the United States. The code sets requirements for insulation and windows, heating and cooling design, lighting, and many other aspects of energy use in buildings. California is working toward requiring zero net energy—where buildings produce all of their own energy—in the 2020 standards for residential buildings and 2030 standards for nonresidential buildings.

In addition to environmental benefits, energy efficiency delivers economic benefits, and conveys a competitive advantage for California companies. For every dollar spent on electricity, California manufacturers produce 55 percent more value than the national average, according to the Air Resources Board.[53]

51 Energy Sage, "California Net Metering: Everything You Need to Know About NEM 2.0," https://news.energysage.com/net-metering-2-0-in-california-everything-you-need-to-know/

52 ~~American Council for an Energy Efficient Economy (ACEEE), State and Local Policy Database~~, June 2017, https://database.aceee.org/state/california

53 ~~California ARB, 2017 Scoping Plan, https://~~www.arb.ca.gov/cc/scopingplan/scoping_plan_2017.pdf

III.

Environmental and Social Issues

THE production, transportation, and use of electricity has enormous ecosystem, health and social impacts. Fuel production and combustion contribute to air and water pollution, large solar plants can cause land use impacts, and power lines can disrupt habitats. The cost of energy can be a burden for low-income consumers and can encourage or discourage certain kinds of industrial activity. Policies to encourage energy efficiency can raise first costs for appliances, even as they lower operating costs, affecting purchasing decisions.

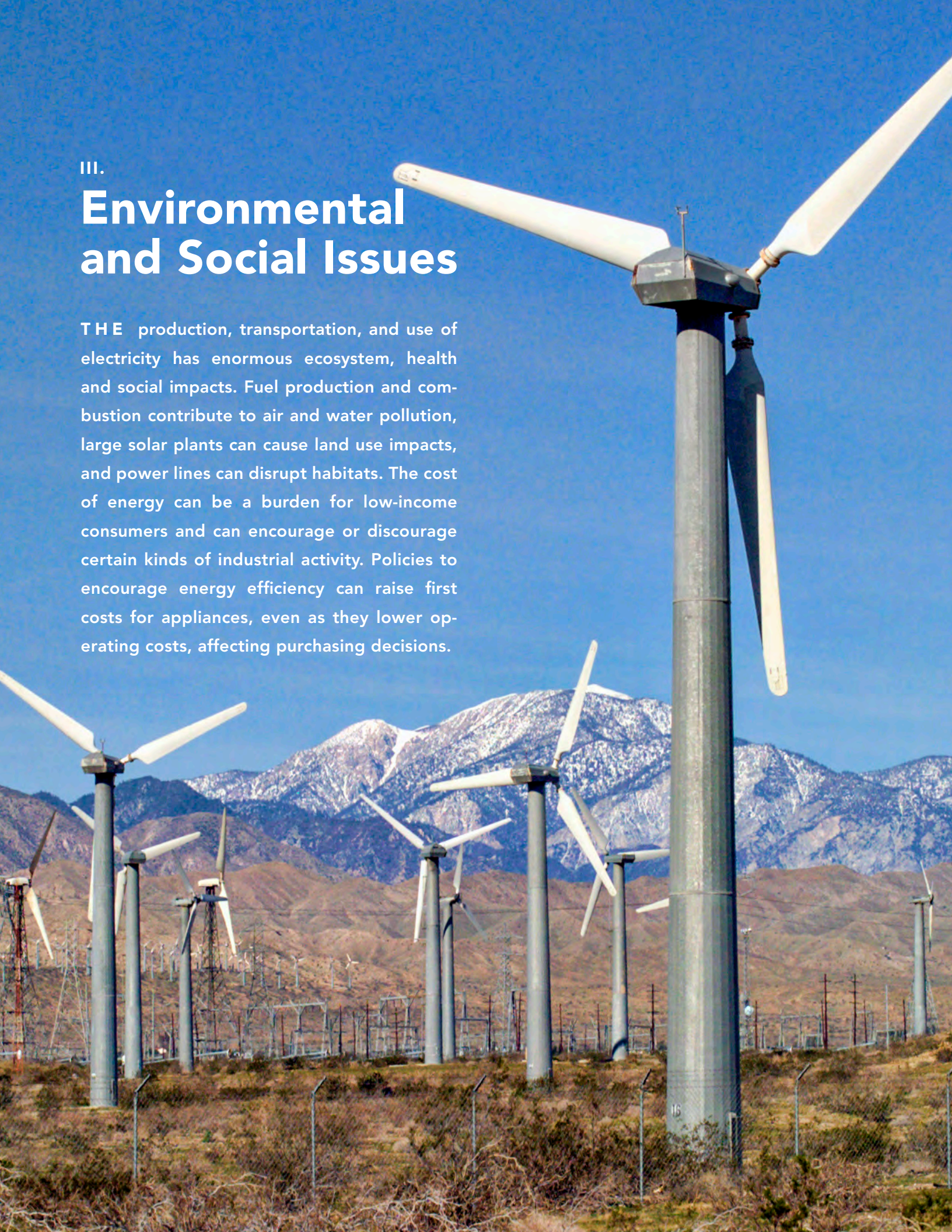
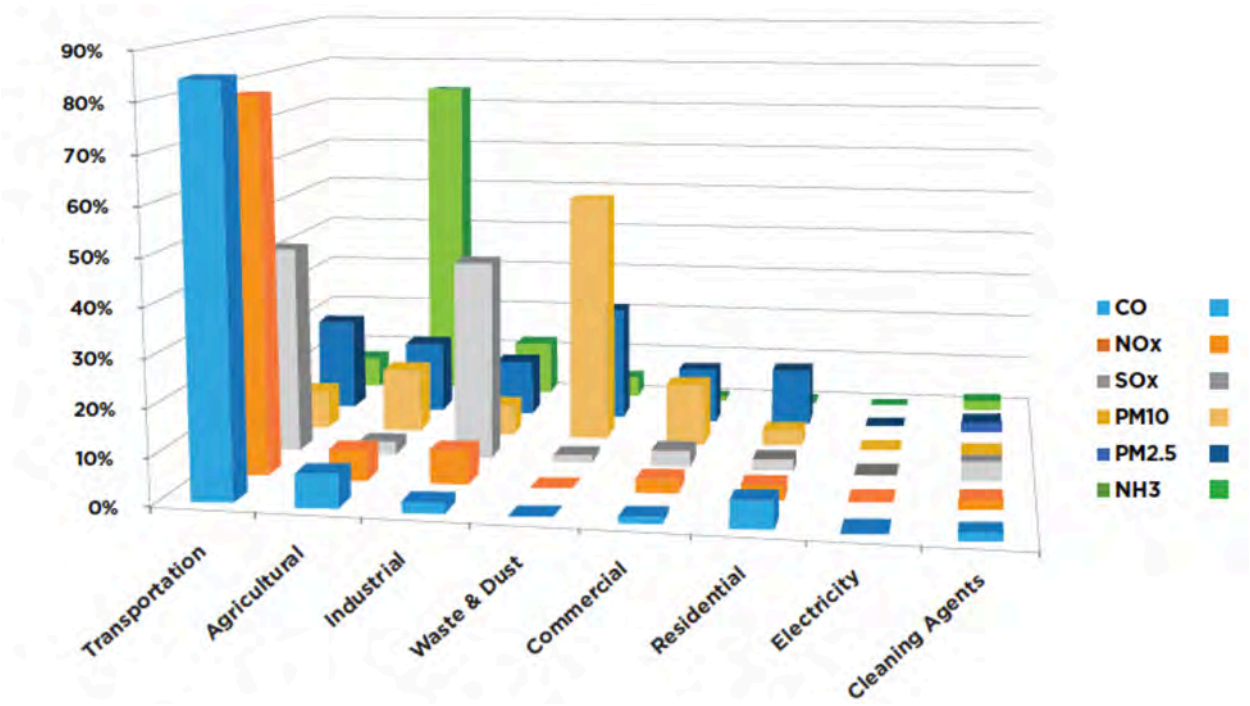


FIG 9 California Air Quality Emissions per Sector (2012 Estimated Annual Average)



Source: California Energy Commission using California Air Resources Board data.[54]

Environmental Issues

AIR POLLUTION

Many people immediately think of air pollution when it comes to power generation, picturing a smokestack belching pollution. In fact, California's power generation fleet is among the cleanest in the world.

According to data from the California Air Resources Board (CARB), electricity production is among the cleanest sectors in the state for "criteria" pollutants like nitrogen oxides and particulates, as shown in Figure 9. These pollutants cause respiratory disease, trigger asthma attacks, and shorten lives. Transportation is the most polluting category, while agriculture and industrial processes are significant contributors of some pollutants.

The power sector contributes about 19 percent of greenhouse gas emissions (GHGs, primarily carbon dioxide) in the state. The transportation sector (including fuel refining) and fossil fuels used in space and water heating now produce almost three times as many GHGs as the electric sector and more than 80 percent of the air pollution in California.[55]

The power sector is so clean largely because California has very little coal power in the state, instead relying on a mix of natural gas, nuclear and renewable energy. Coal is by far the dirtiest source of electricity production, for both criteria pollutants and greenhouse gases.

Other regions that are more dependent on coal have much higher power sector emissions. In 2016, in-state generators produced an average of 0.48 kilograms of carbon dioxide per kilowatt hour, about half of the national average of 0.97.[56]

54 Executive Summart of the 2017 Integrated Energy Policy Report, CEC. See http://www.energy.ca.gov/2017_energypolicy/.

55 Southern California Edison, *Clean Power and Electrification Pathway. Realizing California's Environmental Goals,* November 2017, https://www.edison.com/content/dam/eix/documents/our-perspective/g17-pathway-to-2030-white-paper.pdf

56 Data from Energy Information Administration, https://www.eia.gov/electricity/data/state/

To reduce statewide GHG emissions, California adopted AB 32, the Global Warming Solutions Act of 2006, supplemented by SB 32 ten years later.[57] Together the laws set a cap on total GHGs in most sectors of the economy to help the state reduce emissions to 40 percent below 1990 levels by 2030, and 80 percent below by 2050. Regulated entities that reduce emissions below their cap can trade those surplus reductions with other entities, hence the cap-and-trade system.

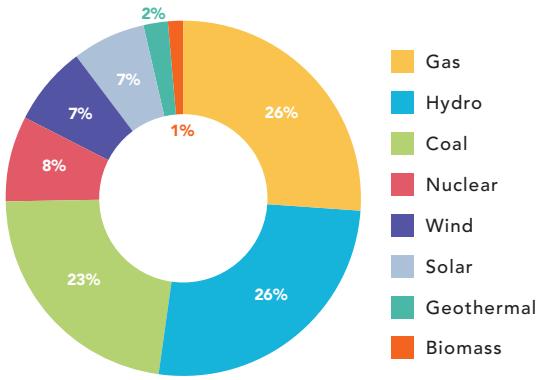
As renewable energy generation grows, the power sector is getting even cleaner, creating a tremendous opportunity to reduce emissions in other sectors by converting their energy sources to electricity. Electric cars, buses, and trains are the most obvious opportunity, but furnaces and boilers, water heaters and pumps can also be converted.

Still, there are some air quality impacts from power plants that burn natural gas, from biomass and landfill gas power plants, and from power imported from coal plants in other states. Natural gas power plant emissions can contribute to smog formation, and gas drilling operations can leak methane, which is both a local hazard and a powerful greenhouse gas.

While California has no major in-state coal plants, it does rely on coal generation from other Western states. The Los Angeles Department of Water and Power (LADWP) has traditionally been the biggest importer of coal-by-wire, but sold their share in a coal plant in Arizona in 2016 and is converting their last coal plant in Utah to natural gas by 2025.

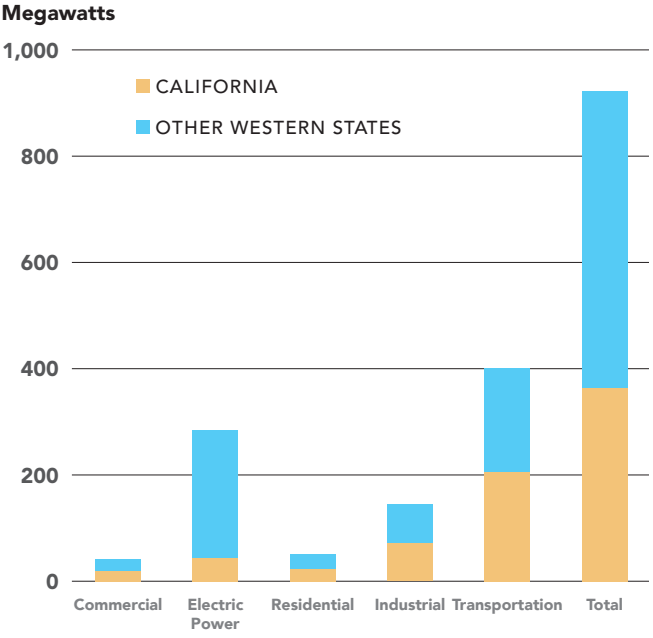
Coal power can also come to California through the daily spot market, as undifferentiated "system power." Still, coal is generally in decline in the West, making up only 23 percent of generation in 2017, comparable to gas and hydroelectric power. Nuclear and renewables made up the last quarter. The entire West produces about as much coal power as Texas and Pennsylvania put together.

FIG 11 Renewable Electricity Sources, 2017



Source: U.S. Energy Information Administration.[58]

FIG 12 CO2 Emissions from Energy Use in the West, By Sector, 2015



Source: U.S. Energy Information Administration.[59]

57 California Senate, "SB-32 California Global Warming Solutions Act of 2006: emissions limit," Senate floor analysis, August 24, 2016, https://leginfo.legislature.ca.gov/faces/billAnalysisClient.xhtml?bill_id=201520160SB32#

58 Electricity Data Browser, EIA. See https://www.eia.gov/electricity/data/browser/

59 Energy-Related Carbon Dioxide Emissions by State, 2000-2015, EIA. See https://www.eia.gov/environment/emissions/state/analysis/.

Coal is also the most carbon-intensive source of electric fuel, with about two pounds of CO2 emitted per kWh of generation. Natural gas, burned in an efficient combined-cycle plant, can produce less than half as much. Nuclear and renewable energy have no carbon emissions from generation.

WATER USE AND POLLUTION

Electricity generation can also affect water resources. The most obvious impacts come from hydroelectric dams that block rivers, affecting fish and wildlife habitats. California has 1,400 dams, including 267 that produce electricity.

Thermal power plants are also massive consumers of water for steam production and cooling. Plants can discharge large amounts of heat into bodies of water, impacting aquatic life. As mentioned, California regulators are restricting the ability of power plants to dump heat into the ocean, leading to the retirement of a number of these coastal plants.

Solar thermal power plants, which use concentrating mirrors to produce steam for power production, can also consume water. While the volume of water used is much less than for a coal plant, solar plants typically operate in deserts where water is scarce.

Thermal power plants can use dry cooling to cut water consumption, though it can reduce the overall efficiency of the plant.

Coal plants also create large volumes of ash that is typically stored in landfills. Heavy rains can cause the ash to leak into groundwater and spill into rivers, carrying with it a variety of toxic metals like arsenic and mercury. As California has few coal plants and strong limits on ash disposal, the state is less likely to have problems with coal landfills than other parts of the country

LAND USE

Any kind of power generation, transmission lines, or other infrastructure can cause land use impacts if not sited properly. But ground-mounted solar power is by far the most land intensive form of power generation, requiring 5 to 13 acres per megawatt of capacity, depending on the technology.[60]

The use of desert land for solar has been extremely contentious in California. The Desert Renewable Energy Conservation Plan (DRECP) was developed between 2008 and 2016 for 22.5 million acres in Southern California by the California Energy Commission, California Department of Fish and Wildlife, the U.S. Bureau of Land Management (BLM), and the U.S. Fish and Wildlife Service.[61]

Phase 1 of the plan covered 10.8 million acres of BLM land, allocating 6.5 million acres for wildlife conservation and only 800,000 acres for renewable energy development. Out of 2.1 million acres with "high-quality" wind resources, only 78,779 acres were made available for wind power development. Since the BLM put the plan into place, the agency has received only one filing for a new solar project, and none for wind.[62] The Trump Administration has responded to complaints from the energy industry and reopened the plan, holding hearings in spring 2018.[63]

Developing solar on private lands can also cause land impacts, such as by displacing agriculture. While California has a great deal of farm land (25 million acres), some of it is among the most valuable farm land in the country, making the state number one in the value of farm products.

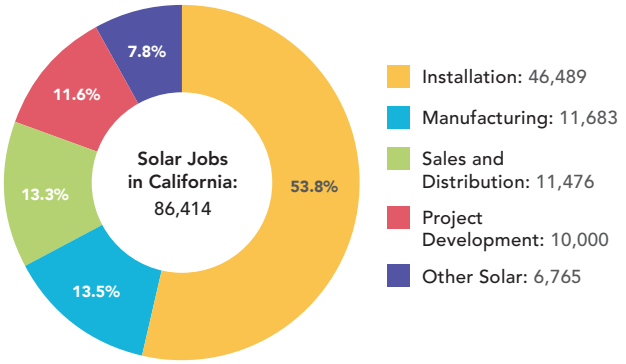
60 National Renewable Energy Lab (NREL), *Land-Use Requirements for Solar Power Plants in the United States,* June 2013, https://www.nrel.gov/docs/fy13osti/56290.pdf

61 Desert Renewable Energy Conservation Plan, accessed April 2018, https://www.drecp.org.

62 Sammy Roth, The Desert Sun, "Solar and wind are booming — just not in the California desert," May 8, 2017, https://www.desertsun.com/story/tech/science/energy/2017/05/09/solar-and-wind-booming-just-not-california-desert/311540001/

63 Bureau of Land Management, "BLM to Consider Changes to Desert Renewable Energy Conservation Plan," February 1, 2018, https://www.blm.gov/california/BLM-to-consider-changes-desert-renewable-energy-conservation-plan

FIG 13 Solar Jobs in California, 2017



Source: The Solar Foundation.[64]

Ideal locations for solar have low value for either conservation or agriculture. One such area is the Westlands Water District, south of Fresno. The district has 100,000 acres of land that has been heavily damaged by poor irrigation practices and is no longer viable for farming or grazing. The area has several large solar projects already operating and a proposal for a huge 2,400 megawatt project.[65]

Social Issues

ENVIRONMENTAL JUSTICE

While electricity undoubtedly is a great positive for society, our electricity system and policies can also cause significant impacts. Gas power plants are often sited in industrial zones that can be adjacent to low-income communities and communities of color. Power lines are often built in communities that provide the least resistance in the siting process. As a result, the impacts of electricity production are not shared equitably by all Californians.

The research group PSE Healthy Energy cross-checked the location of gas-fired power plants with communities that are exposed to multiple sources of pollution and that are particularly vulnerable to that pollution, as designated under the state EPA's CalEnviroScreen model. They found that 84 percent of gas peaker plants are located in the most disadvantaged half of communities, while half of the plants are located in the most disadvantaged 30 percent of communities.[66]

The state has developed a number of policies to increase the equity of the power system. Siting policies are guided primarily by the California Environmental Quality Act (CEQA), which has had environmental justice provisions since 1995.[67] The CalEnviroScreen model was developed by the California EPA to identify communities that are disproportionately burdened by multiple sources of pollution. It is used to guide programs that require a focus on disadvantaged communities, such as the use of funds from the state cap and trade program or the recently enacted Solar on Multifamily Affordable Housing (SOMAH) program.

64 Solar Jobs Census 2017: California, The Solar Foundation. See https://www.thesolarfoundation.org/solar-jobs-census-factsheet-2017-ca/.

65 Westlands Water District, "Renewable Energy," accessed April 2018, https://wwd.ca.gov/renewable-energy/

66 PSE Healthy Energy, Natural gas power plants in California's disadvantaged communities, April 2017, https://www.psehealthyenergy.org/wp-content/uploads/2017/04/CA.EJ_.Gas_.Plants.pdf

67 California Energy Commissions, Environmental Justice FAQ, accessed May 2018, http://www.energy.ca.gov/public_adviser/environmental_justice_faq.html

JOBS AND JOB TRAINING

Cleaning up the power system through energy efficiency and distributed renewables is a potential win-win: it reduces pollution impacts in vulnerable communities and can provide new job opportunities for low-income workers.

According to Next 10's California Green Innovation Index 2017, about 150,000 Californians work directly on energy efficiency, including auditors, installers, software programmers, and manufacturers of energy efficient equipment. An equal number work in the heating, ventilation and air conditioning (HVAC) sector, which often involves installing more efficient equipment.[68]

Another 55,000 work on smart grid, microgrids, and energy storage technologies. The conventional transmission system employs almost 100,000 workers in the state.

California is home to the largest number of solar workers in the US, with 86,414 employed in 2017 according to the Solar Foundation. Over half of these jobs are in installation, with the rest spread across manufacturing, sales, and project development (see Figure 12). Solar jobs in the state dropped 14 percent between 2016 and 2017 due to fewer utility-scale projects being built.[69] The imposition of 30 percent tariffs on imported solar panels by President Trump is expected to cause further job loss, especially in installation jobs.[70]

Research by the UC Berkeley Labor Center shows that the renewable energy construction union workforce largely reflects the ethnic makeup of the state, though women are heavily underrepresented.[71]

ENERGY COSTS AND LOW-INCOME CUSTOMERS

Electricity costs can be a significant burden on low-income households. Studies have shown that low-income households (defined as below 80 percent of area median income) pay 7.2 percent of their household income on utilities, over three times as much as households with higher incomes.[72]

To alleviate this burden, many state and federal programs offer bill payment and energy efficiency assistance. California Alternate Rates for Energy (CARE) are available for low-income customers, who get a 30-35 percent discount on their electric bill and a 20 percent discount on their natural gas bill. Annual budgets are around $1.3 billion, with funds coming from other California ratepayers.[73]

The federal Low Income Home Energy Assistance Program (LIHEAP) and Weatherization Assistance Program (WAP) are administered by state agencies. In FY18, LIHEAP served about 200,000 California households with income below 60 percent of the state median, with a total budget of just over $191 million.[74]

There are various state and federal programs to help reduce energy bills for low-income households. The largest in California is the state Energy Savings Assistance program, which provides no-cost weatherization services to households eligible for discounts. Annual budgets are over $370 million.[75]

68 Next10, 2017 California Green Innovation Index, August 22, 2017, http://next10.org/2017-gii

69 Solar Foundation, Solar Jobs Census 2017, https://www.solarstates.org/#state/california/counties/solar-jobs/2017

70 Solar Energy Industries Association, Press release: President's Decision on Solar Tariffs is a Loss for America, January 22 2018, https://www.seia.org/news/presidents-decision-solar-tariffs-loss-america

71 UC Berkeley Labor Center Green Economy Program, Diversity in California's Clean Energy Workforce: Access to Jobs for Disadvantaged Workers in Renewable Energy Construction, August 2017, http://laborcenter.berkeley.edu/pdf/2017/Diversity-in-Californias-Clean-Energy-Workforce.pdf.

72 Ariel Drehobl and Lauren Ross, American Council for an Energy Efficient Economy, Lifting the High Energy Burden in America's Largest Cities: How Energy Efficiency Can Improve Low-Income and Underserved Communities, April 20, 2016, http://aceee.org/research-report/u1602

73 California Public Utilities Commission, CARE/FERA Programs, http://www.cpuc.ca.gov/General.aspx?id=976; and California Alternate Rates for Energy and Energy Savings Assistance Program Fact Sheet, http://www.cpuc.ca.gov/WorkArea/DownloadAsset.aspx?id=6442453786. Both accessed April 2018.

74 U.S. Department of Health and Human Services, Administration for Children & Families, "LIHEAP Clearinghouse," accessed April 2018, https://liheapch.acf.hhs.gov/profiles/California.htm

75 CPUC, California Alternate Rates for Energy and Energy Savings Assistance Program Fact Sheet, accessed April 2018. http://www.cpuc.ca.gov/WorkArea/DownloadAsset.aspx?id=6442453786.

The state Department of Community Services and Development (CSD) has offered a Low-Income Weatherization Program (LIWP) since 2014, using between $75 and $100 million per year from the state Greenhouse Gas Reduction Fund, which is solely funded by cap-and-trade proceeds. CSD requires that all of the households served by LIWP are located within disadvantaged communities.[76]

The federal Weatherization Assistance Program provided an additional $6.2 million to California residents in 2017.

There are also a growing number of programs aimed at providing access to solar power for low-income households. The principle programs have been the Single Family and Multi-Family Affordable Solar Home programs (SASH and MASH). Created in 2006, the SASH program has installed over 6000 solar systems on single-family homes, with a capacity of 20 MW and program cost of $103 million. It also referred over 5,500 low-income homeowners to the Energy Savings Assistance programs and trained over 28,000 volunteers. Since 2008, the MASH program has supported 427 projects that served 10,900 tenants with about 50 megawatts of on-site solar.[77]

The MASH program is fully subscribed and it is unclear whether it will be extended or replaced by the newly created Solar on Multifamily Affordable Housing (SOMAH) program, which strives to install 300 megawatts of solar for low-income renters over 10 years. The $1 billion program will be funded from the Greenhouse Gas Reduction Fund.[78]

While California has among the highest electricity prices in the country, it also has among the lowest expenditures per capita.[79] Low electricity bills are the result of both a moderate climate in many parts of the state and many years of effort to encourage energy efficiency—funded largely by consumers.

76 Department of Community Services and Development, Low-Income Weatherization Program Program Guidelines, November 30, 2017, http://www.csd.ca.gov/Portals/0/Documents/LIWP/LIWP-SF_ProgramGuidelines2015-16_FINAL_Amended_113017.pdf

77 CPUC, Implementation of AB 693 - Solar on Multifamily Affordable Housing (SOMAH), accessed April 2018, http://www.cpuc.ca.gov/General.aspx?id=6442454736; and CSI Single-Family Affordable Solar Homes (SASH) Program, http://www.cpuc.ca.gov/General.aspx?id=3043

78 CPUC, Implementation of AB 693 - Solar on Multifamily Affordable Housing (SOMAH), accessed April 2018, http://www.cpuc.ca.gov/General.aspx?id=6442454736; and Christian Roselund, PV Magazine, "California approves $1 billion low-income multifamily solar program," December 15, 2017, https://pv-magazine-usa.com/2017/12/15/california-approves-1-billion-low-income-multifamily-solar-program

79 US Energy Information Administration (EIA), "Electricity prices are highest in Hawaii but expenditures are highest in South Carolina," February 13, 2018, https://www.eia.gov/todayinenergy/detail.php?id=34932

IV.

Visions of the Future

CALIFORNIA'S power system is changing rapidly, and it will have to continue to change to address the problems and opportunities of the future.

The biggest challenge will be evolving along with the state's initiatives to address climate change. California's clean and diverse power system is already a global leader in producing low-carbon energy. But it must continue to evolve—to be completely carbon-free—to effectively address climate change.

The retirement of the state's two large nuclear plants is potentially a step backward on carbon emissions, if their output is replaced with fossil fuels. Fortunately, solar and wind power have become mature and cost-effective technologies, so a high-renewables power supply is viable and need not be expensive. But because wind and solar vary with the weather and time of day, they have a limited ability to provide power on demand and require the development of energy storage and a much more flexible power system.

Flexibility can come in part from fast-acting natural gas turbines, but if the state is aiming for a zero-carbon power supply those turbines would have to capture and store their carbon emissions, which limits locations and increases costs. Wind and solar generators are able to provide some kinds of flexibility, such as being ramped down or up, but only as much as their output at that moment would allow. Solar panels produce no power at night.

California will have to increase the number of supply-side and customer-side options for zero-emission flexibility, including demand response, energy storage, greater geographic diversity, more dispatchable renewables (like geothermal, biomass, and hydro power), and greater electrification.

A carbon-free power system will be the workhorse of decarbonization, enabling the clean-up of other sectors of the economy. Transportation is the greatest opportunity, as more affordable and high-performing electric vehicles come to market. Space heating, water heating, and industrial energy use will need greater focus from policies and programs to convert to electric and low-carbon fuels.

California already has strong policies on the books moving toward a low-carbon future. AB 32 and SB 32, mentioned previously, set a target of reducing emissions of greenhouse gases to 40 percent below 1990 levels by 2030 and to 80 percent below 1990 levels by 2050. The Clean Energy and Pollution Reduction Act of 2015 (SB 350) expanded state renewable energy goals to 50 percent and end-use energy efficiency to be doubled by 2030.

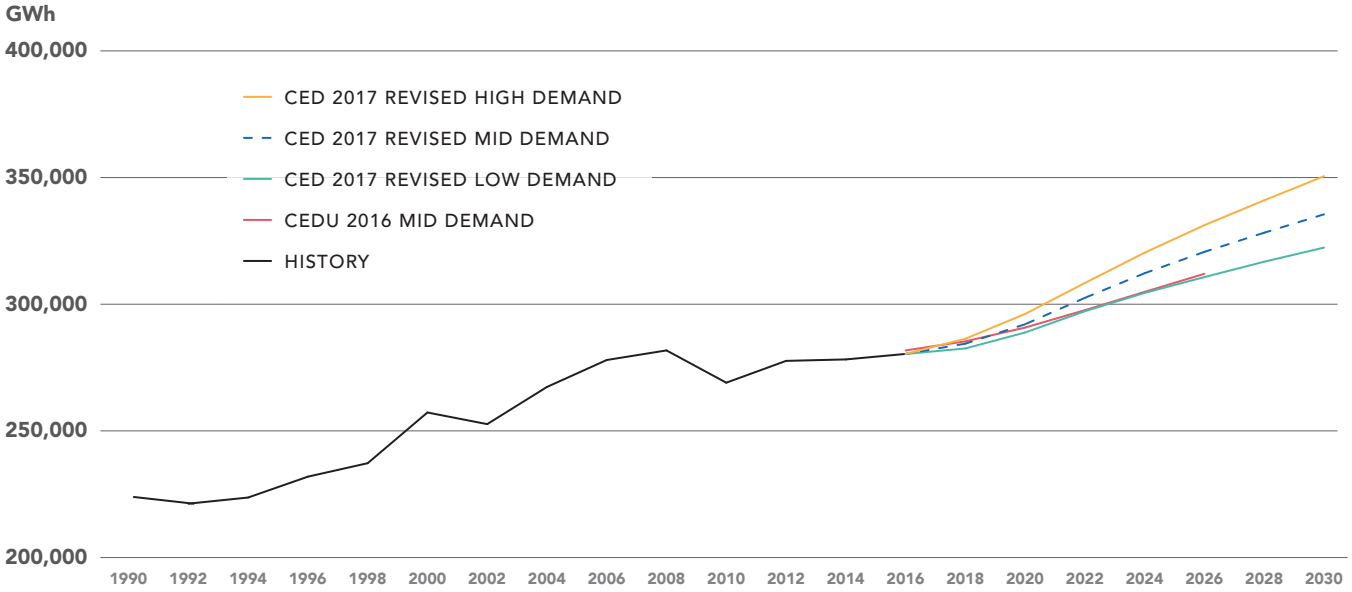
Renewable generation has been growing well ahead of the amounts required in current renewable energy requirements. The three investor-owned utilities expect to hit 50 percent by 2020, ten years ahead of the statutory requirement.[80] On the other hand, uncertainty caused by the loss of sales to CCAs and customer self-generation is causing utilities to slow down in procuring new renewables, while CCAs are just ramping up procurement. This delay is occurring just as federal tax credits are winding down, causing California to lose out on a substantial cost-sharing opportunity.

The state legislature is debating SB 100, which would raise the current 2030 renewables goal from 50 percent to 60 percent, and set a standard of 100 percent carbon-free electricity by 2045. With or without the legislation, the trend toward more renewables is likely to continue, based on their low cost.

SB 350 sets a goal of doubling end-use efficiency by 2030. California has long been a global leader on energy efficiency, and currently spends over $1.5 billion per year on utility programs to cut gas and electricity consumption. The Energy Commission also sets leading edge efficiency standards for appliances and buildings, and recently updated the 2019 building code to require solar on new housing, among other things. State efficiency policies have kept electricity demand nearly flat in California for the last decade, even as the population and economy have boomed.

80 CPUC, California's Renewables Portfolio Standard Annual Report, November 2017, http://www.cpuc.ca.gov/uploadedFiles/CPUC_Website/Content/Utilities_and_Industries/Energy/Reports_and_White_Papers/Nov%202017%20-%20RPS%20Annual%20Report.pdf

FIG 14 California Electricity Demand Forecast Through 2030



Source: California Energy Commission, Energy Assessments Division, 2017.

Despite the accomplishments in improving energy efficiency, electricity demand could still increase due to a booming economy, rising population, and the electrification of other sectors. In the 2017 Integrated Energy Policy Report (IEPR), shown in Figure 14, the California Energy Commission forecast electricity demand to rise by as much as 25 percent by 2030, with a low-case estimate of 16 percent. Electric vehicles could increase electricity demand by between 11 and 16 terawatt-hours (TWh) per year. At the same time, customer-owned solar generation could increase from the current 6.5 GW to between 11 and 26 GW, producing between 20 and 46 TWh per year by 2030, absorbing some of the gain in power demand.[81]

For deep decarbonization, the electric system may increasingly interact with the natural gas system. Converting appliances from natural gas to electricity is one way to cut fossil fuel use. Another is renewable natural gas, commonly made through the anaerobic digestion of organic materials, such as animal waste and sewage. Renewable gas can also be made using surplus renewable electricity, making the gas system another way to store energy and provide flexibility. These "power to gas" approaches are being researched in Europe, and at the UC Irvine campus.[82]

81 California Energy Commission, *Final 2017 Integrated Energy Policy Report*, Publication #CEC-100-2017-001-CMF, February 2018, https://efiling.energy.ca.gov/getdocument.aspx?tn=223079

82 UCI News, "Greening the grid: UCI tests integration of renewable hydrogen into existing natural gas systems," January 3, 2017. https://news.uci.edu/2017/01/03/greening-the-grid/

V.

Conclusions

CALIFORNIA'S power system is undergoing significant disruption as the state strives to decarbonize as quickly as possible. This paper is intended to help California's decision-makers understand the full range of issues facing the grid in order to adequately plan for rapid change.

As discussed in the Appendix, there have been a number of studies modeling future scenarios for the California power system,[83] and how it can maintain affordability and reliability while cutting out carbon emissions. There are some common themes that emerge from these varying analyses:

- California must develop a diverse portfolio of clean energy resources and strategies to reduce risk and foster innovation. This means diversity among large-scale renewables as well as among distributed energy resources, along with policies that can accommodate many business models.
- As always, California must maintain a strong focus on energy efficiency across all sectors, to cut carbon as well as control the cost of energy services and maintain global competitiveness.
- System flexibility is vital to incorporate very large amounts of wind and solar power. Rather than forecasting electricity demand and meeting it with controllable generation, we will need to forecast wind and solar generation and meet it with controllable demand.
- The power system must be better integrated with other sectors, including transportation, heat, water, and natural gas systems. Abundant wind and solar power can help cut emissions in those sectors, while benefiting from the flexibility they can offer.

While these challenges are substantial, there are many indications that California is in a good position to succeed.

- There is strong political consensus for climate action, thanks to the economic and environmental benefits that clean energy offers to all parts of the state.
- California's resource diversity, combined with a willingness to innovate, is creating opportunities for leadership, environmental improvement, and economic growth.
- Renewable energy is affordable and abundant, and there are a growing set of options for managing the variability of wind and solar power.
- There is growing consensus among policymakers and industry about the desirability of electrifying transportation and other sectors.
- Rapid innovation in distributed energy technologies is expanding the role of customers, saving energy, lowering costs, reducing emissions, and providing more reliable service.

California's ambitious efforts to combat climate change have spurred innovation and made the state a home for advanced energy technologies. The next challenge for the Golden State is to evolve the policies and infrastructure needed to successfully integrate these technologies, creating a 21st century power system and a global model for a decarbonized economy.

83 A vision for the transition to 100% wind, water & solar energy in California, The Solutions Project. See http://www.thesolutionsproject.org/why-clean-energy/#/map/states/location/CA.

VI.

APPENDIX: Future Visions

FUTURE VISIONS

There have been a number of studies modeling future scenarios for the California power system, and how it can maintain affordability and reliability while cutting out carbon emissions.

LOW CARBON GRID STUDY

One view of the future comes from the Low Carbon Grid Study by the National Renewable Energy Lab, GE Consulting, and others. That study found that California's power system could cut emissions in half by 2030 "with minimal rate impact, minimal curtailment of renewable energy, and without compromising reliability."[84]

They cite five key strategies:

- A focus on carbon emissions during procurement and operation
- Maintaining a diverse portfolio of renewables and energy efficiency
- Increasing the use of flexible load
- Cooperation throughout the West
- Efficient use of the natural gas fleet

E3 PATHWAYS PROJECT

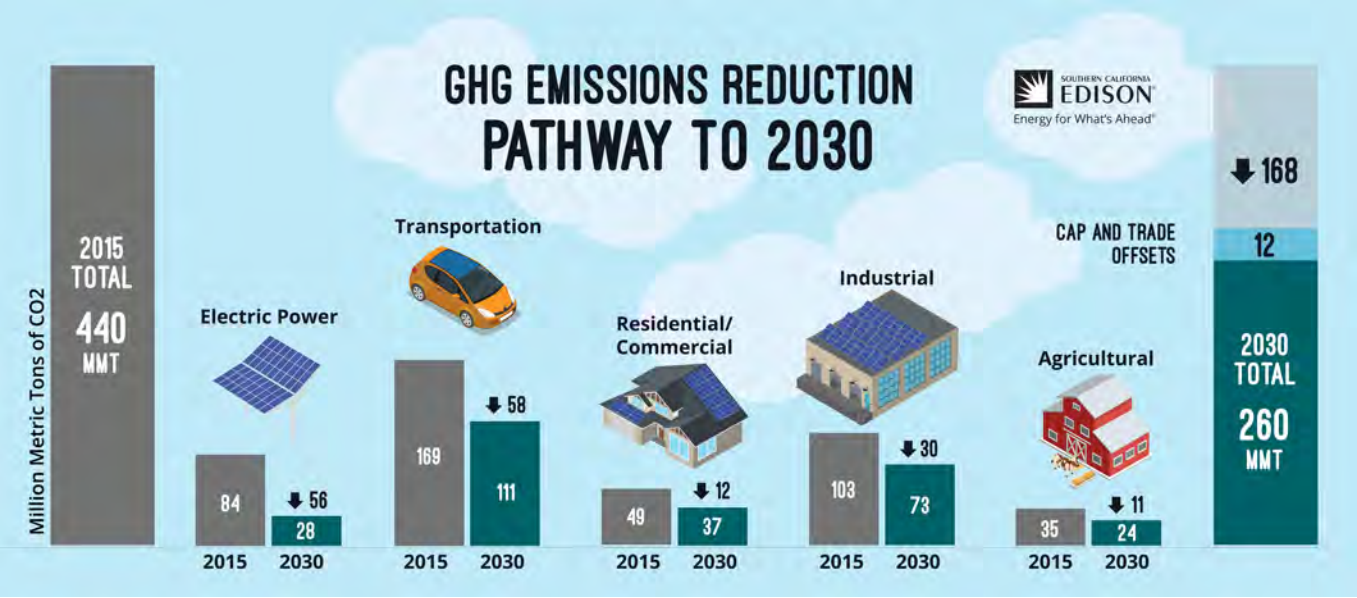
Another view comes from the consulting firm E3, who have done a number of studies for the state agencies and utilities. In a 2015 study, E3 modeled scenarios to achieve an 80 percent economy-wide reduction in GHGs by 2050, in accord with long-term AB32 goals.[85] To hit that goal, the state would have to:

- Double the amount of energy efficiency achieved in buildings and industry, relative to current policy, by 2030;
- Increase renewables to 50% to 60% of electricity sales by 2030;
- Ensure that half of new sales of residential water heaters and HVAC systems for buildings are high efficiency electric heat pumps or over half of natural gas demand is supplied with biogas by 2030;
- Put 6-7 million EVs and plug-in hybrid vehicles (PHEVs) on the road by 2030; and
- Produce 4 billion gallons of renewable diesel or gasoline in 2030.

84 National Renewable Energy Laboratory and Center for Energy Efficiency and Renewable Technologies, *Low Carbon Grid Study: Analysis of a 50% Emission Reduction in California*, January 2016, http://lowcarbongrid2030.org

85 Energy & Environmental Economics (E3), *Summary of the California State Agencies' PATHWAYS Project: Long-term Greenhouse Gas Reduction Scenarios*, April 6, 2015, http://www.ethree.com/wp-content/uploads/2017/02/E3_Project_Overview_20150406.pdf

FIG A1 SCE Analysis of Reaching 2030 GHG Goals



Source: Southern California Edison.

SCE CLEAN POWER AND ELECTRIFICATION PATHWAY

Southern California Edison has also weighed in on future plans, with their Clean Power and Electrification Pathway.[86] The Pathway is an integrated approach to reduce GHG emissions and air pollution by taking action in three California economic sectors: electricity, transportation and buildings.

By 2030, it calls for an electric grid supplied by 80 percent carbon-free energy; more than 7 million electric vehicles on California roads; and using electricity to power nearly one-third of space and water heaters, in increasingly energy-efficient buildings.

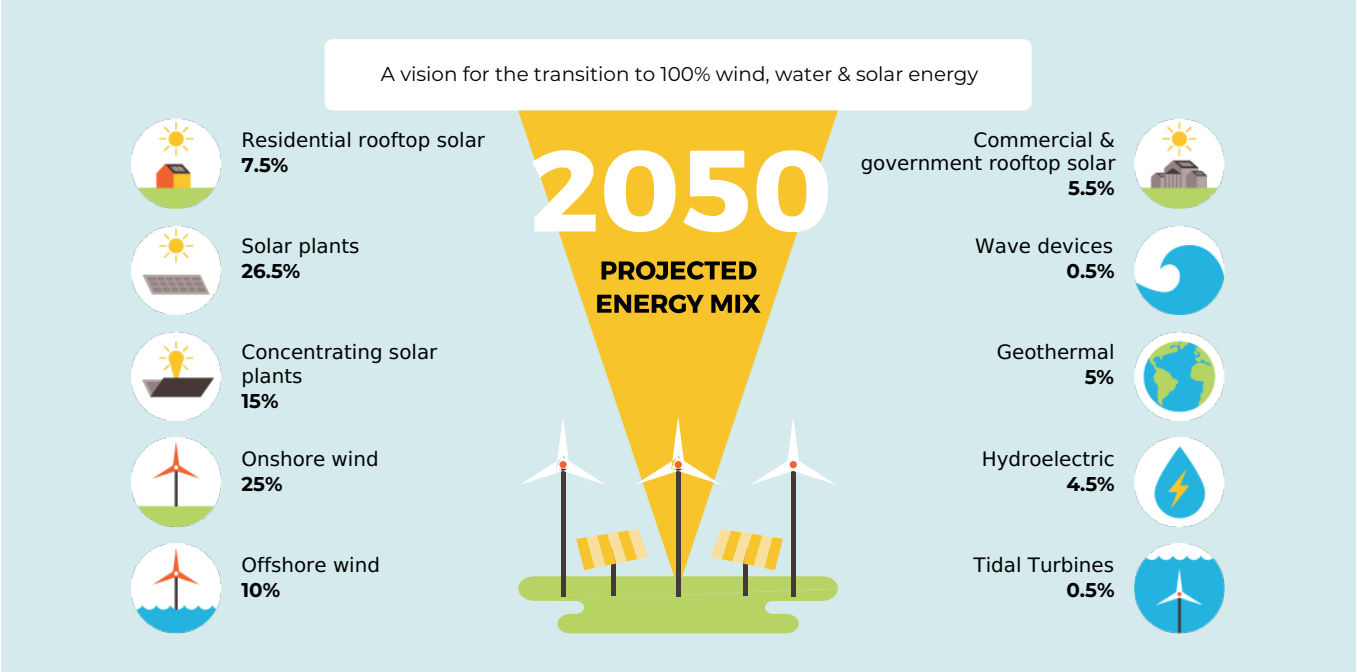
An electrification pathway has an incremental abatement cost of $79/ton [of CO2], they find, compared to higher cost scenarios focused on renewable natural gas and hydrogen. Plus, electrification infrastructure is widespread and familiar, while end use applications like EVs and heat pumps are commercially available.

To reach the total 2030 emission reduction of 40 percent below 1990 levels, California will have to cut 180 million metric tons (MMT) of CO_2. Edison sees the largest reductions coming from more renewables in the power supply (56 MMT) and more electric vehicles (58 MMT). Buildings, industry (including oil refineries), and agriculture add up to a combined 53 MMT, while cap-and-trade offsets supply the rest. Thanks to the growth of renewables, electric generation emissions fall even as demand increases through electrification of other sectors.

86 Southern California Edison, *Clean Power and Electrification Pathway: Realizing California's Environmental Goals,* November 2017, https://www.edison.com/content/dam/eix/documents/our-perspective/g17-pathway-to-2030-white-paper.pdf

87 The Clean Power and Electrification Pathway, SoCal Edison. See https://www.edison.com/content/dam/eix/documents/our-perspective/g17-pathway-to-2030-white-paper.pdf.

FIG A2 Stanford Vision of 100% Renewables in California



Source: The Solutions Project.[88]

STANFORD WIND, WATER & SUN

These three plans have largely focused on 2030 goals. A longer term vision has been laid out by researchers at Stanford University, who have studied how the entire economy – not just the power sector – can be run on "wind, water, and sun," or wind power, solar power and hydroelectric power, by 2050.[89]

In a state-by-state analysis, researchers modeled an electricity supply for California that was 40 percent PV, 15 percent solar thermal, and 35 percent wind (with the balance from hydro, wave, and geothermal sources). By relying on energy efficiency improvements and electrification, state primary energy consumption was 44 percent lower than current levels.

Critical to making the system work with so much variable generation was a variety of storage techniques, including using summer solar electricity to heat underground reservoirs that are tapped for winter-time heat.

88 A vision for the transition to 100% wind, water & solar energy in California, The Solutions Project. See http://www.thesolutionsproject.org/why-clean-energy/#/map/states/location/CA.

89 Jacobsen et al., "100% clean and renewable wind, water, and sunlight (WWS) all-sector energy roadmaps for the 50 United States, Energy and Environmental Science, May 2015, http://web.stanford.edu/group/efmh/jacobson/

TABLE A1 Trends and Tasks for the California Power System, from CAISO

8 Trends	8 Tasks
1: Electricity is used far more efficiently	**1:** Strengthen standards and incentives that promote efficient use of electricity.
2: Gas-fired generation declines significantly as the grid is modernized	**2:** Develop a comprehensive strategy for reducing reliance on fossil resources for power generation.
3: The system is shaped by the variable output of wind and solar resources	**3:** Re-orient regulatory policy to base system operation on non-fossil resources.
4: Demand becomes as important as supply in balancing the system	**4:** Develop a long-term strategy for enabling demand to provide essential grid services, like supply does today.
5: Electric service is increasingly decentralized	**5:** Develop a framework for coordinating decentralized electric service with the bulk power system.
6: Regional collaboration supports efficient grid operations	**6:** Explore ways to share resources across the West for the benefit of all states.
7: Transportation and building energy use is integrated with electric service	**7:** Develop policies and programs to integrate transportation and building energy use with electric service.
8: Develop ways to enable everyone to contribute to, and benefit from, the transition away from fossil fuels	**8:** Ensure consistent state policy direction sufficient to support sustained public and private sector investment in clean energy.