STATE OF CALIFORNIA ENERGY COMMISSION

PUBLIC UTILITIES COMMISSION STATE OF CALIFORNIA

CALIFORNIA AIR RESOURCES BOARD

2021 SB 100 Joint Agency Report

Achieving 100 Percent Clean Electricity in California: An Initial Assessment

Gavin Newsom, Governor
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PREFACE

The SB 100 Joint Agencies

The California Energy Commission's primary functions include forecasting electricity and natural gas demand for state planning, siting and licensing thermal power plants 50 megawatts or greater, investing in energy innovation, setting the state's appliance and building energy efficiency standards, and planning for and directing state response to energy emergencies. The CEC also publishes the Integrated Energy Policy Report, which provides an assessment of major energy trends and issues facing California's electricity, natural gas, and transportation fuel sectors.

The California Public Utilities Commission regulates services and utilities, protects consumers, safeguards the environment, and assures Californians' access to safe and reliable utility infrastructure and services. The essential services regulated include electric, natural gas, telecommunications, water, railroad, rail transit, and passenger transportation companies. The CPUC does resource planning for 80 percent of California's electric grid through the Integrated Resource Planning proceeding and implements programs such as the RPS, efficiency incentives, transportation electrification investments, customer solar, and building decarbonization.

The California Air Resources Board's mission is to promote and protect public health, welfare, and ecological resources through effective reduction of air pollutants while recognizing and considering effects on the economy. CARB is the lead agency for climate change programs and oversees all air pollution control efforts in California to attain and maintain health-based air quality standards.

The Climate Imperative

In 2020, Californians witnessed the impacts of climate change as never before. The state experienced its hottest August on record — the month ranked third hottest across the United States. On August 16, Death Valley, reported a high temperature of 130 degrees Fahrenheit. If verified, this would be the hottest August temperature ever recorded for the United States and among the hottest temperatures recorded on Earth. In September, Woodland Hills hit 121 degrees F, the hottest temperature ever recorded in Los Angeles County.

Along with record-breaking heat came a record-breaking fire season. The 2020 wildfire season was the largest in history, burning more than 4 million acres and shattering the previous record set in 2018. Five of the six largest wildfires in California history occurred in 2020 and the August Complex Fire was the single largest fire, having burned over 1 million acres. The 2020 fire season took 33 lives, and more than 10,400 structures were destroyed.

> ***"The debate is over around climate change. Just come to the state of California. Observe it with your own eyes"*** — Governor Newsom noted during a September 2020 press conference following a tour of the destruction of the North Complex Fire.

Without drastic mitigation measures, climate change-related events will continue to become more frequent, catastrophic, and costly. And the impacts are often disproportionately borne by the state's most vulnerable and disadvantaged populations.

California is only one piece of the climate solution. But as the fifth largest economy in the world, the state has an outsized role in demonstrating to other states and countries that a clean energy future is not only possible, but beneficial to the well-being of its residents and the economy. Moving to a clean electric grid is a foundational step that will unlock and support economywide opportunities to achieve carbon neutrality and address the most catastrophic impacts of climate change.

ABSTRACT

The *2021 SB 100 Joint Agency Report* (2021 Report) includes a review of the policy to provide 100 percent of electricity retail sales and state loads from renewable and zero-carbon resources in California by 2045. The report assesses various pathways to achieve the target and an initial assessment of costs and benefits. The report includes results from capacity expansion modeling and makes recommendations for further analysis and actions by the joint agencies.

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EXECUTIVE SUMMARY

Senate Bill 100 (SB 100)

The 100 Percent Clean Energy Act of 2018 (Senate Bill 100, De León, Chapter 312, Statutes of 2018) is a landmark policy that establishes a target for renewable and zero-carbon resources to supply 100 percent of retail sales and electricity procured to serve all state agencies by 2045. The bill also increases the state’s Renewables Portfolio Standard (RPS) to 60 percent of retail sales by December 31, 2030 and requires all state agencies to incorporate these targets into their relevant planning.

The statute calls upon the California Public Utilities Commission (CPUC), California Energy Commission (CEC), and the California Air Resources Board (CARB) to use programs under existing statutes to achieve this policy and issue a joint policy report to the Legislature by January 1, 2021, and every four years thereafter. The report shall be completed as part of a public process and include specified information relating to policy implementation.

SB 100 is an Ongoing Effort

The analysis in the 2021 Senate Bill 100 Joint Agency Report (2021 Report) is intended to be a first step in an iterative and ongoing effort to assess barriers and opportunities to implementing the 100 percent clean electricity policy. This report includes system modeling to provide directional insights into what a 2045 portfolio of renewable and zero-carbon resources may look like, as well as the associated costs and resource build rates (the average amount of new generation required each year) required to achieve such a portfolio. The analysis builds on the modeling and assumptions used for CPUC’s integrated resource planning and considers California’s overarching priorities on energy, climate, equity, and public health.

Initial findings suggest that the goals of SB 100 are achievable, though opportunities remain to reduce overall system costs. This report presents various scenarios to meet the 100 percent clean electricity target with existing technologies, as well as alternative scenarios that explore additional factors. All these scenarios require additional analysis. The preliminary findings are intended to inform state planning and are not intended as a comprehensive nor prescriptive roadmap to 2045. As discussed in Chapter 4, future work will delve deeper into critical topics such as system reliability and land use and further address energy equity and workforce needs.

A robust public process informed the 2021 Report. The joint agencies held a year-long series of public workshops to solicit comments on the report’s scope, analysis, and process. The agencies consulted with the California balancing authorities — which balance supply and demand and maintain electric frequency on the grid — as required by SB 100. The agencies also consulted with the Disadvantaged Communities Advisory Group, which consists of members from and representing disadvantaged communities and advises the CEC and CPUC on energy equity issues.

Moving to 100 Percent Clean Electricity

California has long led the nation and the world in setting ambitious renewable energy and climate policies, working toward a clean economy that is healthier and more just. The state now aims to achieve carbon neutrality by 2045 and net negative emissions thereafter

Decarbonizing the electric grid is imperative to achieve economywide carbon neutrality. The Renewables Portfolio Standard (RPS) has been a primary driver for increasing clean electricity generation, requiring the state's electric utilities to make renewable energy sources like solar and wind an ever-greater percentage of their power base. Although California is ahead of schedule in meeting its 33 percent renewable energy target by 2020 and on track to achieve 60 percent renewable energy by 2030, deep decarbonization of the electricity sector to meet climate change objectives will require continued transformational change in the state's electric system.

As California enters a new climate reality and moves toward a majority renewable grid, the state's planning processes likewise need to evolve to meet the needs of all Californians who depend on safe, affordable, and reliable electricity every day. Effectively integrating 100 percent renewable and zero-carbon electricity and achieving carbon neutrality in the state by 2045 will require rigorous analysis of implementation considerations, as well as coordinated planning across state agencies. While there remains work to do, achieving 100 clean electricity is a core pillar in the transition to a clean energy economy enjoyed by all Californians.

Benefits of 100 Percent Clean Electricity

In addition to serving as a central policy in the state's efforts to address climate change, successful implementation of SB 100 can benefit residents across the state by:

Improving Public Health

Implementing SB 100 is expected to reduce criteria air pollution emissions as renewable and zero-carbon resources replace fossil fuel in generating electricity. Today, more than 28 million Californians live in areas that exceed the federal health-based standards for ozone and fine particulate matter ($PM_{2.5}$). Disadvantaged communities (see glossary for definition) will reap the highest health benefits from the phaseout of fossil fuels in generating electricity; half of the state's natural gas power plants are in communities that rank among the 25 percent most disadvantaged.

The public health benefits are expected to grow substantially throughout the state as the transition from fossil fuels to clean electricity accelerates in transportation and buildings. Increased conversion of cars, trucks, and buses, as well as home appliances to electric technologies can improve health and reduce mortalities associated with air pollution across the state.

Advancing Energy Equity

The joint agencies are committed to ensuring the benefits of cleaner, more efficient energy are enjoyed by all Californians, including those in low-income and disadvantaged communities, as well as tribal and rural communities. To ensure equitable outcomes, SB 100 will need to be implemented in ways that help these communities overcome barriers to clean energy, including:

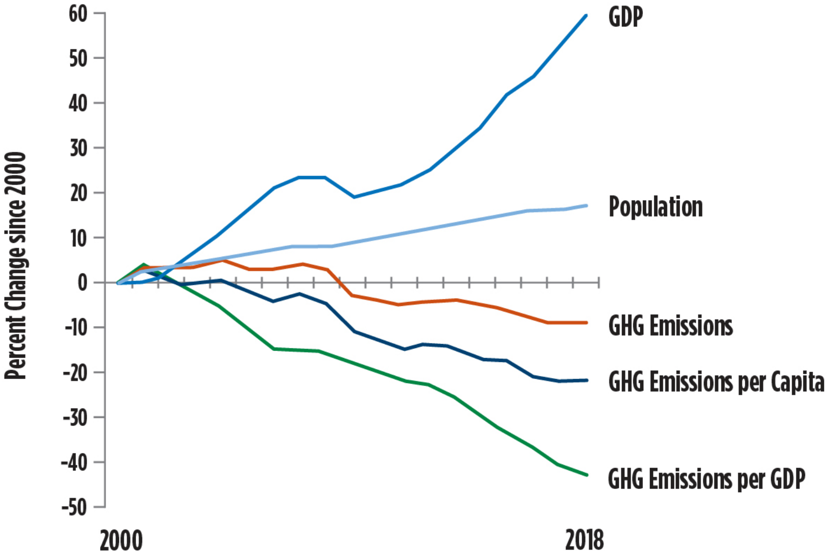
- Keeping electricity affordable, with an emphasis on vulnerable populations and households that pay a disproportionately high share of their household income on energy.
- Reducing air pollution from local power plants, particularly in communities that experience a disproportionate amount of air pollution.
- Strengthening communities' ability to function during power outages and enjoy reliable energy in a changing climate.
- Funding of training for high-quality jobs and careers in the growing clean energy industry.

Supporting a Clean Energy Economy

As a clean energy leader boasting one of the world's largest economies, California has shown that economic growth and environmental protection are not mutually exclusive. For decades, the state has reduced GHG emissions while growing its economy at a rate that has consistently outpaced the U.S. national average.

California's policies have spurred innovation and created markets for renewable energy, energy efficiency, energy storage, low-carbon fuels, and zero-emission vehicles. The state is a leader in patent registrations across all major clean technology (cleantech) categories and California's companies have received more than 50 percent of all U.S. venture capital investment in cleantech.

Figure 1: Statewide Trends of Emissions and Indicators (2000–2018)



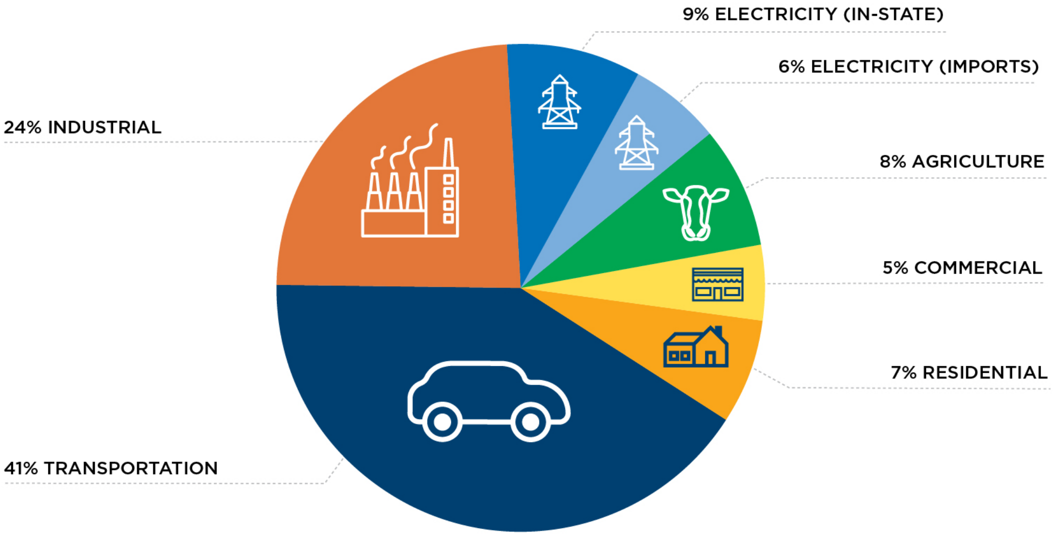
Source: CARB Emissions Inventory

As of 2020, California had more than 530,000 clean energy jobs, more than half the total energy-related jobs in the state. While the global COVID-19 pandemic has dramatically affected California's energy sector, clean energy jobs remain an important component of the state's economy. SB 100 provides an opportunity to create more high-quality clean energy jobs and increase diversity in the state's clean energy workforce.

A Cornerstone of California's Clean Energy Efforts

Successful implementation of SB 100 alone will not achieve statewide carbon neutrality, but it is pivotal to the success of California's climate-fighting efforts that collectively can reach the target. A clean electricity grid can serve as a backbone to support the decarbonization of transportation, buildings, and some industries. Together, with the electricity sector, these sectors account for 92 percent of the state's GHG emissions.

Figure 2: California GHG Emissions by Sector



Source: CARB Emissions Inventory

SB 100 sits within a portfolio of related key clean energy efforts to reduce climate and air pollution emissions while maintaining a reliable and affordable electric grid. These efforts include:

- **Transportation Electrification** — While the transportation sector remains among the state's biggest decarbonization challenges, California has already positioned itself as a leader in clean transportation with more than 566,000 zero-emission vehicles (ZEVs) on the road and nearly half of the total U.S. ZEV sales. Building on this success, Governor Gavin Newsom issued an executive order in September 2020 requiring all new passenger car and truck sales to be zero-emission by 2035. This transformation will require close coordination and planning across the electric and transportation sectors.
- **Building Decarbonization** — The construction of and conversion to zero-emission buildings has rapidly emerged as a key decarbonization strategy in recent years. State agencies are assessing pathways to reduce emissions from this important sector and considering implications of migrating more building energy uses, such as space and water heating, to the electric grid.
- **Energy Efficiency** — Prioritizing cost-effective energy efficiency measures remains critical as the state moves toward 100 percent clean electricity. Taking steps to reduce energy demand can offset the need for additional generation capacity, saving customers money while reducing land-use and other environmental impacts associated with the construction of new generation facilities.

- **Load Flexibility** — Load flexibility — the ability to shift electricity consumption to other parts of the day — is critical to supporting grid reliability, especially in a high-renewables future, and reducing the total cost of the electric system. The state has efforts underway to research and implement a variety of load flexibility applications.
- **Research and Innovation** — Given the urgency of achieving an electricity system powered by renewable and carbon-free electricity, continued prioritization of research and development of new and more cost-effective solutions is imperative. State agencies are also working to ensure these investments benefit all Californians.

2021 Report Analysis and Findings

The analysis for this report used the RESOLVE California model, a capacity expansion model developed by Energy and Environmental Economics, Inc. (E3). The RESOLVE model produces a least-cost resource portfolio, given policy and reliability constraints. The modeling inputs and assumptions build upon previous state efforts, including the CPUC's Integrated Resource Planning (IRP) 2045 Framing Study, and were informed through public and stakeholder comments.

The analysis examines estimated resource requirements and cost impacts of various SB 100 implementation pathways. Although capacity expansion is an important tool, it is just the first step in a series of modeling phases to develop reliable portfolios that meet all applicable policy objectives. Further analysis is needed to evaluate topics such as reliability and land use and better reflect equity, workforce, and additional planning and implementation considerations.

Modeled Scenarios

While the primary focus of this report is to analyze scenarios based on established cost and performance data and the joint agencies' interpretation of SB 100, the joint agencies recognize the importance of analyzing outcomes beyond these assumptions to support broader energy and climate planning and public health efforts. As such, scenarios are broken into two categories, "core scenarios" and "study scenarios," described below. A 60 percent RPS scenario was also modeled and used as a counterfactual, or reference baseline, to evaluate the impacts of the 100 percent clean electricity policy.

Core Scenarios

The "core scenarios," shown **Table 1**, modeled for the 2021 Report are consistent with the joint agencies' interpretation of the statute and include only commercialized technologies with publicly available cost and performance data.

Table 1: SB 100 Core Scenario Classification List

Scenario Classification	Scenario Description
SB 100 Core Scenario	Includes retail sales and state loads; high electrification demand; all candidate resources available
SB 100 Core, Demand Sensitivities	Change: demand scenarios or load shape
SB 100 Core, Resource Sensitivities	Change: candidate resource availability

Source: CEC, CPUC, and CARB. Developed by consensus

Study Scenarios

The "Study Scenarios," shown in **Table 2**, are exploratory analyses that examine outcomes outside the scope of the joint agencies' interpretation of the SB 100 policy. They are intended to provide additional information for consideration and support broader state energy, climate planning, and public health efforts. Study scenarios should not be interpreted as asserting the state's ability or intention to regulate beyond the interpreted scope of SB 100.

Table 2: Study Scenario Classification List

Scenario Classification	Scenario Description
Expanded Load Coverage	Adds storage and system losses to included loads; high electrification demand; all candidate resources available. Demand and resource sensitives were also analyzed.
No Combustion	No conventional combustion resources included (fossil and biomass based); retires all in-state combustion resources by 2045.
Zero Carbon Firm Resources	Adds generic zero carbon firm resources to candidate resources as a proxy for emerging zero-carbon technologies.
Accelerated Timelines	Accelerates 100% target to 2030, 2035, and 2040.

Source: CEC, CPUC, and CARB. Developed by consensus

Zero-Carbon Resources Modeled

SB 100 does not define "zero-carbon resources," and the state had no legal definition prior to the bill becoming law. For modeling, the joint agencies interpreted "zero-carbon resources" to mean energy resources that either qualify as "renewable" in the most recent Renewables Portfolio Standard (RPS) Eligibility Guidebook or generate zero greenhouse gas emissions on site.

Only commercialized technologies with vetted and publicly available cost and performance data and an anticipated pipeline of development were included for the core scenarios. Moreover, the joint agencies excluded energy resources from some or all scenarios if the use of these resources would have significant negative effects on public health or the environment or were otherwise at odds with state policies and priorities. Excluded technologies may be included in future SB 100 analyses if assessments change. Staff will update modeling as emerging technologies become commercialized.

Table 3 lists technologies that could meet the SB 100 criteria for renewable and zero-carbon resources, as interpreted by the joint agencies. The list is not prescriptive but rather used to evaluate potential SB 100 implementation strategies.

Table 3: Generation Technologies Included in Modeling

Technology	Eligibility Basis	Scenarios
Solar PV	RPS	Core and Study
Solar Thermal (existing only)	RPS	Core and Study
Onshore Wind	RPS	Core and Study
Offshore Wind	RPS	Core and Study
Geothermal	RPS	Core and Study
Bioenergy	RPS	Core and Study
Fuel Cells (using green hydrogen)	RPS	Core and Study
Small Hydro (existing only)	RPS	Core and Study
Large Hydro (existing only)	Zero-Carbon	Core and Study
Nuclear (existing only)	Zero-Carbon	Core and Study
Generic Firm Dispatchable Resource	Zero-Carbon	Study Only
Generic Firm Baseload Resource	Zero-Carbon	Study Only

Source: CEC, CPUC, and CARB. Developed by consensus

Technologies that could meet the zero-emissions criteria but have other barriers to development were excluded from modeling for the reasons listed in **Table 4**.

Table 4: Considered Technologies Excluded From Modeling

Technology	Reason for Exclusion
New in-state nuclear	State effectively has a moratorium on new in-state nuclear power plants under the Warren-Alquist Act.
Drop-in renewable fuels (green hydrogen and biomethane)	Technology for synthetic drop-in renewable fuels not yet commercially available in California or inadequate cost and supply data for modeling or both. Inadequate supply potential for biomethane in the power sector.
Natural gas generation with carbon capture and sequestration	Lack of cost and performance data for 100 percent carbon capture.
Coal-fired generation with carbon capture and sequestration	Incompatible with the state's public health priorities and lack of cost and performance data for 100 percent carbon capture.
New small hydroelectric generation	Inadequate data on new capacity cost and resource availability for modeling purposes.
New concentrating solar power	Lack of proposed new development and high cost relative to other solar resources.
New large hydroelectric generation	Limited development feasibility at this time and environmental concerns.

Source: CEC, CPUC, and CARB joint agency consensus

Modeling Results

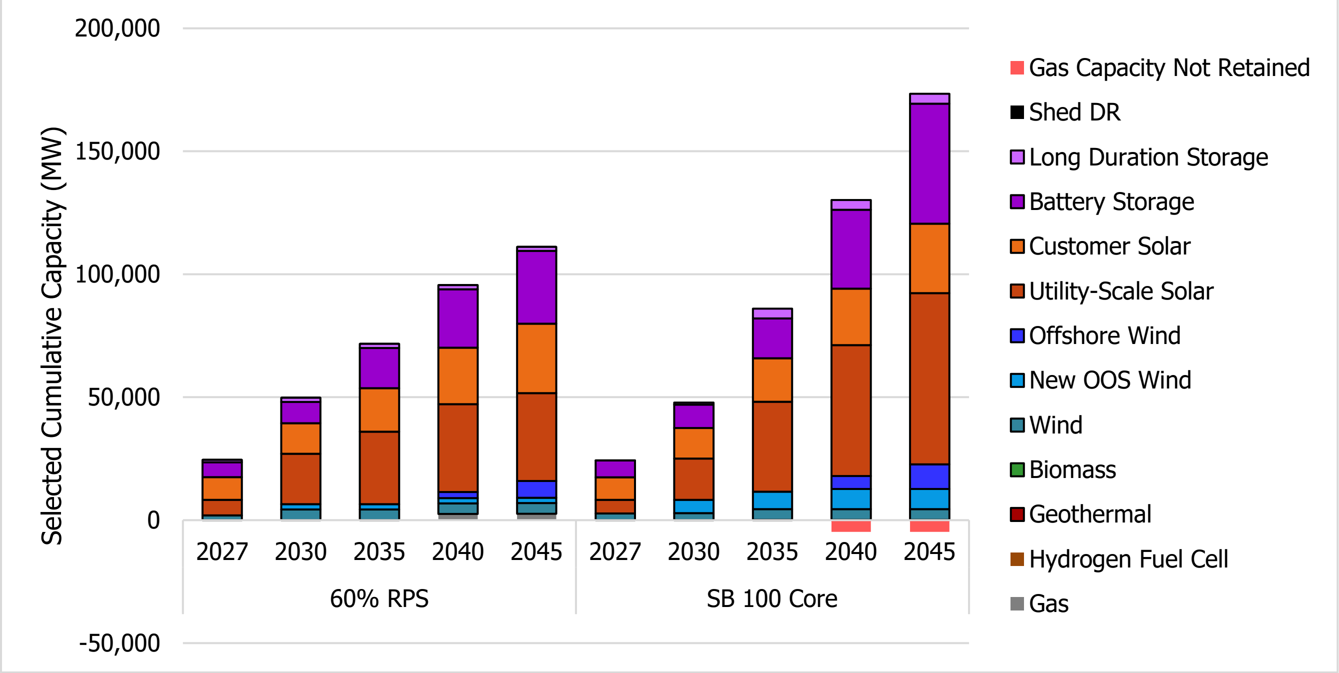
All scenarios modeled for the 2021 Report result in significant capacity additions. However, numerous factors affect the total resource need, overall system costs, and makeup of a 2045 resource portfolio. Select modeling results are shown below. For complete results, see Chapter 3.

Core Scenarios

SB 100 Core Scenario

Figure 3 shows cumulative capacity additions for the 60 percent RPS and SB 100 Core scenarios. The SB 100 Core scenario shows an approximate tripling of generation resources relative to today's installed capacity, which is driven by the conversion to clean electricity resources and growing electricity demand.

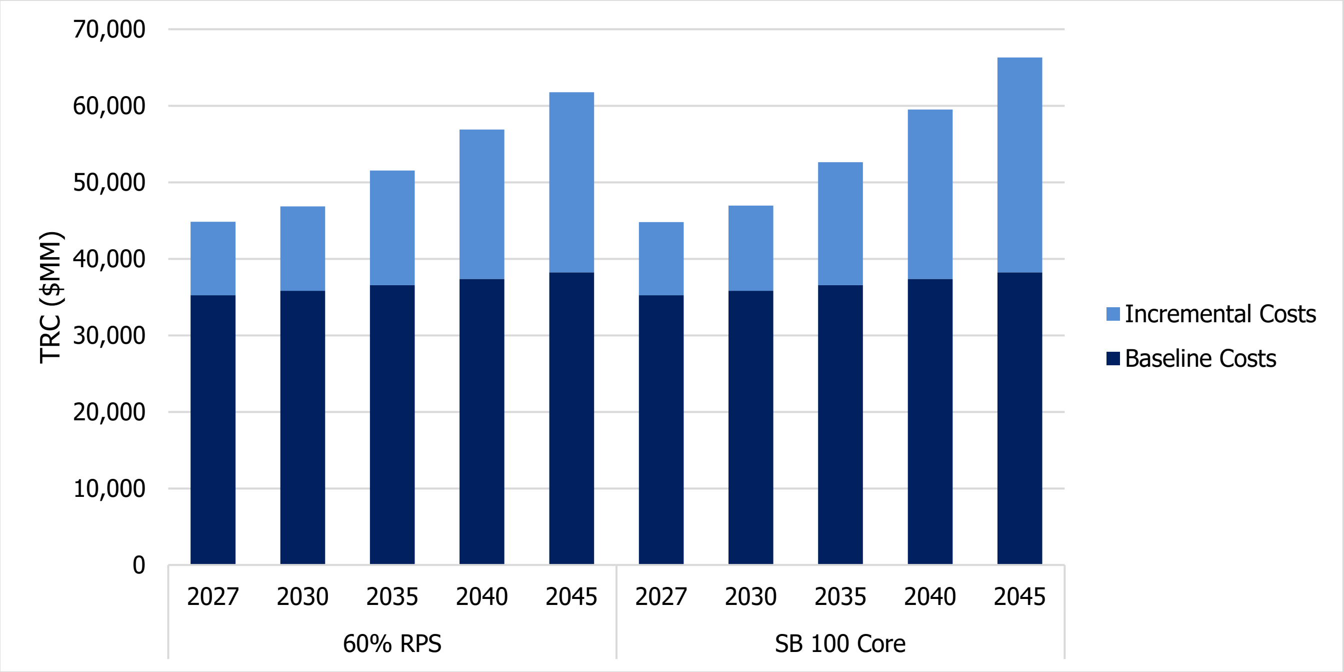
Figure 3: Cumulative Capacity Additions for SB 100 Core Scenario and 60 Percent RPS Reference Scenario



Source: CEC staff and E3 analysis

The SB 100 Core scenario results in nearly $4.5 billion in additional annual total resource cost (TRC) in 2045, or a 6 percent increase over the 60 percent RPS reference, as shown in **Figure 4**. Investments in renewables, storage and transmission constitute the primary differences in costs. All costs presented are directional and require further analysis.

Figure 4: Total Resource Cost of the 60 Percent RPS and SB 100 Core Scenarios

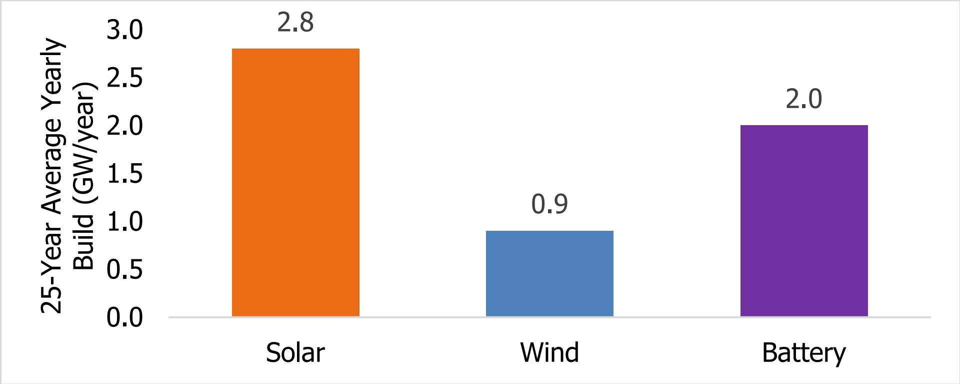


Source: CEC staff and E3 analysis

Given the magnitude of the capacity additions, the average build rates provide important implications for implementing the 100 percent clean electricity goal. Build rates can indicate whether there could be bottlenecks in supply-chain or regulatory and permitting processes, resulting in barriers to procurement of new clean energy generation.

Over the last decade, California has built on average 1 gigawatt (GW) of utility-scale solar and 300 MW of wind per year, with a maximum annual build of 2.7 GW of utility-scale solar and 1 GW of wind capacity. As shown in **Figure 5**, the SB 100 Core Scenario requires 25-year average build rates consistent with or greater than the single-year historical build rates.

Figure 5: Average Resource Build Rates for Solar, Wind and Batteries in the SB 100 Core High Electrification Scenario

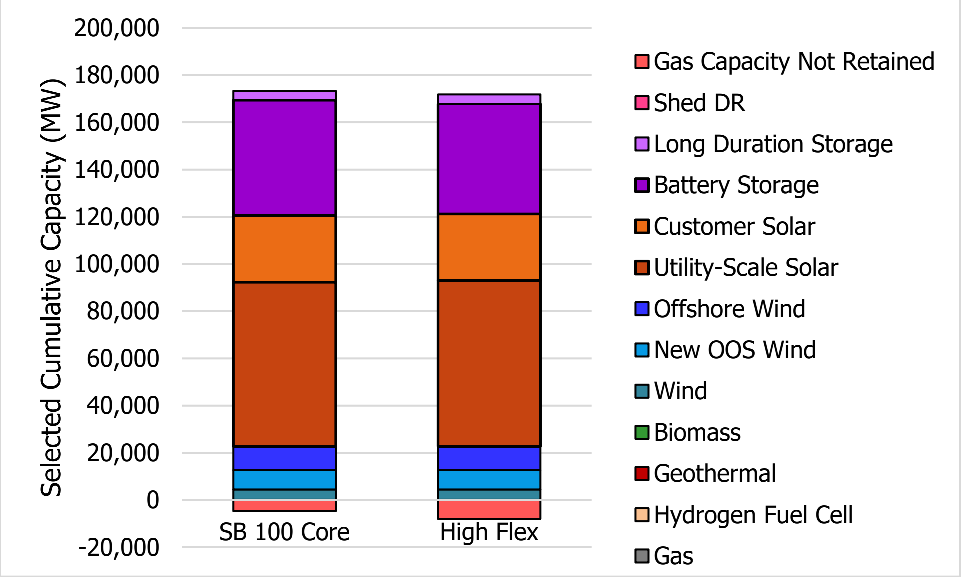


Source: CEC staff and E3 analysis

SB 100 Core: High Flexibility Scenario

The shape and flexibility of electricity loads can significantly impact cost and resource build. While RESOLVE cannot at this time explicitly model load flexibility, a high flexibility scenario was developed with a modified load shape and reduced resource adequacy requirement to represent a future with greater load flexibility. As shown in **Figure 6**, the High Flexibility Scenario results in 2.7 GW avoided battery storage build and a decrease in economic gas retention by 3.3 GW compared to the SB 100 Core Scenario, with the same annual electric energy demand. The High Flexibility Scenario also results in nearly $1 billion of annual supply cost savings in 2045, compared to the SB 100 Core Scenario.

Figure 6: Cumulative Capacity Additions in 2045 for the SB 100 Core and High Flexibility Scenarios



Source: CEC staff and E3 analysis

Study Scenarios

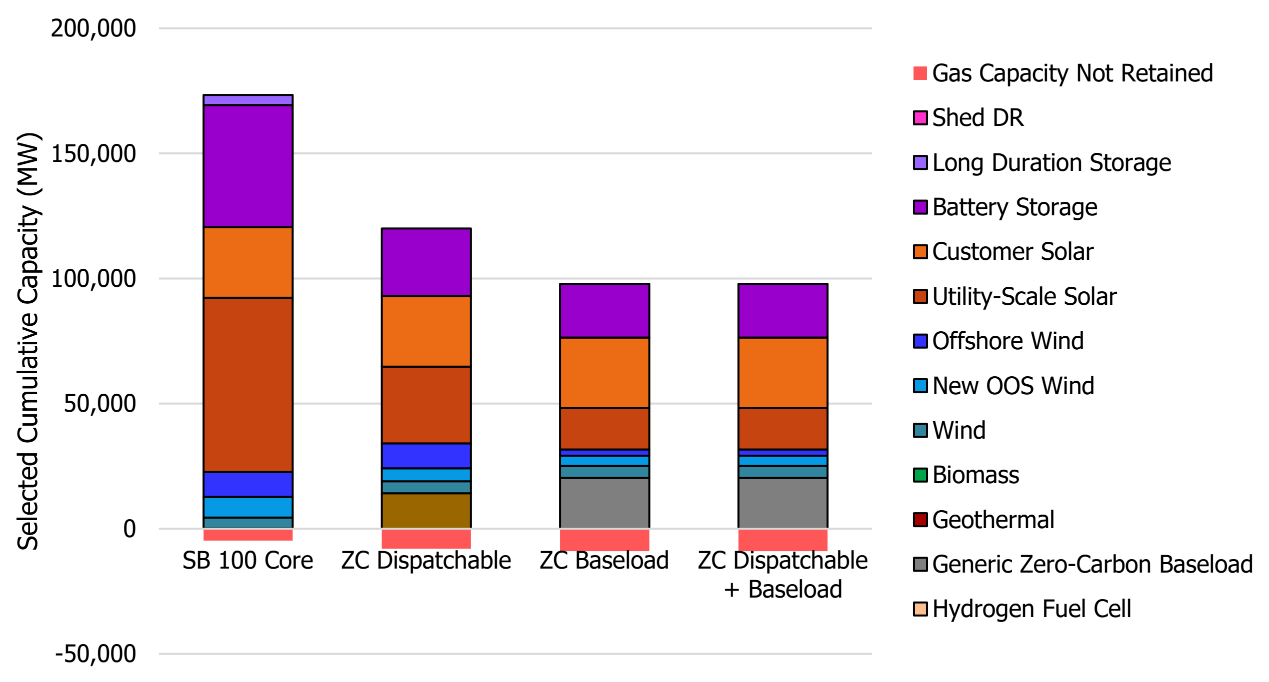
Study: Generic Zero-Carbon Firm Resources Scenario

A number of emerging zero-carbon technologies could play an important role in achieving the 100 percent renewable and zero-carbon electricity target. However, due to high uncertainty in the available cost and performance data of pre-commercialized technologies, some technologies were not included in the core scenarios. Instead, the joint agencies included study scenarios to begin to evaluate the potential impact of commercialization of cost-competitive, zero-carbon firm resources.

The "generic dispatchable" resource and "generic baseload" resource included in these scenarios could represent a wide variety of emerging technologies, such as natural gas with 100 percent carbon capture, 100 percent green hydrogen combustion, or other renewable fuels, if they are able to achieve the modeled cost profiles. The study scenarios could also indicate the effects of higher-cost existing resources achieving the modeled cost profiles.

In scenarios where either the generic dispatchable resource, generic baseload resource, or both are included as a candidate resource, the model selects about 15 GW of either or both resources in total, as shown in **Figure 7**. The inclusion of the lower-cost zero-carbon firm resources significantly lowers the utility-scale solar and battery storage selected in the model and reduces TRC in 2045 by $2 billion, or about 3 percent.

Figure 7: Cumulative Capacity Additions for the SB 100 Core and Generic Zero-Carbon Firm Resource Scenarios in 2045



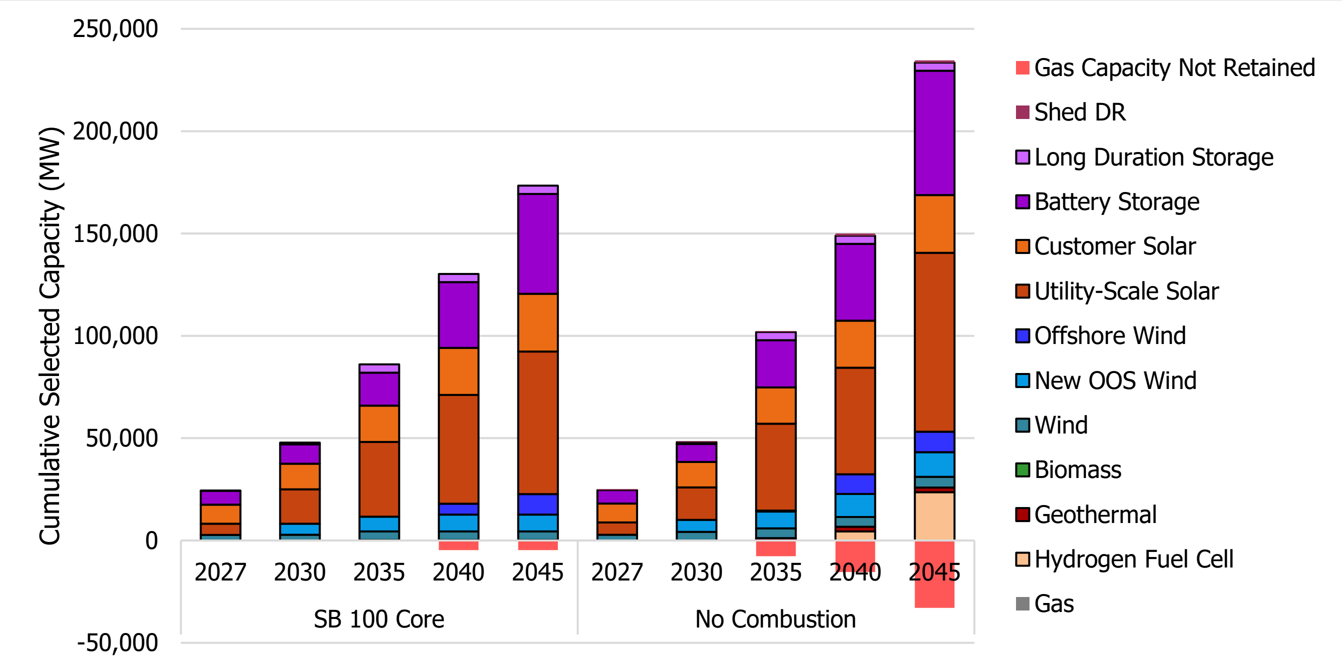
Source: CEC staff and E3 analysis

Study: No Combustion Scenario

SB 100 does not preclude combustion resources from being a part the state's resource portfolio. However, studying scenarios in which combustion resources are expressly retired can inform pathways to significantly reduce criteria pollutants and toxic air contaminants from electricity generation. To that end, the No Combustion Scenario retires all combustion resources by 2045, and no combustion resources are available as candidate resources.

With the retirement of all combustion resources, 61 GW of additional capacity is selected compared to the SB 100 Core Scenario, including 25 GW of hydrogen fuel cells, as shown in **Figure 8**. Given the significant capacity additions in the No Combustion Scenario, there is an increase annual TRC by $8 billion, or about 12 percent, compared to the SB 100 Core Scenario.

Figure 8: Cumulative Capacity Additions for the SB 100 Core and No Combustion Scenarios



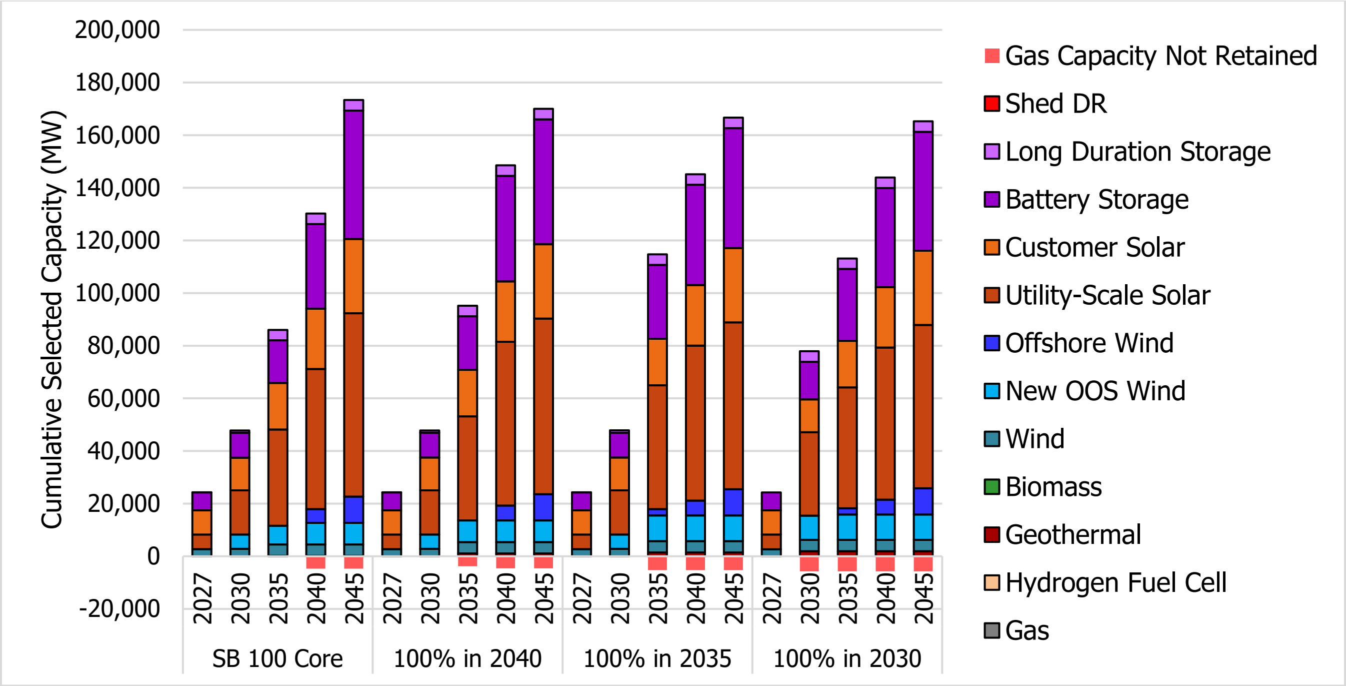
Source: CEC staff and E3 analysis

Study: Accelerated Timeline Scenarios

The final set of study scenarios examine the impacts of accelerating the 100 percent renewable and zero-carbon target to 2030, 2035, and 2040. Each accelerated timeline scenario shows a significant jump in resource build in the 100 percent target year, while the 2045 portfolio remains similar across scenarios, as shown in

Figure 9. The final set of study scenarios examine the impacts of accelerating the 100 percent renewable and zero-carbon target to 2030, 2035, and 2040. Each accelerated timeline scenario shows a significant jump in resource build in the 100 percent target year, while the 2045 portfolio remains similar across scenarios, as shown in **Figure 9**.

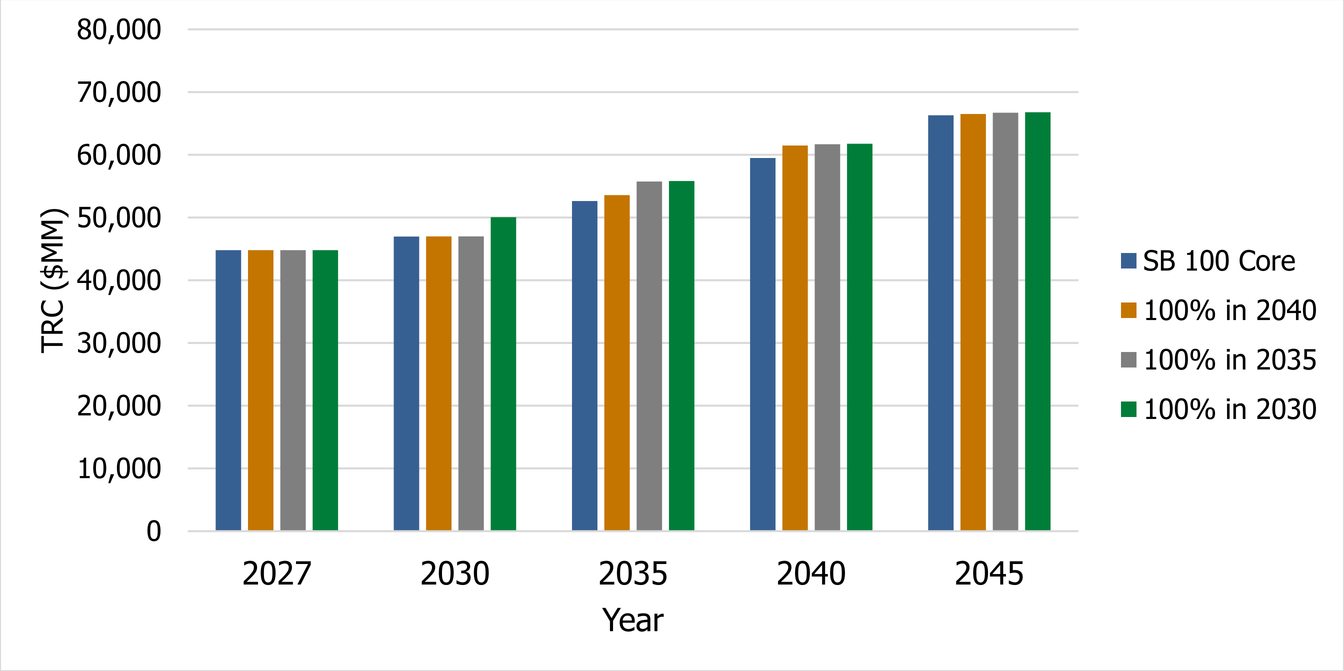
Figure 9: Cumulative Capacity Additions for the SB 100 Core (2045 SB 100), 100 Percent in 2040, 100 Percent in 2035, and 100 Percent in 2030 Scenarios



Source: CEC staff and E3 analysis

Each accelerated timeline scenario results in increased annual TRC compared to the SB 100 Core scenario for every modeled year except 2027, as shown in **Figure 10**. In general, the TRC shows a significant jump in the year the 100 percent target is set to be achieved. By 2045, the accelerated scenarios result in less than a 1 percent increase in TRC relative to the SB 100 Core scenario.

Figure 10: Total Resource Costs for the SB 100 Core, 100 Percent in 2040, 100 Percent in 2035, and 100 Percent in 2030 Scenarios



Source: CEC staff and E3 analysis

Key Takeaways From Modeling

1. SB 100 Is Achievable

Initial analysis demonstrates that SB 100 is technically achievable, though additional analysis is needed to evaluate reliability and other factors more comprehensively. The preliminary modeling in this report suggests the total resource cost of achieving SB 100 is about 6 percent higher than a 60 percent RPS future in 2045. This cost may be lower if the cost trends for renewables continue to fall faster than projections. Cost reductions and innovation in zero-carbon technologies, as well as load flexibility and energy storage development, can further reduce implementation costs.

- **Increased Resource Diversity Lowers Overall Costs**

  Resource portfolio diversity, both technological and geographical, generally lowers total resource costs. Nearly all out-of-state or offshore wind resources are selected when made available, and even a modest amount of load flexibility can reduce battery storage requirements, decrease gas capacity and lower total costs. If zero-carbon firm technologies can reach a cost of about $60/megawatt-hour (MWh), they could reduce system costs by an estimated $2 billion annually in 2045.

- **Gas Capacity Is Retained for Reliability Needs, but Cost Reductions and Innovation in Zero-Carbon Firm Resources and Storage May Reduce Gas Capacity Needs**

  Natural gas capacity is the most economic option to provide capacity for reliability needs with current resource assumptions and demand scenarios. Cost reductions and innovation in zero-carbon firm resources and storage may reduce the amount of gas generation needed. Further analysis is needed to evaluate costs associated with maintaining an aging gas fleet operating in a high-renewables system.

2. Sustained Record-Setting Build Rates Will Be Required to Meet SB 100 in a High-Electrification Future

The need for a significant amount of new generation resources is driven by the 100 clean electricity target and increasing electricity demand to achieve economywide decarbonization. The projected record-setting resource development rates needed have implications for workforce needs, land-use planning, technology supply chains, and regulatory and permitting processes that must be considered for implementing SB 100 successfully.

3. Goals Beyond SB 100 May Be Achievable but Require Additional Analysis

The study scenarios are beyond the scope of SB 100. However, they provide directional insight to inform the state's energy and climate planning efforts and contribution toward environmental and public health goals.

Eliminating all in-state combustion resources results in a significant increase in the amount of storage and zero-carbon firm resources selected by the model to replace natural gas capacity. This scenario adds an estimated $8 billion to annual system costs in 2045 compared to the SB 100 Core scenario. Further analysis could identify public health benefits, particularly in disadvantaged communities where a disproportionate amount of combustion resources is located. This analysis may estimate the relative public health benefits along with the additional costs.

Accelerating the SB 100 timeline to achieve the 2045 target by 2030, 2035, or 2040 results in increased total resource costs and required additional capacity in the target year. All scenarios resulted in similar annual resource costs and resource portfolios by 2045.

4. Current SB 100 Analysis Is Directional, and Further Analysis Is Necessary

This analysis is the first step in an ongoing effort to evaluate and plan for the SB 100 policy. Further analysis is necessary to determine reliability of the portfolios, better capture the impact and value of resources that are either not represented or not well valued in the current modeling framework — including long-duration storage, hybrid resources, demand-side resources, load flexibility, and emerging technologies, such as green hydrogen and natural gas with 100 percent carbon capture and sequestration — as well as assess local community impacts.

Next Steps for Analysis

The analysis in the 2021 Report is intended to be a first step in an iterative and ongoing effort to assess barriers and opportunities to implementing the 100 percent clean energy policy. The modeling of this report provides directional insights into what a 2045 portfolio of renewable and zero-carbon resources may look like, as well as the associated costs and resource build requirements to achieve such a portfolio. Topics for additional assessment include:

- *Reliability*: The joint agencies plan to evaluate resource portfolios developed in this report in a multistep process to ensure reliability for all hours of the year in line with state planning requirements while meeting clean energy and climate goals.
- *Emerging Technologies and Innovation*: Future analyses will be updated to incorporate market trends and aim to better evaluate the potential impact of emerging resources, such as offshore wind, long-duration energy storage, green hydrogen technologies, and demand flexibility.
- *Land-Use and Environmental Impacts:* The joint agencies plan to review methods to include land-use impacts in system modeling and assess needs to update previous land use studies to reflect the increased resource requirements of SB 100.
- *Non-Energy Benefits (NEBs) and Social Costs:* Emerging cost analysis tools and methods may better integrate social costs and NEBs. Stakeholders recommended the joint agencies integrate at least the following NEBs and social costs into SB 100 planning:
    - Land-use impacts
    - Public health and air quality
    - Water supply and quality
    - Economic impacts
    - Resilience

Additional Considerations for Implementation

As the SB 100 scenarios are refined in the future, additional factors must be considered in planning for SB 100 implementation and coordination with complementary proceedings and programs:

- *Equity:* Steps must be taken to ensure equitable implementation of SB 100 and benefit communities in a meaningful and measurable way.
- *Affordability:* Meeting the 100 percent clean electricity target will likely require substantial new investments in the electric system, which may have impacts on electricity rates for consumers. Further analysis is required to better understand how these costs will be factored into rates that directly affect consumers.
- *Safety:* California is assessing how to address numerous new risks associated with electric and gas infrastructure and how to pay for needs including system maintenance, hardening, repurposing, upgrades, or retirement. State planners must incorporate

safety challenges in long-term planning and identify approaches to decarbonization that enhance public safety.

- *Electric System Resilience:* Cost-effective achievement of the 100 percent clean electricity target requires that investments in electricity generation and infrastructure consider climate change impacts. State agencies are also exploring options for clean backup power when there are disruptions to the grid.
- *Addressing Barriers to Project Development:* The analysis indicates that resources with lengthy permitting requirements and development times will be necessary, necessitating long lead-time planning. Stakeholders raised concerns about delays, which may need to be addressed to meet the SB 100 target.
- *Collaboration Across Western States:* There are opportunities for increased coordination and market development to ease importation and integration of additional renewable energy facilities and take advantage of the geographic diversity of loads and resources.

Recommendations

Following the results of the 2021 Report analysis and comments from stakeholders and the public, the joint agencies propose a number of key recommendations to support the implementation of SB 100 and inform long-term planning, which are summarized below.

Areas for Further Study in the 2025 SB 100 Report

1. **Perform a comprehensive reliability assessment as the next step in the modeling process.**

   Additional modeling is needed to evaluate whether the projected portfolios meet system reliability requirements. Projected portfolios can be adjusted as needed in an iterative process to ensure reliability requirements are met and inform the state's long-term system planning.

   The CEC and CPUC are assessing resource availability to complete this modeling ahead of the next report. The joint agencies will continue to consult with the California balancing authorities when developing the tools and metrics for this analysis.

2. **Continue to assess the role and impacts of emerging technologies and nongeneration resources.**

   Future analyses should be updated to reflect market trends, including changes in price, the commercialization of new technologies, and updates to total resource potential. Furthermore, the joint agencies should continue to evaluate and consider ways to better assess the impacts of less-proven technologies that could significantly impact a 2045 resource mix and total cost.

3. **Analyze projected land-use impacts of scenarios and opportunities to reduce environmental impacts.**

   The CEC is developing tools to better assess the total land area required to implement SB 100, areas where new resources could be located, and relative environmental impacts. As state agencies work to better quantify the carbon stored in natural and working lands, these areas must also be incorporated into electricity land-use planning. Closer collaboration with other state agencies, tribal governments, local and regional jurisdictions, and stakeholders, to plan for development will be important to balance clean electric grid infrastructure needs with efforts to restore, conserve, and strengthen natural and working lands.

4. **Define and include social costs and non-energy benefits (NEBs) in future analyses.**

   The joint agencies will continue evaluating available modeling tools and metrics to capture non-energy benefits and social costs in future SB 100 analyses, including those for:

   - Land-use impacts
   - Public health and air quality
   - Water supply and quality
   - Economic impacts
   - Resilience

5. **Continue to study opportunities and impacts related to achieving the 100 percent clean electricity target before 2045.**

   The joint agencies plan to continue analysis of the 2030, 2035, and 2040 scenarios in future SB 100 report analyses.

Process and Engagement for SB 100 Reports

6. **Convene an annual joint agency SB 100 workshop in years between reports.**

   Hosting an annual workshop will support alignment between agencies on relevant topics and proceedings and enhance continuity between SB 100 reports. These workshops will also provide an opportunity for joint agency leadership and staff to hear from stakeholders and the public on topics related to SB 100 progress.

7. **Align future SB 100 planning with findings and outcomes from relevant state efforts.**

   The joint agencies aim to incorporate findings and outcomes from other relevant efforts in future SB 100 reports. Relevant efforts include:

   - The CEC's energy demand forecasts, including electrification trends and updates for extreme climate event planning.

- Transmission planning and development.
- Reliability planning, including possible updates to resource adequacy requirements.
- Electric system resilience planning.
- Assessments from CPUC’s Integrated Resource Planning, CEC’s Integrated Energy Policy Report, and CARB’s Scoping Plan.

8. **Consult with advisory groups to guide equitable planning and implementation.**

   The DACAG and other environmental justice, health, and equity stakeholders provided valuable input for this report. For the 2025 SB 100 Report, the joint agencies plan to continue and build upon this collaboration to help ensure SB 100-related efforts benefit all Californians.

9. **Retain and expand upon best practices for community outreach and accessibility.**

   The joint agencies worked to ensure broad access to the 2021 Report process by holding workshops across the state, conducting significant outreach by phone, email, and social media, and offering remote attendance options for all workshops. The agencies will retain these best practices for the 2025 SB 100 Report while exploring additional methods to maximize participation and access to meeting information and materials for California residents.

Supporting Achievement of the 100 Percent Target

10. **Continue state support for research and innovation in clean energy technologies.**

    Continued investments in research and innovation can accelerate technology performance and cost improvements that can make progress toward the SB 100 goal easier and faster and reduce costs to electricity ratepayers. California’s research and innovation programs, including the Electric Program Investment Charge (EPIC), will continue to catalyze advancements to support the cost-effective implementation of SB 100. The state’s ongoing collaboration with cleantech incubators, research labs, and private investment firms will be critical to leveraging state funding in innovation.

11. **Continue to prioritize energy efficiency and load flexibility to minimize total implementation costs.**

    Prioritizing cost-effective energy efficiency and load-flexibility measures remains critical as the state moves toward a 100 percent clean electricity future. Taking steps to reduce energy demand can offset the need for additional generation capacity, saving Californians money, while reducing land-use and other environmental impacts associated with the construction of new facilities.

12. **Identify and address bottlenecks in project permitting and development.**

    Because SB 100 implementation is projected to require sustained record-setting construction rates, barriers to project development need to be addressed early and comprehensively. The CEC and CPUC should engage with stakeholders — including developers, utilities, balancing authorities, local governments, and community organizations — to better understand specific barriers and advance strategies to address them.

13. **Promote workforce development programs that focus on high-quality job creation.**

    Implementation of SB 100 creates a significant opportunity to support California companies, benefit local economies, and create family-sustaining jobs while optimizing climate outcomes. The joint agencies should continue collaborating with the California Workforce Development Board (CWDB) to identify strategies and best practices to support an equitable clean energy workforce and high-quality job creation, including findings from CWDB's 2020 report, Putting California on the High Road. The agencies should also seek the expertise of the DACAG workforce subcommittee.

CHAPTER 1: Background

Clean Energy Efforts Across the Nation

In 2018, California became the second state, after Hawaii, to establish a 100 percent clean electricity target. Today, 17 states, plus Washington D.C. and Puerto Rico, have adopted similar policies, along with more than 200 cities and counties.[1] More than one-third of Americans, or roughly 111 million residents, live in a state or community committed to 100 percent clean electricity.[2]

The SB 100 joint agencies engage with the other committed states and entities through the 100 Percent Clean Energy Collaborative, established by the Clean Energy States Alliance, to promote knowledge-sharing and updates on implementation efforts.

Decades of Climate Leadership

California has long led the nation and the world in setting ambitious renewable energy and climate policies, working toward a clean economy that is healthier and more just. The state became a global leader in climate policy with the passage of the California Global Warming Solutions Act of 2006,[3] which requires a reduction of statewide GHG emissions to 1990 levels by 2020.41F[4] California met the target four years early and continues to accelerate decarbonization economywide.

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1 Clean Energy States Alliance. 100% Clean Energy Collaborative - Table of 100% Clean Energy States https://www.cesa.org/projects/100-clean-energy-collaborative/table-of-100-clean-energy-states/, and UCLA Luskin Center for Innovation. November 2019. *Progress Toward 100% Clean Energy in Cities and States Across the U.S.* https://innovation.luskin.ucla.edu/wp-content/uploads/2019/11/100-Clean-Energy-Progress-Report-UCLA-2.pdf.

2 Ibid.

3 California Global Warming Solutions Act of 2006 (Assembly Bill 32, Núñez, Chapter 488, Statutes of 2006).

4 For more information, see the link to the California Air Resources Board AB 32 Overview Webpage, http://www.arb.ca.gov/cc/ab32/ab32.htm.

Table 5: California's Key Greenhouse Gas Reduction Policies

Year	Policy	Description
2006	AB 32 (Núñez)	Reduce statewide GHG emissions to 1990 levels by 2020.
2006	SB 1368 (Perata)	Prohibits long-term investments in baseload power plants[5] with GHG emission rates higher than those of natural gas combined-cycle generation.
2015	SB 32 (Pavley)	Reduce statewide GHG emissions to 40 percent below 1990 levels by 2030.
2015, 2005	Executive orders B-30-15 and S-3-05	Reduce statewide GHG emissions to 80 percent below 1990 levels by 2050.
2018	Executive Order B-55-19	Achieve carbon neutrality no later than 2045 and maintain net negative emissions thereafter.

Source: CEC staff

Putting a Price on Carbon

California launched a Cap-and-Trade Program in 2012 to ensure its climate goals are achieved cost-effectively. It places a firm, declining cap on the largest sources of GHG emissions, such as large power plants, importers of electricity, industrial plants, and natural and transportation fuel suppliers.

The program covers 80 percent of the state's GHG emissions and creates a powerful economic incentive for significant investment in cleaner, more efficient technologies. Companies covered by the program have flexibility to reduce emissions onsite or use allowances bought at state-administered auctions or from another company with excess allowances. All covered entities in the Cap-and-Trade Program are subject to existing air quality permit limits for criteria and toxic air pollutants.

The California Climate Investments initiative spends the auction revenue on projects that further reduce greenhouse gas emissions, strengthen the economy, and improve public health and the environment. Cumulatively, the program has invested $6.3 billion in these projects.[6]

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[5] Those intended to run constantly at near capacity levels.

[6] State of California - California Climate Investments Data Dashboard Web page https://www.caclimateinvestments.ca.gov/cci-data-dashboard.

Increasing Renewable Energy Generation

The Renewables Portfolio Standard (RPS), established by law in 2002,[7] has been a primary driver for increasing clean electricity generation. The law and subsequent amendments require the state's electric utilities to make renewables an ever-greater percentage of their power base. SB 100 expands the RPS and requires 60 percent of electricity retail sales to be met by eligible renewable resources by December 31, 2030.

The CPUC implements and administers RPS compliance for California's retail sellers of electricity, which include investor-owned utilities (IOUs), electric service providers (ESPs) and community choice aggregators (CCAs). The CEC oversees enforcement of RPS procurement requirements of public owned utilities (POUs) and is responsible for the certification of eligible renewable energy resources.

Eligible Renewable Energy Resources[8]

For RPS compliance, generation must be procured from certified facilities, which include:

- Solar
- Wind
- Geothermal
- Biomass, such as crop residues, forest waste, and landscape trimmings
- Biomethane from landfills and organic waste digesters
- Small hydroelectric
- Fuel cells using renewable fuel or qualifying hydrogen gas

State efforts have also supported rapid growth of the distributed solar industry. The California Solar Initiative of 2006[9] was particularly successful. The $3.4 billion, decade-long effort created a self-sustaining solar market. Thousands of home and business owners earned rebates by installing solar energy systems through the suite of incentives of the initiative.

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7 Senate Bill 1078 (Sher, Chapter 516, Statutes of 2002) created the RPS with an initial target of 20 percent renewable electricity by 2017, citing an opportunity to "promote stable electricity prices, protect public health, improve environmental quality, stimulate sustainable economic development, create new employment opportunities, and reduce reliance on imported fuels." The CPUC regulates RPS rules for California's retail sellers of electricity. The California Energy Commission (CEC) administers the certification of electrical generation facilities as eligible renewable energy resources and regulates RPS requirements for public owned utilities. For more information, see CPUC RPS Program website and CEC RPS Program website.

8 For more information see California Energy Commission. *Renewables Portfolio Standard Eligibility Guidebook, Ninth Edition (Revised)*. Publication Number: CEC-300-2016-006-ED9-CMF-REV. January 2017. https://efiling.energy.ca.gov/getdocument.aspx?tn=217317.

9 Senate Bill 1 (Murray, Chapter 132, Statutes of 2006), Senate Bill 1 (Murray, Chapter 132, Statutes of 2006).

In 2018, the CEC adopted a building energy efficiency code[10] requiring most new homes to have solar photovoltaic systems (or be powered by a solar array nearby) starting January 1, 2020. With continuing cost declines, solar is now cost-effective for new home construction across the state. In 2019, California reached the milestone of 1 million solar rooftop installations.[11]

Key Renewable Energy Policies

Table 6: Key Renewable Energy Legislation

Year	Policy	Description
2002	SB 1078 (Sher)	Established RPS program and target of 20 percent renewable energy in state's electricity mix by 2017
2006	SB 1 (Murray)	Codified California Solar Initiative, a $3.4 billion decade-long program to create a self-sustaining solar market
2006	SB 107 (Simitian)	Accelerated the 20 percent RPS target from 2017 to 2010
2011	SB X1-2 (Simitian)	Added RPS target of 33 percent by 2020
2015	SB 350 (De León)	Adds RPS target of 50 percent by 2030, a doubling of energy efficiency by 2030, and steps to ensure all Californians, including those in the most vulnerable communities, realize benefits of a clean energy economy
2018	SB 100 (De León)	Increases RPS mandate to 60 percent by 2030 and set a 2045 target for renewable and zero-carbon resources to supply 100 percent of retail sales and electricity procured for all state agencies.
2018	2019 Building Energy Efficiency Standards	Requires solar photovoltaic systems on new homes starting in 2020

Source: CEC staff and California Legislative Information

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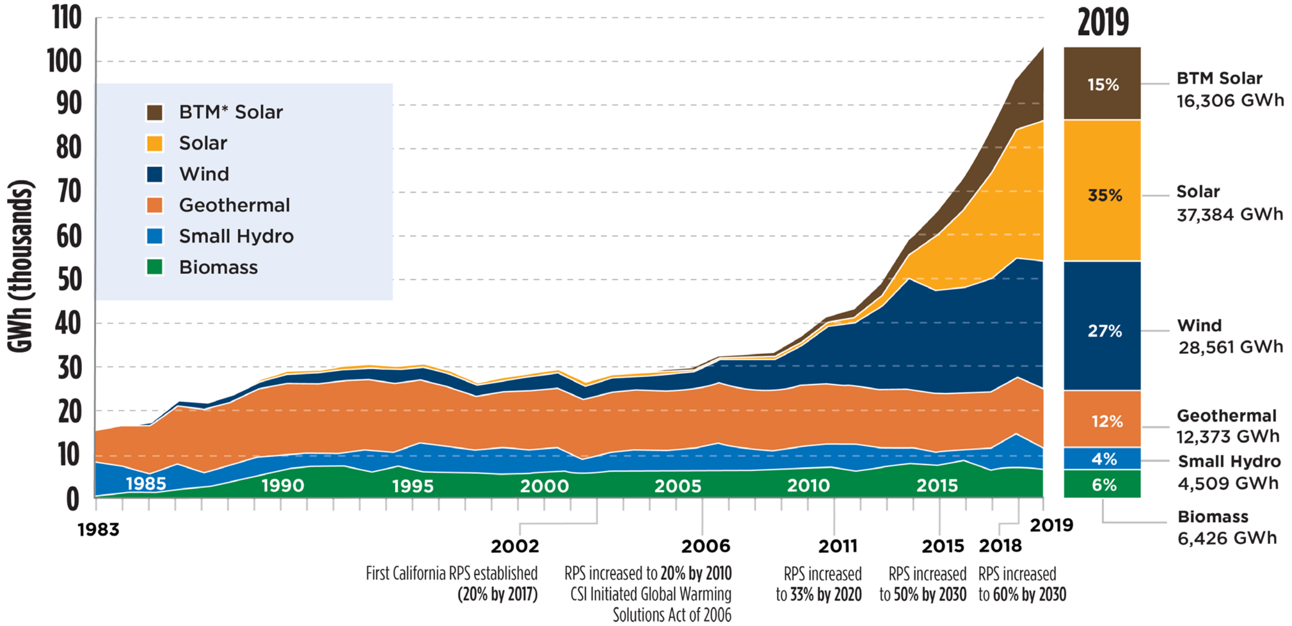
[10] See CEC 2019 Building Energy Efficiency Standards Web page https://www.energy.ca.gov/programs-and-topics/programs/building-energy-efficiency-standards/2019-building-energy-efficiency.

[11] California Solar +_Storage Association, December 12, 2019. *California Celebrates Reaching One Million Solar Roofs Milestone; New Focus On "One Million Solar Batteries" Goal*. Link to article titled California Celebrates Reaching One Million Solar Roofs Milestone; New Focus On "One Million Solar Batteries" Goal https://calssa.org/press-releases/2019/12/12/california-celebrates-reaching-one-million-solar-roofs-milestone-new-focus-on-one-million-solar-batteries-goal.

The effects of these policies can be seen in

Figure 11. In the past five years, solar generation has increased more than 350 percent, and behind-the-meter (BTM) solar resources have more than doubled.

Figure 11: Total Renewable Generation Serving California Load by Resource Type



Source: CEC Tracking Progress – Renewable Energy, February 18, 2020, Link to CEC Tracking Progress – Renewable Energy, https://www.energy.ca.gov/sites/default/files/2019-12/renewable_ada.pdf.

Benefits of 100 Percent Clean Electricity

Improving Public Health

Statewide, more than 28 million Californians live in areas that exceed the federal health-based standards for ozone and fine particulate matter (PM$_{2.5}$).[12] Implementation of SB 100 is expected to reduce these emissions as renewable and zero-carbon resources replace fossil fuels in generating electricity. Prioritizing this transition in disadvantaged communities will reap the highest public health benefits. Today, half of the state's natural gas power plants are in communities that rank among the 25 percent most disadvantaged.[13]

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[12] CARB. Workshop Discussion Draft: 2020 Mobile Source Strategy. September 30, 2020. https://ww2.arb.ca.gov/sites/default/files/2020-09/Workshop_Discussion_Draft_2020_Mobile_Source_Strategy.pdf.

[13] Physicians, Scientists, and Engineers for Healthy Energy. Research brief: 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.

Public health benefits are expected to grow substantially throughout the state as the transition from fossil fuels to clean electricity accelerates in transportation and buildings. Cars, trucks, and buses are leading sources of air pollution in California. Research has shown that Latinos, African Americans, and low-income communities are exposed to substantially higher levels of vehicle pollutants than other demographic groups.[14]

Air pollution from heating and cooking with natural gas also poses a significant public health risk. Natural gas appliances emit several harmful air pollutants, including carbon monoxide, nitrogen oxides (NOx), particulate matter, and formaldehyde. Researchers with the UCLA Fielding School of Public Health recently explored the link between these appliances and various acute and chronic health effects, such as respiratory illness, cardiovascular disease, and premature death. They found that if all residential gas appliances in California were immediately replaced with clean electric alternatives, the reduction of outdoor NO_X and $PM_{2.5}$ would result in 354 fewer deaths over a year.[15]

The compound health effects of air pollution were recently highlighted when researchers at the Harvard University T. H. Chan School of Public Health found that higher levels of the tiny, dangerous $PM_{2.5}$ particles in air were associated with higher death rates from COVID-19.[16] Dr. Aaron Bernstein,[17] interim director at the school's Center for Climate, Health, and the Global Environment, said the findings are particularly important for people in poor neighborhoods and communities of color: "Higher death rates [from COVID-19 infection] that have been observed among the poor and people of color in the United States reflect existing health and economic inequalities that both contribute to, and result from, greater exposure to air pollution."[18]

Advancing Energy Equity

California's energy and environmental efforts focus on low-income and "disadvantaged communities," a state designation for low-income census tracts that suffer additional burdens, such as poor health, high unemployment and poor air or water quality. The joint agencies are committed to ensuring the benefits of cleaner, more efficient energy are enjoyed by all

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[14] Union of Concerned Scientists. "Inequitable Exposure to Air Pollution from Vehicles in California (2019)" January 28, 2019. https://www.ucsusa.org/resources/inequitable-exposure-air-pollution-vehicles-california-2019.

[15] UCLA Fielding School of Public Health. *Effects of Residential Gas Appliances on Indoor and Outdoor Air Quality and Public Health in California*. April 2020. https://ucla.app.box.com/s/xyzt8jc1ixnetiv0269qe704wu0ihif7.

[16] *Science Advances Magazine*. "Air pollution and COVID-19 mortality in the United States: Strengths and limitations of an ecological regression analysis" Volume 6, No. 45, November 4, 2020. https://advances.sciencemag.org/content/6/45/eabd4049. More recently, CARB is funding two studies to examine the impacts of chronic air pollution exposure on the risk, progression, and severity of COVID-19.

[17] Dr. Bernstein, an assistant professor at Harvard Medical School, was not involved in the study.

[18] Harvard T. H. Chan School of Public Health, Coronavirus and Air Pollution Web page, https://www.hsph.harvard.edu/c-change/subtopics/coronavirus-and-pollution/.

Californians, including those in low-income and disadvantaged communities, as well as tribal and rural communities.

To ensure equitable outcomes,[19] SB 100 will need to be implemented in ways that help these communities overcome barriers to clean energy, including:

- Keeping electricity affordable, with an emphasis on vulnerable populations and households that pay a disproportionately high share of their household income on energy.
- Reducing air pollution from local power plants, particularly in communities that experience a disproportionate amount of air pollution.
- Strengthening their ability to function during power outages and enjoy reliable energy in a changing climate.
- Funding of training for high-quality jobs and careers in the growing clean-energy industry.

Disadvantaged Communities Advisory Group

The Clean Energy and Pollution Reduction Act of 2015 (SB 350) called for the formation of this group to ensure that disadvantaged communities, including tribal and rural communities, benefit from clean energy and pollution reduction initiatives. The 11-member group meets several times a year to review CEC and CPUC clean energy programs and policies. Members are either from or represent disadvantaged communities.

In 2018, the DACAG adopted an Equity Framework[20] that can serve as a guide for SB 100 program design, outreach, and workforce development efforts. During the development of this report, the group also formed a subcommittee focused on SB 100. The subcommittee and other environmental justice and equity organizations provide valuable insights on ways to ensure energy equity as the state advances toward a clean energy future.

Supporting a Clean Energy Economy

As a clean energy leader boasting one of the world's largest economies, California has shown that economic growth and environmental protection are not mutually exclusive. For decades,

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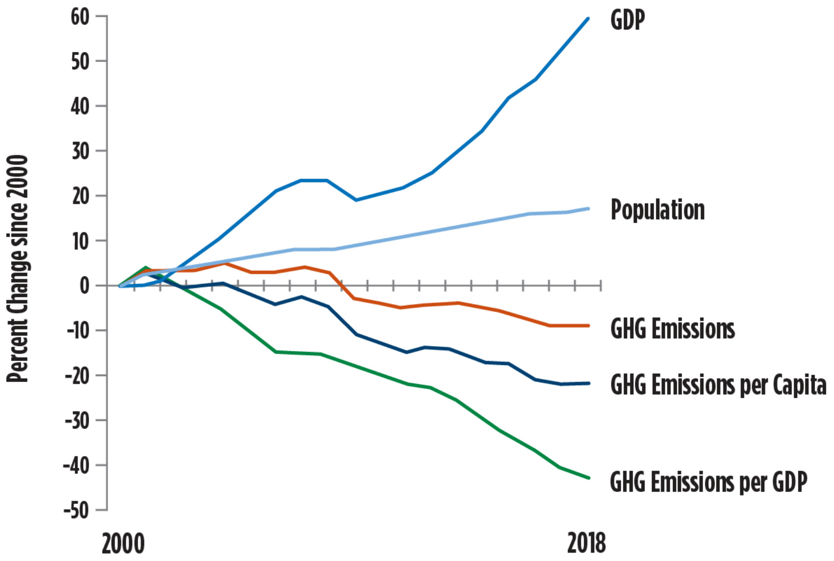
[19] "Equity" is defined as reducing disparities between different populations. Environmental equity, then, is (at least in part) about ensuring disadvantaged populations have equitable access to clean energy and other "environmental goods/services." Economic equity in this clean energy context, would therefore aim to ensure disadvantaged workers have equitable access to high-quality clean energy jobs or careers.

[20] Disadvantaged Communities Advisory Group, Equity Framework, https://www.cpuc.ca.gov/uploadedFiles/CPUCWebsite/Content/UtilitiesIndustries/Energy/EnergyPrograms/Infrastructure/DC/DAC%20AG%20Equity%20Framework%20(Revised).pdf.

the state has reduced GHG emissions while growing its economy at a rate that has consistently outpaced the U.S. national average.[21]

Figure 12: Statewide Trends of Emissions and Indicators (2000–2018)



Source: CARB[22]

California's policies have spurred innovation and created markets for renewable energy, energy efficiency, energy storage, low-carbon fuels, and zero-emission vehicles. The state is a leader in patent registrations across all major clean technology (cleantech) categories, with 3.5 times more patents than the next highest state, Texas.[23] Patents in energy storage, a key technology to achieving SB 100 goals, increased more than 65 percent from 2017 to 2018.[24]

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[21] Bureau of Economic Analysis. "Gross Domestic Product by State, 2nd Quarter 2020." Released October 2, 2020. https://www.bea.gov/data/gdp/gdp-state.

[22] California Air Resources Board. GHG Emission Inventory Graphs https://ww2.arb.ca.gov/ghg-inventory-graphs.

[23] Next10.org. 2019 California Green Energy Innovation Index, 11th Edition. October 2019. https://www.next10.org/sites/default/files/2019-10/2019-california-green-innovation-index-final.pdf.

[24] Next10.org. 2019 California Green Energy Innovation Index, 11th Edition. October 2019. https://www.next10.org/sites/default/files/2019-10/2019-california-green-innovation-index-final.pdf.

In addition, California's companies have received more than 50 percent of all U.S. venture capital investment in cleantech.[25]

As of 2020, California had more than 530,000 clean energy jobs,[26] more than half of the total energy-related jobs in the state. The cleantech companies range from start-ups to large manufacturers in the fields of renewable energy, grid modernization, energy storage, energy efficiency, and clean vehicles.[27] Most of these jobs require workers skilled in the construction trades and crafts.[28] Examples include performing building energy retrofits, solar and wind system installation, electric vehicle charging equipment installation, and battery storage maintenance and repair.

The global COVID-19 pandemic has dramatically affected California's energy sector. The cleantech industry has suffered some of largest job losses since social distancing and other precautions took hold in March 2020. During the first three months, the clean energy workforce declined by 20 percent, roughly 110,000 jobs.[29] The latest available data shows jobs slowly increasing from June through October, yet net losses remained at more than 76,000 jobs.

A Cornerstone of California's Clean Energy Efforts

Successful implementation of SB 100 alone will not achieve statewide carbon neutrality, but it is a cornerstone of California's climate-fighting efforts that collectively can reach the target. A clean electricity grid can serve as a backbone to support the decarbonization of transportation, buildings, and some industries that, together with the electricity sector, account for 92 percent of the state's GHG emissions.

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25 Next10.org. *2020 California Green Energy Innovation Index, 12th Edition*. December 2019. https://www.next10.org/sites/default/files/2020-12/2020-california-green-innovation-index-final_0.pdf.

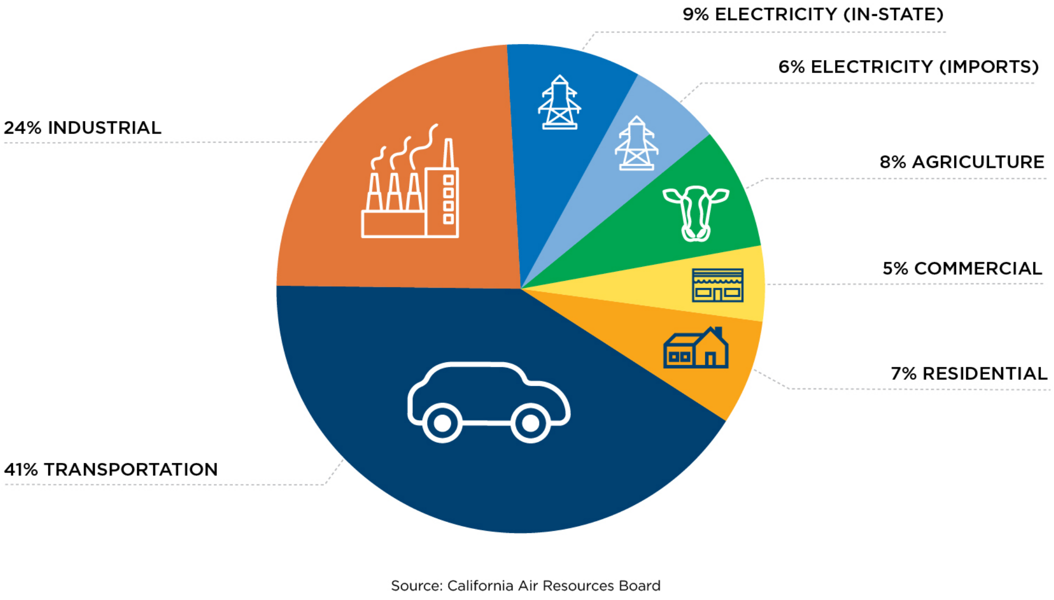
26 E2.org. Clean Jobs California 2020. June 25, 2020. https://e2.org/reports/clean-jobs-california-2020/.

27 The Clean Jobs California 2020 Report, sponsored by the CEC and CPUC, details employment demographic data from more than 4,500 energy employers in the last quarter of 2019.

28 According to E2, one in five construction workers are employed in clean energy, 43 percent of solar and wind energy jobs are in construction, and nearly 6 in 10 energy efficiency employees work in construction. Source: Clean Jobs America. April 2020. https://e2.org/wp-content/uploads/2020/04/E2-Clean-Jobs-America-2020.pdf.

29 BW Research Partnership. Clean Energy Employment Initial Impacts from the COVID-19 Economic Crisis, October 2020. November 12, 2020. https://e2.org/wp-content/uploads/2020/11/Clean-Energy-Jobs-October-COVID-19-Memo-Final.pdf.

Figure 13: California GHG Emissions by Sector



Source: CARB Emissions Inventory[30]

SB 100 sits within a portfolio of related key clean energy efforts to reduce climate and air pollution emissions while maintaining a reliable and affordable electric grid. These include:

Transportation Electrification

The transportation sector remains the largest source of GHG emissions in California, responsible for 50 percent of the state's climate-altering pollution.[31] Vehicle exhaust also accounts for 80 percent of smog-forming gases and other air pollutants linked to premature deaths from respiratory and heart disease.[32] Economywide, GHG emissions have been decreasing in recent years, but transportation emissions have largely increased since 2013 and remain the state's biggest decarbonization challenge.

In 2018, Governor Edmund G. Brown Jr. established by executive order[33] a target of 5 million zero-emission vehicles (ZEVs) on California roads by 2030. The order also called for the

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[30] California Air Resources Board. GHG Emission Inventory Graphs https://ww2.arb.ca.gov/ghg-inventory-graphs.

[31] When including emissions associated with production and refining of fossil fuels for transportation.

[32] California Air Resources Board. 2016 Mobile Source Strategy Web page https://ww2.arb.ca.gov/resources/documents/2016-mobile-source-strategy.

[33] Governor Edmund G. Brown, Jr. Executive Order B-48-18, January 26, 2018. https://www.ca.gov/archive/gov39/2018/01/26/governor-brown-takes-action-to-increase-zero-emission-vehicles-fund-new-climate-investments/index.html.

installation of 250,000 publicly available electric vehicle charging ports and 200 hydrogen fueling stations by 2025. In September 2020, Governor Gavin Newsom expanded this goal when he issued an executive order[34] requiring that all new cars and passenger trucks be zero-emission by 2035 and all medium- and heavy-duty vehicles on the road be zero-emission by 2045.

These targets are ambitious, but California has already positioned itself as a leader in clean transportation. Many state programs are encouraging more motorists to shift to zero-emission vehicles, including:

- CPUC-approved investments in building more charging ports.
- CARB's Clean Vehicle Rebate Project, which has provided nearly $900 million in rebates to ZEV buyers[35]
- A CARB program that gives vehicle fuel producers credits toward meeting the state's Low Carbon Fuel Standard by funding the installation of fast (direct current) electric vehicle chargers and hydrogen fuel stations.
- CEC's Clean Transportation Program, which invests up to $100 million annually to accelerate the development and deployment of ZEV chargers and advanced clean transportation technologies.

Today, California has more than 566,000 ZEVs on the road and more than 763,000 cumulative ZEV sales — nearly half of all ZEV sales in the nation. The state also home to 34 ZEV-related manufacturers.[36] In 2019, electric vehicles became the state's second-largest export, valued at more than $7 billion.[37]

Despite these major advancements, big challenges lie ahead on the road to 100 percent zero-emission transportation. Primarily, the charging infrastructure must be greatly expanded to support many electric vehicles.

Having so many more vehicles tapping the state's electricity system will require closely coordinated planning between the power and transportation sectors. It will also create new green jobs and opportunities for innovators. Through a process known as vehicle-grid integration, electric cars help manage loads on the grid. Standardized, smart charging

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[34] Governor Gavin Newsom. Executive Order N-79-20. September 23, 2020. https://www.gov.ca.gov/wp-content/uploads/2020/09/9.23.20-EO-N-79-20-text.pdf.

[35] Center for Sustainable Energy (2020). California Air Resources Board Clean Vehicle Rebate Project, Rebate Statistics. https://cleanvehiclerebate.org/eng/rebate-statistics.

[36] CEC Analysis, includes ZEV, ZEV component, and ZEV infrastructure manufacturers and employers.

[37] United States Census Bureau. Foreign Trade: State Exports from California Web page https://www.census.gov/foreign-trade/statistics/state/data/ca.html.

technologies will make it easy for drivers to charge up with enough energy for their trips at the least possible cost.

Building Decarbonization

Another significant source of California's GHG emissions are those linked to everyday use of buildings, mainly natural gas heating and cooking. Decarbonizing energy use in new and existing buildings has recently emerged as a key climate-fighting strategy. In July 2019, Berkeley became the first U.S. city to ban natural gas in new buildings.[38] As of December 2020, 41 California cities have passed ordinances to either ban natural gas or favor electric heating.[39]

Assembly Bill 3232 (Friedman, Chapter 373, Statutes of 2018)[40] requires the CEC to identify and evaluate ways to reduce the GHG emissions of buildings by 40 percent below 1990 levels by 2030. The assessment will compare costs of different decarbonization pathways, estimate effects on the electricity grid, and recommend state actions.[41] Preliminary findings suggest switching from gas to highly efficient electric appliances such as heat pump water and space heaters is an effective strategy. A final report is planned for release in 2021.

The CPUC recently authorized $435 million through 2024 to spur the clean building technologies market.[42] Programs under development include:

- BUILD (Building Initiative for Low-Emissions Development): Provides incentives for installation of decarbonizing technologies such as heat pumps in all-electric, low-income new construction.
- TECH (Technology and Equipment for Clean Heating): Provides incentives to manufacturers and training for installers of low-emission space and water heaters in early stages of market development.

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[38] City of Berkeley. Ordinance No. 7,672–N.S. Adding a New Chapter 12.80 to the Berkeley Municipal Code Prohibiting Natural Gas Infrastructure in New Buildings Effective January 1, 2020 https://www.cityofberkeley.info/uploadedFiles/Planning_and_Development/Level_3_-_Energy_and_Sustainable_Development/2019-07-23%20Item%20C%20Prohibiting%20Natural%20Gas%20Infrastructure.pdf.

[39] Sierra Club. California's Cities Lead the Way to a Gas-Free Future https://www.sierraclub.org/articles/2020/12/californias-cities-lead-way-gas-free-future.

[40] Assembly Bill 3232 https://leginfo.legislature.ca.gov/faces/billTextClient.xhtml?bill_id=201720180AB3232.

[41] CEC. 2019. *2019 California Energy Efficiency Action Plan.* CEC-400-2019-010-CMF. Link to Final Commission Report: 2019 California Energy Efficiency Action Plan, https://efiling.energy.ca.gov/GetDocument.aspx?tn=231260&DocumentContentId=62914.

[42] See "Fact Sheet – Heat Pump Water Heater Incentive Programs," available for download at the CPUC Building Decarbonization Web page https://www.cpuc.ca.gov/buildingdecarb/.

Energy Efficiency

California has been a global leader in energy efficiency for more than 40 years, beginning in the 1970s with the CEC's adoption of the nation's first energy conservation standards for buildings and appliances. Since 1990, these standards have saved Californians more than $100 billion in utility costs.[43]

Today's standards cover much of the home and work environments, from computers to lighting, toilets, faucets, water heaters, insulation, windows, and household appliances. New buildings are becoming increasingly energy-efficient as the CEC updates and improves standards, about every three years. A home built under 2019 standards, for instance, will use 53 percent less energy than one built under 2016 codes.

The CPUC oversees hundreds of utility ratepayer-funded programs across the state to improve compliance with building and appliance codes and encourage businesses, industries, and homeowners to use new technologies that exceed the standards. In 2019 alone, these programs saved more than 2,700 GWh of electricity and 84 million therms of natural gas — enough to power 328,000 homes for a year.

Load Flexibility on the Electricity Grid

Load flexibility — the ability to shift electricity use to other parts of the day — is critical to maintaining a reliable and affordable supply of electricity. Load flexibility can also reduce GHG emissions by maximizing electricity use when grid power is least polluting.

The CPUC and CEC are laying the groundwork for automating load flexibility by taking steps to implement time-dependent electricity rates and moving forward a range of additional actions including:

- Building Energy Efficiency Standards (Energy Code): The 2019 Energy Code provides compliance credit for battery storage systems and heat pump water heaters that meet specific load flexibility requirements.
- Load Management Standards: These are designed to increase flexibility of demand through rates, storage, and automation — minimizing costs and improving reliability.
- CalFlexHub: The California Flexible Load Research and Deployment Hub is a new CEC program to fund research, development, and deployment of flexible demand technologies.
- Flexible Demand Appliance Standards:[44] The CEC is developing standards that would require specified appliances sold in California to include flexible-demand technologies

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[43] California Energy Commission. California Energy Commission Tracking Progress - Energy Efficiency. September 2018. https://www.energy.ca.gov/sites/default/files/2019-12/energy_efficiency_ada.pdf.

[44] Under Senate Bill 49 (Skinner, Chapter 697, Statutes of 2019) https://leginfo.legislature.ca.gov/faces/billTextClient.xhtml?bill_id=201920200SB49.

that enable operations to be scheduled, shifted, or curtailed to help reduce GHG emissions and maintain system reliability at lowest cost.

- Vehicle-Grid Integration (VGI): The CPUC and CEC are working with other state agencies and stakeholders to assess opportunities and develop policies that support VGI, which will allow owners of battery-electric vehicles to program smart charging in a way that helps balance demand and supply on the grid.

Research and Innovation

Since 2012, California ratepayers have invested more than $1 billion in emerging technologies that help make energy more affordable, reliable, and environmentally sustainable. EPIC, California's flagship electricity R&D program administered by the CEC, invests more than $130 million annually to support the development of emerging clean energy technologies. Moving forward, EPIC will continue to catalyze advancements to support the cost-effective implementation of SB 100 in:

- Renewable and zero-carbon generation.
- Long-duration energy storage.
- Energy efficiency.
- Electric load flexibility.

State agencies are working to ensure the benefits of these investments benefit all Californians. As much as 65 percent of EPIC technology demonstration projects are in disadvantaged and low-income communities, surpassing the 35 percent target set by Assembly Bill 523 (Reyes, Chapter 551, Statutes of 2017).[45]

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[45] Assembly Bill 523 (Reyes, Chapter 551, Statutes of 2017) https://leginfo.legislature.ca.gov/faces/billTextClient.xhtml?bill_id=201720180AB523.

Removing Carbon From the Atmosphere

In the 2015 Paris Agreement, scientists agreed that carbon neutrality — the point at which the removal of carbon pollution from the atmosphere equals or exceeds emissions — must be achieved by midcentury to stabilize the climate.[46] Three years later, Governor Brown issued an executive order that California become carbon neutral by 2045. To reach that target, state leaders are going beyond GHG emissions reduction measures. They are taking steps to remove greenhouse gases from the atmosphere are store them underground — a strategy known as "carbon capture and sequestration," as shown in **Figure 14**. In October 2020, Governor Newsom directed CARB to set a science-based target for removal of carbon from "natural and working lands," primarily agricultural.[47]

While engineered carbon removal technologies may also be an important tool, sequestering carbon on land including farms and ranches costs less and improves soil health and crop production. Using cover crops, reducing tillage, and applying compost and other organic matter are among the methods that strengthen the ability of the soil to store carbon.[48] California's Healthy Soils Initiative, a collaboration of state agencies, funds demonstration projects and financially assists farmers and ranchers in putting soil-improving practices to work on their lands to sequester carbon and reduce GHG emissions. The program is funded by revenue from the state's cap-and-trade auctions.[49]

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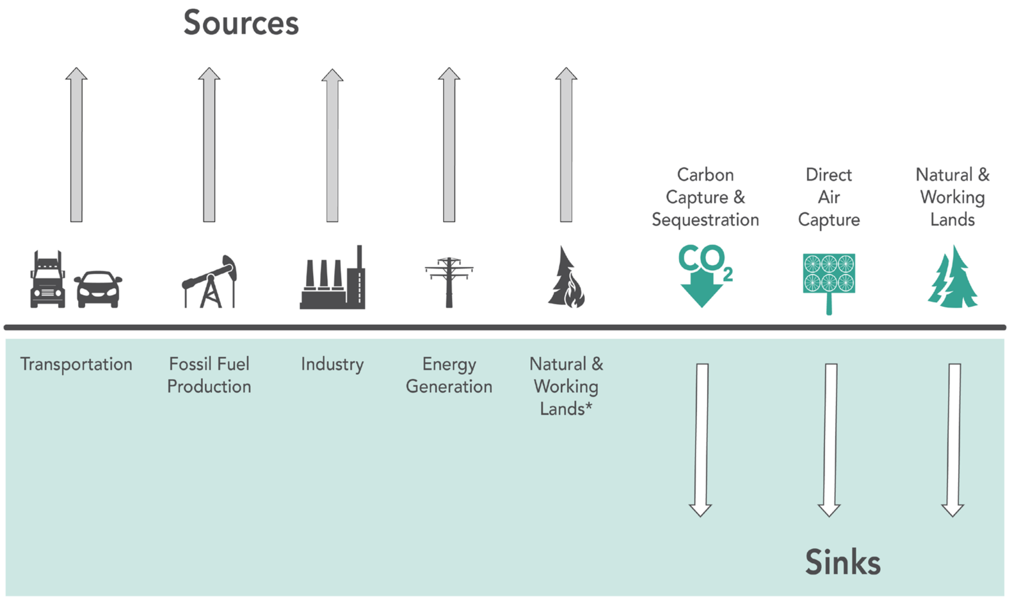
[46] United Nations. Paris Agreement, Article 4.1. December 12, 2015. https://unfccc.int/files/essential_background/convention/application/pdf/english_paris_agreement.pdf

[47] Governor Gavin Newsom. Executive Order N-82-20. October 7, 2020. https://www.gov.ca.gov/wp-content/uploads/2020/10/10.07.2020-EO-N-82-20-signed.pdf.

[48] California Climate Investments. *2020 Annual Report to the Legislature on California Climate Investments Using Cap-and-Trade Auction Proceeds*. March 2020. https://ww2.arb.ca.gov/sites/default/files/classic/cc/capandtrade/auctionproceeds/2020_cci_annual_report.pdf; and Kat Kerlin, UC Davis, "A Climate Change Solution Beneath Our Feet." May 15, 2017. "Soil sequesters carbon through a complex process that starts with photosynthesis. A plant draws carbon out of the atmosphere and returns to the soil what isn't harvested in the form of residue and root secretions. This feeds microbes in the soil. The microbes transform the carbon into the building blocks of soil organic matter and help stabilize it, sequestering the carbon." https://climatechange.ucdavis.edu/news/climate-change-solution-beneath-feet/.

[49] California Department of Food and Agriculture, Office of Environmental Farming & Innovation. Healthy Soils Program Web page. https://www.cdfa.ca.gov/oefi/healthysoils/.

Figure 14: Midcentury Carbon Neutrality



Natural and working land emissions include wildfire, disease, land and agricultural management practices, and other sources.

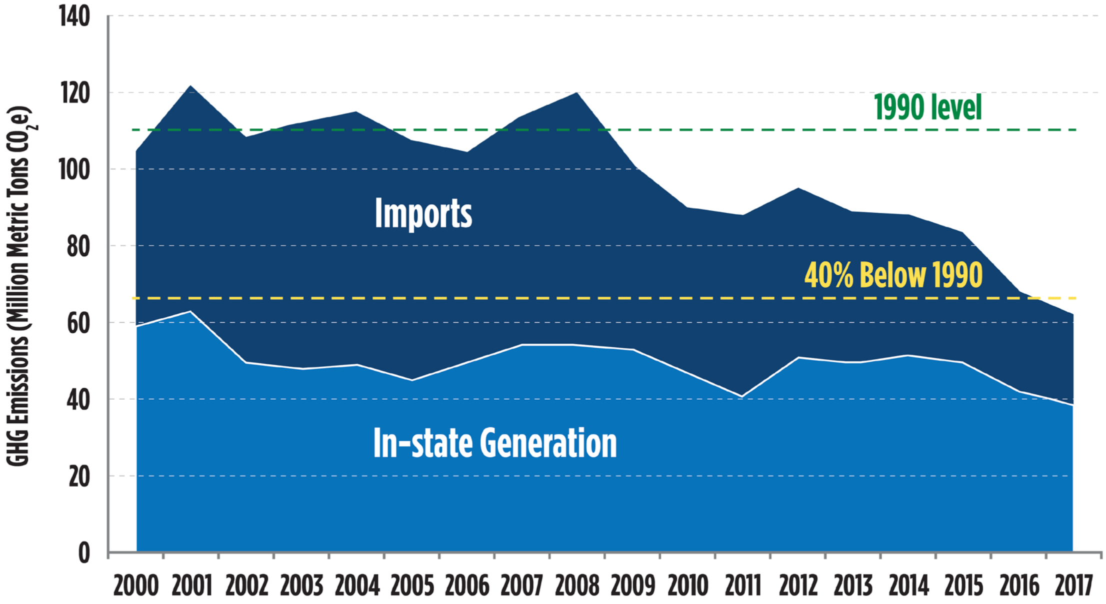
Source: CARB.

California’s Electric Grid Today

Declining Emissions

GHG emissions from power generation have dropped by more than 40 percent since 2000, as shown in **Figure 15**. The declines are largely attributable to increased use and reduced cost of renewable energy, particularly solar, the state’s energy efficiency standards, and greatly reduced use of coal-fired power plants. Although emissions are on an overall downward trend, the availability of hydroelectric power can significantly affect GHG emissions levels in wet versus dry years.

Figure 15: The Electricity Sector Has Significantly Reduced GHG Emissions Since the Turn of the Century



Sources: California Air Resources Board and CEC staff analysis, December 2019

Increasing Clean Generation

The proportion of California's electricity from renewable sources has increased dramatically since the establishment of the Renewables Portfolio Standard in 2002. Preliminary data show the state exceeded the 2020 target of 33 percent in 2019 with a total of 36 percent of retail sales supplied by eligible renewable energy resources.[50]

In 2019, nearly two-thirds of California's electricity came from carbon-free sources,[51] as shown in **Figure 16**. By 2025, out-of-state coal generation is projected to be eliminated from the state's resource mix altogether. The grid also is using less natural gas because of the increasing amount of renewable sources, In the near term to midterm, however, natural gas generation will continue to play a critical role in ensuring grid reliability.

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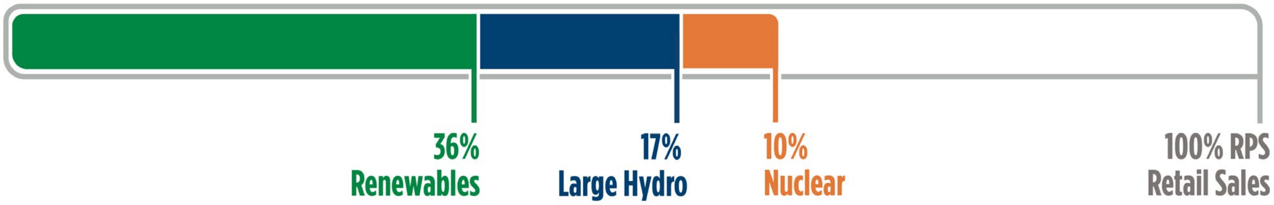
[50] California Energy Commission. California Energy Commission Tracking Progress – Renewable Energy. February 2020. https://www.energy.ca.gov/sites/default/files/2019-12/renewable_ada.pdf.

[51] For purposes of the GHG inventory, these include solar, wind, large and small hydropower, and nuclear.

Figure 16: 63 Percent of 2019 Retail Sales From Nonfossil Resources



Source: CEC, Tracking Progress, 2020

The increasing integration of renewable resources into the grid is changing system planning and operations. With the growth in intermittent renewables, system operators need generators with flexible capabilities to balance supply and demand. The swift rise in solar and wind power coming onto the grid has resulted in more frequent instances of oversupply during the middle of the day, when the sun is brightest. In certain times of the year, the daily net load — the difference between forecasted load and expected electricity production from variable generation resources — is lower during the midday then quickly ramps up.[52]

Although several tools are available to rapidly adjust supply and demand, natural gas power plants provide about 75 percent of the flexible capacity of the grid (the ability to quickly ramp energy production up or down to match supply and demand). While some natural gas power plants are retiring, others are still needed to maintain grid reliability as more renewable power enters the system. In the long term, other resources such as demand-side management and storage are essential to maintaining reliability while integrating high penetrations of renewables. This need can also be supported through increased coordination and the evolution of markets in the western region, which are already helping better integrate renewables.

Overview of California's Electricity System

Agency Oversight

California has several energy organizations with different electricity related responsibilities:

- **The CEC** is the state's lead energy policy and planning agency. The CEC's primary functions include forecasting electricity and natural gas demand for state planning, siting and licensing thermal power plants 50 MW or greater, investing in energy technology, setting the state's appliance and building energy efficiency standards, and planning for and directing the state's response to energy emergencies. The CEC also publishes the *Integrated Energy Policy Report*, which assesses major energy trends and issues facing California's electricity, natural gas, and transportation fuel sectors.

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[52] California Independent System Operator. Fast Facts: What the Duck Curve Tells Us About Managing a Green Grid. 2016. https://www.caiso.com/Documents/FlexibleResourcesHelpRenewables_FastFacts.pdf.

- **The CPUC** regulates services and utilities, protects consumers, safeguards the environment, and assures Californians' access to safe and reliable utility infrastructure and services. The essential services regulated include electric, natural gas, telecommunications, water, railroad, rail transit, and passenger transportation companies. The CPUC does resource planning for 80 percent of California's electric grid through the IRP proceeding and implements programs such as the RPS, efficiency incentives, transportation electrification investments, customer solar, and building decarbonization.
- **CARB's** mission is to promote and protect public health, welfare, and ecological resources through effective reduction of air pollutants while recognizing and considering effects on the economy. CARB is the lead agency for climate change programs and oversees all air pollution control efforts in California to attain and maintain health-based air quality standards.
- **City, county, and tribal governments** also influence statewide energy decisions and have permitting authority for transmission lines, thermal power generators under 50 MW and nonthermal power generators, including solar and wind operations on nonfederal lands.

Load-Serving Entities (LSEs)

California's electric load is met through a variety of LSEs, which serve retail customers.[53] The primary LSEs are the following:

- **Investor-owned utilities (IOUs)** provide transmission and distribution services to all electric customers in their service territory. The utilities also provide generation service for "bundled" customers, while "unbundled" customers receive electric generation service from an alternate provider, such as a community choice aggregator (CCA). California's electric IOUs are Pacific Gas and Electric, Southern California Edison, and San Diego Gas & Electric.
- **Publicly owned utilities (POUs),** or municipal utilities, are publicly financed and controlled by citizen-elected governing boards. The Los Angeles Department of Water and Power and Sacramento Municipal Utility District are among the largest POUs that together serve about 27 percent of the state's electricity demand.
- **Community choice aggregators (CCAs).** Growing numbers of California communities have formed these local agencies to buy electricity on behalf of their residents and businesses, often aiming to provide lower rates and greener electricity than offered by the default utility. CCAs are a relatively new type of load-serving entity

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[53] CPUC. California Customer Choice: An Evaluation of Regulatory Framework Options for an Evolving Electricity Market. August 2018. https://www.cpuc.ca.gov/uploadedFiles/CPUC_Public_Website/Content/Utilities_and_Industries/Energy_-_Electricity_and_Natural_Gas/Cal%20Customer%20Choice%20Report%208-7-18%20rm.pdf.

and have grown rapidly, projected to serve about 38 percent of the load within IOU service territories by 2022.[54]

- **Electric service providers (ESPs),** or direct access providers, are nonutility entities that market electric service directly to customers. However, the customer load service by ESPs is set at a limited amount. Like CCAs, ESPs must comply with resource adequacy, RPS, and IRP requirements overseen by the CPUC.

Grid Balancing

California's grid is divided into five balancing authority areas. The following balancing authorities balance supply and demand and maintain electric frequency on the grid. The authorities are:

- California ISO, which manages about 80 percent of the state's flow of electricity.
- Los Angeles Department of Water and Power.
- Balancing Authority of Northern California.
- Imperial Irrigation District.
- Turlock Irrigation District.

Western States Coordination

California is part of a larger integrated electricity system called the Western Interconnection, which includes all or parts of 14 western states as well as Alberta, British Columbia, and Baja California. Several of these jurisdictions have also adopted clean energy goals or standards,[55] expanding opportunities for market development and knowledge-sharing on integrating increasing amounts of renewable generation.[56]

In 2014, the California ISO initiated the Western Energy Imbalance Market (EIM), a real-time wholesale energy trading market with PacifiCorp as its first member.[57] The EIM manages

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[54] CalCCA. 2010-2020: A Decade of CCA in California. May 1, 2020. https://cal-cca.org/celebrating-10-years-of-cca-in-california/.

[55] For details on states with clean energy or renewable goals or standards, see the Link to State Policy Climate Maps at https://www.c2es.org/content/state-climate-policy/ or the CESA 100% Clean Energy Collaborative - Table of 100% Clean Energy States at https://www.cesa.org/projects/100-clean-energy-collaborative/table-of-100-clean-energy-states/.

[56] These entities are described in the CEC's Western Energy Planning Fact Sheet at https://www.energy.ca.gov/sites/default/files/2019-06/Western_Energy_Planning.pdf.

[57] The Western Energy Imbalance Market (EIM) is a real-time wholesale energy trading market that enables participants anywhere in the West to buy and sell energy when needed. The EIM platform balances fluctuations

congestion on high-voltage transmission lines to maintain grid reliability, supports integration of renewable resources, and makes excess renewable energy available to participating utilities at low cost rather than turning the generating units off.

The EIM has grown to 11 member entities, and another 11 plan to join by 2023, which will account for 82 percent of the load in the Western Interconnection.[58] This market is credited with achieving $1.18 billion in savings from increased operational efficiencies and a 1.3 million MWh reduction in curtailment of renewable energy.[59] There is interest in building off the EIM's success, including with the California ISO's Extended Day-Ahead Market (EDAM) Initiative.[60] The EDAM initiative, which is still in the early stages, aims to improve renewable integration and market efficiency through day-ahead scheduling and unit commitment across a larger area.

California is engaged with several other regional government and industry groups to ensure its energy interests are represented. They include:

- Western Electricity Coordinating Council: A nonprofit corporation that promotes bulk power system reliability and security in the Western Interconnection.
- Western Interstate Energy Board: An organization of 11 western states and three western Canadian provinces that promotes coordinated development of energy policies.
- Western Interconnection Regional Advisory Body: Created by western governors under the Federal Power Act to provide advice on grid reliability to the Federal Energy

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in supply and demand by automatically finding lower-cost resources to meet real-time power needs. The EIM manages congestion on high-voltage transmission lines to maintain grid reliability and supports integrating renewable resources. Further, it enhances reliability by increasing operational visibility across electricity grids. In addition, the market makes excess renewable energy available to participating utilities at low cost rather than turning the generating units off.

58 The entities and their dates of entry include the following: PacifiCorp (2014), NV Energy (2015), Arizona Public Service (2016), Puget Sound Energy (2016), Portland General Electric (2017), Idaho Power (2018), Powerex (2018), the Balancing Authority of Northern California/Sacramento Municipal Utility District (2019), Seattle City Light (2020), and Salt River Project (2020). Entities and their planned dates of entry include Los Angeles Department of Water and Power (2021), Northwestern Energy (2021), Turlock Irrigation District (2021), Public Service Company of New Mexico (2021), Balancing Authority of Northern California Phase 2 [Modesto Irrigation District, City of Redding, City of Roseville, and Western Area Power Administration–Sierra Nevada Region] (2021), Avista Utilities (2022), Tucson Electric Power (2022), Tacoma Power (2022), Bonneville Power Administration (2022), Xcel Energy – Colorado (2022), and El Paso Electric (2023).

59 California ISO, Western EIM Benefits Report, Fourth Quarter 2020, January 29, 2021, available at https://www.westerneim.com/Documents/ISO-EIM-Benefits-Report-Q4-2020.pdf.

60 Link to Extended Day-Ahead Market Initiative information on the California ISO's Web page http://www.California ISO.com/informed/Pages/StakeholderProcesses/ExtendedDay-AheadMarket.aspx.

Regulatory Commission, the North American Electric Reliability Corporation, and the Western Electricity Coordinating Council.

- Western Governors' Association: An instrument of the governors of 19 states and 3 U.S. territories for bipartisan policy development, information exchange, and collective action on issues of critical importance to the western United States.

Planning for a Midcentury Grid

Designing for a Changing Climate

California's electric grid must meet the state's clean energy goals while maintaining reliability and affordability, protecting public health and the environment, and distributing benefits of clean energy to all Californians — all in the face of fiercer and more frequent wildfires, droughts (reduced hydropower availability), and heat waves (higher loads from air conditioning). Meeting the state's goals also requires scientifically informed, flexible, and adaptive strategies to increase energy sector resilience to climate stressors, with particular attention to high fire threat areas and vulnerable populations. Future investments in electric generation, storage, distribution, and transmission must be designed and operated for a changing climate.

Changes in Supply and Demand

Planning a midcentury grid requires accommodating the variable nature of solar, wind and hydroelectric power; the increasing integration of renewable generation from utilities and customers; and increasing loads from building and transportation electrification. With the right policies, technologies, and price signals, a surge in all-electric vehicles and buildings can not only be accommodated, but could potentially support grid reliability.

August 2020 Rolling Blackouts Highlight Planning Needs

On August 14 and 15, 2020, the state experienced rotating outages during an extreme heat wave that spread across the West. An analysis[61] developed jointly by California ISO, CPUC, and CEC found a series of factors contributed to the emergency:

- The extreme, climate change-induced heat wave resulted in electricity demand exceeding supply; the existing resource planning processes are not designed to fully address an extreme heat wave like the one experienced in mid-August.
- Resource planners have not kept pace with the rapid rise of solar and wind power on the grid, resulting in insufficient supply to meet the high demand in the early evening in extreme conditions.

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[61] California ISO, CPUC, and CEC. *Final Root Cause Analysis –: Mid-August 2020 Extreme Heat Wave*. January 13, 2021., January 13, 2021, http://www.caiso.com/Documents/Final-Root-Cause-Analysis-Mid-August-2020-Extreme-Heat-Wave.pdf.California ISO, CPUC, and CEC. *Preliminary Root Cause Analysis – Mid-August 2020 Heat Storm*. http://www.caiso.com/Documents/Final-Root-Cause-Analysis-Mid-August-2020-Extreme-Heat-Wave.pdf.

- Some practices in the day-ahead energy market exacerbate supply challenges when the grid is under high stress.

The heat wave that persisted from August 14 through 19 brought temperatures 10 to 20 degrees Fahrenheit above average. During this period, California experienced four out of the five hottest August days since 1985. Typically, California's hot daytimes in the summer are offset by cool evenings. During the extreme heat events, however, the high temperatures persisted into the evening and overnight, and air conditioners drove up electricity demand beyond normal.

The extreme heat also pinched electricity supply. Natural gas power plants ran less efficiently, and fewer imports of electricity were available as other western states also endured the extreme heat. At the same time, high clouds covered parts of California, reducing solar generation.

Heats waves of such severity and compounding factors are no longer outside the realm of planning contingencies. State agencies are busy recalibrating electricity supply and demand planning to more accurately reflect the increasing risk of extreme weather events.

SB 100: A Foundation for California's Clean Energy Future

SB 100 provides a tremendous opportunity for state agencies to collaboratively plan for a midcentury grid. As California moves toward a majority renewable grid in a changing climate, the state's planning processes likewise need to evolve to meet the needs of all Californians who depend on safe, affordable, and reliable electricity. Effectively integrating 100 percent renewable and zero-carbon electricity and achieving carbon neutrality by 2045 will require coordinated planning across state agencies, local governments, and electric utilities.

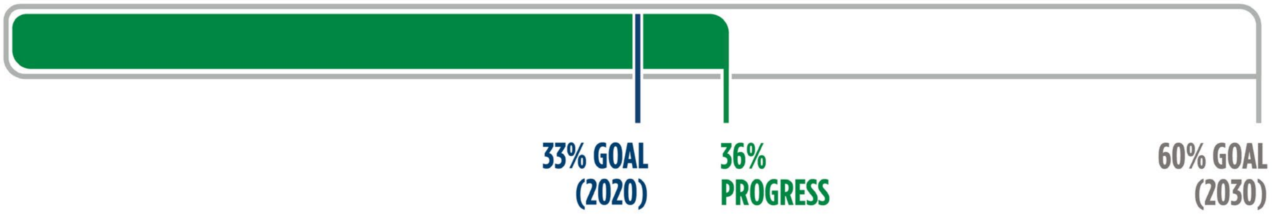
CHAPTER 2:
SB 100 Overview and Report Development Process

100 Percent Clean Electricity by 2045

The 100 Percent Clean Energy Act of 2018 (Senate Bill 100, De León) is California's keystone climate mitigation policy to drastically reduce greenhouse gas emissions in the power sector and help make California's economy carbon neutral by 2045.[62] SB 100:

- Sets a December 31, 2045 target for eligible renewable and zero-carbon energy resources to supply 100 percent of California's electricity to consumers and state agencies.[63]
- Increases the state's Renewables Portfolio Standard to 60 percent of electricity retail sales by December 31, 2030, and raises interim procurement requirements by amounts consistent with this increase.
- Requires that the joint agencies — CPUC, CEC, and CARB — use existing programs to achieve this policy and issue the Legislature a report on the implementation of the law by January 1, 2021, and every four years thereafter.

Figure 17: Progress Toward the 2030 60 Percent RPS Target



Source: CEC 2020, Tracking Progress – Renewable Energy, https://www.energy.ca.gov/sites/default/files/2019-12/renewable_ada.pdf

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[62] Governor Jerry Brown's September 10, 2018 Executive Order No. B-55-18, a complement to SB 100, states: "A new statewide goal is established to achieve carbon neutrality as soon as possible, and no later than 2045, and achieve and maintain net negative emissions thereafter. This goal is in addition to the existing statewide targets of reducing greenhouse gas emissions."

[63] Public Utilities Code Section 454.53 https://codes.findlaw.com/ca/public-utilities-code/puc-sect-454-53.html.

State Agency Requirements

Under SB 100, the CPUC and CEC, in consultation with CARB, must ensure California's transition to a zero-carbon electric system is consistent with the Commerce Clause (which describes an enumerated power listed in the United States Constitution) and does not cause greenhouse gas (GHG) emissions to increase elsewhere in the western grid.

In addition, all state agencies must:

1. Maintain the safety and reliability of the electric system.
2. Prevent the implementation of the law from causing "unreasonable impacts" to customers' utility rates and bills, taking into "full consideration" the economic and environmental costs and benefits of clean electricity.
3. To the extent feasible and authorized under law, take actions to reduce greenhouse gas emissions in other economic sectors (industrial, commercial, agricultural, residential, transportation) to ensure equity between those sectors and the electricity sector.[64]

SB 100 Reports

SB 100 specifies that the joint agency reports be informed by public participation and consultation with California balancing authorities. The reports shall include:

1. A review of the 100 percent clean electricity policy focused on electricity technologies, forecasts, transmission, reliability, affordability, and environmental and public safety protection.
2. An evaluation of the potential effects of the law on electricity system reliability, statewide and local.
3. Anticipated costs and benefits to utilities and ratepayers (electric, gas, and water).
4. Identification of barriers to implementing the policy and benefits of achieving it.
5. Alternative scenarios to achieve the policy, with estimated costs and benefits.

SB 100 also emphasizes the need to benefit disadvantaged communities.[65] The joint agency reports consider how the implementation of the law affects disadvantaged communities, as well as tribal and rural communities.[66]

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[64] Public Utilities Code Sections 399.11–399.33, 454.51, 454.52, 9621, and 9622.

[65] This definition derives from CalEPA's CalEnviroScreen, a tool that identifies census tracts disproportionately burdened by and vulnerable to multiple sources of pollution. https://oehha.ca.gov/calenviroscreen/report/calenviroscreen-30. In April 2017, CalEPA released its list of disadvantaged communities for SB 535.

[66] For more detail, see the Disadvantaged Communities Advisory Group Equity Framework, https://www.cpuc.ca.gov/uploadedFiles/CPUCWebsite/Content/UtilitiesIndustries/Energy/EnergyPrograms/Infrastructure/DC/DAC%20AG%20Equity%20Framework%20(Revised).pdf.

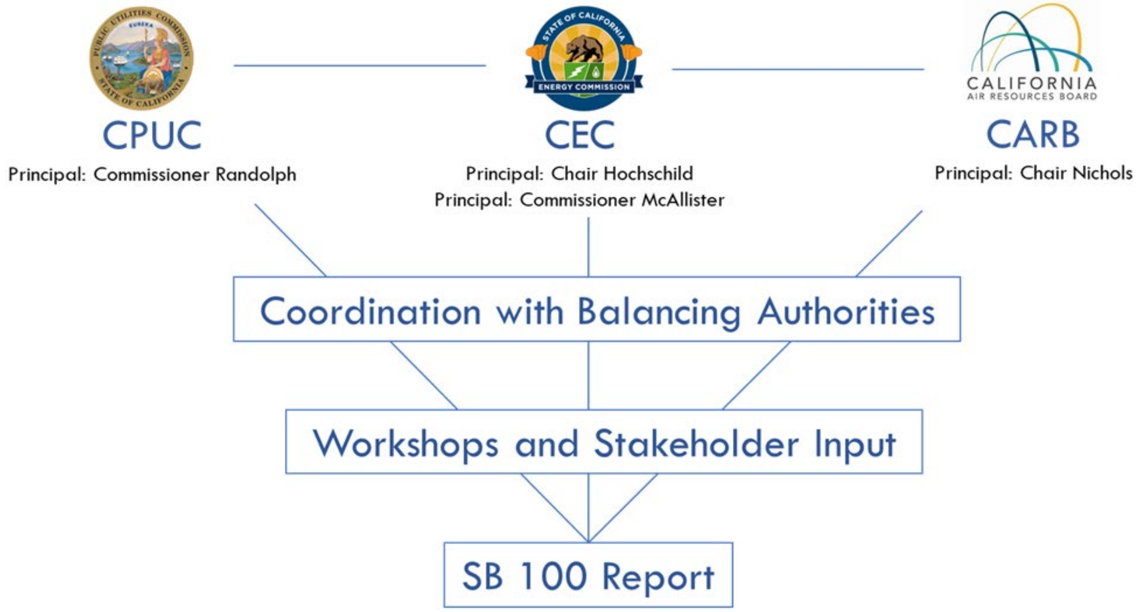
2021 Report Scope

This report examines implications of the 100 percent clean electricity policy under SB 100. Chapter 3 provides preliminary assessments of resource needs and projected costs of various implementation pathways.

The exploration builds on the modeling and assumptions used for CPUC's Integrated Resource Planning and considers California's overarching priorities on energy, climate, equity, and public health.

This report is neither a comprehensive nor prescriptive roadmap to 2045. As discussed in Chapter 4, future reports will delve deeper into critical topics such as system reliability and land use and further address energy equity and workforce needs.

Figure 18: SB 100 Joint Agency Coordination Process



Source: CEC, CPUC, and CARB. Developed by consensus

Public Engagement

The joint agencies held a year-long series of public workshops to solicit comments on the scope, analysis, and process of the report. A September 2019 kickoff workshop in Sacramento was followed by regional scoping workshops in Fresno, Redding, and Diamond Bar in Los

Angeles County and two technical workshops on the scenario modeling.[67] The agencies also held workshops on the draft modeling results and draft report.

The CEC conducted the outreach by email, phone, social media, and agency listservs. Most workshops had hundreds of attendees. The Draft Modeling Results Workshop drew nearly 400 participants via Zoom. The joint agencies received hundreds of comments at the workshops and online through the SB 100 docket.

Table 7: SB 100 Workshop Summary

Activity	Date
Kickoff Workshop (Sacramento)	September 5, 2019
Scoping Workshop 1: Central Valley (Fresno)	September 30, 2019
Scoping Workshop 2: Northern California (Redding)	October 25, 2019
Scoping Workshop 3: Southern California (Diamond Bar)	October 29, 2019
Technical Workshop (San Francisco)	November 18, 2019
Modeling Inputs & Assumptions Workshop (Sacramento)	February 24, 2020
Draft Modeling Results Workshop (Remote Only)	September 2, 2020
Draft Report Workshop (Remote Only)	December 4, 2020

Source: CEC, CPUC, and CARB

Consultation With Balancing Authorities

In September 2019, the joint agencies initiated consultation with the balancing authorities,[68] as required by SB 100.[69] The balancing authorities staff suggested inputs and assumptions for modeling the pathway scenarios and participated in the workshops as panelists. They were

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[67] For a complete record of the SB 100 report proceeding and public comments, see the SB 100 Joint Agency Report Webpage at https://www.energy.ca.gov/sb100 and the SB 100 docket at https://efiling.energy.ca.gov/Lists/DocketLog.aspx?docketnumber=19-SB-100.

[68] "Balancing authorities" are responsible for balancing electricity supply with demand to ensure the generation, transmission and distribution of electricity all working reliably to meet California's energy needs. California's balancing authorities include the California Independent System Operator, Los Angeles Department of Water and Power, the Balancing Authority of Northern California, Imperial Irrigation District, and Turlock Irrigation District.

[69] Public Utilities Code section 454.53 (d)(2) states: "In consultation with all California balancing authorities, as defined in subdivision (d) of Section 399.12, as part of a public process, issue a joint report to the Legislature by January 1, 2021, and at least every four years thereafter."

particularly informative on wildfire threats and the future reliability of the state's electricity system in a changing climate.

Kickoff Workshop

September 5, 2019, Sacramento

State Resources Secretary Wade Crowfoot and Alice Reynolds, the Governor's Senior Energy Advisor, stressed the importance of SB 100 in helping the state meet its climate goals. The agency principals for the report[70] discussed the need to align the clean electricity goals of SB 100 with state efforts to decarbonize California's economy as a whole and ensure a safe, reliable, and equitable energy future for all Californians.

The workshop prompted a wide variety of oral and written comments (19 stakeholders made oral comments at the workshop, while 17 commenters submitted written comments following the workshop), including requests that the 2021 Report include the roles of energy conservation and storage, synergies between the electricity sector and other economic sectors, near-term system reliability needs, and a definition of "zero-carbon resource" that does not preclude nuclear power and large hydroelectric generation.[71]

Regional Scoping Workshops

- Central Valley, September 30, 2019, in Fresno
- Northern California, October 25, 2019, in Redding
- Southern California, October 29, 2019, in Diamond Bar

At each workshop, a diverse panel of local leaders and experts fielded questions on energy equity, grid reliability, and land use.[72] More than 150 attendees attended each workshop, either in person or online, and more than 100 sets of written comments were received.

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[70] CEC Chair David Hochschild, CARB Chair Mary Nichols, CPUC Commissioner Liane Randolph, and CEC Commissioner Andrew McAllister.

[71] Commenters also cited a letter submitted to the Senate Daily Journal stating the bill language was intended to include all existing carbon resources currently under contract, such as nuclear and large hydro resources.

[72] The Central California Scoping Workshop occurred in Fresno on September 30, 2019. A stakeholder panel included representatives of Turlock Irrigation District, San Joaquin Valley Latino Environmental Advancement and Policy Project and Leadership Counsel for Justice and Accountability. The Northern California Scoping Workshop occurred in Redding on October 25, 2019. A stakeholder panel included representatives of Blue Lake Rancheria, Redding Electric Utility, the American Wind Energy Association California Caucus, the Balancing Area of Northern California, and the California Independent System Operator. The Southern California Scoping Workshop occurred in Diamond Bar on October 29, 2019. A stakeholder panel included representatives of California Environmental Justice Alliance, Port of Long Beach, the Los Angeles Department of Water and Power, and Imperial Irrigation District.

Commenters asked that the state's definition of "zero-carbon resource" include electricity from large hydroelectric dams, small modular nuclear power plants, hydrogen-based power, and bioenergy resources. They also stressed energy equity, workforce training, consumer protection, and greater system reliability as wildfires become fiercer and more frequent.

Technologies and Scenarios Workshop

November 18, 2019, San Francisco

Staff with the three agencies presented a framework for modeling SB 100 implementation scenarios and evaluating the associated costs, benefits, and impacts. They proposed to leverage existing modeling analyses, such as the 2018 Deep Decarbonization in a High Renewables Future: Updated Results from the California PATHWAYS Model[73] and the SB 100 2045 Framing Study for the CPUC IRP,[74] and include the publicly owned utility perspective.

Staff presented the "RPS+" interpretation of "zero-carbon resources" — technologies that are RPS-eligible or have zero onsite emissions — and a "zero-combustion" interpretation recommended by environmental justice advocates. Stakeholders overwhelmingly supported the former interpretation.

In addition to the 20 panelists and public commenters who spoke at the workshop, 26 stakeholders submitted written comments. Comments included requests for consideration of:

- All types and durations of energy storage.
- Natural gas-fired resources with carbon capture and sequestration.
- Hydrogen and fuel cell technologies.
- Implications of an energy storage accounting that excludes losses.
- Grid reliability risk analysis.

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[73] Mahone, Amber, Zachary Subin, Jenya Kahn-Lang, Douglas Allen, Vivian Li, Gerrit De Moor, Nancy Ryan, Snuller Price. 2018. *Deep Decarbonization in a High Renewables Future: Updated Results from the California PATHWAYS Model*. CEC. Publication Number: CEC-500-2018-012. Link to Deep Decarbonization in a High Renewables Future: Updated Results from the California PATHWAYS Model https://www.ethree.com/wp-content/uploads/2018/06/Deep_Decarbonization_in_a_High_Renewables_Future_CEC-500-2018-012-1.pdf.

[74] See the 2045 Framing Study results starting in Appendix A on slide 145 of the CPUC Energy Division's November 6, 2019 *2019-20 IRP: Proposed Reference System Plan*. https://www.cpuc.ca.gov/uploadedFiles/CPUCWebsite/Content/UtilitiesIndustries/Energy/EnergyPrograms/ElectPowerProcurementGeneration/irp/2018/2019%20IRP%20Proposed%20Reference%20System%20Plan_20191106.pdf.

Modeling Inputs and Assumptions Workshop

February 24, 2020, Sacramento

Three panels of experts discussed implementation of SB 100 and related implications for electricity rates, grid reliability, land use, workforce development, environmental justice, and energy equity. In addition to the panelists, 17 stakeholders provided public comments. More than 30 written comments were also received following the workshop.

Stakeholders reiterated requests for a more inclusive definition of "zero-carbon" energy resources that considers their land-use impacts. Others commented on the modeling — including assumptions, limitations, and scenarios — and the use of modeling results in developing policy recommendations.

Modeling Results and Implications Workshop

September 2, 2020, Online

CEC staff summarized the modeling study and detailed the results.[75] The modeling consultant, E3, joined staff in fielding audience questions. The workshop then broke out into panels on three topics: energy resource build requirements, grid planning implications, and energy equity and workforce considerations.

The agencies received more than 100 written comments after the workshop. Many favored accelerating the SB 100 target to 2030 and stressed the importance of maintaining grid reliability as the state transitions to 100 percent clean electricity. Other commenters stressed:

- Careful land-use planning to minimize environmental impacts.
- New transmission infrastructure.
- Energy production cost modeling to assess reliability.
- Modeling improvements to better refine technology costs, attributes, and performance.
- Energy equity, non-energy benefits, and affordability of electricity.

Draft 2021 Report Workshop

December 4, 2020, Online

CEC staff summarized the draft report, providing an overview of modeling results and updates made after the draft results workshop, areas for further analysis, additional considerations, and joint agency recommendations.

Stakeholder comments focused on the need to assess the reliability and operational feasibility of the scenarios, inclusion of non-energy benefits and social costs into the analytical

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[75] As background, the joint agencies released two documents: the August 31, 2020 SB 100 Joint Agency Report Modeling Framework and Scenarios Overview and the Inputs & Assumptions: CEC SB100 Joint Agency Report.

framework, and requests to change technology assumptions and add technologies into future modeling.

Additional Outreach and Engagement

Clean Energy States Alliance (CESA)

The joint agencies exchange knowledge and ideas with their counterparts in 18 other states and entities in the United States (District of Columbia and Puerto Rico) that have 100 percent clean electricity and carbon neutrality goals. They engage through the 100% Clean Energy Collaborative, run by the Clean Energy States Alliance, a nonprofit coalition of public agencies and organizations working to advance clean energy.

In a May 2020 CESA webinar, CEC Chair David Hochschild discussed California's 100 percent clean energy policy and how other states could benefit by adopting a similar goal.

On July 21, 2020, staff with the CEC and an official with the New Jersey Board of Public Utilities presented on integrating energy equity considerations into 100 percent clean energy policy and implementation, generating interest in deeper discussion within the collaborative.

Disadvantaged Communities Advisory Group and Equity Stakeholders

In advance of the Modeling Inputs and Assumptions workshop, CEC staff presented an overview to the DACAG, the formal body that advises the CEC and CPUC on energy equity issues. Members moved to establish DACAG's SB 100 subcommittee to more closely track and assume responsibility for proceeding comments. In addition, the joint agencies included environmental justice and equity representatives on workshop panels to discuss implementation considerations.

The DACAG and a separate group of community and environmental justice organizations later submitted letters[76] urging the joint agencies to analyze at the local level how SB 100 implementation will affect communities' public health, land use, economic well-being, and air and water quality. The letters also urged consideration of communities' cumulative burdens resulting from the COVID-19 pandemic and the growing number and severity of heat waves and wildfires, particularly in under resourced communities that already bear the brunt of pollution.

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[76] See RE: SB 100 Joint Agency Report: Charting a path to a 100% Clean Energy Future Docket #: 19-SB-100, June 12, 2020, https://efiling.energy.ca.gov/GetDocument.aspx?tn=233461&DocumentContentId=65990; and RE: SB 100 Joint Agency Report, Docket #: 19-SB-100, August 21, 2020, https://efiling.energy.ca.gov/GetDocument.aspx?tn=234415&DocumentContentId=67287.

Other Western States

On October 8, 2019, CEC staff gave a presentation titled "Senate Bill 100: Toward Zero-Carbon Electricity" at a meeting of the Joint Committee on Regional Electric Power Cooperation-Western Interconnection Regional Advisory Body.

Statutory Interpretation for Modeling

To model SB 100 implementation scenarios, the joint agencies needed to interpret the meaning of "zero-carbon resources"[77] in the law and determine the electric loads subject to the policy.

Zero-Carbon Resources Interpretation

SB 100 does not define "zero-carbon resources," and the state had no legal definition before the bill becoming law. The joint agencies interpreted "zero-carbon resources" to mean energy resources that either qualify as "renewable" in the most recent RPS (Renewables Portfolio Standard) Eligibility Guidebook[78] or generate zero greenhouse gas emissions on site.[79] SB 100 workshops and documents refer to these criteria as "RPS+".

Additional Criteria for Modeled Resources

Staff further limited the pool of modeled resources to those meeting the following criteria:

- Alignment with state policies and priorities
    - Staff excluded energy resources from some or all scenarios if the use of these resources in generating electricity would have significant negative effects on public health or the environment or were otherwise at odds with state policies and priorities.
- Technology readiness and resource availability
    - Only commercialized technologies with vetted and publicly available cost and performance data were included for core scenarios. Moreover, only technologies that have an anticipated pipeline of development were included. (For example,

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[77] Senate Bill 100 (De León, Chapter 312, Statutes of 2018, 454.53 [a]), revises state policy in "that eligible renewable energy resources and zero-carbon resources supply 100 percent of all retail sales of electricity to California end-use customers and 100 percent of electricity procured to serve all state agencies by December 31, 2045. https://leginfo.legislature.ca.gov/faces/billNavClient.xhtml?bill_id=201720180SB100.

[78] California Energy Commission. *Renewables Portfolio Standard Eligibility Guidebook, Ninth Edition (Revised)*. Publication Number: CEC-300-2016-006-ED9-CMF-REV. January 2017. https://efiling.energy.ca.gov/getdocument.aspx?tn=217317.

[79] For modeling, this list does not acknowledge de minimis emissions associated with included technologies. SB 100 compliance programs would need to establish clear requirements for qualification as a zero-carbon generation resource.

although solar thermal is a well-proven renewable technology, little development is anticipated at this time, primarily because it cannot compete with solar photovoltaic on cost.)

  - ○ Generic firm zero-carbon resources were included in the exploratory study scenarios to illustrate the possible impact of emerging resources such as green hydrogen generation and natural gas generation with carbon capture if they are able to achieve specified costs.
  - ○ Excluded technologies may be included in future SB 100 analyses. Staff will update modeling as emerging technologies become commercialized.

Technologies Included in Modeling

Table 8 lists technologies that could meet the SB 100 criteria for renewable and zero-carbon resources, as interpreted by the joint agencies. The list is not prescriptive, but rather for evaluating potential SB 100 implementation strategies. This list may be updated for future SB 100-related modeling.

Table 8: Generation Technologies Included in Modeling

Technology	Eligibility Basis	Scenarios
Solar PV	RPS	Core and Study
Solar Thermal (existing only)	RPS	Core and Study
Onshore Wind	RPS	Core and Study
Offshore Wind	RPS	Core and Study
Geothermal	RPS	Core and Study
Bioenergy	RPS	Core and Study
Fuel Cells (green H_2)	RPS	Core and Study
Small Hydro (existing only)	RPS	Core and Study
Large Hydro (existing only)	Zero-Carbon	Core and Study
Nuclear (existing only)	Zero-Carbon	Core and Study
Generic Firm Dispatchable Resource[80]	Zero-Carbon	Study Only
Generic Firm Baseload Resource[81]	Zero-Carbon	Study Only

Source: CEC, CPUC, and CARB. Developed by consensus

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[80] For example, natural gas with 100 percent carbon capture and sequestration or 100 percent drop-in renewable fuels.

[81] For example, low-cost geothermal or imports of emerging nuclear generation technologies.

Zero-Carbon Resources Not Modeled

Technologies that could meet the zero-emissions criteria but have other barriers to development were excluded from modeling for the reasons listed in **Table 9** and discussed in more detail below.

Table 9: Considered Technologies Excluded From 2020 Modeling

Technology	Reason for Exclusion
New in-state nuclear	State effectively has a moratorium on new in-state nuclear power plants under the Warren-Alquist Act.[82]
Drop-in renewable fuels[83] (green hydrogen and biomethane)	Technology for synthetic drop-in renewable fuels not yet commercially available in California or inadequate cost and supply data for modeling or both. Inadequate supply potential for biomethane in the power sector.
Natural gas generation with carbon capture and sequestration	Lack of cost and performance data for 100 percent carbon capture.
Coal-fired generation with carbon capture and sequestration	Incompatible with the state's public health priorities and lack of cost and performance data for 100 percent carbon capture.
New small hydroelectric generation	Inadequate data on new capacity cost and resource availability for modeling.
New concentrating solar power	Lack of proposed new development and high cost relative to other solar resources.
New large hydroelectric generation	Limited development feasibility at this time and environmental concerns.

Source: CEC, CPUC, and CARB joint agency consensus

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[82] California Energy Commission. January 2020. Warren-Alquist Act 2020 Edition, Sections 25524.1 and 25524.2. Publication Number: CEC-140-2020-001. https://ww2.energy.ca.gov/2020publications/CEC-140-2020-001/CEC-140-2020-001.pdf.

[83] Green electrolytic hydrogen and synthetic methane are gaining breakthroughs and cost reductions as "drop-in" or replacement fuels in natural gas-fired power plants and potential zero-carbon dispatchable generation resources.

New In-State Nuclear

Since 1976, California law[84] has prevented the permitting of new nuclear fission power plants until adequately safe technologies exist for fuel rod reprocessing and disposal of high-level nuclear waste. Until these conditions can be satisfied, expansion of new in-state nuclear generating capacity is infeasible.

Imported nuclear power could be considered a zero-carbon resource, but uncertainty in cost projections for new nuclear projects excluded this resource from the core scenarios.

Drop-In Renewable Fuels

Green electrolytic hydrogen, synthetic methane, and biomethane are gaining breakthroughs and cost reductions as “drop-in” or replacement fuels in natural gas-fired power plants and potential zero-carbon dispatchable generation resources.

Hydrogen can be blended with natural gas to reduce emissions in the near term, and industry aims to eventually use 100 percent hydrogen fuel in retrofitted gas plants. Hydrogen can also be synthesized into renewable methane as a drop-in fuel. The Los Angeles Department of Water and Power is exploring the conversion of its Intermountain Power Plant in Utah to 30 percent hydrogen by 2025 and eventually 100 percent hydrogen fuel.

Fully converted plants could significantly affect the 2045 energy portfolio. However, staff excluded the drop-in fuels in this round of modeling because of inadequate publicly available cost and performance data, including costs to produce and transport the fuels. The generic zero-carbon resources modeled in the study scenarios could serve as proxies for these technologies if they are able to reach the specified price point.

Staff excluded biomethane because of the higher value in the other sectors.

Natural Gas Generation With Carbon Capture and Sequestration (CCS)

There are growing interest and investment in natural gas generation with CCS to provide more flexibility and reliability in the state’s electricity grid. However, technological and economic barriers to full decarbonization of fossil fuels remain high. Partially decarbonized resources (that is, with less than 100 percent of onsite carbon emissions captured and stored) did not meet the joint agencies’ criteria for zero-emission technologies.

The generic zero-carbon flexible resource modeled in the study can serve as a proxy for the effect natural gas with 100 percent CCS might have on the 2045 portfolio at the specified price point.

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[84] California Energy Commission. January 2020. Warren-Alquist Act 2020 Edition, Sections 25524.1 and 25524.2. Publication Number: CEC-140-2020-001. https://ww2.energy.ca.gov/2020publications/CEC-140-2020-001/CEC-140-2020-001.pdf.

Coal-Fired Generation With CCS

Coal-fired generation with CCS also faces significant technical and economic barriers. Furthermore, the agencies have significant public health concerns regarding the use of coal-fired power plants, even with total carbon capture. Coal-fired plants emit 84 of the 187 hazardous air pollutants identified by the U.S. Environmental Protection Agency (EPA).[85] Of the suite of toxic metals present, the arsenic and mercury in solid coal combustion commonly pose the greatest public health risk because of the associated prevalence and high toxicity. The same is true of the prevalence of polycyclic aromatic hydrocarbons (PAHs) and related precursors in solid petroleum-based fuels (for example, coal). While gas-fueled combustion may also produce toxics, the amounts and toxicity are less impactful than coal combustion. Coal combustion also emits criteria pollutants and related precursors at higher levels than natural gas combustion.[86]

Coal extraction, transport, and storage, and waste storage are associated with additional health and environmental impacts.[87] Further, coal miners suffer from respiratory health issues, including black lung disease, and are at high risk for workplace fatalities.[88]

New Small Hydroelectric Generation

The modeling included current operations as zero-carbon resources, but there are inadequate resource potential and planned development for inclusion as a candidate resource in this round of modeling.

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[85] U.S. EPA. Air Toxics Standards for Utilities: Utility MACT ICR Data. Part I & II: Final draft (version 2) of selected EU MACT ICR response data (excludes facility contact information), including; All Part I (General Facility Information); and All Part II (Fuel Analysis and Emission Data); including all Hg CEMs data. Available at https://www3.epa.gov/ttn/atw/utility/utilitypg.html.

[86] SO_2 emission rates from coal plants far exceed those from natural gas plants, even with best available control technology. Sources: (a) U.S. EPA. RACT/BACT/LAER Clearinghouse (RBLC) Basic Information. Available at https://www.epa.gov/catc/ractbactlaer-clearinghouse-rblc-basic-information. (b) Emission levels from Intermountain Power Generating Station Unit 3. Air pollution controls include low NOx burners, over fire air, selective catalytic reduction, baghouse/fabric filter, wet flue gas desulphurization, and use of low sulfur coal. Accessed August 4, 2020, from U.S. EPA RACT/BACT/LAER Clearinghouse (RBLC) at https://www.epa.gov/catc/ractbactlaer-clearinghouse-rblc-basic-information. (c) South Coast Air Quality Management District. Huntington Beach Energy Project Final Determination of Compliance. 2016. Numbers represent controlled, steady-state emission levels. Available at https://efiling.energy.ca.gov/Lists/DocketLog.aspx?docketnumber=12-AFC-02C.

[87] EIA. *Coal Explained: Coal and the Environment*. Available at https://www.eia.gov/energyexplained/coal/coal-and-the-environment.php.

[88] CDC. The National Institute for Occupational Safety and Health. *Mining Topic: Respiratory Diseases*. Available at https://www.cdc.gov/niosh/mining/topics/RespiratoryDiseases.html.

Concentrating Solar Power (CSP)

Solar thermal power plants with CSP technology, which use mirrors to collect the sun's energy, represent a small share of California's renewable generation. Because of the higher costs relative to solar photovoltaic and wind energy, there is limited development potential, and solar thermal plants were ruled out of the modeling study. Concerns regarding the environmental impacts of CSP projects — including avian mortality from power tower flux and evaporation ponds[89] — have also been a barrier to development, though recent technological and operation changes have reduced the mortality.

New Large Hydro Generation

While hydroelectric generation is considered a zero-carbon resource, the potential for developing costly new water diversions and dams with large environmental impacts is too small for this resource to be included in the modeling study.

Stakeholder Comments on Zero-Carbon Resource Definition

Many commenters supported the "RPS+" criteria for selecting energy resources in the study, and many urged the joint agencies to keep eligibility broadly defined to allow resource innovation and diversity.

The agencies carefully considered the high number of comments in favor of including or excluding specific technologies and made changes where appropriate. For a full list of technologies, inputs, and assumptions used for 2020 modeling, refer to the SB 100 Inputs & Assumptions document.[90]

Electricity Loads Subject to SB 100

SB 100 speaks only to retail sales and state agency procurement of electricity. The joint agencies interpret this to mean that other loads — wholesale or nonretail sales and losses from storage and transmission and distribution lines — are not subject to the law. The modeling reflects this interpretation.

The loads subject to SB 100 are therefore the total of the utility supplied retail sales and the state agency procurements — effectively the Department of Water Resources' (DWR) purchases of electricity to run the State Water Project pumping plants. The pump load is the largest consumer of electricity in California.

As shown in blue in **Figure 20,** these loads accounted for roughly 82 percent of total state consumption in 2018. The joint agencies considered the remaining loads to be outside the

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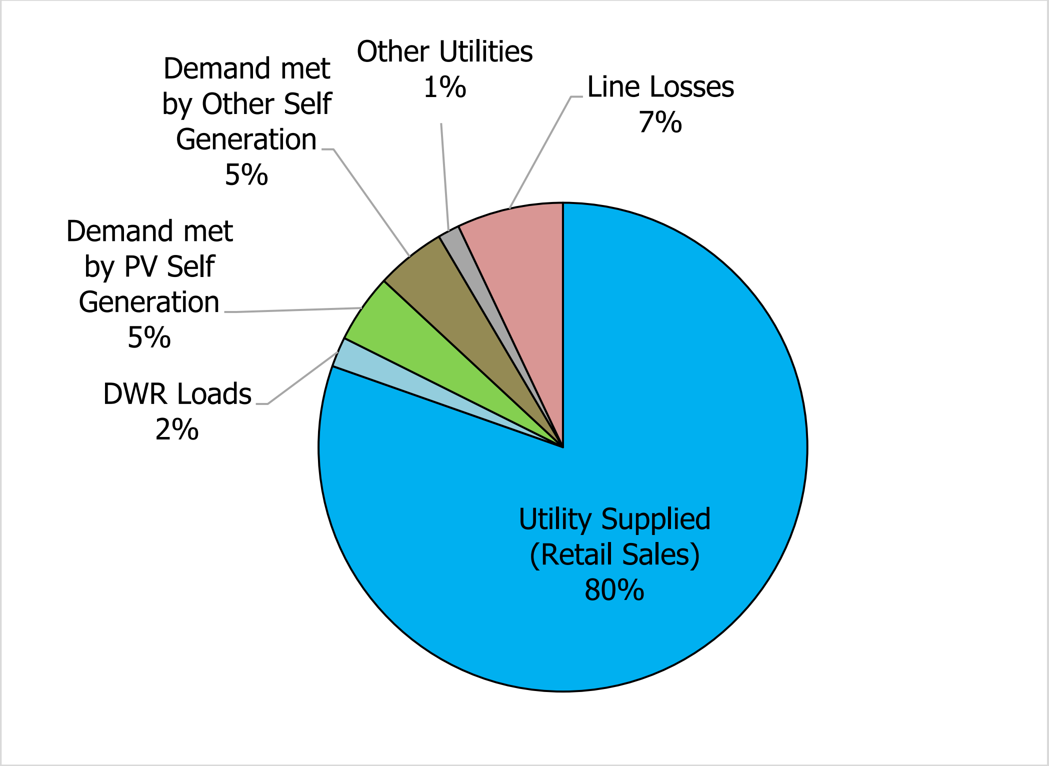
[89] California Energy Commission staff. October 2016. *Final 2016 Environmental Performance Report of California's Electrical Generation System*. CEC. Publication Number: CEC-700-2016-005-SF. https://efiling.energy.ca.gov/getdocument.aspx?tn=214098.

[90] E3. Inputs and Assumptions: CEC SB100 Interagency Report. June 2020. https://efiling.energy.ca.gov/getdocument.aspx?tn=234532.

scope of the 2045 goal of the law. Solar self-generation accounted for an additional 5 percent of total consumption in 2018.

Figure 19: 2018 California Electricity Loads



Source: 2019 California Energy Demand and the Quarterly Fuels and Energy Report Demand filings

The modeled scenarios also reflect assumptions made about electricity demand. The joint agencies analyzed a reference demand case using an extrapolation from the 2019 Integrated Energy Policy Report California Energy Demand Forecast,[91] as well as high electrification, high biofuels, and high hydrogen scenarios — building off the analysis in the 2018 Deep Decarbonization in a High Renewables Future report.[92]

Several stakeholders commented on the scope of loads covered SB 100. As noted above, the law states "that eligible renewable energy resources and zero-carbon resources supply 100%

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[91] California Energy Commission. February 2020. *2019 Integrated Energy Policy Report*. CEC. Publication Number: CEC-100-2019-001-CMF. https://www.energy.ca.gov/data-reports/reports/integrated-energy-policy-report/2019-integrated-energy-policy-report.

[92] Energy and Environmental Economics, Inc. June 2018. *Deep Decarbonization in a High Renewables Future.* California Energy Commission, https://ww2.energy.ca.gov/2018publications/CEC-500-2018-012/CEC-500-2018-012.pdf.

of retail sales of electricity to California end-use customers and 100% of electricity procured to serve all state agencies by December 31, 2045."

Commenters favoring inclusion of system losses interpreted "supply" to include the upstream generation needed to deliver the retail sales of electricity.

After careful consideration, the joint agencies determined "supply" to mean only retail sales and state loads — an interpretation consistent with the state's Renewables Portfolio Standard.

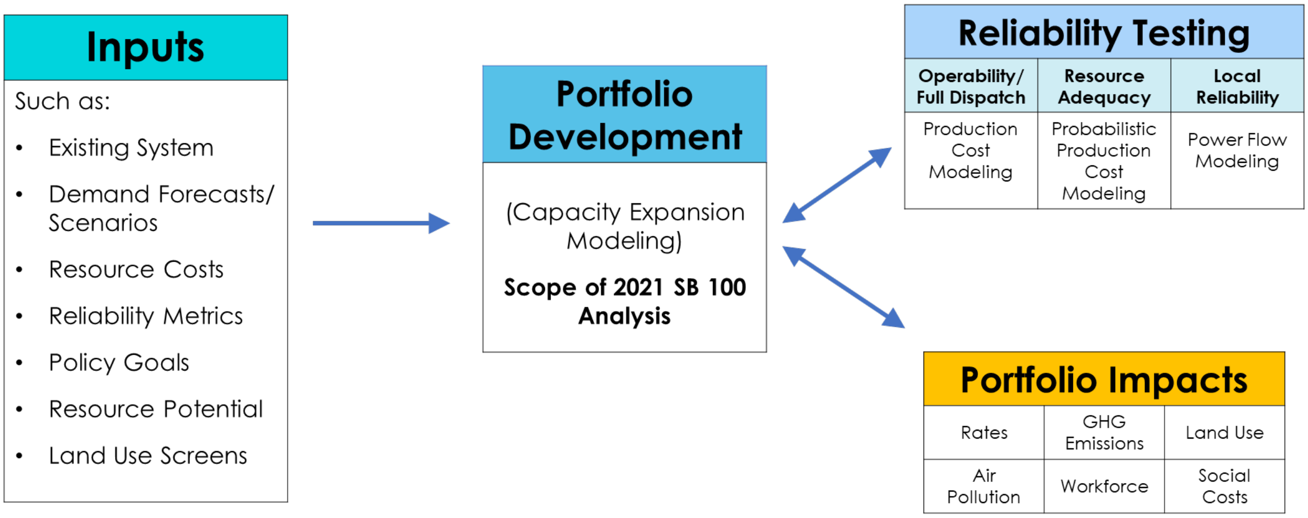
CHAPTER 3:
Capacity Expansion Modeling and Discussion

Modeling Scope

The 2021 Report uses capacity expansion modeling as a first step in evaluating the 2045 policy. Capacity expansion modeling optimizes new resource investments over the planning horizon, given the policy and reliability constraints. Typically, simplifications are necessary in capacity expansion modeling due to the computational complexity of optimizing resource selection over a long time horizon. Thus, resource planning typically includes multiple modeling steps to evaluate the reliability of the developed portfolios, as shown in **Figure 21**.

Ideally, in a statewide, long-term analysis such as SB 100, production cost modeling (to test operability and verify resource dispatch) and probabilistic production cost modeling (to determine resource adequacy) would also be completed. Comprehensive studies also evaluate the relevant environmental, economic, and societal impacts of the portfolio. If any assessments do not meet the reliability constraints or policy objectives, the portfolio or capacity expansion model would be adjusted and reassessed.

Figure 20: Resource Planning Modeling Steps



Source: CEC staff

All portfolios presented in this report are directional and intended to inform and complement ongoing analysis within the joint agencies. A comprehensive reliability assessment is not included in this first report; so the portfolio composition and associated costs may change after a more rigorous analysis is completed. Quantitative evaluation of environmental, health, and other societal impacts are also not included in the scope of the 2021 Report.

The modeled zero-carbon candidate resources represent a subset of possible resources that could qualify as "zero-carbon." Only commercialized resources with established and vetted publicly available cost and performance data, as well as an anticipated development pipeline, were included in the core modeling scenarios, as described in Chapter 2: SB 100 Overview and Report Development Process. Drop-in renewable fuels that could partially decarbonize a generating unit were not included as these generating resources do not meet the "zero-carbon resource" criteria of emitting zero or negligible greenhouse gas (GHG) emissions. Generating resources operating on 100 percent renewable fuels were not included due to lack of established and vetted cost and performance data. Generic zero-carbon firm candidate resources[93] were included in a set of study scenarios and could indicate the potential impact of 100 percent renewable fuels at a specific cost point.

The study includes two types of scenarios, which are described in the Scenario Framework section of this chapter:

- Core scenarios, which reflect the joint agencies' interpretation of the 2045 target in SB 100
- Study scenarios, which are outside the joint agencies' interpretation of the 2045 target in SB 100 and provide information to further support California energy and climate planning and public health considerations

Modeling Framework

Modeling Tools

The 2021 Report modeling builds on existing studies, namely the CPUC Integrated Resource Planning (IRP) 2045 Framing Study, as presented in the 2019–21 IRP cycle.[94] The 2045 Framing Study provided guiding information about the state's long-term policy goals for the IRP's 2030 Reference System Plan. While the 2045 Framing Study is the basis for the SB 100 analysis, the version of the RESOLVE model used for the 2021 Report differs from the version used for the 2019–20 IRP cycle. The framework and modeling assumptions were updated to align with the goals of the 2021 Report. Some key changes are noted in the next section.

RESOLVE California Model

The RESOLVE California model is a capacity expansion model developed by Energy and Environmental Economics, Inc. (E3) The RESOLVE model produces a least-cost resource

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[93] "Firm resources" are generating resources that can generate electricity at any given time. Examples of zero-carbon firm resources include geothermal, biomass, hydroelectric, and nuclear power.

[94] CPUC Energy Division. [2019-20 IRP: Proposed Reference System Plan](https://www.cpuc.ca.gov/uploadedFiles/CPUCWebsite/Content/UtilitiesIndustries/Energy/EnergyPrograms/ElectPowerProcurementGeneration/irp/2018/2019%20IRP%20Proposed%20Reference%20System%20Plan_20191106.pdf). November 6, 2019. https://www.cpuc.ca.gov/uploadedFiles/CPUCWebsite/Content/UtilitiesIndustries/Energy/EnergyPrograms/ElectPowerProcurementGeneration/irp/2018/2019%20IRP%20Proposed%20Reference%20System%20Plan_20191106.pdf. The modeling for this report has been prepared by E3 for the joint agencies. This report is separate from any work E3 is doing for the California Public Utilities Commission. However, the joint agencies will continue work together to implement SB 100, which will be informed by the findings and modeling in this report.

portfolio, or selection of new electricity generating resources, required to meet an assumed future electric demand by optimizing the net-present value of capital investments and operational costs under policy and reliability constraints.

RESOLVE contains two modules, investment and operational, that co-optimize for the least-cost resource portfolio. The RESOLVE optimization directly captures the linkages between investment decisions and system operations in a single stage. The operational module simulates hourly resource dispatch over a representative 37 independent days for each year modeled in the planning horizon. The investments and operations within the planning horizon are modeled under several potential constraints, including Renewables Portfolio Standard policy, GHG emissions, resource adequacy constraints to maintain reliability, and operational restrictions on generators and resources.

The resource adequacy constraint ensures there is sufficient capacity to meet the system resource adequacy requirement, or capacity requirement, in each modeled year using a net qualifying capacity approach for thermal generators, and an effective load carrying capacity (ELCC) approach for renewables and storage resources.[95] The system resource adequacy requirement is 115 percent of typical peak load.[96] Further reliability analysis for the selected portfolios is necessary and planned for future work, as described in Chapter 4 of this report.

Several changes were made from the CPUC 2019 IRP version of the RESOLVE model for the 2021 Report, including:

- Increasing the geographic footprint from the California ISO to include all balancing authority areas in California.
- Updating baseline resources to reflect the supply provided by additional balancing authority areas included in the geographic footprint.
- Updating the resource cost assumptions to the reflect the most current datasets available at the time of modeling. Details on cost assumptions are described in the Resource Assumptions section and in the Input and Assumptions documentation.

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95 "Effective load carrying capability" (ELCC) is the increment of load that could met by the resource while maintaining the same level of reliability. The ELCC of a variable renewable energy resource is based on the capacity coincident with peak load and the profile and quantity of existing variable renewable energy resources. For a detailed description of ELCC implementation in RESOLVE, see page 87 of the Inputs and Assumptions documentation.

96 As stated in the *Final Root Cause Analysis: Mid-August 2020 Extreme Heat Wave*, *Final Root Cause Analysis: Mid-August 2020 Extreme Heat Wave* , *Preliminary Root Cause Analysis: Mid-August 2020 Heat Storm*, the CEC and CPUC recognize that planning for a combination of a 1-in-2 peak with a 15 percent planning reserve margin may not be enough in a high renewables system, particularly when combined with the increasing impacts of extreme heat events, such as those experienced by California and the Western United States in 2020. Any changes to the current resource adequacy and reliability planning processes will be reflected in future assessments.

- Removing the GHG constraint to evaluate the impact of the 100 percent clean electricity policy without the impact of a potentially more stringent constraint.[97]
- Adding hydrogen fuel cells to the candidate resource options. Hydrogen was assumed to be produced off-grid by electrolyzers powered by renewables.
- Expanding the out-of-state (OOS) wind potential to 12 gigawatts (GW) and offshore wind potential to 10 GW.
- Changing how storage is constrained to a feasible dispatch pattern by placing a daily cycling limitation on battery energy storage and removing storage losses from the load portion of the compliance accounting method. For more details, please refer to the Inputs and Assumptions documentation.

Limitations of RESOLVE

Although capacity expansion modeling is an important tool, it is just the first step in a series of modeling phases to develop reliable portfolios that meet all applicable policy objectives. While RESOLVE does include a planning reserve margin constraint to represent system capacity needs, this constraint is not a substitute for probabilistic modeling to calculate a loss of load expectation or similar metrics.

There are specific limitations with RESOLVE that have implications for the modeling results:

- RESOLVE optimizes California as one zone. It does not reflect the impacts of separate balancing authority or load-serving entity requirements or policy objectives or evaluate local reliability needs. Furthermore, the model does not address land-use and spatial constraints that could limit the areas that are assumed by the model to be available for renewable or zero-carbon energy development.
- RESOLVE independently simulates dispatch for 37 representative days of any modeled year. These representative days, sampled from historical meteorological data from 2007 through 2009, are assigned weights to create a reasonable representation of the complete distribution of potential conditions in a full 8,760-hour (the number of hours in a year) simulation. While this representation is sufficient for the primary function of RESOLVE, capacity-expansion modeling, a model with more geographic and temporal granularity is necessary to simulate full dispatch operations and determine the reliability of the selected portfolio.
- RESOLVE includes minimal demand-side resource options for selection. This version of RESOLVE includes customer-side solar and shed demand response (DR). Resources such as energy efficiency, shift DR, and customer-side battery storage are not

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[97] The CPUC IRP version of RESOLVE includes a 2030 GHG constraint to reflect the SB 350 requirement of planning to meet an electric sector GHG target. The 2045 Framing Study also includes a GHG constraint reflective the 80 percent economywide reduction in GHG emissions by 2050 scenarios. A GHG constraint may be more stringent than the statutory requirements in SB 100 and were removed to best evaluate the 2045 statutory goal. The 2030 GHG emissions for all scenarios are within the established 2030 GHG range.

candidate resources. As such, a sensitivity exploring the potential value of load flexibility was included in the analysis.

- As configured for this study, RESOLVE optimizes only storage resources within each modeled 24-hour day, so as long duration storage resources cannot be optimized across days and are thus not fully valued by the model. Tool development is underway to better evaluate the benefits of and compare types of long-duration storage in RESOLVE.[98] RESOLVE also does not represent hybrid resources, such as solar plus battery storage.

Finally, the analysis presented in this report does not include uncertainty or risk analysis. Given the limitations of the current modeling paradigm, all scenarios and results are intended to provide directional information and serve as a foundation for future analyses.

Inputs and Assumptions

Resource Assumptions

Supply-side candidate resources for selection in the optimization include renewable and zero-carbon resources (as described in Chapter 2), gas resources, storage resources, and transmission resources. Demand-side candidate resources for selection include customer-side solar, customer-side storage, and shed demand response.

RPS-eligible and zero-carbon resources that can be selected as candidate resources include utility-scale solar, wind resources — which are divided between in-state wind, out-of-state wind on new transmission (OOS wind), and offshore wind (OSW) — geothermal, biomass, and hydrogen fuel cells. Solar and wind resources are counted toward the system resource adequacy requirement based on an ELCC approach, as described on page 87 of the Input and Assumptions documentation. Gas resources include combustion turbine and combined-cycle gas turbine generators. Existing gas resources can also be economically retired by the model.

The costs for all generating resources are based on the National Renewable Energy Laboratory (NREL) 2019 Annual Technology Baseline (ATB), except hydrogen fuel cells, which are based on the Department of Energy’s Hydrogen Analysis Project. Resource costs are shown in

Figure 22.[99] Hydrogen is assumed to be produced off grid by electrolyzers powered by renewables.

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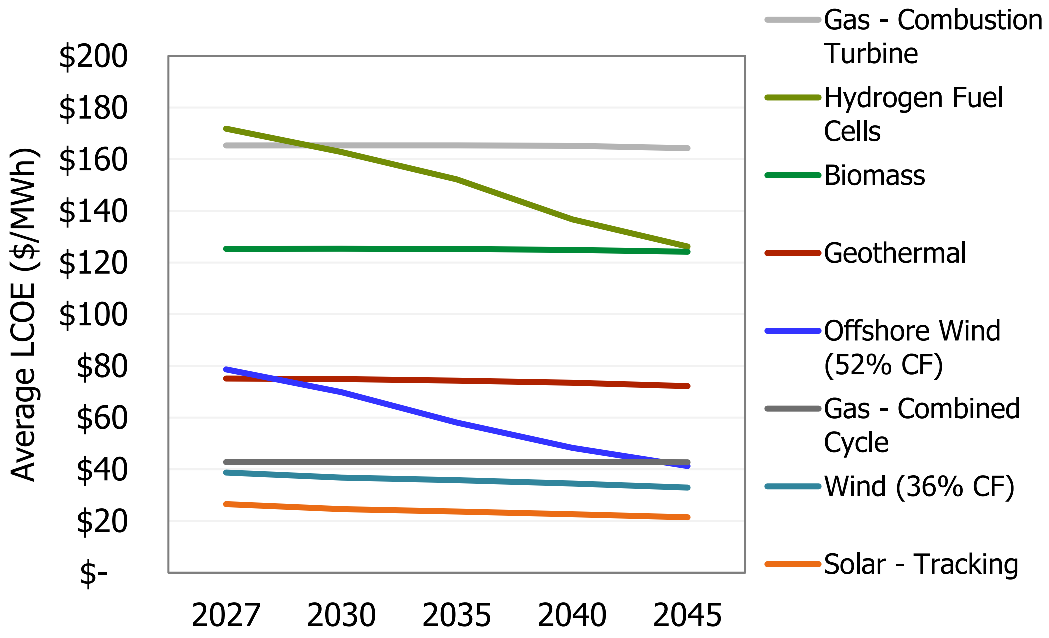
98 California Energy Commission. GFO-19-308- Assessing Long-duration Energy Storage Deployment Scenarios to Meet California’s Energy Goals, https://www.energy.ca.gov/solicitations/2020-01/gfo-19-308-assessing-long-duration-energy-storage-deployment-scenarios-meet.

99 National Renewable Energy Laboratory. NREL 2019 Annual Technology Baseline Web page, https://atb.nrel.gov/electricity/2019/; and U.S. Department of Energy. DOE H2A Analysis Web page, https://www.hydrogen.energy.gov/h2a_analysis.html.

Figure 21: Implied Levelized Cost of Energy (LCOE) of Average Technologies (2016$/MWh)



Source: CEC staff and E3 analysis

Several storage resources are available for selection by the model, including lithium-ion battery storage and long-duration storage, which is modeled as pumped hydroelectric energy storage. The model can select the duration for each storage resource. Long-duration storage capacity is limited to 4,000 MW.[100] Storage resources are counted toward the resource adequacy requirement based on an ELCC approach, as described on page 89 of the Input and Assumptions documentation. Storage resource costs are based on Lazard's Levelized Cost of Storage Analysis 5.0 and supplemented by NREL's Solar and Storage Report.[101]

For more information on resource assumptions, see the Inputs and Assumptions documentation.

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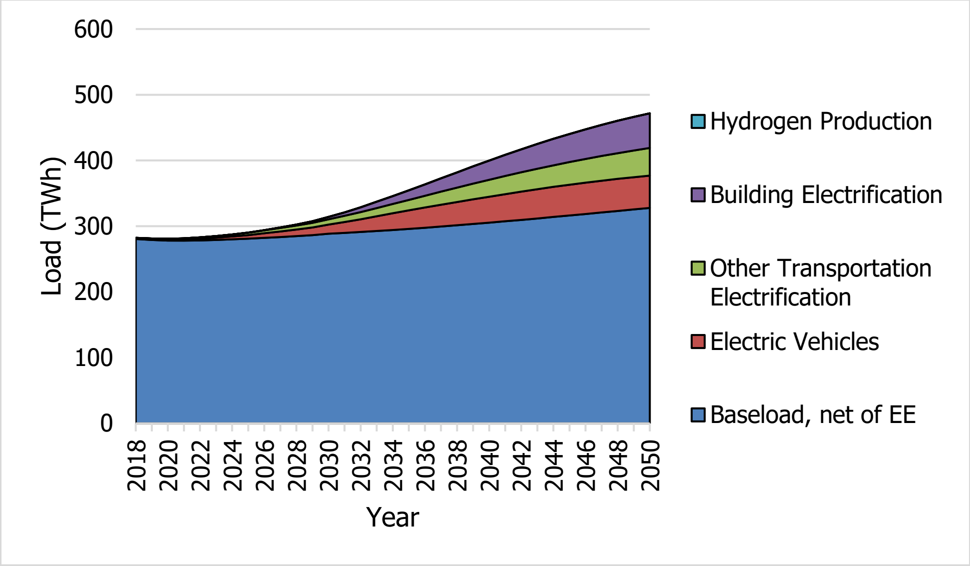
[100] Long duration storage is generally considered storage resources that can sustain maximum output for 8 hours or longer.

[101] Lazard. November 2019. Lazard's Levelized Cost of Storage Analysis- Version 5.0, https://www.lazard.com/media/451087/lazards-levelized-cost-of-storage-version-50-vf.pdf; and National Renewable Energy Laboratory. November 2018. 2018 U.S. Utility-Scale Photovoltaics Plus-Energy Storage System Costs Benchmark, https://www.nrel.gov/docs/fy19osti/71714.pdf.

Demand Scenarios

Demand scenarios are a key driver of resource portfolio development. This study used several demand scenarios, representing a range of future economywide scenarios, developed through the E3 PATHWAYS model. PATHWAYS is an economywide scenario tool used to evaluate potential pathways to meet economywide GHG reduction targets. Like the IRP 2045 Framing Study, this study uses three mitigation scenarios that meet the goal of 80 percent economywide reduction in GHG emissions by 2050[102]: high electrification (**Figure 23**), high biofuels (**Figure 24**), and high hydrogen[103] (**Figure 25**).[104]

Figure 22: High Electrification Demand Scenario Annual Loads by Category



Source: E3 analysis

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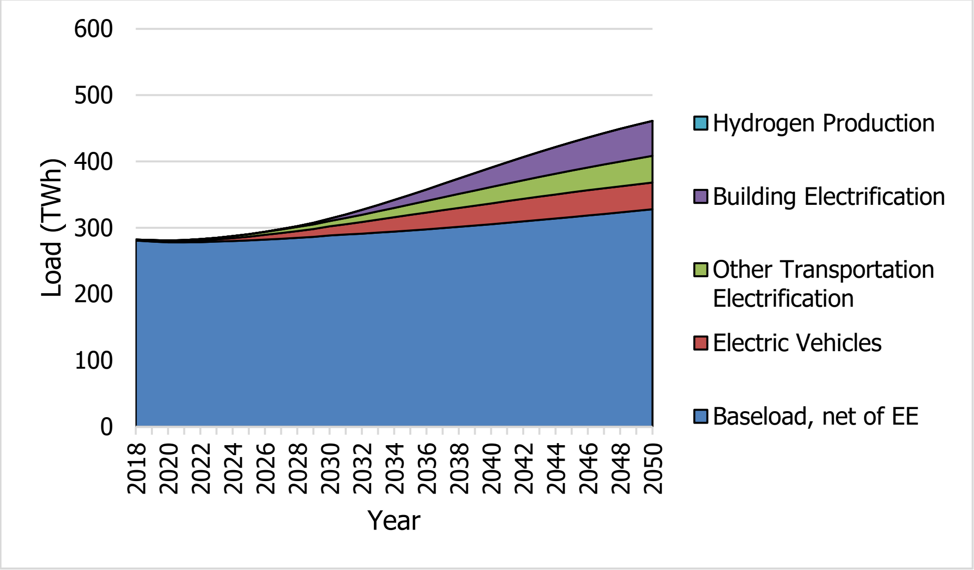
[102] Governor Arnold Schwarzenegger, Executive Order S-3-05, June 1, 2005, https://www.library.ca.gov/Content/pdf/GovernmentPublications/executive-order-proclamation/5129-5130.pdf.

[103] Hydrogen for demand-side end uses (such as vehicles) was assumed to be produced on-grid (in other words, have corresponding electric load), while hydrogen for the supply-side hydrogen fuel cell was assumed to be produced off-grid.

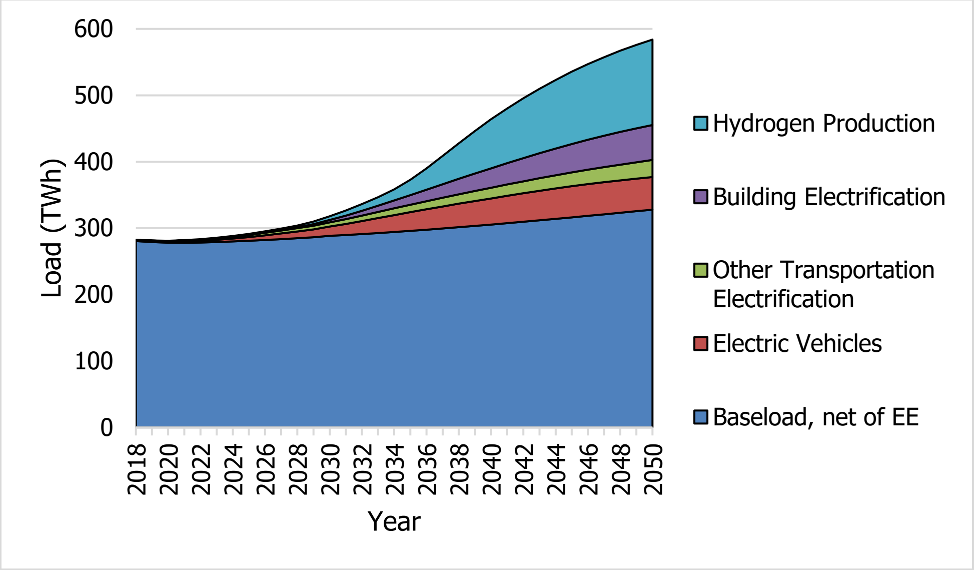
[104] Mahone, Amber, Zachary Subin, Jenya Kahn-Lang, Douglas Allen, Vivian Li, Gerrit De Moor, Nancy Ryan, Snuller Price. 2018. *Deep Decarbonization in a High Renewables Future: Updated Results from the California PATHWAYS Model*. California Energy Commission. Publication Number: CEC-500-2018-012. https://ww2.energy.ca.gov/2018publications/CEC-500-2018-012/CEC-500-2018-012.pdf.

Figure 23: High Biofuels Demand Scenario Annual Loads by Category



Source: E3 analysis

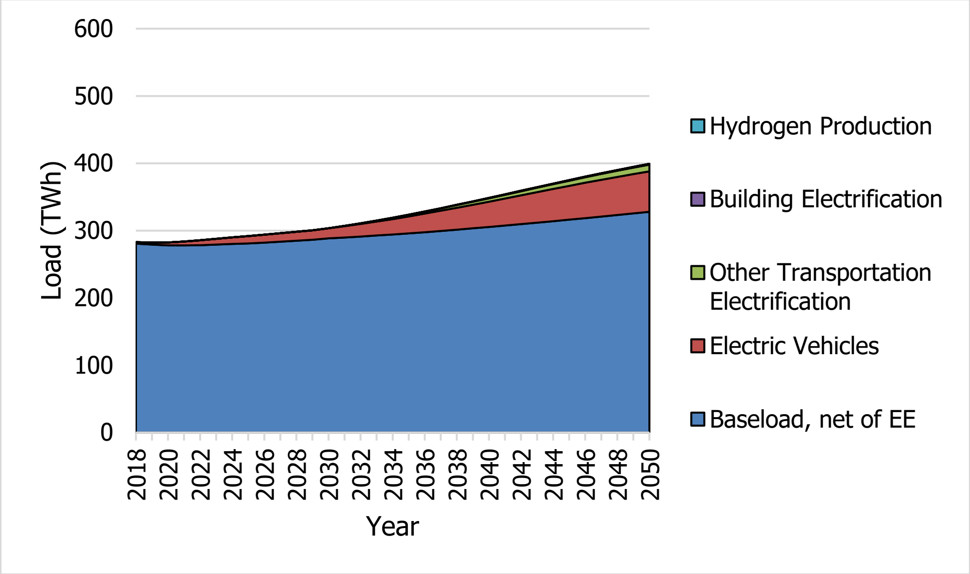
Figure 24: High Hydrogen Demand Scenario Annual Loads by Category



Source: E3 analysis

Moreover, the study used a reference scenario developed to align with the 2019 California Energy Demand Forecast through 2030 and an extrapolation of that forecast through 2045,[105] as shown in **Figure 26**.

Figure 25: Reference Demand Scenario



Source: E3 analysis

Each of the demand scenarios includes a significant increase in demand from 2020, ranging between a 22 percent increase by 2045 in the reference scenario and an 87 percent increase in the high hydrogen scenario.

With the substantial growth in annual loads by 2045, each scenario shows a near doubling of resource adequacy requirements compared to present day, as shown in **Figure 27**.[106]

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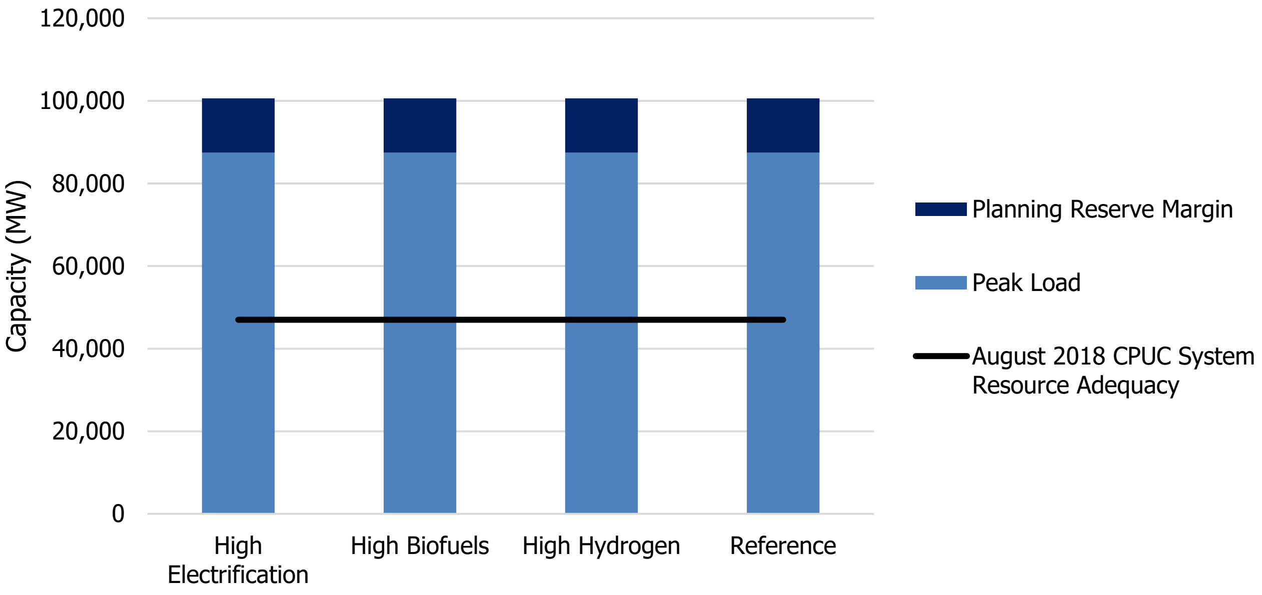
105 California Energy Commission. February 2020. *2019 Integrated Energy Policy Report*. CEC. Publication Number: CEC-100-2019-001-CMF. https://www.energy.ca.gov/data-reports/reports/integrated-energy-policy-report/2019-integrated-energy-policy-report.

106 The RESOLVE reliability module resource adequacy requirement is peak load plus a 15 percent planning reserve margin; this reserve margin value is a user-configurable input variable. Figure 7 references the August 2018 CPUC System Resource Adequacy resource total. This number represents the capacity requirement for roughly 80 percent of state loads. Publicly owned utilities have separate resource adequacy processes.

Figure 26: 2045 Resource Adequacy Requirement for the High Electrification, High Biofuels, High Hydrogen, and Reference Demand Scenarios



Source: CEC staff and E3 analysis

Additional information about the demand scenarios and demand assumptions can be found in the Input and Assumptions documentation.

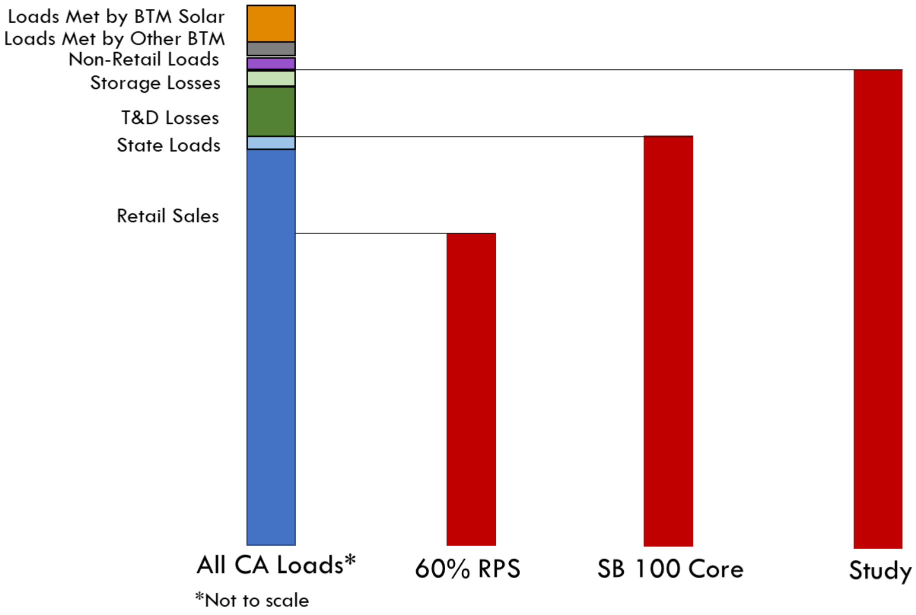
Zero-Carbon Load Coverage

Three zero-carbon load coverage targets, as illustrated in **Figure 28**, were considered in this study:

- A "60 percent RPS" load coverage target with a constant 60 percent of retail sales being met by RPS-eligible resources through 2045. This load coverage target acts as a counterfactual — or reference — to evaluate impacts of the 2045 100 percent clean electricity target.
- The "SB 100 core" load coverage target is consistent with the joint agencies' interpretation of SB 100, and 100 percent of retail sales plus state agency loads in 2045 are met by zero-carbon generation. Interim years include a linear zero-carbon target from 2030 to 2045.
- The "study" load coverage target goes beyond the joint agencies' interpretation of SB 100, and 100 percent of retail sales, state loads, transmission and distribution losses, and storage losses in 2045 are met by zero-carbon resources. Interim years include a linear zero-carbon target from 2030 to 2045.

All scenarios include a 60 percent RPS target in 2030 as required by SB 100.

Figure 27: 2045 Zero-Carbon Load Coverage Targets



Source: CEC, CPUC, CARB. Developed by consensus.

Scenario Framework

SB 100 states that the joint agency report shall include "alternative scenarios in which the policy … can be achieved and the estimated costs and benefits of each scenario." Furthermore, the statute requires the 2021 Report to include "a review of the policy … focused on technologies, forecasts, then-existing transmission, and maintaining safety, environmental and public safety protection, affordability, and system and local reliability."

The modeling included in this report evaluates the costs and benefits of various technological pathways to meet the 2045 target, while acknowledging that costs, performance, and availability of commercialized technologies will change over the next 25 years. Future modeling will be updated accordingly.

While the primary focus of this report is to analyze scenarios based on established cost and performance data and the joint agencies' interpretation of SB 100, the joint agencies recognize the importance of analyzing outcomes beyond these assumptions to support broader energy and climate planning and public health considerations. As such, scenarios are broken into two categories, "core scenarios" and "study scenarios."

Core Scenarios

The "Core Scenarios" modeled for the 2021 Report are consistent with the joint agencies' interpretation of the statute and, therefore, include the proposed loads subject to SB 100 (retail sales plus state agency loads) in the zero-carbon target. Generation applied toward meeting the zero-carbon target includes generation from resources that meet the zero-carbon criteria as described in the Modeling Scope section of this chapter.

The scenarios reflect a central, "SB 100 Core Scenario," with the default assumptions of the SB 100 Core Load Coverage Target, High Electrification Demand Scenario, and all candidate resources available for selection by the model. Sensitivities then explore the effect of changing specific assumptions. Core scenarios are listed in **Table 10**.

Table 10: SB 100 Core Scenario Classification List

Scenario Classification	Scenario Description
60% RPS (Counterfactual)	60% RPS through 2045
SB 100 Core Scenario	Core Load Coverage; High Electrification Demand; All candidate resources available
SB 100 Core, Demand Sensitivities	Change: Demand Scenarios or Load Shape
SB 100 Core, Resource Sensitivities	Change: Candidate Resource Availability

Source: CEC, CPUC, and CARB. Developed by consensus.

Study Scenarios

The "study scenarios" are exploratory analyses that examine outcomes outside the scope of the joint agencies' working interpretation of the SB 100 policy. They are intended to provide additional information for consideration and support broader state energy, climate planning, and public health efforts. Study scenarios should not be interpreted as asserting the state's ability or intention to regulate beyond the interpreted scope of SB 100. Rather, they are intended to advance an understanding of long-term planning beyond the scope of SB 100. Study scenarios are listed in **Table 11**.

Table 11: Study Scenario Classification List

Scenario Classification	Scenario Description
Expanded Load Coverage	Core Load Coverage plus storage and T&D losses; High Electrification Demand; All candidate resources available
Expanded Load Coverage, Demand Sensitivities	Change: Demand Scenarios
Expanded Load Coverage, Resource Sensitivities	Change: Candidate Resource Availability
Zero Carbon Firm Resources	Add generic zero carbon firm resources to candidate resources as a proxy for emerging zero-carbon technologies
Accelerated Timelines	Accelerate 100% target to 2030, 2035, and 2040
No Combustion	No conventional combustion resources included (fossil and biomass based); retire all in-state combustion resources by 2045

Source: CEC, CPUC, and CARB. Developed by consensus.

Preliminary Results

The initial SB 100 modeling resulted in the following key findings:

- SB 100 is achievable and will require significant resource capacity to meet the 2045 target and increasing electric demand.
- Gas capacity is maintained for resource adequacy, although gas generation decreases by half compared to a 60 percent RPS future.
- SB 100 reduces electric sector GHG emissions to around 24 MMT CO_2 in 2045 in a high-electrification future.
- Demand is a significant driver of new resource needs.
- Demand flexibility reduces total new resource needs and total supply cost.
- Cost-competitive zero-carbon firm resources would reduce total resource needs and total system costs.
- A no-combustion scenario appears technically achievable and results in significant new capacity and increased total resource cost compared to the SB 100 core scenario.

Central Core and Study Scenario Results

All scenarios modeled result in significant capacity additions. **Figure 29** shows the cumulative capacity additions, plus the assumed new customer-side solar, for three scenarios with different zero-carbon load coverage targets, 60 percent RPS (60 percent of retail sales), SB 100 core (100 percent of retail sales and state loads), and study (core loads plus system losses) with high-electrification demand. Across all scenarios, the customer-side solar included is a modeling input, representative of projected customer-side solar adoption. No additional customer-scale solar was selected in the optimization.

In the 60 percent RPS scenario, 73 GW if utility-scale capacity is added by 2045, including:

- All 4.3 GW of assumed available in-state wind.
- 2.2 GW of out-of-state wind.
- 36 GW of utility-scale solar.
- 30 GW of battery storage.
- 1.7 GW of pumped storage.
- 440 MW of shed DR.
- 2.6 GW of new gas generation.

While the RPS target remains at 60 percent after 2030, increased electricity demand in the high-electrification demand scenario still drives the need for a significant amount of additional renewable energy resources, storage, and some gas resources.

In the SB 100 core scenario, 145 GW of utility-scale capacity additions are selected by 2045, including:

- All 4.3 GW of assumed available in-state wind.
- All 10 GW of assumed available offshore wind.
- All 4 GW of assumed available long-duration storage.
- 8.2 GW of out-of-state wind.
- 70 GW of utility-scale solar.
- 135 MW of geothermal.
- 49 GW of battery storage.

Moreover, the model economically retires 4.7 GW of gas capacity.

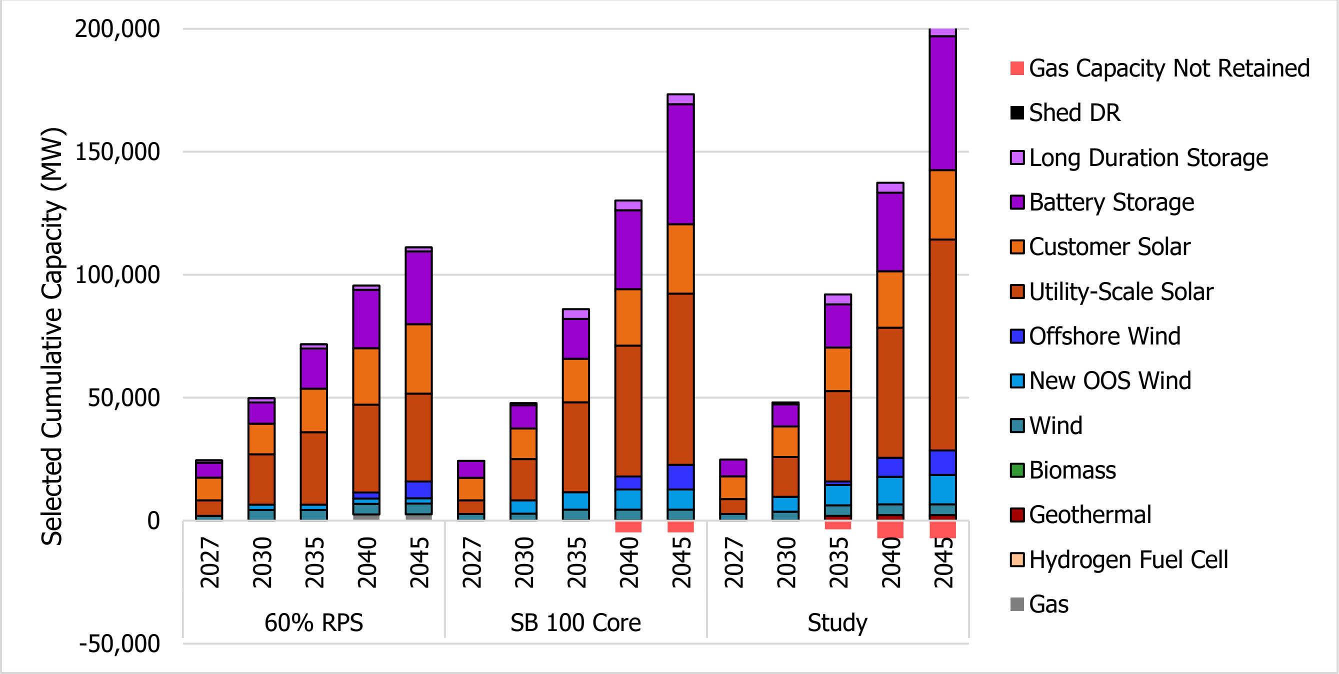
In the study scenario (expanded load coverage), 173 GW of utility-scale capacity additions are selected by 2045, including:

- All 4.3 GW of assumed available in-state wind.
- All 10 GW of assumed available offshore wind.
- All 4 GW of assumed available long-duration storage.
- 11.9 GW of out-of-state wind.

- 86 GW of utility-scale solar.
- 2.3 GW of geothermal.
- 55 GW of battery storage.

Furthermore, the model economically retires 7.2 GW of gas capacity.

Figure 28: Cumulative Capacity Additions for the 60 Percent RPS, SB 100 Core, and Study Scenarios

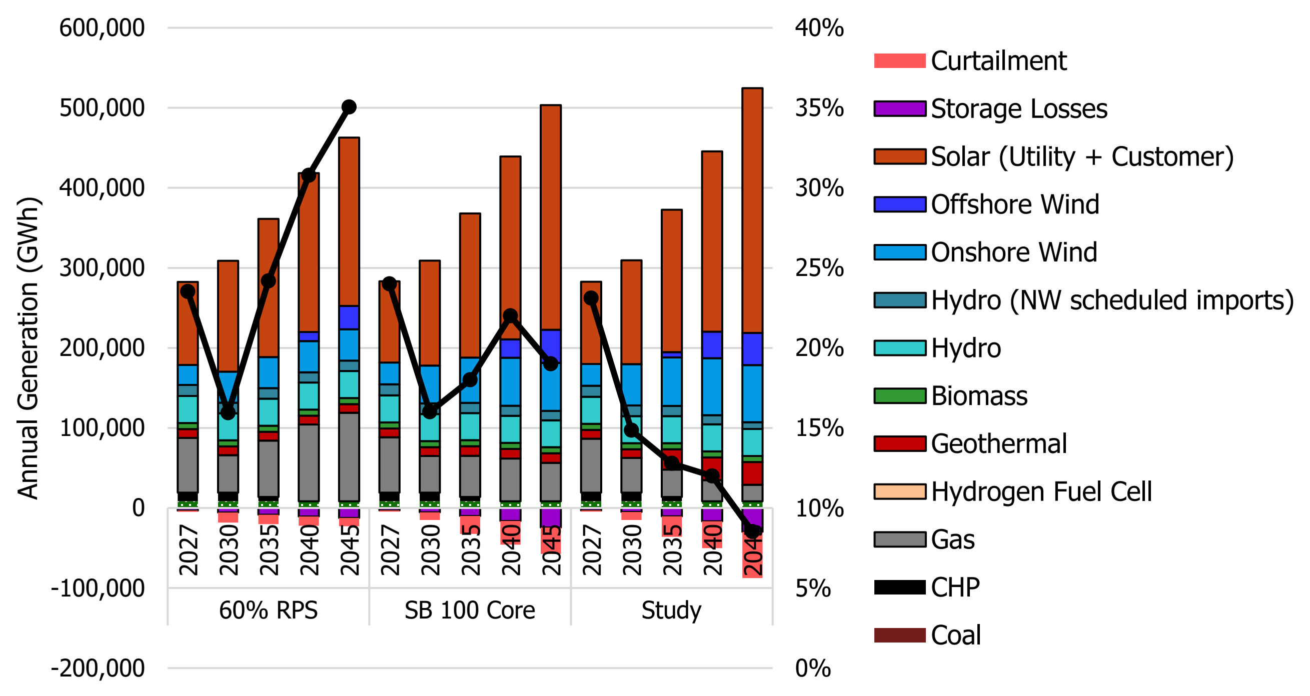


Source: CEC staff and E3 analysis

The annual generation in each of the scenarios increases significantly over the modeled years, as shown in **Figure 30**. In the 60 percent RPS scenario, gas generation and the gas fleet capacity factor increase between 2030 and 2045 (that is, gas generator are run more often). On the other hand, in both the SB 100 core and study (expanded load coverage) scenarios, gas generation and gas fleet capacity factors decrease between 2027 and 2045.

Renewable curtailment increases with the stringency of the zero-carbon target. In 2045, curtailment reached 2 percent in the 60 percent RPS scenario, 7 percent in the SB 100 core scenario, and 11 percent in the study (expanded load coverage) scenario.

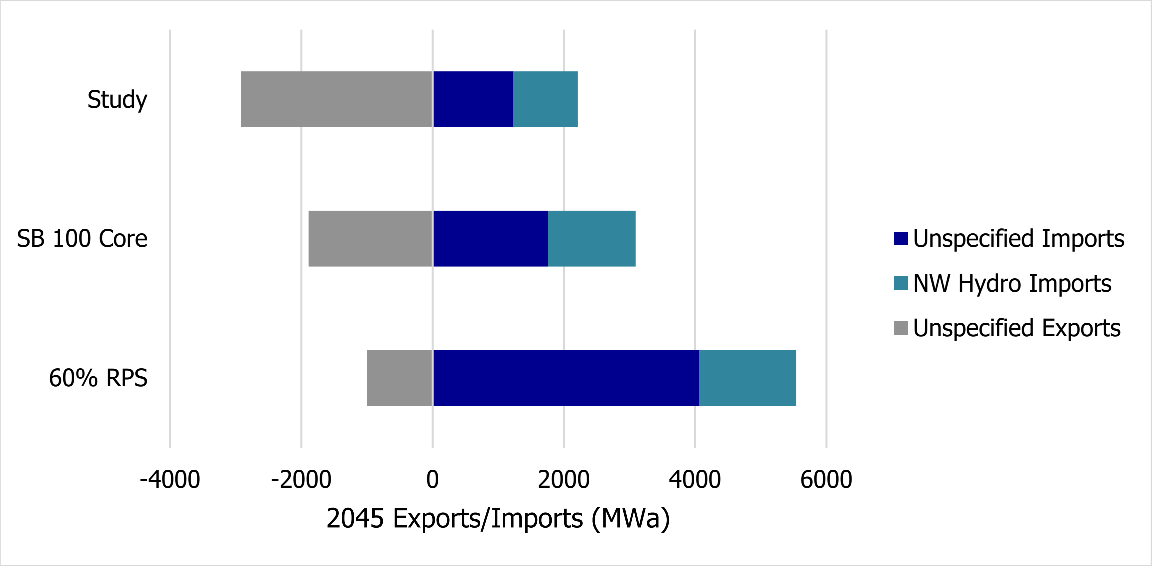
Figure 29: Annual Generation for the 60 Percent RPS, SB 100 Core, and Study Scenarios



Source: CEC staff and E3 analysis

As shown in **Figure 31**, as the stringency of the zero-carbon target increases, average imports decrease and average exports increase.

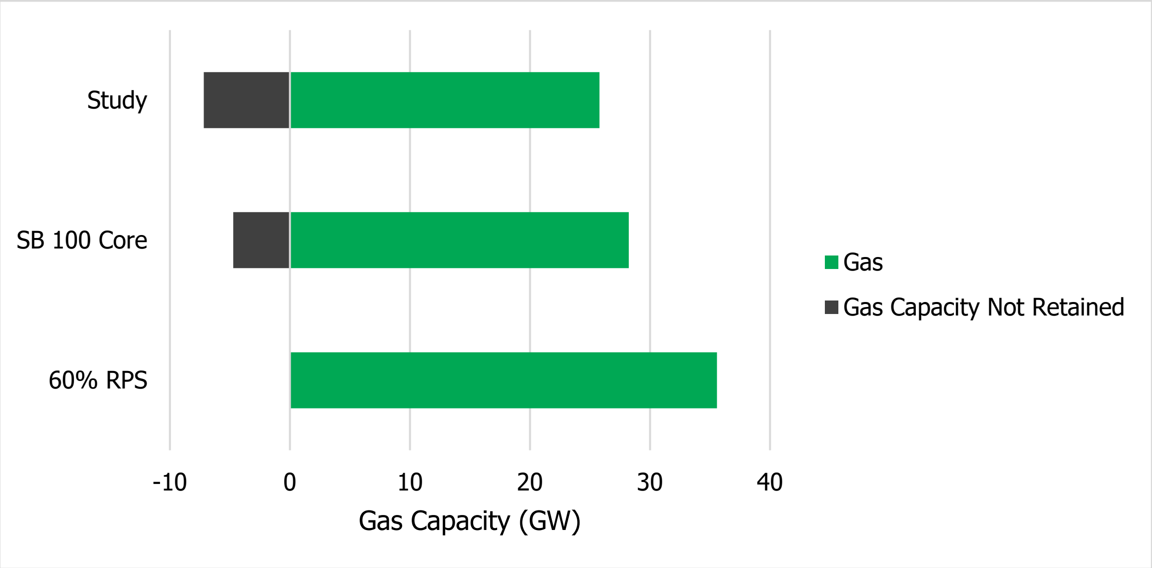
Figure 30: Average Imports and Exports in 2045 for the 60 Percent RPS, SB 100 Core and Study Scenarios



Source: CEC staff and E3 analysis

While both the SB 100 core and study (expanded load coverage) scenarios show decreases in gas generation, much of the gas fleet is retained, as shown in **Figure 32**.

Figure 31: Total Installed (Existing and New) and Retired Gas Capacity for the 60 Percent RPS, SB 100 Core and Study Scenarios



Source: CEC staff and E3 analysis

This analysis assumes no additional gas generators retirements beyond those planned at the time of modeling.[107] Additional retirements before the first modeled year would likely increase economic gas retention or storage additions or both. Gas maintenance costs are consistent with the NREL ATB's projected fixed operations and maintenance (O&M). Comparison to CPUC resource adequacy reported average contract prices suggest that costs included in NREL's ATB may be an underestimate of gas maintenance costs.[108] Higher than modeled gas fleet maintenance costs may decrease economic gas retention or increase total scenario cost or both.

Significant gas capacity is economically retained to contribute to meeting the system resource adequacy requirements, as shown in **Figure 33**.[109] Comparing across scenarios, despite the significant increase in variable renewable energy nameplate capacity, the ELCC contributions increase relatively little, with a marginal ELCC for solar at 2 percent and a marginal ELCC for wind at 19 percent. In scenarios where the optimization results in more battery storage, there are increases in economic gas retirements. While there is a resource adequacy constraint in the model (i.e., a 15 percent planning reserve margin), a full resource adequacy analysis is necessary to determine whether the portfolios produced are resource adequate.

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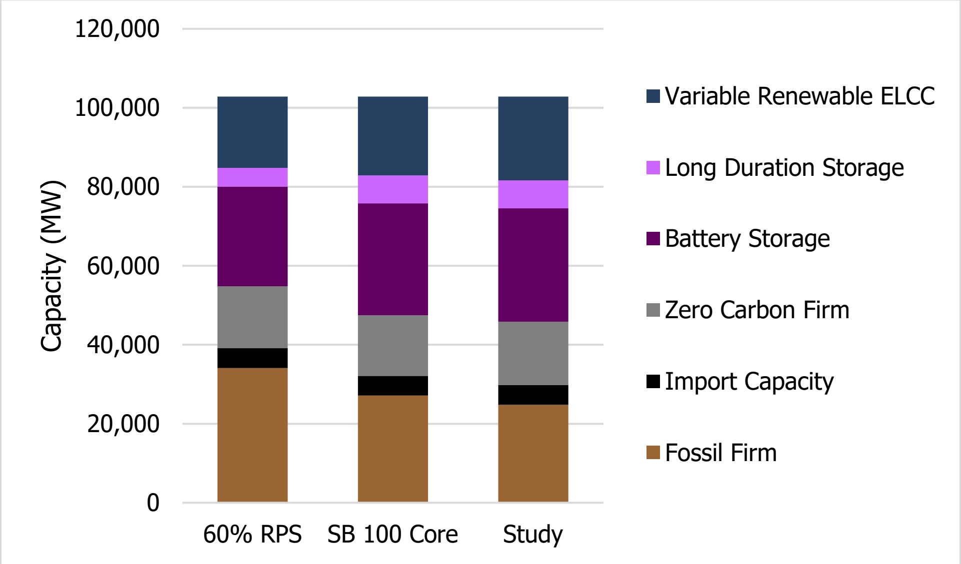
107 It is assumed the remaining once-through-cooling units retire on the planned retirement schedule. No other gas generators are assumed to retire.

108 California Public Utilities Commission. August 2019. *2018 CPUC Resource Adequacy Report*, https://www.cpuc.ca.gov/uploadedFiles/CPUC_Public_Website/Content/Utilities_and_Industries/Energy/Energy_Programs/Electric_Power_Procurement_and_Generation/Procurement_and_RA/RA/2018%20RA%20Report.pdf.

109 Economic retention does not mean gas resources are the only resource that can provide capacity but are the most economic resource to do so in these scenarios, given current inputs and assumptions.

Figure 32: System Resource Adequacy Contributions for the 60 Percent RPS, SB 100 Core, and Study Scenarios



Source: CEC staff and E3 analysis

Figure 34 shows that total percentage of load served by renewable and zero-carbon generation increases with the stringency of the zero-carbon load coverage target. The SB 100 core target results in 90 percent of generation coming from renewable and zero-carbon resources.[110]

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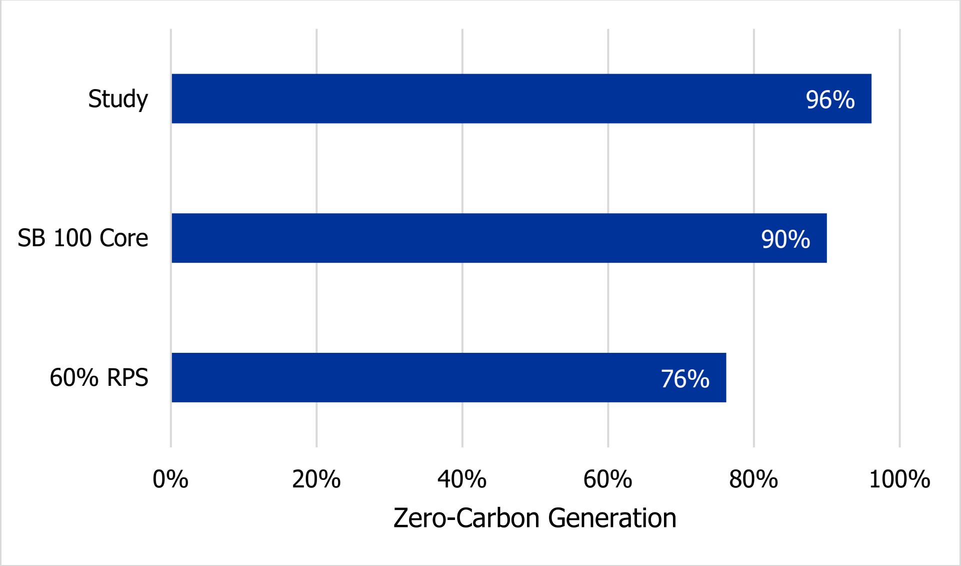
[110] Zero-carbon generation, as reported here includes customer-side solar, which does not count toward the SB 100 target.

Figure 33: Load Served by Renewable and Zero-Carbon Generation for the 60 Percent RPS, SB 100 Core, and Study Scenarios



Source: CEC staff and E3 analysis

The total electric sector GHG emissions for each scenario trends inversely with the zero-carbon load coverage, as shown in **Figure 35**. None of the scenarios modeled include a GHG constraint. However, the scenarios provide an opportunity to understand GHG emission reductions that could occur under different resource futures. The GHG emissions for the 60 percent RPS scenario, at 57 million metric tons CO_2-equivalent (MMT) in 2045, are only 10 percent below present-day electric sector GHG emissions, at 63 MMT,[111] despite the increased RPS target due to increased loads driven by electrification.[112] The SB 100 core and study (expanded load coverage) scenarios result in emissions decreasing to 24 MMT and 12 MMT, respectively.

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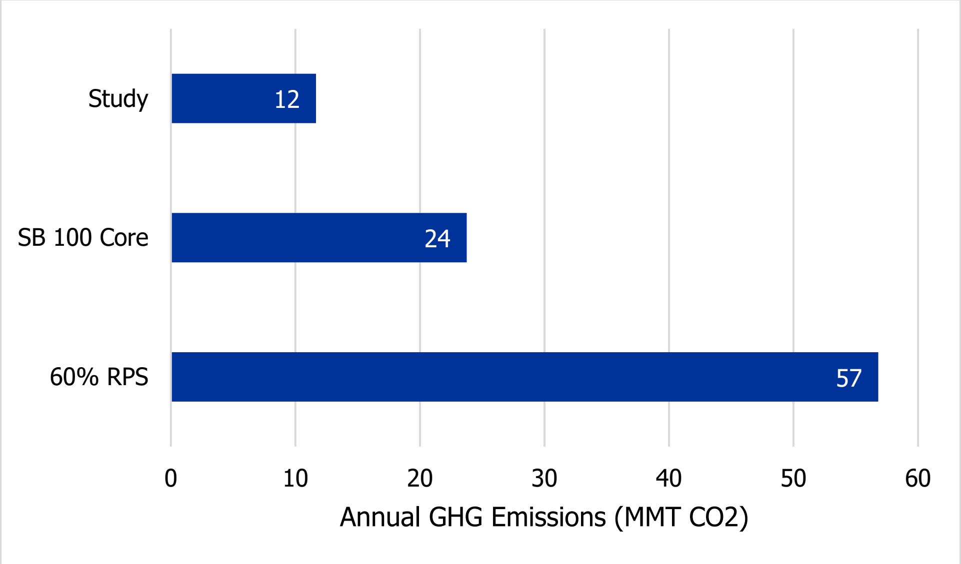
111 California Air Resources Board. California Greenhouse Gas Inventory for 2000-2018- by Category as Defined in the 2008 Scoping Plan, https://ww3.arb.ca.gov/cc/inventory/data/tables/ghg_inventory_scopingplan_sum_2000-18.pdf.

112 This analysis does not assess economywide emission reductions that may be associated with electrification.

Figure 34: Greenhouse Gas Emissions for the 60 Percent RPS, SB 100 Core, and Study Scenarios



Source: CEC staff and E3 analysis

The annual total resource cost (TRC) for each scenario increases with the tightening of the zero-carbon load coverage level. (All costs presented are directional and require further analysis.) The TRC includes nonmodeled, existing costs that are the same across all scenarios, as well as scenario-specific nonmodeled costs that vary by demand sensitivities. It also includes scenario-specific fixed costs, which are levelized capital investments associated with generation, transmission, storage, and shed demand response resources selected in the model, as well as operating costs, as shown in **Table 12**. A full breakdown of costs associated with all scenarios can be found in the SB 100 Modeling Data Tables.

These do not include costs associated with new utility programs or distribution upgrades. “Average cost” as represented in **Table 12**, and all cost summary tables in this report do not represent projected retail rates and are intended to illustrate the average impact across customer classes of each scenario for each kWh of retail load. Investments in renewables, storage, and transmission constitute the primary differences in costs.

Table 12: 2045 Annual Cost Summary for the 60 Percent RPS, SB 100 Core, and Study Scenario

$ Billions (2016)	60% RPS	SB 100 Core	Study
Nonmodeled Costs	$38	$38	$38
Scenario Fixed Costs[113]	$9.8	$18.8	$25.0
Total Operating Costs	$7.0	$2.5	$0.5
Total Revenue Requirement	**$55**	**$60**	**$64**
Customer Costs	$6.7	$6.7	$6.7
Total Resource Costs	**$62**	**$66**	**$70**
Retail Sales (TWh)	372	372	372
Average Cost (¢/kWh)	**14.8**	**16.0**	**17.1**

Source: CEC staff and E3 analysis

Demand Sensitivities

Evaluating the impact of different demand scenarios provides insight into how various economywide approaches to decarbonization affect the pathway to achieving SB 100. As shown in **Figure 36**, different economywide scenarios do not change the composition of the portfolio but do significantly impact the total capacity added, particularly the quantity of solar and battery storage capacity added.

Across all scenarios, the maximum available long-duration storage, in-state wind, and offshore wind resources made available to the model are selected. The selection of new out-of-state wind ranges from 7 GW in the reference scenario to 11 GW in the high hydrogen scenario. The amount of solar selected by 2045 ranges from 44 to 70 GW. The amount of battery storage selected by 2045 ranges from 38 to 48 GW.

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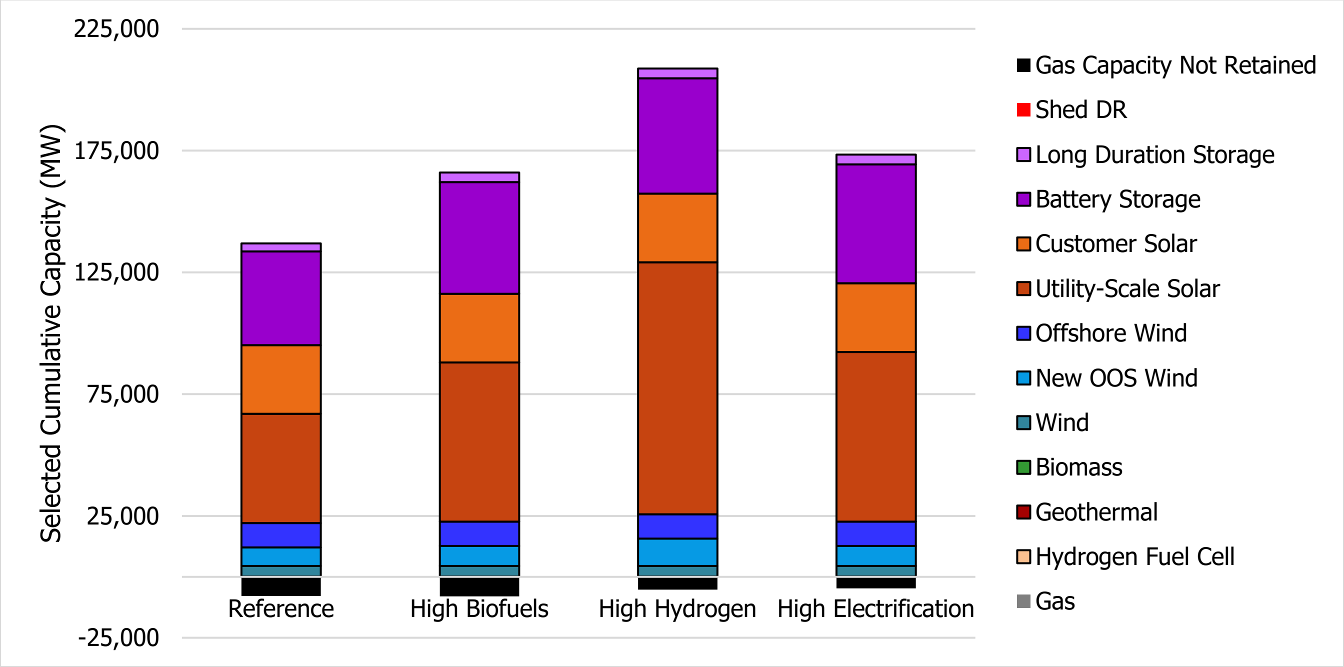
[113] Scenario fixed costs include baseline thermal fixed costs, new thermal fixed costs, new renewables fixed costs, new storage fixed costs, new DR fixed costs, and new transmission fixed costs.

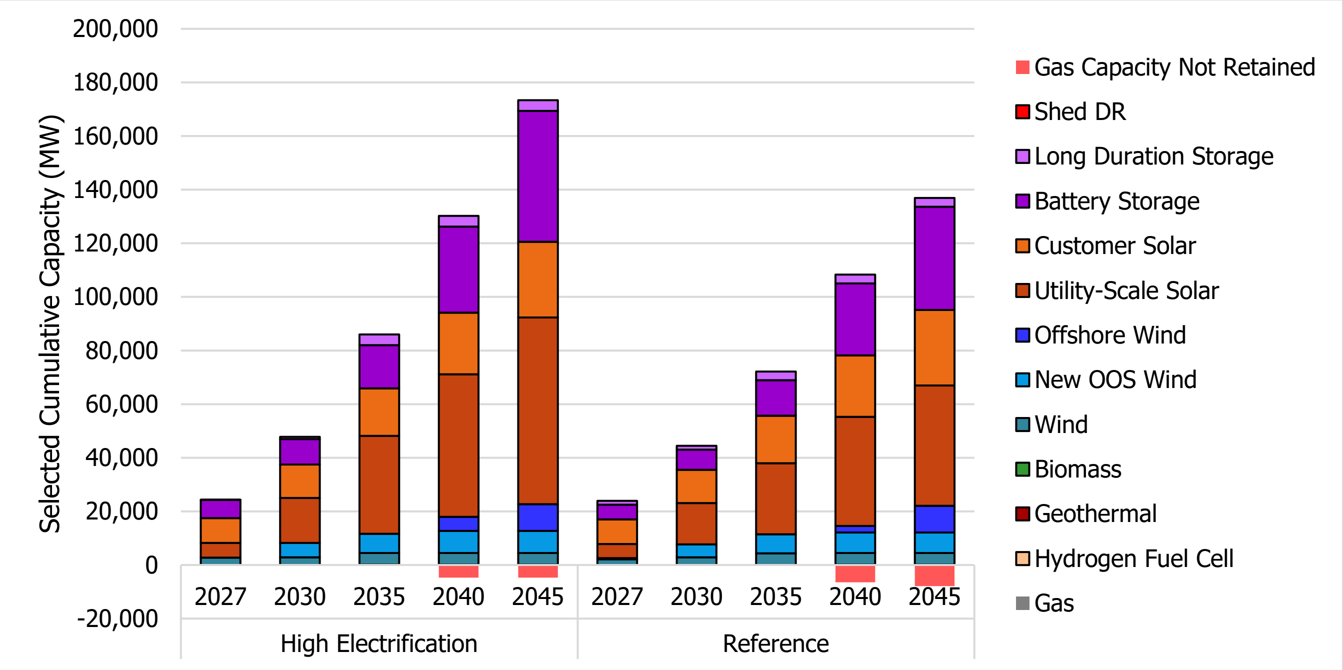
Figure 35: Cumulative Resource Build in 2045 for High Electrification, High Biofuels, High Hydrogen, and Reference Demand Scenarios



Source: CEC staff and E3 analysis

The timing of wind selection does not change between the reference and high electrification demand scenarios, as shown in **Figure 37**. After 2030, the high electrification scenario requires increasing solar and battery capacity each year compared to the reference scenario.

Figure 36: Cumulative Capacity Additions for the Reference and High Electrification Demand Scenarios



Source: CEC staff and E3 analysis

The TRC for the demand sensitivities increase with increased annual loads. However, the average cost per kWh decreases. While increased electricity demand can provide downward pressure on rates, infrastructure associated with hydrogen production or high levels of electrification are not included in this analysis, which could offset part of or all the rate decrease. The scenarios do not include costs associated with electrification, such as distribution upgrades or incentive programs, or other infrastructure required for biofuels and hydrogen, which may impact the relative cost to utility ratepayers. Average costs presented in **Table 13** are directional comparisons of demand scenarios and require additional analysis to include infrastructure costs associated with the demand scenarios.

Table 13: 2045 Annual Electricity Cost Summary for the High Electrification, High Biofuels, High Hydrogen, and Reference Demand Scenarios

$ Billions (2016)	High Elec.	High Biofuels	High Hydrogen[114]	Reference
Nonmodeled Costs	$38	$38	$38	$38
Scenario Fixed Costs	$19	$18	$24	$14
Total Operating Costs	$2.6	$2.4	$3.1	$1.8
Total Revenue Requirement	**$60**	**$58**	**$65**	**$53**
Customer Costs	$6.7	$6.7	$6.7	$6.7
Total Resource Costs	**$66**	**$65**	**$72**	**$60**

Source: CEC staff and E3 analysis

While the previous demand sensitivities focused on different economywide scenarios and varied by total annual electric energy demand, the shape and flexibility of electricity loads can significantly impact cost and resource build. While RESOLVE cannot at this time explicitly model load flexibility, the load shape and resource adequacy requirements can be modified to represent a future with greater load flexibility.

To achieve this, a high-flexibility scenario was created. Load modifiers in the high electrification demand scenario were adjusted to reflect managed charging profiles by electric vehicle drivers based on utility time-of-use rates and building flexibility based on the base case scenario in Lawrence Berkeley National Laboratory's (LBNL's) California Demand Response Study Phase 3.[115] It was also assumed that flexible load could contribute 6 GW to the annual system resource adequacy requirement.

Figure 38 shows the high-flexibility scenario results in 2.2 GW avoided battery storage build and a decrease in economic gas retention by 3.3 GW compared to the SB 100 core scenario, with the same annual electric energy demand.

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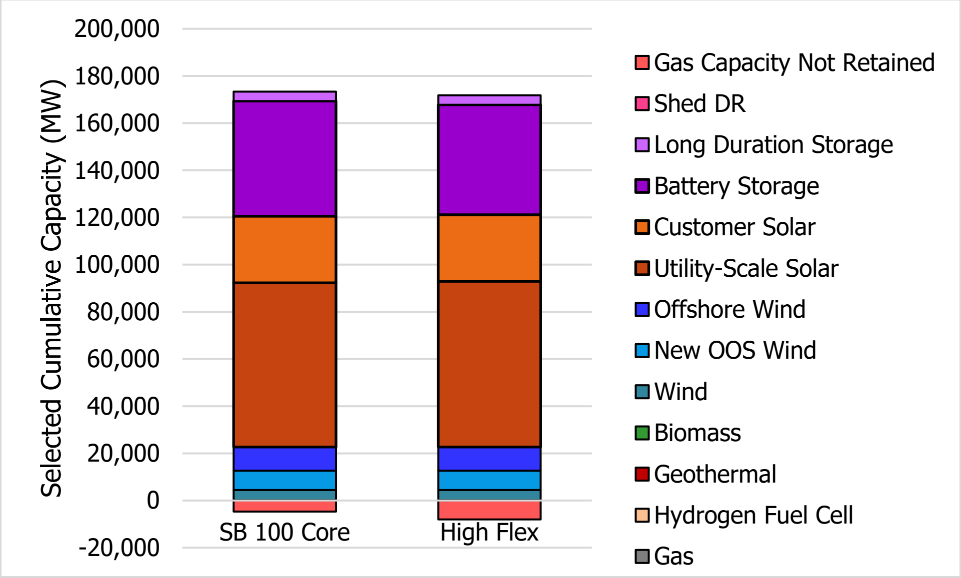
[114] The High Hydrogen demand scenario includes all electrolysis loads for hydrogen production as retail sales.

[115] Lawrence Berkeley National Laboratory. July 2020. The California Demand Response Potential Study, Phase 3: Final Report on the Shift Resource through 2030. https://eta-publications.lbl.gov/sites/default/files/ca_dr_potential_study_-_phase_3_-_shift_-_final_report.pdf. The Base Scenario assumed DR-enabling technology prices and performance are frozen at present-day values.

Figure 37: Cumulative Capacity Additions in 2045 for the SB 100 Core and High-Flexibility Scenarios



Source: CEC staff and E3 analysis

The high-flexibility scenario also results in nearly $1 billion of annual cost savings in 2045 compared to the SB 100 core scenario, primarily from avoided storage fixed costs, as shown in **Table 14**. The costs associated with programs to encourage flexible load are not included in this analysis.

Table 14: 2045 Annual Cost Summary for the SB 100 Core and High-Flexibility Scenarios

$ Billions (2016)	SB 100 Core	High Flex
Nonmodeled Costs	$38	$38
Scenario Fixed Costs	$19	$18
Total Operating Costs	$2.6	$2.5
Total Revenue Requirement	**$60**	**$59**
Customer Costs	$6.7	$6.7
Total Resource Costs	**$66**	**$65**
Retail Sales (TWh)	372	372
Average Cost (¢/kWh)	**16.0**	**15.8**

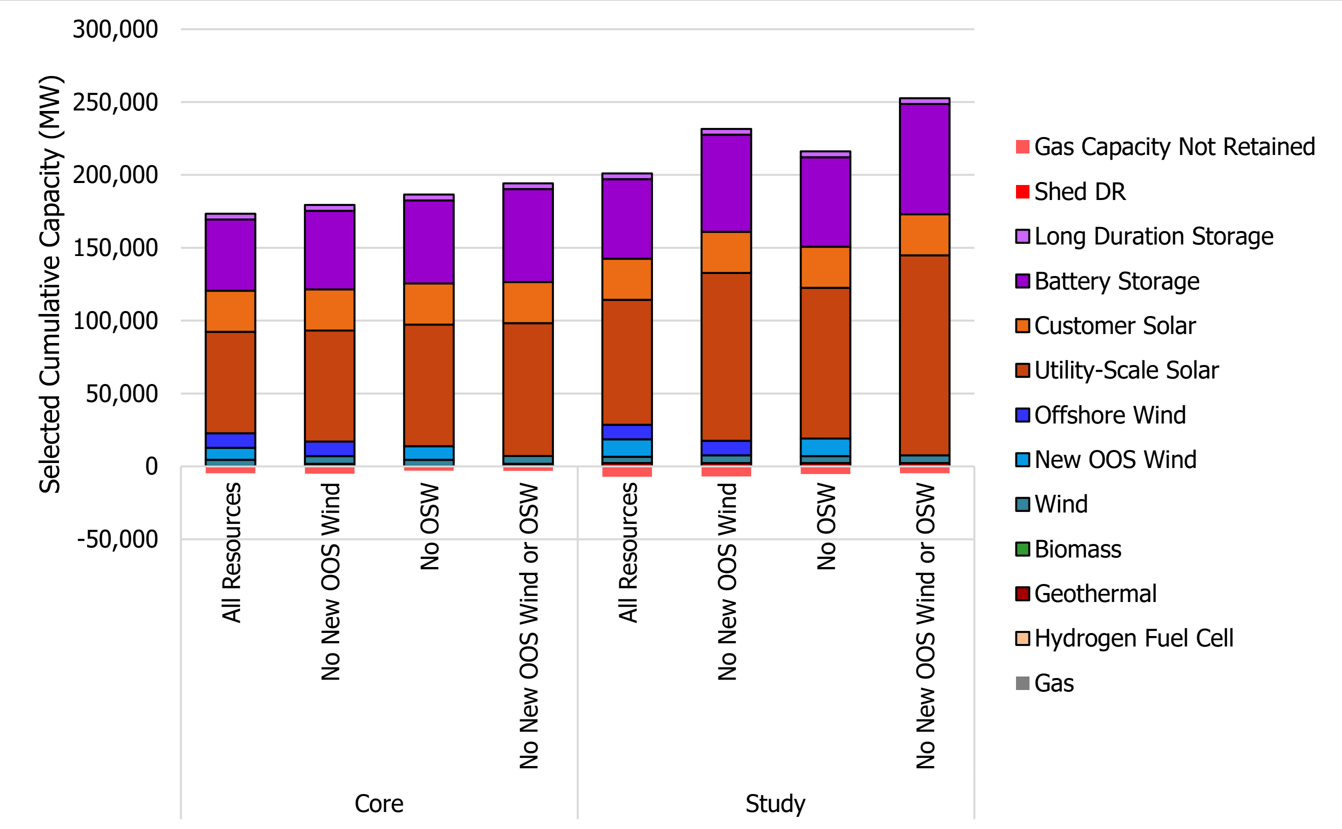
Source: CEC staff and E3 analysis

Resource Sensitivities

Evaluating futures where one or more resource types are not available or are not pursued can provide valuable planning information, especially for resources with long lead times for development. Resource sensitivities were included to evaluate the impact or benefit of pursuing new out-of-state wind resources and offshore wind resources.

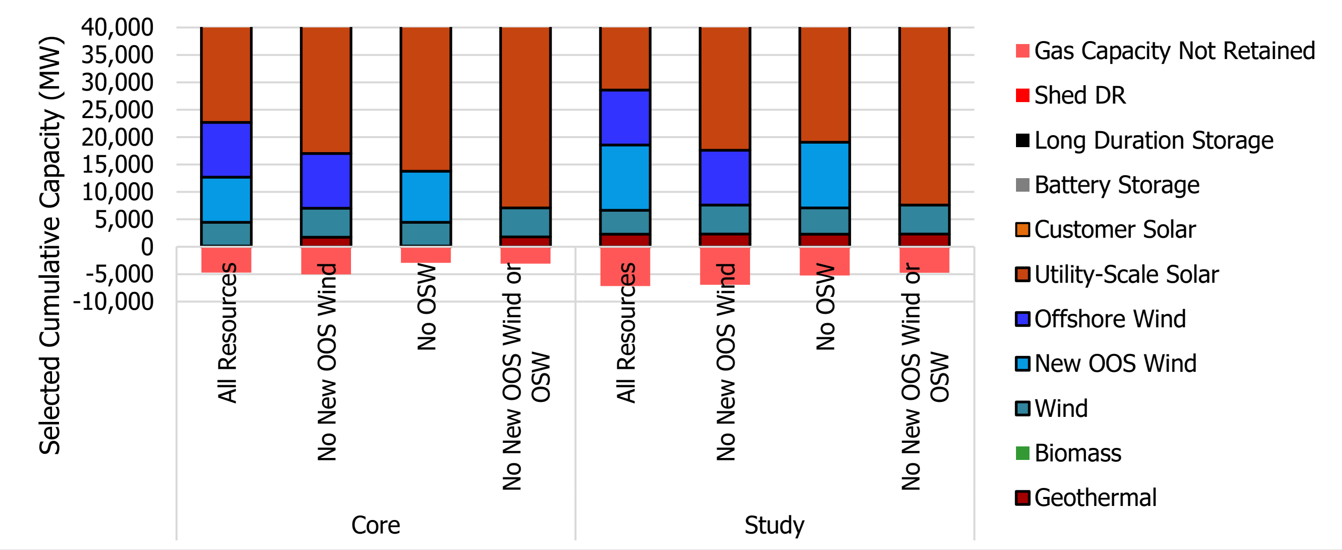
Figure 39 and Figure 40 show resource sensitivities that include "no new out-of-state (OOS) wind," "no offshore wind (OSW)," and "no new OOS wind or OSW" under the SB 100 core and study load coverages. In nearly all scenarios in which either or both the wind resources are not available or not pursued, the model selects increased geothermal capacity. Utility-scale solar and battery storage meet the remaining energy and capacity needs. The "SB 100 core no new OOS wind or OSW" requires 22 GW more solar capacity and 15 GW more storage capacity than the "SB 100 core all resources scenario."

Figure 38: Cumulative Resource Builds for the Core and Study Resource Sensitivities in 2045



Source: CEC staff and E3 analysis

Figure 39: Close up of Cumulative Resource Builds for the Core and Study Resource Sensitivities in 2045



Source: CEC staff and E3 analysis

The TRC increases in each of the scenarios where one or both the wind resources are not available or not pursued are not included, as shown in **Table 15**. The primary contributor to increased costs are increased renewable resource and storage costs.

Table 15: 2045 Annual Costs Summary for the SB 100 Core All Resources, No New OOS Wind, No OSW, and No New OOS Wind or OSW Scenarios

$ Billions (2016)	All Resources	No New OOS Wind	No OSW	No New OOS Wind or OSW
Non-modeled Costs	$38	$38	$38	$38
Scenario Fixed Costs	$19	$19	$20	$20
Total Operating Costs	$2.6	$2.7	$2.6	$2.8
Total Revenue Requirement	**$60**	**$60**	**$60**	**$61**
Customer Costs	$6.7	$6.7	$6.7	$6.7
Total Resource Costs	**$66**	**$67**	**$67**	**$68**
Retail Sales (TWh)	372	372	372	372
Average Cost (¢/kWh)	**16.0**	**16.1**	**16.2**	**16.4**

Source: CEC staff and E3 analysis

Study Scenario: Generic Zero-Carbon Firm Resources

Given the uncertainty of a 25-year planning horizon and the relatively conservative criteria for zero-carbon resource cost data used in the core scenarios, the joint agencies included study scenarios to evaluate the potential impact of commercialization of cost-competitive zero-carbon firm resources.

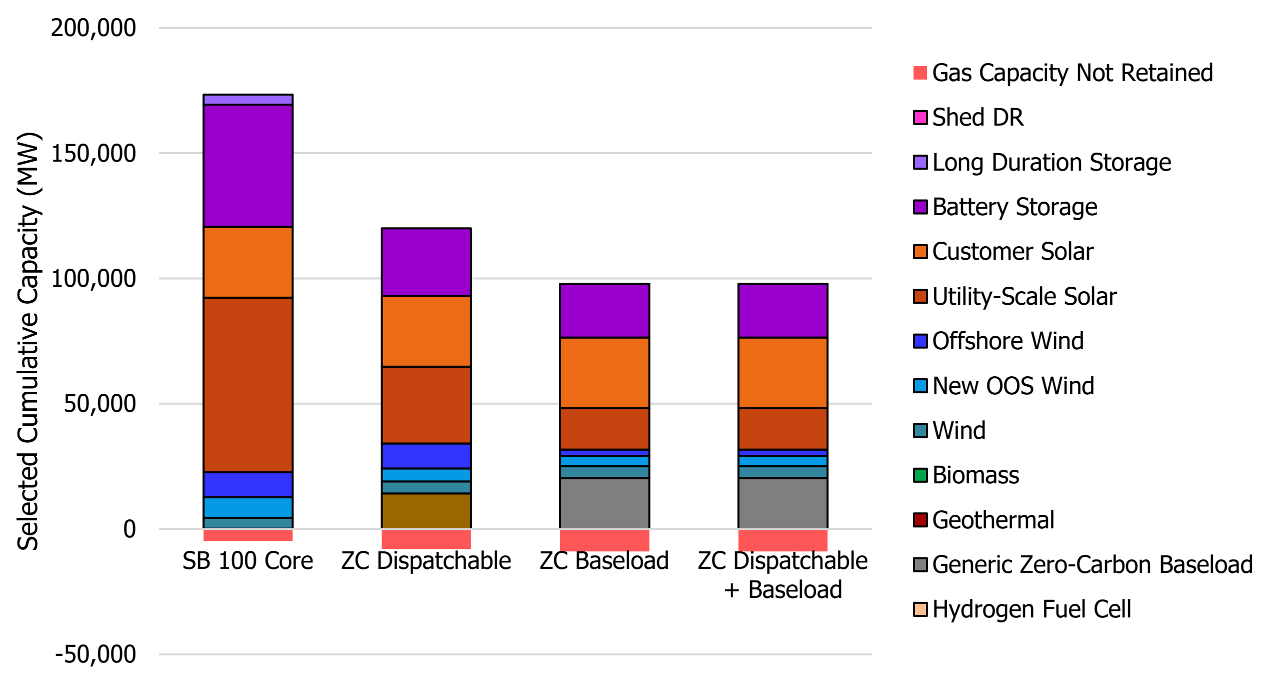
Several zero-carbon firm resources — geothermal, biomass, and hydrogen fuel cells — are already included in the core scenarios as candidate resources. Of these, 135 MW of geothermal is selected in the SB 100 core scenario, up to about 2 GW when new OOS wind or offshore wind are not available to the model. Neither biomass nor hydrogen fuel cells are selected in the core scenarios with the currently assumed cost projections.

The "generic dispatchable" resource and "generic baseload" resource included in these scenarios could represent already included technologies, should cost reductions be achieved, or a wide variety of emerging technologies, such as natural gas with 100 percent carbon capture, 100 percent green hydrogen combustion, or other renewable fuels, should the cost profiles be similar to one of the modeled generic resources.

The "generic dispatchable" resource includes a moderate capital cost and operating cost. The "generic baseload" resource includes a high capital cost and low operating cost. The LCOE of both resources are about $60/MWh when operating at a 90 percent capacity factor.

In scenarios where either the generic dispatchable resource, generic baseload resource, or both are included as a candidate resource, the model selects about 15-20 GW of either or both resources in total, as shown in **Figure 41**. The inclusion of the lower-cost zero-carbon firm resources also significantly lowers the utility-scale solar and battery storage selected in the model. Utility-scale solar selected by 2045 is reduced to 17-30 GW from 70 GW, while battery storage selection is reduced to 21-27 GW from 49 GW. Furthermore, long-duration storage selection is not selected and new OOS wind selected is reduced from 8.2 GW to 4.1-5.2 GW.

Figure 40: Cumulative Capacity Additions for the SB 100 Core and Generic Zero Carbon Firm Resource Scenarios in 2045



Source: CEC staff and E3 analysis

The Evolving Role of Geothermal

While the joint agencies attempt to use the most current publicly available and vetted cost data, there can be significant changes in available data after the modeling has been conducted. The NREL ATB is updated annually, usually with incremental adjustments to cost data. The 2020 ATB update, which was released after modeling for this report was underway, however, included a 30 percent reduction in geothermal cost projects, based on the Department of Energy Geovision Report.[116]

This cost-reduction projection places the geothermal LCOE below the LCOE of the generic zero-carbon firm resources modeled in these scenarios. As significant generic zero-carbon firm capacity was selected in the study scenario, it is likely that geothermal would be selected to a much greater extent should the updated cost data be used.

Geothermal costs are heterogeneous and can vary widely depending on project location. Coproduction of lithium from geothermal brine may also provide additional revenue streams, effectively lowering the cost of geothermal power, and will be evaluated by the Blue-Ribbon Commission on Lithium Extraction in California.[117]

Each of the generic zero-carbon firm resource scenarios resulted in significant decreases in TRC compared to the SB 100 core scenario, as shown in **Table 16**. Cost reductions are driven by new renewable and transmission fixed costs.

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116 NREL ATB 2020 vs. 2019 Changes Reductions in geothermal costs are attributed to trends and predicted advancements in drilling efficiency and enhanced geothermal systems.

117 Ventura, Susanna, Srinivas Bhamidi, Marc Hornbostel, and Anoop Nagar. 2020. Selective Recovery of Lithium from Geothermal Brines. California Energy Commission. Publication Number: CEC500-2020-020. https://ww2.energy.ca.gov/2020publications/CEC-500-2020-020/CEC-500-2020-020.pdf. Assembly Bill 1657 (E. Garcia, Chapter 271, Statutes of 2020), Blue Ribbon Commission on Lithium Extraction in California.

Table 16: 2045 Annual Costs Summary for the SB 100 Core, Generic Dispatchable, Generic Baseload, and Generic Dispatchable + Baseload Scenarios

$ Billions (2016)	SB 100 Core	Generic Dispatchable	Generic Baseload	Gen. Dis. + Baseload
Non-modeled Costs	$38	$38	$38	$38
Scenario Fixed Costs	$19	$13	$14	$14
Total Operating Costs	$2.6	$6.0	$2.8	$2.8
Total Revenue Requirement	**$60**	**$58**	**$55**	**$55**
Customer Costs	$6.7	$6.7	$6.7	$6.7
Total Resource Costs	**$66**	**$64**	**$62**	**$62**
Retail Sales (TWh)	372	372	372	372
Average Cost (¢/kWh)	**16.0**	**15.5**	**15.0**	**15.0**

Source: CEC staff and E3 analysis

Study Scenario: No Combustion

While SB 100 does not preclude combustion resources from the resource portfolio, studying pathways in which combustion resources are expressly retired can provide insight into what it would take to significantly reduce the contribution to criteria pollutants and toxic air contaminants in California from supply-side electricity generation. To that end, a "no combustion" scenario in which all combustion resources are retired over the planning horizon and no combustion resources are available as candidate resources was included as a study scenario.

In this scenario, all units that use a combustion technology, combustion turbines, combined cycle, combined heat and power,[118] and biomass, retire over the planning horizon, as shown in **Figure 42**. The high-electrification demand scenario was used.

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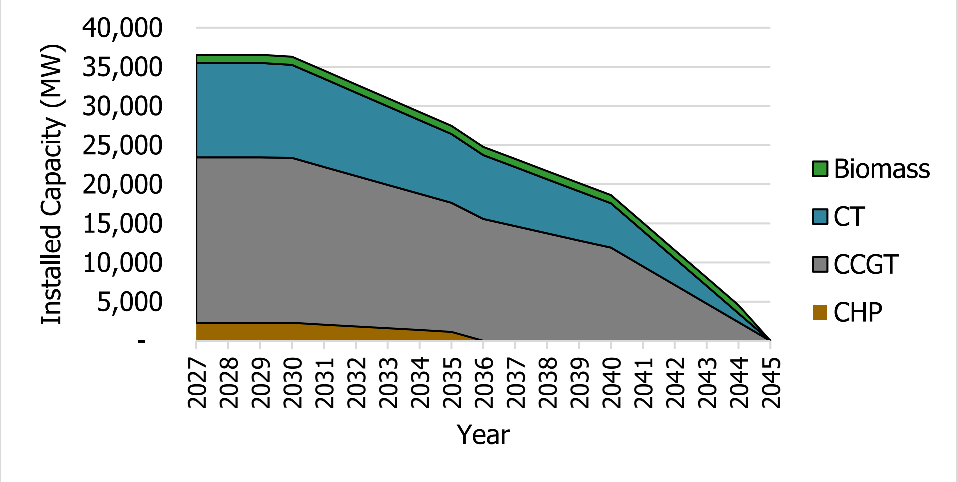
[118] All combined heat and power facilities are assumed to retire after 2035 in all scenarios in this report.

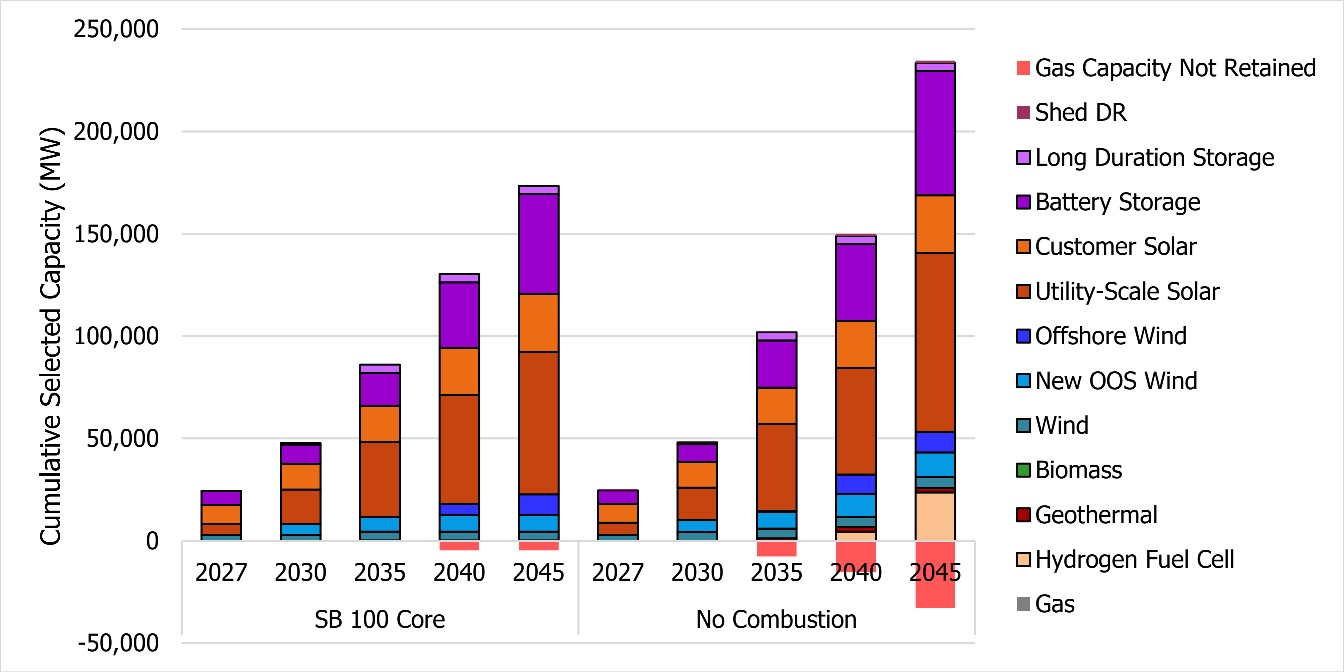
Figure 41: Retirement Schedule for Biomass, Combustion Turbines (CT), Combined Cycles (CCGT), and Combined Heat and Power (CHP) Resources



Source: CEC staff and E3 analysis

With the retirement of all combustion resources, 61 GW of additional capacity is selected compared to the SB 100 Core Scenario. In addition to the resources selected in the SB 100 core scenario, 24 GW of hydrogen fuel cells, the remaining 2.3 GW of geothermal, the remaining 3.8 GW new OOS wind, 18 GW of utility scale solar, 12 GW of battery storage and 1.1 GW of shed demand response were selected, as shown in **Figure 43**.

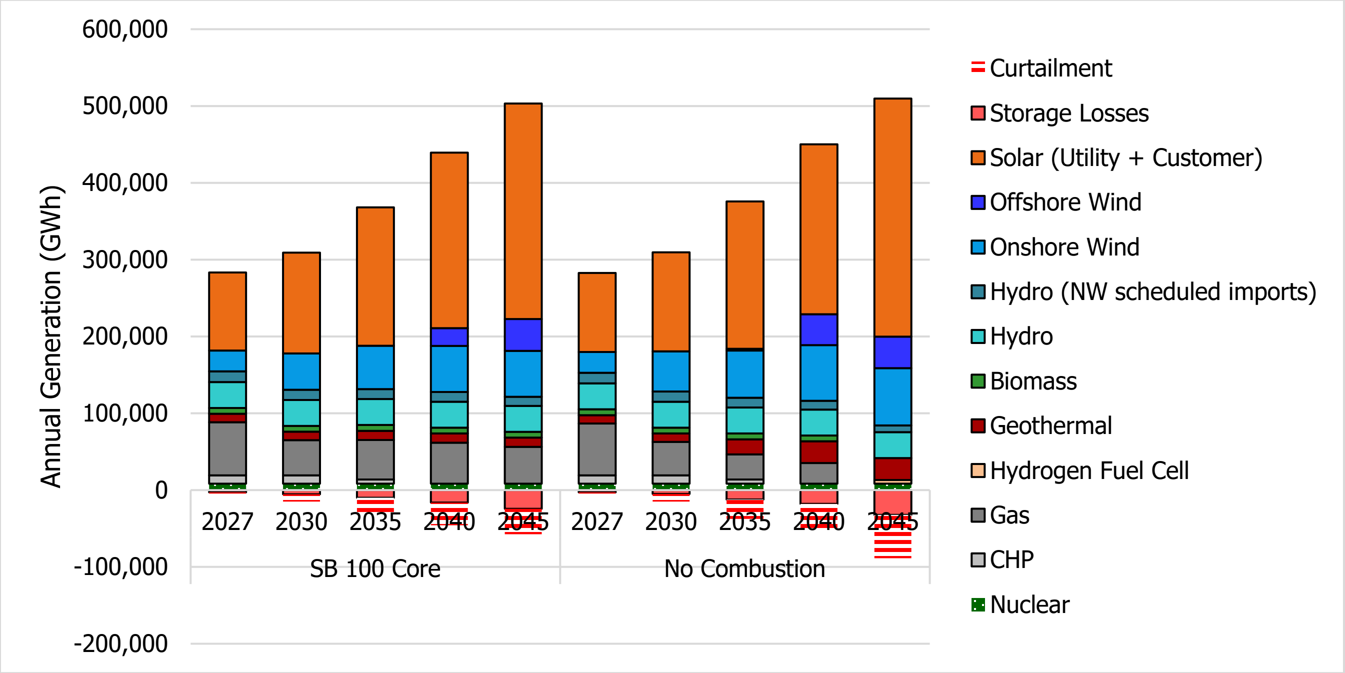
Figure 42: Cumulative Capacity Additions for the SB 100 Core and No Combustion Scenarios



Source: CEC staff and E3 analysis

While significant hydrogen fuel cell capacity was selected, it generates very little energy, as shown in **Figure 44**. The hydrogen fuel cells were selected for the capacity value and function as a peaking resource.

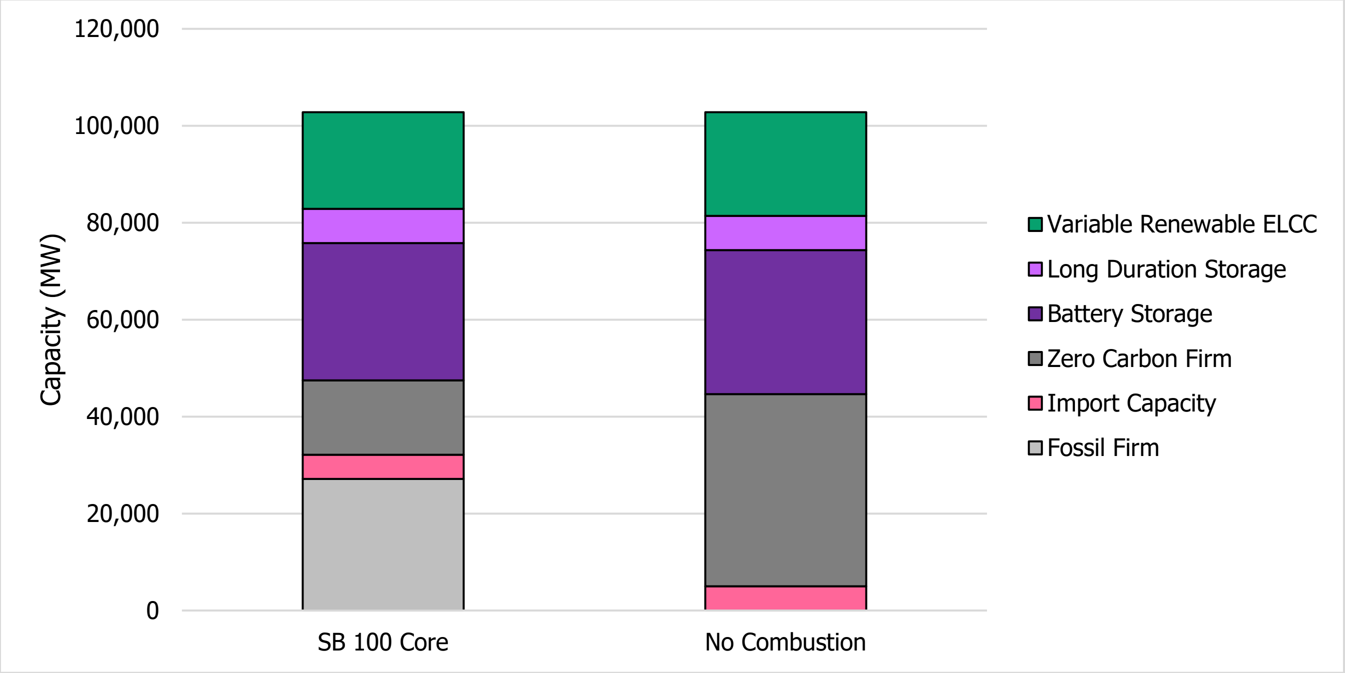
Figure 43: Annual Generation for the No Combustion Scenario



Source: CEC staff and E3 analysis

While fossil firm resources contribute a significant amount to the resource adequacy need in the SB 100 Core scenario, the retirement of these resources requires new resources to be selected to meet the capacity need in the No Combustion scenario. As shown in **Figure 45**, the fossil firm resource contributions are largely replaced by zero-carbon firm, which includes hydrogen fuel cells and new geothermal resources. While there is a resource adequacy constraint in the model (a 15 percent planning reserve margin), a full resource adequacy analysis is necessary to determine whether the portfolios produced meet other established reliability planning standards.

Figure 44: Resource Adequacy Contributions for the SB 100 Core and No Combustion Scenarios



Source: CEC staff and E3 analysis

Given the significant capacity additions in the no combustion scenario, there are increased annual TRC costs compared to the SB 100 core scenario, as shown in **Table 17**. The primary contributors to cost increases are new renewable resources, hydrogen fuel cells, storage, and transmission fixed costs.

Table 17: 2045 Annual Cost Summary of the SB 100 Core and No Combustion Scenarios

$ Billions (2016)	SB 100 Core	No Combustion
Non-modeled Costs	$38	$37
Scenario Fixed Costs	$19	$28
Total Operating Costs	$2.6	$1.8
Total Revenue Requirement	**$60**	**$67**
Customer Costs	$6.7	$6.7
Total Resource Costs	**$66**	**$74**
Retail Sales (TWh)	372	372
Average Cost (¢/kWh)	**16.0**	**18.1**

Source: CEC staff and E3 analysis

While all California combustion and virtually all GHG-emitting resources are retired[119] in the no combustion scenario, 11 MMT of GHG emissions attributed to the California electric grid remain, due to unspecified imports,[120] as shown in **Figure 46**.

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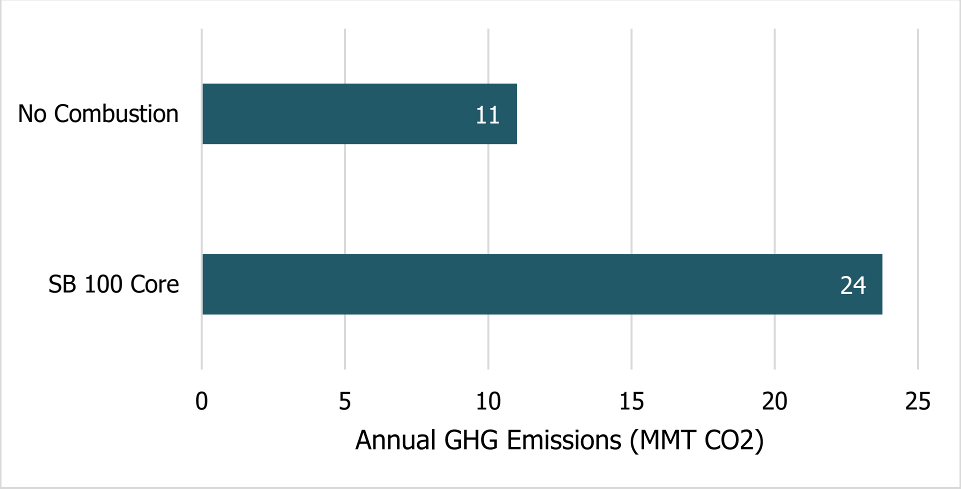
[119] Geothermal resources are not retired and do emit some GHG emissions.

[120] As RESOLVE optimizes operations to best reflect energy market dynamics, in periods where the marginal price of energy in California is higher than the price of unspecified imports, unspecified imports are dispatched to California. Implementation of a GHG target in RESOLVE may limit the GHG emissions but may not necessarily reflect market dynamics.

Figure 45: GHG Emissions for the SB 100 Core and No Combustion Scenarios



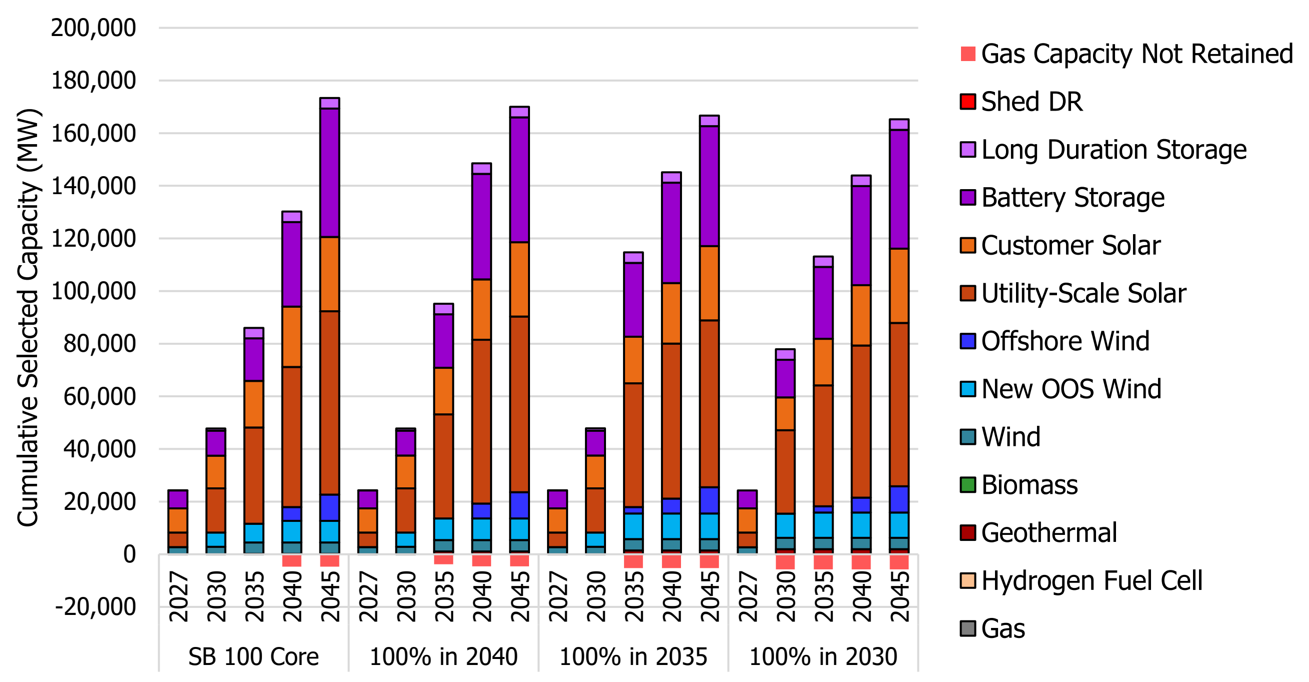
Source: CEC staff and E3 analysis

Study Scenarios: Accelerated Timelines

The final set of study scenarios examines the impacts of accelerating the 100 percent renewable and zero-carbon target to 2030, 2035, and 2040. For each of these scenarios, the SB 100 Core target was accelerated with a linear interim zero-carbon target between 2030 and the target year. After the target year, the 100 percent target is held constant through 2045. The high electrification demand scenario was used for all accelerated timeline scenarios.

In **Figure 47**, each accelerated timeline scenario shows a significant jump in resource build in the 100 percent target year, while the 2045 portfolio remains similar across scenarios. All the accelerated timeline scenarios result in an increase of geothermal resource selection by at least 1 GW. Accelerating the 100 percent target to 2030 or 2035 results in increased new OOS wind selection by 1.3–1.4 GW and decreases in utility-scale solar selection by 6-7 GW and battery storage by 3 GW. Accelerating the target to 2030 or 2035 also results in a 0.5-1 GW of decreased economic gas retention.

Figure 46: Cumulative Capacity Additions for the SB 100 Core (2045 SB 100), 100% in 2040, 100% in 2035 and 100% in 2030 Scenarios



Source: CEC staff and E3 analysis

Each accelerated timeline scenario results in increased annual TRC compared to the SB 100 Core scenario for every modeled year except 2027, as shown in **Table 18**. In general, the TRC shows a significant jump in the year the 100 percent target is set to. By 2045, the TRC for the accelerated scenarios result in less than a 1 percent increase over the SB 100 Core scenario.

Table 18: Annual Total Resource Cost for the SB 100 Core, 100 Percent in 2040, 100 Percent in 2035, and 100 Percent in 2030 Scenarios

TRC ($B)	2027	2030	2035	2040	2045
SB 100 Core	$44.8	$47.0	$50.6	$59.5	$66.3
100% in 2040	$44.8	$47.0	$53.6	$61.5	$66.5
100% in 2035	$44.8	$47.0	$55.8	$61.7	$66.7
100% in 2030	$44.8	$50.1	$55.8	$61.8	$66.8

Source: CEC staff and E3 analysis

Resource Build Rates

Given the magnitude of the capacity additions, the average build rates provide important implications for implementation and achievement of the SB 100 2045 policy goal. Build rates can indicate whether there could be bottlenecks in supply-chain or regulatory and permitting processes, resulting in barriers to procurement.

Over the last decade, California has built on average 1 GW of utility solar and 300 MW of wind per year, with a maximum annual build of 2.7 GW of utility scale solar and 1 GW of wind capacity. **Table 19** shows near-term build rates to 2030 are similar regardless of the electricity demand scenarios and are above the historical 10-year average build rate for utility scale solar and wind capacity.

The long-term build rates to 2045, shown in Table 20, differ significantly for utility-scale solar depending on the demand scenario, ranging from 1.8 GW per year in the reference scenario to 4.1 GW per year in the high hydrogen scenario.

Table 19 Average Build Rates for the High Electrification, High Biofuels, High Hydrogen and Reference Demand Scenarios

Year To	Demand Scenario	Solar (GW/year)	Wind (GW/year)	Storage[121] (GW/year)
2030	High Electrification (SB 100 Core)	1.5	0.8	1.1
2030	High Biofuels	1.7	0.8	0.9
2030	High Hydrogen	1.7	0.8	0.9
2030	Reference	1.5	0.8	0.8
2045	High Electrification (SB 100 Core)	2.8	0.9	2.0
2045	High Biofuels	2.6	0.9	1.8
2045	High Hydrogen	4.1	1.0	1.9
2045	Reference	1.8	0.9	1.5

Source: CEC staff and E3 analysis

Inclusion of diverse wind resources in the portfolio also impacts the average solar and storage build rate, disproportionately from the reduction in wind build rate, with an increase of up to 0.8 GW per year for utility scale solar and 0.6 GW per year for battery storage, as shown in Table 20.

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[121] Storage in this table is inclusive of new battery storage selected by the model.

Table 20: Average Build Rates for the SB 100 Core, No New OOS Wind, No OSW, and No New OOS Wind or OSW Scenarios

Year To	Resource Sensitivity	Solar (GW/year)	Wind (GW/year)	Storage (GW/year)
2045	SB 100 Core	2.8	0.9	2.0
2045	No New OOS Wind	3.0	0.6	2.2
2045	No OSW	3.3	0.5	2.3
2045	No New OOS Wind or OSW	3.6	0.2	2.6

Source: CEC staff and E3 analysis

Commercialization of cost-competitive zero-carbon firm resources has the potential to significantly reduce average build rates for utility-scale solar and battery storage resources. **Table 21** show that the utility-scale solar build rate reduces to 0.6-1.2 GW per year — on par with historic build rates — and battery storage build rate reduces to 0.9-1.1 GW per year.

Table 21: Average Build Rates for the SB 100 Core, Generic Dispatchable, Generic Baseload, and Generic Dispatchable + Baseload Scenarios

Year To	Resource Sensitivity	Solar (GW/year)	Wind (GW/year)	Storage (GW/year)
2045	SB 100 Core	2.8	0.9	2.0
2045	Generic Dispatchable	1.2	0.8	1.1
2045	Generic Baseload	0.6	0.5	0.9
2045	Generic Dispatchable + Baseload	0.6	0.5	0.9

Source: CEC staff and E3 analysis

Key Takeaways From Preliminary Modeling

SB 100 Is Achievable

This initial analysis demonstrates that supplying 100 percent of retail sales and state loads with renewable and zero-carbon technologies is technically achievable. The modeling suggests the total resource cost of achieving the target is about 6 percent higher than a 60 percent RPS future in 2045, though additional analysis is needed to validate these findings. These costs may be lower if the cost trends for renewables continue to fall faster than projections. Cost reductions and innovation in zero-carbon technologies, as well as load flexibility and energy storage development, can further reduce implementation costs. Moreover, variations on the scenarios studied will develop over time as reliability is examined, technologies develop, and procurement decisions are made.

Increased Resource Diversity Lowers Overall Costs

Portfolio diversity, both technological and geographical, is generally valued by the model. In scenarios where out-of-state or offshore wind are available, the model always selects a significant quantity, if not all, of the resource potential. Furthermore, even a modest amount of load flexibility can reduce battery storage requirements, decrease economic gas retention, and decrease the total resource cost of achieving SB 100. Commercialization of cost-competitive zero-carbon firm technologies could reduce overall system costs and decrease gas capacity retention. If these technologies reach a cost of roughly $60/MWh, they could reduce system costs by an estimated $2 billion annually in 2045.

Gas Capacity Is Retained for Reliability Needs, but Cost Reductions and Innovation in Zero-Carbon Firm Resources and Storage May Reduce Gas Capacity Needs

Natural gas capacity is largely economically retained in the SB 100 core scenario, but fleetwide utilization decreases by half compared to a 60 percent RPS future. The gas fleet is primarily retained because natural gas capacity is the most economic option to provide capacity for reliability needs with the current resource assumptions. Cost reductions and innovation in zero-carbon firm resources and storage resources may reduce economic gas fleet retention.

Further analysis is needed to evaluate costs associated with maintaining an aging gas fleet operating in a high renewables system, including an evaluation of existing gas capacity maintenance costs and the impact of additional gas retirements.

Sustained Record Setting Build Rates Will Be Required to Meet SB 100 in a High Electrification Future

Growing electricity demand is a significant driver of resource build rates in the SB 100 scenarios. The added demand from the various pathways to achieve economywide decarbonization creates a significant resource need, regardless of the SB 100 policy. This added demand has implications for workforce needs, land-use planning, resource supply chains, and regulatory and permitting processes that must be considered for successful implementation of SB 100. Innovation and cost reductions, leading to greater portfolio diversity, may reduce utility-scale solar and storage build rates necessary to meet the SB 100 policy goals.

Goals Beyond SB 100 May Be Achievable but Require Additional Analysis

The study scenarios are beyond the scope of SB 100. However, they provide directional insight to inform the state’s energy and climate planning efforts and contribution toward other environmental and public health goals.

Eliminating all in-state combustion resources results in a significant increase in storage and zero-carbon firm resource selection to replace natural gas capacity. This scenario adds an estimated $8 billion to annual system costs in 2045 compared to the SB 100 core scenario. Further analysis could identify public health benefits, particularly in disadvantaged communities where a disproportionate number of combustion resources are. This analysis may help determine whether the public health benefits outweigh the additional costs.

Accelerating the SB 100 timeline to achieve the 2045 target by 2030, 2035, or 2040 results in increased total resource costs and required additional capacity in the target year. All scenarios resulted in similar annual resource costs and resource portfolios by 2045.

Current SB 100 Analysis Is Directional, and Further Analysis Is Necessary

This analysis is the first step in an ongoing effort to evaluate and plan for the SB 100 policy. As described in the Limitations of RESOLVE section of this chapter, capacity expansion is a powerful and informative tool but is limited by necessary simplifying of assumptions. Further analysis is necessary to determine reliability of the portfolios.

Future work should better capture the effect and value of resources that are either not represented or not well valued in the current modeling framework. Long-duration storage is not fully valued in RESOLVE due to limitations on dispatch. Hybrid resources are not represented in RESOLVE and should be represented in future analysis, as they are increasingly a part of utility plans. Emerging technologies, such as green hydrogen and natural gas with 100 percent carbon capture and sequestration, should be incorporated in future analysis.

The role of demand-side resources load flexibility should also be further evaluated. Significant customer-side solar was assumed in the model, at 39 GW. No additional customer solar was selected by the model in the optimization. Factors outside system costs, such as customer preference and resilience benefits, may affect customer-side resource adoption. Customer storage was also not selected but may provide local capacity and resilience value not captured by the model.

CHAPTER 4:
Next Steps and Considerations for Implementation

SB 100 Is an Ongoing Effort

The analysis in the 2021 Report is intended to be a first step in an iterative and ongoing effort to assess barriers and opportunities to implementing the 100 percent clean energy policy established by SB 100. As discussed in Chapter 3, this report includes capacity expansion modeling to provide directional insights into what a 2045 portfolio of renewable and zero-carbon resources may look like, as well as the associated costs and resource build requirements to achieve such a portfolio. These results, however, have not undergone a comprehensive assessment for reliability, which is the suggested next step in the process. From there, the projected portfolio may be adjusted in an iterative manner to ensure reliability for all hours of the year in line with state planning requirements, while meeting clean energy and climate goals.

Additional analytical work is needed to better capture emerging zero-carbon resources and nongeneration technologies; provide higher-resolution insights to address equity concerns, including local public health and economic impacts; and address land use and other environmental implications. Topics for consideration in future SB 100 work are discussed below.

Next Steps for Analysis

System Reliability

In August 2020, California experienced rolling blackouts over two consecutive days. While a sustained west-wide heat wave resulted in the tightness in the electricity supply conditions and contributed to the load shed events, the final root cause analysis[122] that was subsequently released jointly by CPUC, California ISO, and CEC identified the need to comprehensively examine reliability in the near term (by summer 2021) and long term (2022 and beyond) as the state rapidly transitions to the stated goals of SB 100. The final root cause analysis identified the need to reflect the uncertainty of weather, operational characteristics of clean energy resources, and market dynamics into the state's reliability planning processes and studies. While the August events emphasized the need for near-term reliability, the state agencies and balancing authorities recognize the need to incorporate these reliability principles into the 2045 time horizon.

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[122] California ISO, CPUC, and CEC. *Final Root Cause Analysis: Mid-August 2020 Extreme Heat Wave*, January 13, 2021, http://www.caiso.com/Documents/Final-Root-Cause-Analysis-Mid-August-2020-Extreme-Heat-Wave.pdf.

The joint agencies plan to evaluate resource portfolios developed in this report for reliability in a multistep process using a production cost model, which will simulate the performance of the portfolio over a year. The first step will evaluate the resource portfolios in all 8,760 hours of the year and highlight potential supply shortfalls in meeting the projected demand. This step will also better capture value provided by some resources, such as long-duration storage, that are not fully captured in a capacity expansion model. After this analysis, the resource portfolio may be adjusted manually, or through revised capacity expansion modeling, to adjust for any operability shortcomings.

The second step will evaluate the revised resource portfolio with a set of probabilistic production cost model runs, which analyzes reliability over a wide range of conditions. This set of runs will explore probabilistic variables, such as loads, renewable energy and hydro availability, and power plant outages to determine the loss of load probability (likelihood of power outages due to insufficient capacity or energy) of the resource mix. A loss of load probability that exceeds, or is significantly under, an acceptable limit will result in additional resource portfolio adjustments and restarting this process at the first step.

Completion of the reliability assessment will provide the joint agencies a more substantiated assessment of pathways to achieve SB 100 while maintaining reliability. This step could be completed as part of the 2025 SB 100 Report or possibly through existing state efforts. The CEC and CPUC are assessing resource availability to complete this modeling ahead of the next report.

Emerging Technologies and Innovation

Additional strategies and technologies have the potential to further enable a high-renewables and decarbonized grid — either by delivering or complementing zero-carbon electricity. State agencies are working together to spur innovation in areas that will be critical to cost-effectively meeting the goals of SB 100.

This collaboration leverages the state’s key role in assessing technology gaps and supporting new and innovative technologies through funding of research, development, and deployment programs, including the Electric Program Investment Charge (EPIC) and the Natural Gas Research and Development Program. The state’s long-term electricity planning processes inform its approach to innovation for a cost-effective clean energy transition, helping identify technology characteristics that can deliver a decarbonized grid, reduce costs, increase resilience and reliability, and contribute to improved air quality.

Listed below are example technology categories that could significantly impact SB 100 planning if development and adoption barriers are overcome and they can be deployed at scale. Future analyses will be updated to incorporate changes in market conditions, costs, and resource availability of new and existing technologies. Other technologies that could affect a 2045 portfolio, such as natural gas generation with carbon capture and sequestration and emerging nuclear technologies, are not discussed here because of cost uncertainty and limited development potential seen at this time.

Offshore Wind

State agencies are exploring opportunities for the development of offshore wind off the California coast. Offshore wind is an attractive technology from a system planning perspective due to the associated generation potential profile that complements solar, with higher output in the evenings, when electricity demand is high and solar production is low. Offshore wind also complements solar seasonally and can provide more consistent output during winter months when solar production is lower.[123]

While there is a significant resource potential off the California coast — an estimated 112 GW of accessible offshore wind resource — there are also considerable barriers. Among the foremost challenges are significant anticipated transmission requirements and competing coastal uses, including shipping, fishing, recreation, marine conservation, and Department of Defense activities. Together, these factors severely limit the feasible resource potential.

In 2016, the BOEM California Intergovernmental Renewable Energy Task Force, a partnership of state, local, and tribal governments and federal agencies, was created to identify potential sites for offshore wind development off the coast. The task force is conducting a public process evaluating possible sites off the Northern and Central Coasts.

Moreover, because California's offshore resource is in water depths greater than 60 meters, floating turbines are needed.[124] While fixed-bottom offshore wind turbines are a proven technology, floating technologies are relatively nascent, with a total of about 66 MW installed worldwide at the end of 2019. However, the global industry for floating turbines is growing rapidly with almost 6.2 GW of global projects in the pipeline, including 64 MW to be installed in the next year, 1,100 MW under construction and planned to be built by 2025, and 7 GW in development.[125]

The National Renewable Energy Laboratory (NREL) recently published a California-focused study on offshore wind. The study estimated LCOE ranges from $57 per megawatt-hour (MWh) to $68 per MWh for offshore wind coming online in 2030.[126] The first commercial scale floating offshore wind projects are projected to have a higher

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[123] National Renewable Energy Laboratory. December 2016. *Potential Offshore Wind Energy Areas in California: An Assessment of Locations, Technology, and Costs*. https://www.nrel.gov/docs/fy17osti/67414.pdf.

[124] National Renewable Energy Laboratory. December 2016. *Potential Offshore Wind Energy Areas in California: An Assessment of Locations, Technology, and Costs*. https://www.nrel.gov/docs/fy17osti/67414.pdf.

[125] Lee, Joyce and Feng Zhao. August 2020. Global Offshore Wind Report 2020. Global Wind Energy Council. https://gwec.net/wp-content/uploads/2020/12/GWEC-Global-Offshore-Wind-Report-2020.pdf

[126] Beiter, Philipp, Walter Musial, Patrick Duffy, Aubryn Cooperman, Matt Shields, Donna Heimiller, and Mike Optis. 2020. *The Cost of Floating Offshore Wind Energy in California Between 2019 and 2032*. Golden, CO: National Renewable Energy Laboratory. NREL/TP-5000-77384. https://www.nrel.gov/docs/fy21osti/77384.pdf.

LCOE than fixed-bottom offshore wind turbines due to a higher degree of financial uncertainty, technical challenges, and a less established supply chain and manufacturing process. Floating offshore wind projects in the next 7-10 years are projected to bid at levels competitive with the first fixed-bottom offshore wind projects.

In 2019, the CPUC included offshore wind as a candidate resource in Integrated Resource Planning sensitivity modeling for the first time. Since then, the CPUC collaborated with BOEM and NREL on their report described above. The CPUC will propose that the transmission needs of offshore wind be studied in the next California ISO Transmission Planning Process, kicking off in February 2021. This study will provide improved understanding of the cost of transmission to deliver offshore wind power to load centers in California and, along with the improved assumptions from NREL, will enhance the state's understanding of the possible contribution of offshore wind in meeting the goals of SB 100.

In 2019, the CEC released a funding opportunity that, for the first time, called for research projects focused on offshore wind energy in California. The solicitation sought two types of projects: (1) projects that develop real-time monitoring systems for offshore wind technologies to help increase productivity, reduce O&M costs, support detection and identification of affected species and habitats, and (2) projects that increase understanding of how offshore energy deployments may affect sensitive species and habitats.

Energy Storage

Energy storage technologies — including batteries, pumped hydro, hydrogen, and other emerging technologies — are expected to play a significant role in helping balance the grid as the state implements SB 100. Storage can help bridge the gap between variable renewable generation and grid energy demands (a role played in large part by natural gas plants today) and provide ancillary services and capacity rapidly to support system stability and reliability.

Nearly all newly procured storage by the California utilities, as required by AB 2514, has been four-hour lithium-ion batteries, driven by rapid declines in battery costs.[127] Since 2010, lithium-ion battery costs have dropped by 90 percent and are expected to decline by another 40 percent by 2024.[128] Though lithium ion dominates the global storage market today, increasing demand is allowing competing technologies to enter the market — including advanced battery chemistries, flow batteries, flywheels, thermal energy storage, and other emerging technologies. This trend will be amplified as other states and nations pursue increasingly clean electric grids and electrify transportation.

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[127] CPUC Energy Storage Web page, https://www.cpuc.ca.gov/General.aspx?id=3462.

[128] BloombergNEF, Electric Vehicle Outlook presentation to CEC for the 2020 IEPR Update, June 11, 2020, slides 17 and 20. https://efiling.energy.ca.gov/GetDocument.aspx?tn=233410&DocumentContentId=65926.

One key area of innovation is in long-duration storage technologies. While there are 4.5 GW of pumped hydro energy storage in California, new longer-duration energy storage systems (for example, 100 or more hours of energy storage) are in the development phase and may be deployed within the next decade with the right market signals. Longer-duration storage technologies, such as advanced batteries, thermal energy storage, liquid air energy storage, and compressed air energy storage, can support reliability and further promote achievement of SB 100 goals.

Additional research and innovation will be important to address a range of outstanding issues, including increasing the cycling rate (number of cycles per day) of battery systems; ensuring reliability of systems over the lifetime of these systems; environmental issues associated with the manufacturing supply chain, including reliance on rare earth minerals; management of thermal runaway and fire potential at storage facilities; and end-of-life disposal and recycling of the battery (for example, some technologies rely upon toxic and extreme pH electrolyte materials). Through EPIC, the state is conducting research to advance storage technologies and better understand the storage needs for meeting SB 100.

Hydrogen

Hydrogen technologies — including as a storage resource, use in fuel cells, and direct combustion — can support the cost-effective implementation of SB 100 by integrating more intermittent renewables and providing flexible supply to balance the grid. Hydrogen may improve the economic efficiency of renewable investments and serve as carbon-free seasonal storage, supplying energy when renewable energy production is low and energy demand is high. A recent study by E3 by Mitsubishi Hitachi Power Systems estimates that the hydrogen market in California could be up to 10 GW by 2045, driven primarily by long-duration energy storage.[129]

Some challenges remain for wider adoption of hydrogen production, storage, and use as a direct source of electricity. Production costs are not cost-competitive with other sources of storage and generation, and additional infrastructure is needed to support the transportation and storage of hydrogen. Moreover, gas pipeline systems have been optimized to transport methane; therefore, introducing hydrogen at a large scale requires addressing regulatory and technical barriers that may persist in distributing hydrogen in the existing natural gas pipelines or developing a new hydrogen-specific distribution system. Continued market, policy, and research advances will be needed to propel technologies and strategies needed to overcome these challenges.

The Natural Gas Research and Development Program and the CEC's Clean Transportation Program are investing in hydrogen fueling infrastructure deployment and vehicle demonstration projects to accelerate market growth of fuel cell-electric vehicles.

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129 E3. Hydrogen Opportunities in a Low Carbon Future. June 2020. https://www.ethree.com/wp-content/uploads/2020/07/E3_MHPS_Hydrogen-in-the-West-Report_Final_June2020.pdf.

Growth in hydrogen demand from the transportation sector, particularly the heavy-duty sector, will assist in achieving scale in the electricity sector, which is necessary to reduce the costs in production and distribution. Furthermore, EPIC is researching the expanded use of hydrogen in the industrial processing and long-term energy storage markets.

Load Flexibility

Flexible load and other demand-side management technologies and strategies — across transportation, buildings, and industry — will be critical for cost-effective implementation of SB 100 and state electrification goals. Load flexibility enables grid balancing by temporarily aligning demand with the availability of preferred supply resources, including intermittent renewable generation and other zero-carbon resources. Load flexibility supports variable renewable electricity supply by providing fast-response flexible load substitutes for ancillary services. These functions will be increasingly important with greater deployment of variable renewables.

Several barriers constrain the growth of load flexibility. First, there are limited mechanisms to compensate for load flexibility in current utility programs and rate designs. Continued work is needed to create incentives commensurate with the value of load flexibility for the grid. The CEC has undertaken several initiatives to help accelerate load flexibility for reliability and meeting the state's environmental goals. The *2019 Building Energy Efficiency Standards*[130] require load-flexibility capability for battery storage and heat pump water heaters to obtain compliance credit. The 2020 Load Management Standards proceeding[131] will create a platform to enable greater automation of load flexibility. The AB 3232 *Building Decarbonization Assessment*[132] assesses the potential and value of load flexibility as a key strategy.

On October 14, 2020, the CEC approved an order instituting rulemaking for the flexible demand appliance standards and labeling requirements included in Senate Bill 49 (Skinner, Chapter 697, Statutes of 2019). Staff will be working throughout 2021 to develop a set of initial proposed flexible demand appliance standards based on a range of considerations relating to technology readiness, load-shifting potential, and estimated GHG emissions savings.

For many applications, the enabling technologies for load flexibility are still in the early development stages. For example, in the transportation space, smart charging and

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[130] CEC 2019 Building Energy Efficiency Standards Web page, https://www.energy.ca.gov/programs-and-topics/programs/building-energy-efficiency-standards/2019-building-energy-efficiency.

[131] CEC 2020 Load Management Rulemaking Web page, https://www.energy.ca.gov/proceedings/energy-commission-proceedings/2020-load-management-rulemaking.

[132] CEC Building Decarbonization Assessment Web page, https://www.energy.ca.gov/data-reports/reports/building-decarbonization-assessment.

bidirectional power flow technologies are largely precommercial, and continued development will improve the associated value proposition. Demand flexibility costs vary significantly by end use. Costs for a range of demand response applications and scenarios are discussed in Lawrence Berkeley National Laboratory's 2025 California Demand Response Potential Study.[133]

Through EPIC, the state is pursuing a wide array of load-flexibility research to further develop the needed technology, lower costs, and foundation for market growth. The CEC released a solicitation (GFO-19-309) in September 2020 to fund a California Flexible Load Research and Deployment hub to conduct R&D and deployment projects that increase the use and market adoption of advanced, interoperable, and flexible demand technologies.

Overall, state agencies can leverage research and development investments in technology innovation to help achieve SB 100 goals. This leveraging will require strategic and coordinated investment over the long term, with a focus on technologies, state incentives, and targeted regulations and strategies that augment or complement existing commercially available solutions.

Land-Use and Environmental Impacts

Natural and working lands are important to the state's climate change strategy because they sequester carbon and support clean air, wildlife and pollinator habitat, and rural economies. They are also critical components of the state's water infrastructure and can be a source and sink for GHG emissions. Keeping these lands and waters intact and functioning ecologically in the future is necessary to supporting the well-being and security of Californians and reducing conversion to intensified uses.

Because renewable and zero-carbon energy technologies often have large footprints and may require new supporting infrastructure to deliver power (for example, transmission), incorporating land use into planning is necessary to minimize adverse societal and environmental impacts and maximize potential environmental, health, and economic co-benefits.

It will be important to incorporate land-use planning into electric system planning to consider trade-offs between energy development and conservation of land for agricultural, natural lands, or housing. Several geospatial studies, such as NREL's GIS mapping of renewable energy resources,[134] have already screened for locations with high renewable energy resource potential in California. However, energy-planning processes have not yet been fully integrated

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[133] Lawrence Berkeley National Laboratory. March 2017. *2025 California Demand Response Potential Study – Charting California's Demand Response Future: Final Report on Phase 2 Results*. https://eta-publications.lbl.gov/sites/default/files/lbnl-2001113.pdf.

[134] National Renewable Energy Laboratory Geospatial Data Science Web page, https://www.nrel.gov/gis/.

with land conservation values to evaluate the environmental and system cost and benefit implications of clean energy policies and siting decisions.

As California considers the more ambitious renewable energy goals of SB 100, proactive landscape-scale planning can help identify opportunities for renewable energy facility and transmission development while reducing adverse effects. Landscape-scale planning considers a wide range of potential constraints and conflicts, including environmental sensitivity, conservation and other land uses, tribal cultural resources, and more when considering future renewable energy development. The benefits of using landscape-level approaches for renewable energy and transmission planning include early identification and resolution of large issues or barriers to development, coordinated agency permitting processes, increased transparency in decision making, increased collaboration, avoidance of impacts, and more rapid development of environmentally responsible renewable energy projects.

Planning should also reflect the Garamendi Principles,[135] encouraging strategies to maximize the use of the existing transmission system and existing rights-of-way before considering the expansion or creation of new rights-of-way. Such strategies include using advanced transmission technologies as well as siting supply resources in strategic locations.

California has already worked extensively with stakeholders and other agencies through science-based collaborative landscape planning processes in multiple geographic areas of the state with renewable energy potential. Previous planning efforts include the first and second Renewable Energy Transmission Initiatives[136] (RETI) processes, the joint agency work on the

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135 California Senate Bill 2431, Chapter 1457, declared that it is in the best interest of the state to conduct transmission siting according to the following principles ("Garamendi Principles"):

1. Encourage the use of existing right-of-way (ROW) by upgrading existing transmission facilities where technically and economically justifiable.
2. When construction of new transmission line is required, encourage expansion of existing ROW, when technically and economically feasible.
3. Provide for the creation of new ROW when justified by environmental, technical, or economic reasons as determined by the appropriate licensing agency.
4. Where there is a need to construct additional transmission capacity, seek agreement among all interested utilities on the efficient use of that capacity.

136 *Renewable Energy Transmission Initiative Phase 2A Final Report*, September 2019, available at: https://web.archive.org/web/20100330223729/http://www.energy.ca.gov/2009publications/RETI-1000-2009-001/RETI-1000-2009-001-F-REV2.PDF. *Renewable Energy Transmission Initiative 2.0 Final Plenary Report*, February 23, 2017, available at https://efiling.energy.ca.gov/getdocument.aspx?tn=216198.

Desert Renewable Energy Conservation Plan (DRECP),[137] and the stakeholder-led San Joaquin Valley Identification of Least-Conflict Lands study.[138]

Through these, federal and state agencies, local governments, tribes, and stakeholders have gained experience with planning approaches to identify the most appropriate areas for renewable energy development and long-term conservation. These planning efforts have also enabled the collection of environmental data and information into a single, publicly accessible portal, the California Statewide Energy Gateway.[139] This information supports science-based conservation planning, decision-making for renewable energy expansion, and future landscape-scale planning.

The CPUC's IRP process includes environment and land-use screens as part of capacity expansion modeling. The CEC then uses the land use and environmental information assembled from these landscape planning efforts to map selected resources to substation busbars for input to the California ISO's transmission modeling for the TPP. The CPUC's inclusion of land-use screens in the upcoming IRP cycle will also inform statewide land-use planning.

California's lands are naturally capable of sequestering huge amounts of carbon to limit climate change and are, therefore, a key component of meeting the state's carbon neutrality goals. Ongoing disturbances to natural and working lands such as severe wildfire, land degradation, and land conversion cause these landscapes to emit more carbon dioxide than they store. Policy in the electricity sector must be made with a clear understanding of the need to balance increased renewable energy demand with loss of ecosystem carbon storage and loss of future sequestration associated with large footprint energy resources such as utility-scale solar. California's climate objectives for natural and working lands are to maintain them as a resilient carbon sink (that is, net-zero or negative GHG emissions) and minimize the net GHG emissions associated with management, biomass disposal, and wildfires.

Moreover, Governor Newsom's Executive Order (N-82-20) requires the state to have a target for the natural and working lands sector in achieving California's carbon neutrality goal. The order directs state agencies to use strategies to maximize the full climate benefits of natural and working lands and sets a first-in-the-nation goal to conserve 30 percent of the state's land and coastal water by 2030 to fight species loss and ecosystem destruction.

In future assessments of land-use impacts, the joint agencies can draw from these efforts and experiences. As next steps, the joint agencies plan to review methods to include land-use

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[137] CEC Desert Renewable Energy Conservation Plan Web page, https://www.energy.ca.gov/programs-and-topics/programs/desert-renewable-energy-conservation-plan.

[138] See *A Path Forward: Identifying Least-Conflict Solar PV Development in California's San Joaquin Valley*. Available at : https://sjvp.databasin.org/pages/least-conflict.

[139] Access the California Statewide Energy Gateway at: https://caenergy.databasin.org.

impacts in system modeling and assess needs to update previous land-use studies to reflect the increased resource requirements of SB 100. Future system modeling and land-use impacts must be coordinated with any recommendations from the Climate Smart Strategy called for in Executive Order N-82-20 and the AB 32 Scoping Plan.

Social Costs and Non-Energy Benefits

Another key area for further analysis is the inclusion of social costs and non-energy benefits (NEBs). For this report, community leaders and advocacy organizations[140] recommended the joint agencies consider an equity scenario that excludes combustion resources and includes social costs and NEBs.

The comment letter states that "social costs" are the negative externalities or impacts on society associated with the construction and operation of energy infrastructure and any associated activity, with a specific focus on localized public health impacts. Non-energy benefits (NEBs) represent the benefits or positive impacts on society associated with the construction and operation of energy infrastructure and any associated activity.

Stakeholders recommended the joint agencies integrate at least the following NEBs and social costs into SB 100 planning:

- Land-use impacts
- Public health and air quality
- Water supply and quality
- Economic impacts
- Resilience

As discussed in Chapter 3, the joint agencies included a study scenario that excludes all new and existing combustion resources in the modeling scope. Further refinement to localized air pollution impacts and the other NEBs listed above was not feasible in this round of modeling, partly because of the modeling tools used, unknowns about where generation resources will be located, and lack of higher resolution data on when and how specific resources will be used.

The joint agencies plan to continue engaging with the DACAG and other stakeholders to explore opportunities to better integrate these topics into future analyses. Land use is addressed in the preceding section, and further discussion on the other recommended NEBs is included below.

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[140] Including the UC Berkeley Environmental Law Clinic, Central California Asthma Collaborative (CCAC), the Center on Race, Poverty & the Environment (CRPE), the Greenlining Institute, GRID Alternatives, Leadership Counsel for Justice and Accountability, Sierra Club California and the California Environmental Justice Alliance.

State Efforts to Evaluate Social Costs

The joint agencies will explore the use of emerging cost analysis tools and methods that integrate social costs. Some of these new methods are being tested in active proceedings such as the CPUC's San Joaquin Valley Affordable Energy proceeding (R.15-03-010) to begin evaluating energy solutions with consideration of NEBs and social costs.

The CPUC is also performing Societal Cost Test modeling, as ordered by IDER D.19-05-019. This work includes changing RESOLVE assumptions to reflect a social discount rate, a social cost of carbon, and an air quality adder. A report that contains this analysis and select sensitivities will be released through the IRP in early 2021. The Public Health and Air Quality section below includes a preliminary social cost assessment for a subset of portfolios.

The joint agencies are monitoring the application of available tools and stakeholder input to determine if they are appropriate for SB 100-related analysis.

Preliminary Analysis on Avoided Social Costs of SB 100

For this report, CARB performed an initial assessment of the avoided social costs of carbon of the SB 100 Core Scenario relative to the 60 percent RPS Scenario (reference). Future assessments will build off this initial analysis and more thoroughly reflect state efforts to quantify social costs.

The social cost[141] of carbon (SC-CO_2) estimates the value of damages avoided by reducing GHGs. It is intended to provide a comprehensive measure of net damages — the monetized value of the net impacts — from global climate change that result from an additional ton of carbon dioxide (CO_2). These include changes in net agricultural productivity, energy use, human health, property damage from increased flood risk, as well as nonmarket damages, such as services that natural ecosystems provide to society. Many of these damages from CO_2 emissions today will affect economic outcomes throughout the next several centuries.[142]

Table 22 presents the range of SC-CO_2 values developed by the Council of Economic Advisors and the Office of Management and Budget-convened Interagency Working Group on the Social

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[141] "Social costs" are generally defined as the cost of an action on people, the environment, or society and are widely used to evaluate the impact of regulatory actions.

[142] From The National Academies, Valuing Climate Damages: Updating Estimation of the Social Cost of Carbon Dioxide, 2017, available at https://www.nap.edu/catalog/24651/valuing-climate-damages-updating-estimation-of-the-social-cost-of.

Cost of Greenhouse Gases (IWG)[143] and used in the *2017 California Climate Change Scoping Plan.*[144]

The SC-CO_2 increases over time as systems become stressed from the cumulative impacts of climate change, and future emissions cause incrementally larger damages. The SC-CO_2 is highly sensitive to the discount rate. Higher discount rates decrease the value today of future environmental damages, reflecting the trade-off of consumption today and future damages.

Table 22: Social Cost of CO2, 2015–2050 (in 2007 Dollars per Metric Ton CO2)

Year	5% Discount Rate	3% Discount Rate	2.5% Discount Rate
2015	$11	$36	$56
2020	$12	$42	$62
2025	$14	$46	$68
2030	$16	$50	$73
2035	$18	$55	$78
2040	$21	$60	$84
2045	$23	$64	$89
2050	$26	$69	$95

Source: CARB staff analysis

Table 23 shows the estimated avoided social costs of the SB 100 core scenario (high electrification demand) relative to the 60 percent RPS scenario. (See calculation details in Appendix C.)[145]

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[143] Originally titled the Interagency Working Group on the Social Cost of Carbon, the IWG was renamed in 2016.

[144] U.S. EPA. The Social Cost of Carbon: Estimating the Benefits of Reducing Greenhouse Gas Emissions. Retrieved on November 19, 2020, from: https://19january2017snapshot.epa.gov/climatechange/social-cost-carbon_.html.

[145] The 2045 values shown in **Table 23** were translated into 2016 dollars and multiplied by the differential between the GHG emissions associated with the two scenarios, as detailed in Chapter 3.

Table 23: Estimated Avoided Social Cost (Avoided Economic Damages) of SB 100 in 2045

Scenario	Social Cost of Carbon, $ million USD (2016 dollars) 5% Discount Rate	Social Cost of Carbon, $ million USD (2016 dollars) 3% Discount Rate	Social Cost of Carbon, $ million USD (2016 dollars) 2.5% Discount Rate
SB 100 Core Scenario relative to 60% RPS Scenario	$887	$2,470	$3,430

Source: CARB staff analysis

The SC-CO_2, while intended to be a comprehensive estimate of the damages caused by carbon globally, does not represent the cumulative cost of climate change and air pollution to society due to modeling and data limitations.[146] The joint agencies will continue engaging with experts to evaluate the comprehensive California-specific impacts of climate change and air pollution.

Public Health and Air Quality

The state's air quality and climate policies, strategies, and regulations strive to maximize public health protection through reducing respiratory, cardiovascular, and other chronic illnesses; reducing early deaths; and promoting healthier and more sustainable lifestyles in all communities. Despite decades of progress in improving air quality, California still suffers some of the worst air quality in the nation, resulting in more than 7,000 premature deaths and thousands of illnesses and emergency room visits each year.

The effects of climate change are already felt today in California. Climate change can impact human health through extreme weather events including drought, precipitation, floods, heat waves, and wildfires.[147] These climate impacts contribute to heat-related illnesses, increases in cardiovascular and respiratory illnesses, increased prevalence of asthma and allergies, increased water-borne and vector-borne diseases, adverse child and reproductive health

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[146] Including costs associated with changes in copollutants and the social cost of other GHGs including methane and nitrous oxide.

[147] (a) U.S. Global Change Research Program. 2018. *Impacts, Risks, and Adaptation in the United States: Fourth National Climate Assessment, Volume II* (Reidmiller, D.R., C.W. Avery, D.R. Easterling, K.E. Kunkel, K.L.M. Lewis, T.K. Maycock, and B.C. Stewart [eds.]). U.S. Global Change Research Program, Washington, D.C., United States of America. https://nca2018.globalchange.gov/. (b) World Health Organization. 2003. *Climate Change and Human Health, Risks and Responses*. Geneva, Switzerland. https://www.who.int/globalchange/publications/climchange.pdf. (c) NRDC. 2019. Climate Change and Health in California. https://www.nrdc.org/sites/default/files/climate-change-health-impacts-california-ib.pdf.

outcomes, and other effects. Climate change is already taking a toll on human health, and taking action to reduce greenhouse gas emissions is a necessity.

Power generated from fossil fuel combustion[148] also emits criteria air pollutants and related precursors, including oxides of nitrogen (NOx) and oxides of sulfur (SOx). While NOx and SOx are directly harmful, they are more impactful on health when they are converted to fine particles by chemical processes in the atmosphere. Fine particle pollution (that is, pollution from particulate matter with a diameter ≤2.5 μm, also known as $PM_{2.5}$) contributes to more fatalities than other air pollutants. Health effects from long-term exposure to fine particle pollution includes increased risk of heart attacks and heart disease, impaired lung development in children, the development and exacerbation of asthma, and premature death. U.S. EPA has determined that fine particles play a causal role in premature death from heart- and lung-related illnesses.[149]

Millions of California residents live in disadvantaged communities that experience a combination of increased vulnerability to adverse health effects from pollution and high levels of exposure to pollution sources. Research has demonstrated higher rates of illness and early death in disadvantaged communities.[150] For these residents, actions to transition from fossil fuel combustion are even more urgent.

Those individuals and communities that are at a social and financial disadvantage are also less able to deal with stresses caused by climate change such as high temperatures and wildfire damages, and they are more likely to suffer physical and psychological harm. Replacing fossil fuel-powered generation plants with clean electricity resources will reduce the burden on public health from air pollution and climate change and help address environmental justice disparities.

Quantifying Health Benefits of SB 100

To illustrate the potential quantified health benefits in 2045 from decreased $PM_{2.5}$ pollution linked to power plant emissions, CARB used a simplified version of its Incidence-Per-Ton (IPT)

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[148] Power generation that uses conventional combustion technologies are typical sources of criteria air pollutant emissions; however, noncombustion thermal technologies can also emit criteria air pollutants.

[149] U.S. EPA. September 2019. *Policy Assessment for the Review of the National Ambient Air Quality Standards for Particulate Matter, External Review Draft*. https://www.epa.gov/sites/production/files/2019-09/documents/draft_policy_assessment_for_pm_naaqs_09-05-2019.pdf.

[150] (a) American Lung Association. 2020. *State of the Air*. https://www.stateoftheair.org/assets/SOTA-2020.pdf. (b) Union of Concerned Scientists, USA. January 28, 2019. *Inequitable Exposure to Air Pollution From Vehicles in California (2019)*. https://www.ucsusa.org/resources/inequitable-exposure-air-pollution-vehicles-california-2019#ucs-report-downloads. (c) Cushing L., Faust J., August L. M., Cendak, R., Wieland, W., and Alexeeff, G. 2015. "Racial/Ethnic Disparities in Cumulative Environmental Health Impacts in California: Evidence From a Statewide Environmental Justice Screening Tool (CalEnviroScreen 1.1)." Am J Public Health 105(11): 2341–2348. https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4605180/.

method, which evaluates the health endpoints of premature mortality, cardiopulmonary hospitalizations, and asthma emergency room (ER) visits.

Health impacts were estimated using California-specific relationships between emissions and air quality. This method is assumed to have an approximately linear relationship between changes in $PM_{2.5}$ emissions and health outcomes. CARB estimated the numbers of health outcomes by multiplying emissions by an incidents-per-ton scaling factor.[151] **Table** 24 summarizes these estimated health impacts for SB 100 at the statewide level for 2045. These are rough estimates using limited emission information and should not be taken as absolute values of the health outcomes of the 100 percent clean electricity policy. Further, this analysis does not attempt to quantify the improved health outcomes from reduction in greenhouse gases nor global climate change, as climate change mitigation requires global actions.

Table 24: Summary of Ranges of Estimated Health Impacts for the SB 100 Scenario in 2045

	Fewer Premature Deaths	Fewer Cardiopulmonary Hospitalizations	Fewer Asthma ER Visits
Primary $PM_{2.5}$	174 (136-213)	61 (8-114)	80 (50-109)

Source: CARB staff analysis. Numbers in parentheses represent the 95% confidence interval.

A more comprehensive analysis can use well-established methods that translate regional emissions reductions in criteria air pollutants into health outcomes.[152] Steps to further analyze the health impacts from criteria air pollution, specifically $PM_{2.5}$, include the following:

1. Estimate $PM_{2.5}$ emissions from power plants for at least two points in time, such as the current year and at full implementation of the SB 100 target in 2045. Key milestone years (for example, achievement of 60 percent renewables by 2030) may also be evaluated, as well as impacts in disadvantaged communities.
2. Use estimates of $PM_{2.5}$ emissions and exposures, together with an effect estimate, to quantify health impacts at the statewide or air basin level. The quantitative analysis should include updated ranges of estimated premature deaths, hospitalizations, and emergency room visits on a statewide basis, as well as cancer risk estimates if sufficient data are available.

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[151] These factors are derived from research studies showing the associations between the number of incidents (premature deaths, hospitalizations, emergency room visits) and exposure to PM2.5.

[152] CARB 2019a, Fann et al. 2009, 2012. Fann, N., C. M. Fulcher and B. J. Hubbell (2009). "The influence of location, source, and emission type in estimates of the human health benefits of reducing a ton of air pollution." Air Qual Atmos Health 2(3): 169-176.

Climate change impacts, such as extreme weather events, can also affect air quality and health. A more comprehensive analysis of health impacts and benefits may include factors related to climate impacts to yield a fuller picture of economic benefits.

Analysis of health impacts is closely connected to economic analysis: the monetized value of avoided illness and premature death provides a helpful measure of the health value of air pollution controls. According to U.S. EPA methodology, the current value of a statistical life (VSL) is nearly $10 million, so the cumulative health impacts of a regulation over decades can be substantial.[153]

As the energy sector continues to evolve and decarbonize, the behavior of facilities and the design of the grid will change, with important distributional effects. Some power plants may operate more flexibly to balance renewables, emerging technologies may become more prevalent, and aging facilities may be replaced. These trends will likely shift patterns of criteria pollutant emissions with local benefits and impacts. Because many existing power plants are in or near disadvantaged communities, it is important that this transition benefits those most burdened by pollution.[154]

Water Supply and Quality

The energy-water nexus is a critical juncture between energy production, environmental impacts, and dependence on water resources. The joint agencies' analysis of NEBs and social costs should therefore encompass energy resource impacts on water quality or quantity and impacts of water supply on the energy system.

Conserving fresh water and avoiding its wasteful use have long been state priorities, as reflected in the State Constitution[155] and state policies. A State Water Resources Control Board (Water Boards) resolution[156] protects beneficial uses of the state's water resources and keep the consumptive use of fresh water for power plant cooling to only essential levels. The policy reflects the state's concerns over discharges from power plant cooling, as well as the conservation of fresh water.

In response to concerns about power plants significantly impacting local water supplies, the CEC adopted a water policy in 2003 that calls for the use of alternative technologies and water sources. Since then, there has been a trend away from the use of fresh water for power plant

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153 National Center for Environmental Economics et al., *Appendix B: Mortality Risk Valuation Estimates, Guidelines for Preparing Economic Analyses* (EPA 240-R-10-001, Dec. 2010) available at https://www.epa.gov/sites/production/files/2017-09/documents/ee-0568-22.pdf.

154 California Health and Safety Code Section 38562(b)(2).

155 Article X, Section 2.

156 Resolution No. 75-58, Water Quality Control Policy on the Use and Disposal of Inland Waters Used for Powerplant Cooling, June 19, 1975, https://www.waterboards.ca.gov/board_decisions/adopted_orders/resolutions/1975/rs75_058.pdf.

cooling compared to previous years, as well as increased use of recycled water, more efficient cooling technologies, dry cooling, and recycling of process wastewater through zero-liquid-discharge systems.[157]

Both solar PV and wind technologies can operate with essentially no water requirements, though PV facilities typically use some water for panel washing. However, because of size, all utility-scale renewable energy facilities can require large amounts of water during construction for dust control and soil grading. With sandy, dry, and windy conditions typical of the desert, where many projects are located (and where significant buildouts may be in the future), the amount of water used for construction can be considerable, especially considering limited water supplies available in many parts of the desert.

Water efficiency in California's electric generation sector will continue to improve as the fleet modernizes and natural gas-fired plants are run less often, recycled water sources are used preferentially, and renewables are deployed. However, given that a reliable supply of water will continue to be a key contributor to a reliable generation sector, it will be imperative for water quality and quantity impacts to be considered in planning and permitting processes.[158]

Economic Development and Impacts

SB 100 presents a significant opportunity for job creation and sustainable careers because of the expected record-setting resource build. While this report does not contain an analysis of local economic impacts or benefits, nor job creation associated with SB 100 implementation, these topics will be explored quantitatively and qualitatively in future SB 100 work.

The joint agencies will continue coordinating with the California Workforce Development Board (CWDB) to maximize alignment between SB 100 implementation and the state's efforts to ensure a just transition into the clean energy future and promote equity in the clean energy workforce. The CPUC has recently entered into an agreement with CWDB to draw upon CWDB's expertise to ensure the state has the workforce and industry-based training partnerships necessary to meet its clean energy goals.

The CWDB's new report titled *Putting California on the High Road: A Jobs and Climate Action Plan for 2030*[159] provides a vision to integrate economic and workforce development into climate policies and programs to help achieve California's major climate goals. The CWDB's report, developed following Assembly Bill 398 (E. Garcia, Chapter 135, Statutes of 2017),

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[157] Even before adoption of the 2003 water policy, a good portion of California's steam-cycle facilities (combined-cycle, steam boiler, and geothermal) used recycled water for cooling.

[158] For more detailed information on the energy-water nexus for California's electric generation system, see the CEC staff report *Final 2016 Environmental Performance Report of California's Electrical Generation System*.

[159] UC Berkeley Labor Center. *Putting California on the High Road: A Jobs and Climate Action Plan for 2030*. June 2020. https://laborcenter.berkeley.edu/wp-content/uploads/2020/09/Putting-California-on-the-High-Road.pdf.

creates a framework for maximizing the positive labor market outcomes of California's climate investments by simultaneously advancing equity and economic mobility for Californians and delivering skills and competitiveness for California employers. Key takeaways from the report include the following:

- Labor should be considered an investment rather than a cost — and investments in growing, diversifying, and upskilling California's workforce can positively affect returns on climate mitigation. In other words, well-trained workers are key to delivering emissions reductions and moving California closer to its climate targets.
- California can achieve greater social equity in labor market outcomes for disadvantaged workers and communities when policy makers pay attention to job quality. Identifying high-quality careers (in other words, ones that offer family-supporting wages, employer-provided benefits, worker voice, and opportunities for advancement) first, and then building pathways up and into such careers, are critical to ensuring that investments in workforce education and training meaningfully improve workers' economic mobility.
- Deliberate policy interventions are necessary to advance job quality and social equity as California transitions to a carbon-neutral economy, just as such efforts are required to reduce pollution, protect human and environmental health, and safeguard communities from an already-changing climate.

DACAG's Equity Framework[160] serves as another guide in assessing local economic and workforce opportunities. The framework states, "Climate policies and programs should invest in a clean energy workforce by ensuring California has a trained and ready workforce prepared to improve our infrastructure and built environment as well as bring green technologies to market by:

- Promoting and funding workforce development pathways to high-quality careers in the construction and clean energy industries, including pre-apprenticeship and other training programs,
- Setting and tracking hiring targets for low-income, disadvantaged, and underrepresented populations (including women, re-entry, etc.) to enter these industries,
- Ensuring that these careers are high-road, with a career-ladder, family-sustaining wages and with benefits,
- Training the next generation of climate leaders and workers for the clean energy economy, and
- Supporting small and diverse business development and contracting."

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[160] CPUC. Disadvantaged Communities Advisory Group Equity Framework, available at https://www.cpuc.ca.gov/uploadedFiles/CPUCWebsite/Content/UtilitiesIndustries/Energy/EnergyPrograms/Infrastructure/DC/DAC%20AG%20Equity%20Framework%20(Revised).pdf.

The road to economic recovery is even more critical now that the COVID-19 pandemic has hit the entire country. People of color are disproportionately impacted by the economic downturn resulting from the pandemic and are overrepresented in nonessential, low-wage jobs.[161] The clean energy economy represents a unique opportunity to focus workforce development efforts in disadvantaged communities. Creating clean jobs and careers with growth potential can help accelerate the economic rebuilding for workers, families, and the greater economy.

Community Resilience

The Governor's Office of Planning and Research defines resilience as "...the capacity of any entity — an individual, a community, an organization, or a natural system — to prepare for disruptions, to recover from shocks and stresses, and adapt and grow from a disruptive experience."[162] Future investments in electric generation, storage, distribution, and transmission facilities must be designed and operated with reliability and resilience in mind to account for a changing climate. In particular, planning for and developing these facilities require an understanding of the challenges posed by increasing wildfire risk, extreme heat, and other effects of climate change. This planning is especially important as the electric grid expands to serve additional end uses, such as transportation.

Resilience to climate impacts is a priority in state policy and program design and implementation. Several state agencies, including the CEC and Strategic Growth Council, administer grant programs focused on improving local resilience to climate impacts. These grants have enabled cities to develop local adaptation plans that consider regional climate threats and identify regionally relevant adaptation strategies. Local adaptation planning may benefit from more refined results from the SB 100 and related proceedings on the resource mix and likely location and operation of resources. A more detailed discussion of electricity system resilience and planning for climate impacts is included later in this chapter.

Accelerating SB 100 Implementation

This report includes study scenarios in which the 100 percent renewable and zero-carbon target is accelerated to 2030, 2035, and 2040. While preliminary modeling results suggest accelerating the implementation timeline of the SB 100 target is technically achievable, these scenarios are exploratory and require more rigorous analysis.

Notably, the accelerated timelines resulted in additional economic gas retirements, increased selection of geothermal resources, and decreased selection of solar and battery storage. These results suggest accelerated implementation could affect the overall 2045 resource portfolio.

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[161] PolicyLink. "Race, Risk, and Workforce Equity in the Coronavirus Economy." June 2020. https://www.policylink.org/our-work/economy/national-equity-atlas/COVID-workforce.

[162] Governor's Office of Planning and Research. 2018. *Planning and Investing for a Resilient California: A Guidebook for State Agencies*. https://opr.ca.gov/docs/20180313-Building_a_Resilient_CA.pdf.

Each accelerated timeline scenario results in increased annual costs compared to the SB 100 Core scenario. In general, the TRC increases in the year in which the 100 percent target is accelerated but largely levels off by 2045. For example, in the 2030 accelerated scenario, the 2045 TRC is less than a 1 percent increase over the SB 100 core scenario. Total cumulative cost differences between these scenarios have not been evaluated.

The joint agencies plan to continue analysis of the 2030, 2035, and 2040 scenarios in the 2025 SB 100 report analyses. In the meantime, the CPUC, in the IRP process, will continue to evaluate requiring load-serving entities to meet reduced GHG emission targets within the range set by CARB. These processes will be done in collaboration with CEC and may support opportunities to accelerate progress toward the SB 100 goal.

Additional Considerations for Implementation

As the joint agencies produce more refined analysis of the SB 100 scenarios, additional factors must be considered in planning for SB 100 implementation and coordination with complementary proceedings and programs.

Equity

As stated by the DACAG, "The impact of climate change on low-income and disadvantaged communities can exacerbate existing inequities but can also be an opportunity to level the playing field through intentional interventions that address climate impacts on these communities directly." In 2018, the DACAG developed an Equity Framework to guide the CEC and CPUC along with other state agencies to help ensure equity is kept "front and center" during all phases of policy design and implementation of clean energy such as SB 100.[163] The Equity Framework includes the following components:

- Health and safety
- Access and education
- Financial benefits
- Economic development
- Consumer protection

Future SB 100 work will consider this framework and other recommendations made by equity experts and community leaders throughout the process, including the AB 32 Environmental Justice Advisory Committee, to benefit communities in a meaningful and measurable way. The Equity Framework priorities will be considered as part of the continued efforts of SB 100, including program design, modeling, analysis, implementation, and evaluation. In addition, AB

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[163] CPUC, Disadvantaged Communities Advisory Group Equity Framework, available at https://www.cpuc.ca.gov/uploadedFiles/CPUCWebsite/Content/UtilitiesIndustries/Energy/EnergyPrograms/Infrastructure/DC/DAC%20AG%20Equity%20Framework%20(Revised).pdf.

617 Community Emissions Reduction Plans provide a resource for actions that will achieve air pollution emission and exposure reductions within disproportionately impacted communities and are tailored to address the communities' air quality priorities.

The joint agencies conducted ongoing engagement with equity stakeholders throughout the development of the 2021 Report, and plan to have continued engagement with the DACAG's SB 100 subcommittee and other stakeholders to further refine the agencies' approach to equity in SB 100 implementation.

Affordability

Meeting the SB 100 2045 target will likely require substantial new investments in the electric system, which may have impacts on electricity rates for consumers. Under some emissions reduction scenarios, modeling conducted for this report indicates that the state's installed electric generation capacity may grow from about 85,000 MW today to between 227,000 MW and 301,000 MW in 2045 — roughly a threefold increase in capacity. As the transportation, buildings, and industrial sectors deploy low-carbon technologies to meet the state's long-term climate goals, they will likely rely more on the electricity sector, which will increase load and customer sensitivity to rates. Maintaining affordable electricity rates is critical to successful achievement of the state's GHG targets across sectors.

As mentioned in Chapter 3, the 2021 Report analysis results provide rough estimates of system costs associated with the various scenarios. However, further analysis is required to better understand how these costs will be factored into rates that directly affect consumers. The modeling does not take into account important factors including costs associated with build-out to maintain local reliability and system hardening efforts for improved system resilience to wildfires and other climate threats.

Through proceeding (R.18-07-006), the CPUC aims to better understand and define affordability for residential utility customers within California. This proceeding has primarily analyzed metrics that may be used to compare affordability as rates change. However, a baseline threshold to determine when something is or is not affordable has not yet been established, and the CPUC continues to assess appropriate methods to do so.

The decision adopted in the first phase of the proceeding defines affordability as "the degree to which a representative household is able to pay for an essential utility service charge, given its socioeconomic status."[164] The decision also adopted three metrics to compare and assess affordability:

> **Household affordability ratio**: a ratio that sums the expected cost for three utility services (energy, telecommunication, and water services — together, these are deemed "essential utility services") and divides them by a household's income less total housing

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[164] California Public Utilities Commission. *Decision Adopting Metrics and Methodologies for Assessing the Relative Affordability of Utility Service*. July 16, 2020. https://docs.cpuc.ca.gov/PublishedDocs/Published/G000/M344/K049/344049206.PDF.

costs. This ratio provides a percentage for how much a household spends of its nonhousing budget on utilities.

Socioeconomic vulnerability index: a 100-point scale that can be used to compare one census tract area to another. The metric is a composite of five socioeconomic indicators that are components of California Office of Environmental Health Hazard Assessment's CalEnviroScreen: educational attainment, housing burden, linguistic isolation, poverty, and unemployment.[165] This metric provides an index that is independent of essential service charges. It answers the question: "What is the underlying socioeconomic vulnerability of a given geography?"

Hours at minimum wage: a statistic based on the estimated total cost for the essential utility services of energy, telecommunication, and water. This total is then compared to the minimum wage for a given locality. The number of hours of minimum wage needed to afford essential utility service is then calculated by dividing the total utility cost by the minimum wage value.

Taken together, these various metrics allow the utility to understand how rate changes may affect affordability for different regions and communities.

Implementing SB 100 with a focus on equity will require statewide focus on energy affordability with an emphasis on vulnerable populations and households in areas of the state that spend a disproportionately high share of their household income on energy. This focus underscores the importance of managing overall energy costs and engaging in thoughtful ratemaking to avoid large price spikes for vulnerable households, and integrated program implementation whereby grants and other targeted programming can be directed toward households that face affordability challenges.

Safety

In the last decade, California has experienced the challenges of safely operating the electric infrastructure that is built to serve high fire-threat areas of the state, and the consequences of underinvestment in the safety of gas storage, transmission, and distribution. California is grappling with how to prioritize the mitigation of numerous new risks associated with electric and gas infrastructure and how to pay for the mitigation. All these present-day safety challenges must be considered in long-term planning to meet the goals of SB 100.

To support the goals of SB 100, some existing energy infrastructure will need maintenance, hardening, repurposing, upgrades, or retirement. Similarly, newly constructed infrastructure under the given scenarios and patterns of the buildout must be capable of safe operation.

The areas of safety that will need to be considered in such analyses include:

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[165] California Office of Environmental Health Hazard Assessment. CalEnviroScreen 3.0 (Updated June 2018) Web page. https://oehha.ca.gov/calenviroscreen/report/calenviroscreen-30.

- Safety in the planning, engineering, construction, operation, and maintenance of the electric, natural gas, biofuel, and hydrogen infrastructure and resources depending on the scenario and pattern of the buildout,
- Safety of workers, customers, and the public.

The CPUC and IOUs must engage in an ongoing assessment of risks and a prioritization of how to address those risks, including how to pay for the costs of mitigation. The risk mitigation strategies related to electric infrastructure being implemented and considered today include:

- System hardening.
- Undergrounding or covered conductors.
- Vegetation management and right-of-way (ROW) management to effectively protect the environment.
- Weather forecasting to develop situational awareness.
- Appropriate retirement schedules given changing climate conditions to ease safe transition.
- New and adaptive infrastructure proposals using California's climate change forecasts in the Fourth Climate Assessment and the forthcoming Fifth Climate Assessment.
- Upgrade transmission and distribution switching protocols to safely and reliably operate the transmission and distribution systems in an islanding mode and/or develop microgrids to minimize the impact of power shut-offs or to avoid the power shut-offs to end users at all.
- Public safety power shutoffs (PSPS) as the last resort.

The CPUC and gas utilities must similarly engage in an ongoing assessment of risks and prioritization of how to address those risks. California's natural gas infrastructure faces an additional layer of complexity under the goals of SB 100: fossil-based gas could be phased out over the long term, but the infrastructure used by the fossil-based gas energy may still be needed if the state embarks on a pathway that includes biofuels energy or hydrogen energy.

These challenges highlight the importance of assessing public safety within the context of 2045 scenario planning. While each scenario with different buildout patterns will present its own unique challenges, the state has a responsibility to ensure this transition and the services provided by new resources and infrastructure occur in a safe, reliable manner — minimizing risk as much as possible and maintaining public safety. State planners should seek to better understand the current state of energy sector public safety in California, identify approaches to decarbonization that enhance public safety, and recommend how to formally incorporate public safety into long-term planning and the road map to the goal of 100 percent clean electricity.

Electric System Resilience

Assessing Climate Impacts

The electric grid must now be designed and operated to be resilient, especially as changing climate causes more unpredictable and extreme weather events. Already, climate change-induced extreme weather events, such as wildfires and heat waves, are affecting the ability of the grid to provide continuous power to customers.

In the last few years, California's grid experienced considerable challenges from wildfires, which resulted in a greater application of public safety power shutoffs (PSPS) — in which California investor-owned utilities (IOUs) turn off power off in areas high winds and dry conditions to reduce the risk of the electric utility infrastructure starting wildfires. While PSPS events are an important tool to reduce the risk of catastrophic wildfires, the duration and frequency of the PSPS events posed challenges to communities and customers who rely on essential services. Moreover, the extreme heat events that occurred in 2020 resulted in rolling blackouts over two days in August and the threat of additional rolling blackouts later in August and again in September, which the state has not experienced since the California Electricity Crisis of 2000–2001.

Cost-effective achievement of SB 100 goals requires that investments in electricity generation and integration technologies and infrastructure consider how climate change may alter the geographic and temporal distribution of renewable energy resources and other impacts to electric infrastructure. Examples of such changes include:

- **Hydropower availability** — Summertime hydroelectric generation, which has historically provided an important renewable resource for meeting peak demand, depends upon spring and summer snowmelt, which is projected to decline substantially within this century.[166] Without additional innovation or cost reductions in zero-carbon dispatchable resources, increased variability in hydropower supplies could induce greater reliance on dispatchable fossil resources.
- **Wind and solar resources** — Climate impacts such as warmer temperatures and changes in wind patterns may alter the output of solar and wind resources.[167] The CEC is supporting research to better understand possible impacts, including one such

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[166] Pierce, D. W., J. F. Kalansky, and D. R. Cayan, (Scripps Institution of Oceanography). 2018. *Climate, Drought, and Sea Level Rise Scenarios for the Fourth California Climate Assessment*. California Energy Commission. Publication Number: CNRA-CEC-2018-006. https://www.energy.ca.gov/sites/default/files/2019-11/Projections_CCCA4-CEC-2018-006_ADA.pdf.

[167] U.S. Department of Energy. *Climate Change and the Electricity Sector: Guide for Climate Change Resilience Planning*. September 2016. https://www.energy.gov/sites/prod/files/2016/10/f33/Climate%20Change%20and%20the%20Electricity%20Sector%20Guide%20for%20Climate%20Change%20Resilience%20Planning%20September%202016_0.pdf.

project[168] that aims to develop methods to improve projections of climate-related parameters that govern availability and distribution of solar and wind resources, with a focus on surface-level solar radiation and hub-height wind fields.

- **Water-energy nexus** — The intensity of drought conditions could impact the availability of water needed for cooling associated with certain renewable energy technologies, such as solar thermal and geothermal power plants.[169] Further, drought exacerbated by higher temperatures increases demand on groundwater supplies, which in turn requires substantial energy for pumping. For example, during California's 2011–2015 drought, farmers' increased reliance on groundwater supplies roughly doubled their energy consumption compared to predrought conditions.[170]
- **Extreme Heat** — Heat waves increase cooling loads, which in extreme cases can lead to supply shortages, such as those experienced in August 2020. Extreme heat can also compromise the performance and accelerate the degradation of generation, transmission, and distribution infrastructure. This strain can also precipitate local power outages, such as occurred in July 2018 when a Southern California heat wave led to more than 700 power outages that affected more than 80,000 customers.[171]
- **Wildfire Risk** — Wildfires can directly damage transmission and distribution systems, and associated ash can also impact performance of nearby solar generation. Further, windy and dry weather conditions raise the risk of fire ignitions from utility infrastructure and indirectly result in planned power shutoffs to protect public safety, such as the series of shutoffs in fall of 2019 and 2020 that have affected millions of Californians.

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168 EPIC-funded grant EPC-16-063 titled "Advanced Statistical-Dynamical Downscaling Methods and Products for California Electricity System Climate Planning." For more information, see the February 2018 *Electric Program Investment Charge 2017 Annual Report* (California Energy Commission Publication Number CEC-500-2018-005, available at http://web.archive.org/web/20181202000310/https://www.energy.ca.gov/2018publications/CEC-500-2018-005/CEC-500-2018-005-CMF.pdf.)

169 Tarroja, Brian (et al.), University of California, Irvine. 2019. *Building a Climate Change Resilient Electricity System for Meeting California's Energy and Environmental Goals*. California Energy Commission. Publication Number: CEC-500-2019-015. https://ww2.energy.ca.gov/2019publications/CEC-500-2019-015/CEC-500-2019-015.pdf.

170 Public Policy Institute of California (PPIC). October 2016. "Energy and water use in California are interconnected." https://www.ppic.org/content/pubs/report/R_1016AER.pdf.

171 Los Angeles Department of Water and Power. July 9, 2018. Weekend of July 6, 2018 Heat Storm Related Power Outages and Response. https://s3-us-west-2.amazonaws.com/ladwp-jtti/wp-content/uploads/sites/3/2018/07/11114410/July-2018-Heat-Storm-Outage-Event-Summary-071118.pdf.

- **Sea-Level Rise** — Climate change-driven tidal inundation, flooding, and erosion increase the risk of physical damage and disruption to coastal substations, transformers, power lines, and other equipment.[172]
- **Out-of-state resources** — Furthermore, the state needs to consider the impacts of climate change on the availability of real-time imports to balance the grid. For example, westwide heat waves, such as the one experienced in August 2020, can result in short-term impacts to the availability of imports as cooling loads can drive sustained energy demand over a large geographic region.

State agencies are working to better understand these impacts and incorporate the latest research into energy planning efforts. Through EPIC, the CEC is advancing the next generation of climate projections and analytics to develop decision-relevant parameters for state agencies and energy sector stakeholders. State-funded climate research has also informed the state's Climate Change Assessments, which provide a scientific foundation for understanding climate-related vulnerabilities. California's Fifth Climate Change Assessment is anticipated for release before the 2025 SB 100 update.

Through its ongoing climate adaptation rulemaking (R.18.04-019), the CPUC has directed the IOUs to develop vulnerability assessments every four years, including anticipated climate change impacts to utility operations, services, and assets, over a 20–30-year horizon. The IOUs will also provide options to address identified vulnerabilities. A key part of the IOUs' development of the vulnerability assessment is deep engagement with disadvantaged vulnerable communities.

Microgrids to Support Resilience

In addition to taking steps to better understand worsening climate impacts to the electric system, state agencies are exploring options for backup power when there are disruptions to the grid. Clean energy microgrids have emerged an important alternative to fossil fuel backup generators, which degrade air quality and emit greenhouse gases. However, like all backup power solutions, clean energy microgrids have limitations, particularly in how long they can keep the power on and the associated relatively high cost. State efforts[173] are underway to

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[172] Bruzgul, Judsen, Robert Kay, Andy Petrow, Tommy Hendrickson, Beth Rodehorst, David Revell, Maya Bruguera, Dan Moreno, Ken Collison. (ICF and Revell Coastal). 2018. *Rising Seas and Electricity Infrastructure: Potential Impacts and Adaptation Actions for San Diego Gas & Electric*. California's Fourth Climate Change Assessment, California Energy Commission. Publication Number: CCCA4-CEC- 2018-004. https://www.energy.ca.gov/sites/default/files/2019-11/Energy_CCCA4-CEC-2018-004_ADA.pdf.

[173] Through EPIC, the CEC has awarded more than $90 million grants to fund nearly 45 microgrid projects across a diverse range of applications. The CEC's *2020 IEPR Update* (planned for release in early 2021) will outline key findings from the state's microgrid research efforts. Through Rulemaking 19-09-009, the CPUC is

explore technological and economic improvements to microgrids and assess the strategic deployment of microgrids as a resilience asset.

Addressing Barriers to Project Development

The initial SB 100 analysis indicates that several resources that have lengthy permitting requirements or development times will be necessary to meet the SB 100 2045 target of 100 percent clean electricity. Offshore wind, long-duration storage, and resources dependent on new transmission, such as out-of-state wind, require significant time between the initial identification of need and interconnection. All these resources may require up to 10 years from permitting to completion. Furthermore, large, long lead-time projects may require multiple off-takers because of the necessary size of the project.

New transmission will also be necessary to achieve the large resource builds needed to meet the SB 100 goals. While California has historically taken a proactive approach to transmission planning for renewable energy goals, it will be necessary to continue to identify appropriate development sites years in advance of when resources will be needed. One key challenge with transmission development is aligning planning between relevant entities. SB 100 is a state energy policy, but project implementation is a local process and must address local resource values. Today, most of California's local jurisdictions are not equipped with plans achieve the state's energy goals. To reach 100 percent clean electricity by 2045, a unified planning process for developing utility-scale energy projects and the respective transmission lines must be considered.

Collaboration Across Western States

As described in Chapter 1, California is part of a larger integrated electricity system in the western United States called the Western Interconnection, which includes all or parts of 14 western states as well as Alberta, British Columbia, and Baja California. Regional coordination is a key component of California's strategy to realize its renewable energy and GHG emission reduction goals. With other states in the West also adopting higher clean energy goals or standards,[174] opportunities exist for increased coordination and market development that can take advantage of the geographic diversity of loads and resources

Coordination offers significant potential to ease importation and integration of additional renewable energy facilities in regions where resource attributes match or complement California's seasonal and daily operational needs. Much of this coordination follows naturally

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assessing microgrid-related actions to reduce the impact of outages associated with public safety power shutoffs or unplanned grid failures. In the longer term, the rulemaking will consider a wider range of microgrid and resilience issues.

[174] For details on states with clean energy or renewable goals or standards, see the Link to the Center for Climate and Energy Solutions State Climate Policy Maps Web page (https://www.c2es.org/content/state-climate-policy/) or the Clean Energy States Alliance (CESA) 100% Clean Energy Collaborative Web page (https://www.cesa.org/projects/100-clean-energy-collaborative/table-of-100-clean-energy-states/).

from peak load diversification; the Northwest peaks in winter, and the rest of the West in summer, allowing each region to rely on the other for a share of its seasonal peak capacity needs. Regional coordination also provides for geographic diversification in renewable energy, allowing for more consistent supply.

The Western Energy Imbalance Market (EIM) serves as the primary platform for interstate coordination across the west. The EIM (described in more detail in Chapter 1) is a real-time wholesale energy trading market that enables participants anywhere in the West to buy and sell energy when needed. This market has proven successful in producing cost savings and reducing renewables curtailment for all Western participants. For instance, when one utility area has excess hydroelectric, solar or wind power, the market optimizes delivery to market participants within the EIM footprint to help meet demands that would otherwise be met by more expensive — and less clean — energy resources.

There are opportunities to build on the success of the EIM and unlock additional benefits associated with increased regional coordination. As successful and valuable as the real-time EIM has been, it is only the tip of the iceberg to unlocking the potential benefits associated with increased regional coordination. There is growing interest in extending the California ISO's day-ahead market to include Western EIM entities on a voluntary basis. To that end, the California ISO launched its Extended Day-Ahead Market (EDAM) Initiative to develop an approach to extend participation in the day-ahead market to EIM entities. The EDAM initiative, which is still in its early stages, would aim to improve renewable integration and market efficiency through day-ahead scheduling and unit commitment across a larger area.

California's continued engagement with regional entities — including the Western Electricity Coordinating Council, Western Interstate Energy Board, Western Interconnection Regional Advisory Board, and Western Governors' Association — is critical to ensuring that California's energy policies and interests are represented in efforts related to reliability, transmission planning, market development, and other issues of interest to states and provinces in the West.

CHAPTER 5: Recommendations

Following the results of the 2021 Report analysis and comments from stakeholders and the public, the joint agencies propose key recommendations for near- and medium-term actions to support the implementation of SB 100 and inform long-term planning. The recommendations highlight areas for further analysis and additional actions to support the successful implementation of the 100 percent policy. For further discussion on these topics, please refer to Chapter 4.

This report does not contain specific recommendations for guidelines and compliance related to a 100 percent clean electricity program. Instead, the joint agencies pose the following for consideration as part of the ongoing efforts that agencies undertake, both in the context of future SB 100 reports and in other existing planning processes, to plan for a 100 percent renewable and zero-carbon electricity grid. Separately and in parallel, the CPUC will also continue to analyze the 2045 goal in its ongoing IRP modeling so that decisions about near-to-medium term portfolio selection and GHG target setting can be informed by the long-term needs of SB 100.

Areas for Further Study in the 2025 SB 100 Report

1. **Perform a comprehensive reliability assessment as the next step in the modeling process.**

   The analytical portion of this report includes capacity expansion modeling, which provides possible resource portfolios that meet the requirements of SB 100. The next step in this process is to perform additional modeling to ensure the projected portfolios meet system reliability requirements. This modeling may be an iterative process to arrive at resource portfolios that meet all requirements. The CEC and CPUC recommend using deterministic production cost modeling to assess operability across all hours of a selected modeled year or years, as well as probabilistic production cost modeling to assess system reliability through metrics such as loss of load probability.

   This step could be completed as part of the 2025 SB 100 Report, or possibly through existing state efforts. The CEC and CPUC are assessing resource availability to complete this modeling ahead of the next report. The joint agencies will continue to consult with the California balancing authorities when developing the tools and metrics for this analysis to best represent their respective areas.

2. **Continue to assess the role and impacts of emerging technologies and nongeneration resources.**

   Modeling inputs and assumptions should be updated in future analyses to reflect market changes in existing and emerging technologies, including changes in price, the commercialization of new technologies, and updates to total resource potential. Furthermore, the joint agencies should continue to evaluate and consider ways to better assess the impacts of less-proven technologies that could have a significant impact to a 2045 resource mix and total cost. This work will build off the "generic" zero-carbon firm resources included in the study scenarios to explore the projected impact of technologies that can achieve specific price milestones. These technologies could include green hydrogen combustion, lower-cost geothermal resources, and gas with carbon capture and sequestration (CCS), among other emerging technologies.

Similarly, future modeling should aim to capture the value of hybrid resources and key nongeneration resources, such as long-duration energy storage, behind-the-meter energy storage, and demand flexibility, which can significantly alter the generation capacity needs in 2045.

3. **Analyze projected land-use impacts of scenarios and opportunities to address environmental impacts.**

   Work to better quantify the carbon stored in natural and working lands is continuing across state agencies, but given the long timelines to change landscapes, actions to manage, restore, and conserve these lands must be incorporated into electricity land-use planning to complement climate measures. Closer collaboration with other state agencies, tribal governments, local and regional jurisdictions, and stakeholders to plan for development will be important to balance the clean electric grid infrastructure needs of the built environment while supporting and investing in efforts to restore, conserve, and strengthen natural and working lands.

   The CEC is developing tools to assess the total land area required to implement SB 100 and the potential areas across the state where new resources could be located. This work can expand to understand how land use impacts vary across scenarios, assess the relative environmental impacts in different areas, and identify strategies to avoid or mitigate environmental impacts and maximize environmental cobenefits. The CPUC's inclusion of land-use screens in the upcoming IRP cycle will also inform state-wide land-use planning.

4. **Define and include social costs and non-energy benefits (NEBs) in future analyses.**

   The joint agencies will continue evaluating available modeling tools and metrics to capture non-energy benefits and social costs in future SB 100 analyses. Stakeholders including the DACAG and environmental justice, equity, and health organizations representing communities throughout the state recommended the inclusion of at least the following NEBs and social costs, which will be included as appropriate:

   - Land-use impacts
   - Public health and air quality

- Water supply and quality
- Economic impacts
- Resilience

The modeling tools used for the analysis in this report do not provide information regarding where generation resources will be located nor data on when and how specific resources will be used. This higher-resolution information needed to meaningfully address the topics above, requires using additional tools and metrics to better understand localized impacts of the 100 percent policy. To this end, the joint agencies plan to continue engaging with the DACAG SB 100 subcommittee and other stakeholders to explore opportunities to better integrate these topics into future analyses. CARB has also already begun work to assess local air pollution impacts associated with climate action. The 2022 Scoping Plan Update will include quantified benefits associated with climate action, specifically less combustion of fossil fuels.

5. **Continue to study opportunities and impacts related to achieving the 100 percent clean electricity target prior to 2045.**

   The joint agencies plan to continue analysis of the 2030, 2035, and 2040 scenarios in future SB 100 report analyses.

Process and Engagement for SB 100 Reports

6. **Convene an annual joint-agency SB 100 workshop in years between reports.**

   Hosting an annual workshop will support alignment between agencies on relevant topics and proceedings and enhance continuity between SB 100 reports. These workshops will also provide an opportunity for joint agency leadership and staff to hear from stakeholders and the public on topics related to SB 100 progress.

7. **Align future SB 100 planning with findings and outcomes from relevant state efforts.**

   The joint agencies aim to incorporate findings and outcomes from other relevant efforts in future SB 100 reports. Relevant efforts include:

   - The CEC's energy demand forecasts, including electrification trends and updates for extreme climate event planning.
   - Transmission planning and development.
   - Reliability planning, including possible updates to resource adequacy requirements.
   - Electric system resilience planning.
   - Assessments from CPUC's Integrated Resource Planning, CEC's Integrated Energy Policy Report, and CARB's Scoping Plan.

8. **Consult with advisory groups to guide equitable planning and implementation.**

   For the 2021 Report, the joint agencies engaged with the DACAG, the advisory body to the CEC and CPUC on clean energy matters, through its SB 100 subcommittee, and other environmental justice, health and equity stakeholders. These groups provided valuable input on the scope of the report, key findings, and considerations for ongoing analyses.

   For the 2025 SB 100 Report, the joint agencies plan to continue collaborating with the DACAG and other equity stakeholders, as well as the Environmental Justice Advisory Committee (EJAC), CARB's advisory body on climate change efforts. DACAG and EJAC are essential liaisons that should convene and coordinate to help ensure SB 100-related efforts benefit all Californians, particularly those in disadvantaged and low-income communities.

9. **Retain and expand upon best practices for community outreach and accessibility.**

   The joint agencies worked to ensure broad access to the 2021 Report process by holding workshops across the state; conducting significant outreach by phone, email listservs, and social media; and offering remote attendance options for all workshops. For future SB 100 reports (every four years), the agencies will retain these best practices while exploring additional methods to maximize participation and access to meeting information and materials for California residents. Specific best practices and recommendations for development of future SB 100 reports include the following:

   - Continue to host workshops in different sites throughout the state to engage with more geographically diverse communities.
   - Continue to promote outreach to state legislators and their constituents, particularly around meetings held in their districts.
   - Build closer partnerships with local governments on workshop outreach and continue to find meeting sites that are trusted and accessible to communities, such as spaces frequently used by community-based organizations and residents.
   - Broaden engagement with tribal governments, particularly on efforts related to land-use planning.
   - Continue to use accessible virtual platforms for all meetings, including those with an in-person attendance option and tailor workshops to accommodate community logistical needs.

Supporting Achievement of the 100 Percent Target

10. **Continue state support for research and innovation in clean energy technologies.**

    While the SB 100 target is achievable with existing technologies, continued investments in research and innovation can accelerate technology performance and cost improvements that can make progress easier and faster and reduce costs to electricity ratepayers. The Electric Program Investment Charge (EPIC) — California's flagship electricity R&D program — invests $130 million annually to support the development of emerging clean energy technologies. In August 2020, the CPUC reauthorized EPIC for another $1.5 billion over the next decade.

    Moving forward, EPIC will continue to catalyze advancements to support the cost-effective implementation of SB 100 in areas including renewable and zero-carbon generation, long-duration energy storage, energy efficiency, and load flexibility. Further, the EPIC-funded California Energy Innovation Ecosystem connects clean energy entrepreneurs with the funding, training, resources, and expertise needed to help turn concepts into products that benefit consumers, companies, and utilities. This ongoing collaboration with cleantech incubators, research labs, and private investment firms will be critical to best leverage state funding in innovation.

11. **Continue to prioritize energy efficiency and load flexibility to minimize total implementation costs.**

    In 2003, the state established a loading order policy that directs that California's energy demands be met first by efficiency and demand response before new generation is considered. Prioritizing cost-effective energy efficiency and load flexibility measures remains critical as the state moves toward a 100 percent clean electricity future. Taking steps to reduce energy demand can offset the need for additional generation capacity, saving Californians money, while reducing land use and other environmental impacts associated with the construction of new facilities.

12. **Identify and address bottlenecks in project permitting and development.**

    Numerous stakeholders highlighted barriers that can slow planning and construction of projects, such as permitting delays and long lead times for transmission projects. Because SB 100 implementation will require sustained record-setting construction rates, these barriers need to be addressed early and comprehensively. The CEC and CPUC should engage with stakeholders — including developers, utilities, balancing authorities, local governments, and community organizations — to better understand the specific barriers to project development and advance strategies to address them.

13. **Promote workforce development programs that focus on high-quality job creation.**

    Implementation of SB 100 creates a significant opportunity to support California companies, benefit local economies, and create family-sustaining jobs while optimizing climate outcomes. The joint agencies should continue collaborating with the California Workforce Development Board (CWDB) and other stakeholders to identify strategies and best practices to support an equitable clean energy workforce and high-quality job creation. The agencies can also seek the expertise of the DACAG's workforce subcommittee. As a starting point, the joint agencies shall consider the takeaways from the CWDB's 2020 report, *Putting California on the High Road*,[175] including the following:

- Labor should be considered an investment rather than a cost, as well-trained workers are key to delivering emissions reductions and moving California closer to its climate targets.
- Identifying high-quality careers that offer family-supporting wages, employer-provided benefits, worker voice, and opportunities for advancement, along with building pathways into such careers, is critical to ensuring investments in workforce education and training meaningfully improve workers' economic mobility.
- Deliberate policy interventions are necessary to advance job quality and social equity as California transitions to a carbon-neutral economy.

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[175] UC Berkeley Labor Center. *Putting California on the High Road: A Jobs and Climate Action Plan for 2030*. June 2020. https://laborcenter.berkeley.edu/wp-content/uploads/2020/09/Putting-California-on-the-High-Road.pdf.

APPENDIX A:
Acronyms and Abbreviations

AB – Assembly Bill

ATB – Annual Technology Baseline

BA – balancing authority

BANC – Balancing Authority of Northern California

BOEM – Bureau of Ocean Energy Management

BTM – behind-the-meter

BUILD – Building Initiative for Low-Emissions Development

CalFlexHub – California Flexible Load Research and Deployment Hub

California ISO – California Independent System Operator

CARB – California Air Resources Board

CCA – Community choice aggregation

CCGT – combined cycle gas turbine

CCS – carbon capture and sequestration

CEC – California Energy Commission

CESA – Clean Energy States Alliance

CHP – combined heat and power

CNG – compressed natural gas

CNRA – California Natural Resources Agency

CO_2 – carbon dioxide

COVID-19 – Coronavirus Disease 2019

CPUC – California Public Utilities Commission

CREPC – Committee on Regional Electric Power Cooperation

CSP – concentrating solar power

CT – combustion turbine

CWDB – California Workforce Development Board

DACAG – Disadvantaged Communities Advisory Group

DR – demand response

DRECP – Desert Renewable Energy Conservation Plan

DWR – California Department of Water Resources

E3 – Energy and Environmental Economics, Inc.

EDAM – extended day-ahead market

EE – energy efficiency

EIM – Western Energy Imbalance Market

EJAC – Environmental Justice Advisory Committee

ELCC – effective load-carrying capacity

EO – executive order

EPIC – Electric Program Investment Charge

ESP – electric service provider

EV – electric vehicle

FERC – Federal Energy Regulatory Commission

GDP – gross domestic product

GHG – greenhouse gas

GW – gigawatt

GWh – gigawatt-hours

HVAC – heating, ventilation, and air conditioning

IEPR – Integrated Energy Policy Report

IID – Imperial Irrigation District

IOU – investor-owned utility

IRP – integrated resource plan

IWG – Interagency Working Group on the Social Cost of Greenhouse Gases

kW – kilowatt

kWh – kilowatt-hour

LADWP – Los Angeles Department of Water and Power

LBNL – Lawrence Berkeley National Laboratory

LCOE – levelized cost of energy

LOLE – loss of load expectation

LOLP – loss of load probability

LSE – load-serving entity

MMT – million metric tons

MMT CO_2e – million metric tons of carbon dioxide equivalent

MW – megawatt

MWh - megawatt-hour

NEB – non-energy benefit

NERC - North American Electric Reliability Corporation

NO_X – oxides of nitrogen

NRDC – Natural Resources Defense Council

NREL - National Renewable Energy Laboratory

O&M – operations and maintenance

OOS – out-of-state

OSW – offshore wind

PAH – polycyclic aromatic hydrocarbon

PG&E – Pacific Gas and Electric

PM – particulate matter

PM2.5 – fine inhalable particles with diameters that are generally 2.5 micrometers and smaller

POU – publicly owned utility

PSPS – public safety power shutoff

PV – photovoltaic

R&D – research and development

RA – resource adequacy

RC – reliability coordinator

RETI – Renewable Energy Transmission Initiative

ROW – right-of-way

RPS – Renewables Portfolio Standard

SB – Senate bill

SC-CO_2 – social cost of carbon

SCE – Southern California Edison

SDG&E – San Diego Gas & Electric

SGIP – Self-Generation Incentive Program

SMUD – Sacramento Municipal Utility District

SoCalGas – Southern California Gas Company

SOx – oxides of sulfur

SWRCB – State Water Resources Control Board

TECH – Technology and Equipment for Clean Heating

TID – Turlock Irrigation District

TPP – Transmission Planning Process

TRC – total resource cost

UCLA – University of California, Los Angeles

USEPA – United States Environmental Protection Agency

USGCRP – United States Global Change Research Program

VGI – vehicle-grid integration

WECC – Western Electricity Coordinating Council

WGA – Western Governors Association

WHO – World Health Organization

WIEB – Western Interstate Energy Board

WIRAB – Western Interconnection Regional Advisory Board

ZEV – zero emission vehicle

APPENDIX B: Glossary

For additional information on commonly used energy terminology, see the following industry glossary links:

- California Air Resources Board Glossary, available at https://ww2.arb.ca.gov/about/glossary
- California Energy Commission Energy Glossary, available at https://www.energy.ca.gov/resources/energy-glossary
- California Energy Commission Renewables Portfolio Standard Eligibility Guidebook, Ninth Edition Revised, available at: https://efiling.energy.ca.gov/getdocument.aspx?tn=217317
- California Independent System Operator Glossary of Terms and Acronyms, available at: http://www.caiso.com/Pages/glossary.aspx
- California Public Utilities Commission Glossary of Acronyms and Other Frequently Used Terms, available at https://www.cpuc.ca.gov/glossary/
- Federal Energy Regulatory Commission Glossary, available at https://www.ferc.gov/about/what-ferc/about/glossary
- North American Electric Reliability Corporation Glossary of Terms Used in NERC Reliability Standards, available at: https://www.nerc.com/pa/Stand/Glossary%20of%20Terms/Glossary_of_Terms.pdf
- US Energy Information Administration Glossary, available at: https://www.eia.gov/tools/glossary/

Adaptation

In human systems, the process of adjustment to actual or expected climate and its effects, in order to moderate harm or exploit beneficial opportunities. In natural systems, the process of adjustment to actual climate and its effects; human intervention may facilitate adjustment to expected climate and its effects.

Ancillary services

Ancillary services include regulation, spinning reserve, non-spinning reserve, voltage support and black start, together with such other interconnected operation services as the California ISO may develop in cooperation with market participants to support the transmission of energy from generation resources to loads while maintaining reliable operation of the CAISO controlled grid in accordance with Western Electricity Coordinating Council standards and good utility practice.

Balancing authority

A balancing authority is the responsible entity that integrates resource plans ahead of time, maintains load-interchange-generation balance within a balancing authority area, and supports interconnection frequency in real time. Balancing authorities in California include the Balancing Authority of Northern California (BANC), California ISO, Imperial Irrigation District (IID), Turlock Irrigation District (TID) and Los Angeles Department of Water and Power (LADWP). The California ISO is the largest of about 38 balancing authorities in the Western Interconnection, handling an estimated 35 percent of the electric load in the West. For more information, see the WECC Overview of System Operations: Balancing Authority and Regulation Overview Web page.

Biodiversity

Biological diversity means the variability among living organisms from all sources, including, inter alia, terrestrial, marine and other aquatic ecosystems and the ecological complexes of which they are part; this includes diversity within species, between species and of ecosystems.

Bioenergy

Energy derived from any form of biomass or its metabolic by-products.

Biogas

Biogas is a type of biofuel that is naturally produced from the decomposition of organic waste (such as food scraps) and includes methane, carbon dioxide, and other gases. Biofuels differ from fossil fuels because a biofuel is fuel from recently living biological matter, where fossil fuels come from long dead biological matter.

Biomass

Biomass energy resources are derived from organic matter. These include wood, agricultural waste and other living-cell material that can be burned to produce heat energy. They also include algae, sewage and other organic substances that may be used to make energy through chemical processes.

Capacity expansion modeling

Capacity expansion modeling analyzes different resource investment options over a planning horizon. The model identifies the least cost resource investments, given the policy and reliability constraints. Due to the large number of resources that can be selected by the model, simplifications are necessary. These simplifications can include, only modeling characteristic days for each year, simplified power plant operating characteristics, and simplified transmission networks. For more information, see the US Department of Energy Overview of Power Sector Modeling.

Cap-and-Trade Program

The Cap-and-Trade Program is a key element of California’s strategy to reduce greenhouse gas (GHG) emissions. It complements other measures to ensure that California cost-effectively meets its goals for GHG emissions reductions. The Cap-and-Trade Regulation establishes a declining limit on major sources of GHG emissions throughout California, and it creates a powerful economic incentive for significant investment in cleaner, more efficient technologies. The Program applies to emissions that cover approximately 80 percent of the State's GHG emissions. CARB creates allowances equal to the total amount of permissible emissions (i.e., the "cap"). One allowance equals one metric ton of carbon dioxide equivalent emissions (using the 100-year global warming potential). Each year, fewer allowances are created and the annual cap declines. An increasing annual auction reserve (or floor) price for allowances and the reduction in annual allowances creates a steady and sustained carbon price signal to prompt action to reduce GHG emissions. All covered entities in the Cap-and-Trade Program are still subject to existing air quality permit limits for criteria and toxic air pollutants. For more information, see the CARB Cap-and-Trade Program Web page.

Carbon capture and sequestration (CCS)

A process in which a relatively pure stream of carbon dioxide (CO_2) from industrial and energy-related sources is separated (captured), conditioned, compressed and transported to a storage location for long-term isolation from the atmosphere. For more information, see the CARB Carbon Capture & Sequestration Web page.

Carbon dioxide (CO_2)

A naturally occurring gas, CO_2 is also a by-product of burning fossil fuels (such as oil, gas and coal), of burning biomass, of land-use changes, and of industrial processes (for example, cement production). It is the principal anthropogenic greenhouse gas (GHG) that affects the Earth's radiative balance. It is the reference gas against which other GHGs are measured and therefore has a global warming potential (GWP) of 1.

Carbon neutrality

Carbon dioxide and other greenhouse gas (GHG) emissions generated by sources such as transportation, power plants, and industrial processes must be less than or equal to the amount of carbon dioxide that is stored, both in natural sinks such as forests and mechanical sequestration such as carbon capture and sequestration. Executive order B-55-18 established a target for California to achieve carbon neutrality by 2045 and maintain net negative emissions thereafter. For more information, see the CARB Carbon Neutrality Web Page.

Carbon price

The price for avoided or released carbon dioxide (CO_2) or CO_2-equivalent emissions. This may refer to the rate of a carbon tax or the price of emission permits. In many models that are used to assess the economic costs of mitigation, carbon prices are used as a proxy to represent the level of effort in mitigation policies.

Carbon sink

A reservoir (natural or human, in soil, ocean, and plants) where a greenhouse gas, an aerosol or a precursor of a greenhouse gas is stored.

Climate

Climate in a narrow sense is usually defined as the average weather, or more rigorously, as the statistical description in terms of the mean and variability of relevant quantities over a period of time ranging from months to thousands or millions of years. The classical period for averaging these variables is 30 years, as defined by the World Meteorological Organization. The relevant quantities are most often surface variables such as temperature, precipitation and wind. Climate in a wider sense is the state, including a statistical description, of the climate system.

Climate adaptation

A growing body of new policies — referred to as "climate adaptation" — is intended to grapple with what is known from climate science and incorporate planning for climate change into the routine business of governance, infrastructure management, and administration.

Climate change

Climate change refers to a change in the state of the climate that can be identified (for example, by using statistical tests) by changes in the mean and/or the variability of its properties and that persists for an extended period, typically decades or longer. Climate change may be due to natural internal processes or external forcings such as modulations of the solar cycles, volcanic eruptions and persistent anthropogenic changes in the composition of the atmosphere or in land use. **Anthropogenic** climate change is defined by the human impact on Earth's climate while **natural** climate change are the natural climate cycles that have been and continue to occur throughout Earth's history. Anthropogenic (human-induced) climate change is directly linked to the amount of fossil fuels burned, aerosol releases, and land alteration from agriculture and deforestation. For more information, see the Energy Education Natural vs Anthropogenic Climate Change Web page.

Climate Change Scoping Plan

CARB's 2022 Scoping plan Update will provide an actionable, cost-effective, and technologically feasible path to achieve economy-wide carbon neutrality by 2045. For more information, see the CARB AB 32 Climate Change Scoping Plan Web page.

CO_2 equivalent (CO_2-e) emissions

The amount of carbon dioxide (CO_2) emissions that would cause the same integrated radiative forcing or temperature change, over a given time horizon, as an emitted amount of a greenhouse gas (GHG) or a mixture of GHGs. There are a number of ways to compute such equivalent emissions and choose appropriate time horizons. Most typically, the CO_2-equivalent emission is obtained by multiplying the emission of a GHG by its global warming potential (GWP) for a 100-year time horizon. For a mix of GHGs it is obtained by summing the CO_2-equivalent emissions of each gas. CO_2-equivalent emission is a common scale for comparing emissions of different GHGs but does not imply equivalence of the corresponding climate change responses. There is generally no connection between CO_2-equivalent emissions and resulting CO_2-equivalent concentrations.

Community choice aggregation (CCA)

Community choice aggregation (or CCA) lets local jurisdictions aggregate, or combine, their electricity load to purchase power on behalf of their residents. In California, community choice aggregators are legally defined by state law as electric service providers and work together with the region's existing utility, which continues to provide customer services (for example, grid maintenance and power delivery). For more information see What Is CCA? or Community Choice Is Transforming the California Energy Industry.

Decarbonization

The process by which countries, individuals or other entities aim to reduce or achieve zero fossil carbon emissions. Typically refers to a reduction of the carbon emissions associated with electricity, industry and transport.

Demand response (DR)

Demand response refers to providing wholesale and retail electricity customers with the ability to choose to respond to time-based prices and other incentives by reducing or shifting electricity use ("shift DR"), particularly during peak demand periods, so that changes in customer demand become a viable option for addressing pricing, system operations and reliability, infrastructure planning, operation and deferral, and other issues. It has been used traditionally to shed load in emergencies ("shed DR"). It also has the potential to be used as a low-greenhouse gas, low-cost, price-responsive option to help integrate renewable energy and provide grid-stabilizing services, especially when multiple distributed energy resources are used in combination and opportunities to earn income make the investment worthwhile.

For more information, see the CPUC Demand Response Web page.

Disadvantaged community

Disadvantaged communities refer to the areas throughout California which most suffer from a combination of economic, health, and environmental burdens. These burdens include poverty, high unemployment, air and water pollution, presence of hazardous wastes, as well as high incidence of asthma and heart disease. One way that the state identifies these areas is by collecting and analyzing information from communities all over the state. CalEnviroScreen, an analytical tool created by the California Environmental Protection Agency, combines different types of census tract-specific information into a score to determine which communities are the most burdened or "disadvantaged." For more information, see the California Office of Environmental Health Hazard Assessment's CalEnviroScreen Web page.

Disadvantaged Communities Advisory Group (DACAG)

The Clean Energy and Pollution Reduction Act of 2015 (also known as Senate Bill 350) called upon the CPUC to help improve air quality and economic conditions in disadvantaged communities by, for example, changing the way the state plans the development and future operations of power plants, or rethinking the location of clean energy technologies to benefit burdened communities. Additionally, Senate Bill 350 required the CPUC and the CEC to create a group representing disadvantaged communities to advise the agencies about in understanding how energy programs impact these communities and could be improved to benefit these communities.

For more information, see the CPUC Disadvantaged Communities Advisory Group Web page.

Distributed energy resources (DER)

Distributed energy resources are any resource with a first point of interconnection of a utility distribution company or metered subsystem. Distributed energy resources include:

- Demand response, which has the potential to be used as a low-greenhouse gas, low-cost, price-responsive option to help integrate renewable energy and provide grid-stabilizing services, especially when multiple distributed energy resources are used in combination and opportunities to earn income make the investment worthwhile.
- Distributed renewable energy generation, primarily rooftop photovoltaic energy systems.
- Vehicle-Grid Integration, or all the ways plug-in electric vehicles can provide services to the grid, including coordinating the timing of vehicle charging with grid conditions.
- Energy storage in the electric power sector to capture electricity or heat for use later to help manage fluctuations in supply and demand.

Effective load carrying capability (ELCC)

Effective load carrying capability" (ELCC) is the increment of load that could met by the resource while maintaining the same level of reliability. The ELCC of a variable renewable energy resource is based on both the capacity coincident with peak load and the profile and quantity of existing variable renewable energy resources. For a detailed description of ELCC implementation in RESOLVE, see page 87 of the Inputs & Assumptions: CEC SB100 Joint Agency Report.

Electric Program Investment Charge Program (EPIC)

The California Energy Commission’s Electric Program Investment Charge (EPIC) program invests in scientific and technological research to accelerate the transformation of the electricity sector to meet the state’s energy and climate goals. The EPIC program invests more than $130 million annually in areas including renewable energy, energy storage, electric system resilience, and electric technologies for buildings, businesses, and transportation. For more information, see the CEC Electric Program Investment Charge Program Web page and the CPUC Energy Research, Development & Deployment Web page.

Electric service provider (ESP)

An electric service provider is a company that purchases wholesale electricity from electricity generators and sells it at a retail level to the general public.

Electrolyzer

A device that breaks a chemical compound down into its elements by passing a direct current through it. Electrolysis of water, for example, produces hydrogen and oxygen.

Energy efficiency

Energy efficiency means adapting technology to meet consumer needs while using less energy. The CEC adopts energy efficiency standards for appliances and buildings, which reduces air pollution and saves consumers money. The CPUC regulates ratepayer-funded energy efficiency programs and works with the investor-owned utilities, other program administrators, and vendors to develop programs and measures to transform technology markets within California using ratepayer funds. For more information, see the CEC Energy Efficiency Web page and the CPUC Energy Efficiency Web page.

Environmental justice

Environmental justice is the fair treatment of people of all races and incomes with respect to development, implementation and enforcement of environmental laws, regulations and policies.

Equity (Energy equity)

Energy equity is the principle of fairness in burden sharing and is a basis for understanding how the impacts and responses to climate change, including costs and benefits, are distributed in and by society in more or less equal ways. It is often aligned with ideas of equality, fairness and justice and applied with respect to equity in the responsibility for, and distribution of, climate impacts and policies across society, generations, and gender, and in the sense of who participates and controls the processes of decision-making.

Extreme weather event

An extreme weather event is an event that is rare at a particular place and time of year. Definitions of rare vary, but an extreme weather event would normally be as rare as or rarer than the 10th or 90th percentile of a probability density function estimated from observations. By definition, the characteristics of what is called extreme weather may vary from place to place in an absolute sense. When a pattern of extreme weather persists for some time, such as a season, it may be classed as an extreme climate event, especially if it yields an average or total that is itself extreme (e.g., drought or heavy rainfall over a season).

Federal Energy Regulatory Commission (FERC)

The *Federal Energy Regulatory Commission*, also known as *FERC*, is an independent agency that regulates interstate transmission of electricity, oil, and natural gas. It also regulates natural gas and hydropower projects in the United States. For more information, see the Federal Energy Regulatory Commission Web page.

Fossil fuels

Carbon-based fuels from fossil hydrocarbon deposits, including coal, oil, and natural gas.

Fuel cell

An energy conversion device that combines hydrogen with oxygen in an electrochemical reaction to produce electricity. A fuel cell powered by **green hydrogen** is an RPS-eligible resource.

Generic firm baseload resource

For modeling purposes, a generic firm baseload resource is a zero-carbon generating technology that is intended to run continuously. Examples include low-cost geothermal or imports of emerging nuclear generation technologies.

Generic firm dispatchable resource

For modeling purposes, a generic firm dispatchable resource is a zero-carbon generating technology that can be dispatched as needed. Examples include natural gas with 100 percent carbon capture and sequestration or 100 percent drop-in renewable fuels.

Geothermal

Natural heat from within the earth, captured for production of electric power.

Green hydrogen

Green hydrogen means hydrogen gas that is not produced from fossil fuel feedstock sources and does not produce incremental carbon emissions during its primary production process.

Greenhouse gas (GHG)

Greenhouse gases are those gaseous constituents of the atmosphere, both natural and anthropogenic, that absorb and emit radiation at specific wavelengths within the spectrum of terrestrial radiation emitted by the Earth's surface, the atmosphere itself and by clouds. This property causes the greenhouse effect. Water vapor (H_2O), carbon dioxide (CO_2), nitrous oxide (N_2O), methane (CH_4) and ozone (O_3) are the primary GHGs in the Earth's atmosphere. Moreover, there are a number of entirely human-made GHGs in the atmosphere, such as the halocarbons and other chlorine- and bromine-containing substances, dealt with under the Montreal Protocol. Beside CO_2, N_2O and CH_4, the Kyoto Protocol deals with the GHGs sulfur hexafluoride (SF_6), hydrofluorocarbons (HFCs) and perfluorocarbons (PFCs). In response to

Assembly Bill 32 (California Global Warming Solutions Act of 2006), the definition of greenhouse gases defined in Health and Safety Code section 38505 includes nitrogen trifluoride (NF3) in addition to those defined under the Montreal and Kyoto Protocols.

Hydroelectric (Large, Small)

A technology that produces electricity by using the kinetic energy of flowing or falling nonmarine water to turn a turbine generator.

A **large hydro facility** is an electrical generation facility employing one or more hydroelectric turbine generators, the sum capacity of which exceeds 30 megawatts. A large hydro facility is not RPS-eligible, but is a zero-carbon resource.

A **small hydro facility** is an electrical generation facility employing one or more hydroelectric turbine generators, the sum capacity of which does not exceed 30 megawatts except in the case of qualifying efficiency improvements under Public Utilities Code Section 399.12.5. A small hydro facility is an RPS-eligible resource.

Integrated Energy Policy Report (IEPR)

Senate Bill 1389 (Bowen, Chapter 568, Statutes of 2002) requires the California Energy Commission to prepare a biennial integrated energy report. The report, which is crafted in collaboration with a range of stakeholders, contains an integrated assessment of major energy trends and issues facing California's electricity, natural gas, and transportation fuel sectors. The report provides policy recommendations to conserve resources, protect the environment, ensure reliable, secure, and diverse energy supplies, enhance the state's economy, and protect public health and safety. For more information, see the CEC Integrated Energy Policy Report Web page.

Integrated Resource Planning (IRP)

The CPUC's Integrated Resource Planning (IRP) process is an "umbrella" planning proceeding to consider all of its electric procurement policies and programs and ensure California has a safe, reliable, and cost-effective electricity supply. The proceeding is also the Commission's primary venue for implementation of the Senate Bill 350 requirements related to IRP (Public Utilities Code Sections 454.51 and 454.52). The process ensures that load serving entities meet targets that allow the electricity sector to contribute to California's economy-wide greenhouse gas emissions reductions goals. For more information see the CPUC Integrated Resource Plan and Long-Term Procurement Plan (IRP-LTPP) Web page.

Investor-owned utility (IOU)

Investor-owned utilities (IOUs) provide transmission and distribution services to all electric customers in their service territory. The utilities also provide generation service for "bundled" customers, while "unbundled" customers receive electric generation service from an alternate provider, such as a Community Choice Aggregator (CCA). California has three large IOUs offering electricity service: Pacific Gas and Electric, Southern California Edison, and San Diego Gas & Electric.

Landscape-scale planning

Landscape-level approaches, also known as landscape-scale planning, take into consideration a wide range of potential constraints and conflicts, including environmental sensitivity, conservation and other land uses, tribal cultural resources, and more when considering future renewable energy development. The benefits of using landscape-level approaches for renewable energy and transmission planning include early identification and resolution of large issues or barriers to development, coordinated agency permitting processes, increased transparency in decision making, increased collaboration, avoidance of impacts, and more rapid deployment of environmentally responsible renewable energy projects.

Levelized cost of energy (LCOE)

The levelized cost of energy (LCOE) is a measure of the average net present cost of electricity generation for a generating plant over its lifetime. The LCOE is calculated as the ratio between all the discounted costs over the lifetime of an electricity generating plant divided by a discounted sum of the actual energy amounts delivered. The LCOE is used to compare different methods of electricity generation on a consistent basis. Inputs to LCOE typically include cost of capital, fuel costs, fixed and variable operations and maintenance costs, financing costs, and an assumed utilization rate.

Load serving entity (LSE)

A load serving entity is defined by the California Independent System Operator as an entity that has been "granted authority by state or local law, regulation or franchise to serve [their] own load directly through wholesale energy purchases." For more information see the California Independent System Operator's Web page.

Loss of load expectation (LOLE)

The expected number of days per year for which available generating capacity is expected to be insufficient to serve the daily peak demand (load). When given in hours/year, it represents a comparison of hourly load to available generation.

Loss of load probability (LOLP)

The proportion (probability) of days per year, hours per year or events per season that available generating capacity/energy is expected to be insufficient to serve the daily peak or hourly demand.

Methane (CH_4)

One of the six greenhouse gases (GHGs) to be mitigated under the Kyoto Protocol and is the major component of natural gas and associated with all hydrocarbon fuels. Emissions also occur as a result of dairy and livestock operations and disposal of organics in landfills, and their management represents a major mitigation option. Methane is a short-lived climate pollutant. Unlike CO_2, which lasts for about 100 years in the atmosphere, reductions of methane can create a relatively quick reduction in global warming.

Metric ton

A metric ton is a unit of weight equal to 1,000 kilograms (or 2,205 pounds).

Microgrid

A microgrid is an interconnected system of loads and energy resources, including, but not limited to, distributed energy resources, energy storage, demand response tools, or other management, forecasting, and analytical tools, appropriately sized to meet customer needs, within a clearly defined electrical boundary that can act as a single, controllable entity, and can connect to, disconnect from, or run in parallel with, larger portions of the electrical grid, or can be managed and isolated to withstand larger disturbances and maintain electrical supply to connected critical infrastructure. (Source: Senate Bill 1339)

Mitigation (of climate change)

A human intervention to reduce greenhouse gas emissions and/or enhance carbon sinks.

Mitigation measures

In climate policy, mitigation measures are technologies, processes or practices that contribute to mitigation, for example, renewable energy technologies, waste minimization processes and public transport commuting practices.

Negative GHG emissions

Removal of greenhouse gases (GHGs) from the atmosphere by deliberate human activities, i.e., in addition to the removal that would occur via natural carbon cycle processes.

Net load

Net load is electricity load minus solar and wind generation.

Net negative emissions

A situation of net negative emissions is achieved when, as result of human activities, more greenhouse gases are removed from the atmosphere than are emitted into it. Where multiple greenhouse gases are involved, the quantification of negative emissions depends on the climate metric chosen to compare emissions of different gases (such as global warming potential, global temperature change potential, and others, as well as the chosen time horizon).

Non-energy benefits (NEBs)

Non-energy benefits (NEBs) represent the benefits or positive impacts on society associated with the construction and operation of energy infrastructure and any associated activity. For more information, see Chapter 4.

Non-spinning reserves

The portion of resource capacity that is capable of being synchronized and ramping to a specified load in ten minutes (or that is capable of being interrupted in ten (10) minutes) and that is capable of running (or being interrupted) for at least thirty (30) minutes from the time it reaches its award capacity.

North American Electric Reliability Corporation (NERC)

The *North American Electric Reliability Corporation*, also known as *NERC*, is an international regulatory authority whose mission is to reduce risks to the reliability and security of the grid. Its area of responsibility spans the continental United States, Canada, and the northern part of Baja California, Mexico. For more information see the NERC Web page.

Nuclear (existing)

Electricity generated by the use of the thermal energy released from the fission of nuclear fuel in a reactor. Because the State effectively has a moratorium on new in-state nuclear power plants under the Warren-Alquist Act, only existing nuclear generating facilities are modeled. A nuclear facility is not RPS-eligible, but is a zero-carbon resource.

Offshore wind

Refers to an ocean-based (or other body of water) technology that converts energy from the environmental movement of air into mechanical energy and then electricity. Offshore wind turbine technologies include both fixed foundation and floating types.

Once-through cooling (OTC)

Once-through cooling technologies intake ocean water to cool the steam that is used to spin turbines for electricity generation. The technologies allow the steam to be reused, and the ocean water that was used for cooling becomes warmer and is then discharged back into the ocean. The intake and discharge have negative impacts on marine and estuarine environments. For more information on the phase-out of power plants in California using once-through cooling, see the Statewide Advisory Committee on Cooling Water Intake Structures Web page and the CEC Once-Through Cooling Phaseout Tracking Progress Report.

Onshore wind

Refers to a land-based technology that converts energy from the environmental movement of air into mechanical energy and then electricity.

Particulate matter

Any material, except pure water, that exists in the solid or liquid state in the atmosphere. The size of particulate matter can vary from coarse, wind-blown dust particles to fine particle combustion products.

PATHWAYS Model

The PATHWAYS model, developed by Energy and Environmental Economics, Inc (E3), is an economy-wide scenario tool used to identify pathways to achieve economy-wide decarbonization. For more information, see PATHWAYS Model.

Planning reserve margin (PRM)

Planning reserve margin (PRM) is used in resource planning to estimate the generation capacity needed to maintain reliability given uncertainty in demand and unexpected capacity outages. A typical PRM is 15% above the forecasted 1-in-2 weather year peak load, although it can vary by planning area.

Power flow modeling

Power flow modeling evaluates the flow of power on the electric grid. Power flow models provide a snapshot of transmission, generation and load and used to determine if the grid is stable and within operating limits for the case study. For more information see North American Transmission Forum's Power Flow Modeling Reference Document.

Precursors

Atmospheric compounds that are not greenhouse gases (GHGs) or aerosols, but that have an effect on GHG or aerosol concentrations by taking part in physical or chemical processes regulating their production or destruction rates.

Production cost modeling

Production cost modeling simulates least-cost dispatch given a set of generating resources, load, fuel prices and transmission and dispatch constraints. Production cost models can be run deterministically or probabilistically. Typically, a deterministic production cost model models all 8,760 hours of each year modeled with specified load and weather conditions. Typically, a probabilistic production cost model simulates the same system with changing inputs, such as load, weather, and generator outages to study how these changes impact the dispatch of the system. This approach can be used to determine the loss-of-load probability of the system.

Public safety power shutoff (PSPS)

A *public safety power shutoff*, also known as *PSPS*, is a system used by utilities to prevent wildfires by proactively turning off electricity when gusty winds and dry conditions present a heightened fire risk. More information can be found at the Prepare for Power Down Web page.

Publicly owned utility (POU)

Publicly owned utilities (POUs), or Municipal Utilities, are controlled by a citizen-elected governing board and utilizes public financing. These municipal utilities own generation, transmission and distribution assets. In contrast to CCAs, all utility functions are handled by these utilities. Examples include the Los Angeles Department of Water and Power and the Sacramento Municipal Utility District. Municipal utilities serve about 27 percent of California's total electricity demand.

Pumped Hydro

An energy storage technology consisting of two water reservoirs separated vertically; during off-peak hours, water is pumped from the lower reservoir to the upper reservoir, allowing the off-peak electrical energy to be stored indefinitely as gravitational energy in the upper reservoir. During peak hours, water from the upper reservoir may be released and passed through hydraulic turbines to generate electricity as needed.

Reliability coordinator

The entity designated by the Western Electricity Coordinating Council (WECC) as responsible for reliability coordination in real time for the area defined by WECC.

Renewables Portfolio Standard (RPS)

The *Renewables Portfolio Standard*, also referred to as *RPS*, is a program that sets continuously escalating renewable energy procurement requirements for California's load-serving entities. The generation must be procured from RPS-certified facilities (which include solar, wind, geothermal, biomass, biomethane derived from landfill and/or digester, small hydroelectric, and fuel cells using renewable fuel and/or qualifying hydrogen gas). More information can be found at the CEC Renewables Portfolio Standard web page and the CPUC RPS Web page.

Resilience

The capacity of social, economic and environmental systems to cope with a hazardous event or trend or disturbance, responding or reorganizing in ways that maintain their essential function, identity and structure while also maintaining the capacity for adaptation, learning and transformation.

RESOLVE Model

The RESOLVE mode is a capacity expansion model developed by Energy and Environmental Economics, Inc. (E3). The tool identifies least-cost resource investments given a set of reliability and policy constraints. For more information, see the Inputs & Assumptions: CEC SB100 Joint Agency Report.

Resource adequacy (RA)

The program that ensures that adequate physical generating capacity dedicated to serving all load requirements is available to meet peak demand and planning and operating reserves, at or deliverable to locations and at times as may be necessary to ensure local area reliability and system reliability. For more information, see the CPUC Resource Adequacy Web page.

Resource build

Resource build is a set of generating, transmission and integration resources identified to meet future policy and reliability goals.

Scenario

A plausible description of how the future may develop based on a coherent and internally consistent set of assumptions about key driving forces (for example, rate of technological change, prices) and relationships. Note that scenarios are neither predictions nor forecasts, but are used to provide a view of the implications of developments and actions.

This report includes three types of scenarios with different zero-carbon load coverage targets:

- The **60% RPS scenario** is based on 60 percent of retail sales
- The **SB 100 Core scenario** is based on 100 percent of retail sales and state loads.
- The **Study scenario** includes the Core loads plus system losses with High Electrification demand.

For more information, see Chapter 3.

Short-lived climate pollutant (SLCP)

A short-lived climate pollutant is an agent that has a relatively short lifetime in the atmosphere, from a few days to a few decades, and a warming influence on the climate that is more potent than that of carbon dioxide. (Source: Senate Bill 605)

Solar PV

A technology that uses a semiconductor to convert sunlight directly into electricity via the photoelectric effect.

Solar Thermal

The conversion of sunlight to heat and the related concentration and use to power a generator to produce electricity.

Solar-plus-storage

A *solar-plus-storage* project is a battery system that is charged by a connected solar system.

Spinning reserves

The portion of unloaded synchronized resource capacity that is immediately responsive to system frequency and that is capable of being loaded in ten (10) minutes, and that is capable of running for at least thirty (30) minutes from the time it reaches its award capacity.

Supply-side measures

Policies and programs for influencing how a certain demand for goods and/or services is met. In the energy sector, for example, supply-side mitigation measures aim at reducing the amount of greenhouse gas emissions emitted per unit of energy produced.

Sustainability

A dynamic process that guarantees the persistence of natural and human systems in an equitable manner.

Sustainable development

Development that meets the needs of the present without compromising the ability of future generations to meet their own needs and balances social, economic and environmental concerns.

Time-dependent electricity rates

Also known as time-of-use rates, time-dependent electricity rates vary depending on the time periods in which the energy is consumed. In a time-of-use rate structure, higher prices are charged during utility peak-load times. Such rates can provide an incentive for consumers to curb power use during peak times.

Total resource cost

Total resource cost (TRC) is the total cost of the system to meet the future policy and reliability goals. The TRC in the SB 100 scenarios includes non-modeled, existing costs which are the same across all scenarios, as well as scenario-specific non-modeled costs that vary by demand sensitivities. It also includes scenario-specific fixed costs, which are levelized capital investments associated with generation, transmission, storage and shed demand response resources selected in the model, as well as operating costs.

Transmission Planning Process (TPP)

The California Independent System Operator's annual transmission plan, which serves as the formal roadmap for infrastructure requirements. This process includes stakeholder and public input and uses the best analysis possible (including the Energy Commission's annual demand forecast) to assess short- and long-term transmission infrastructure needs. For more information, see the California ISO Transmission Planning Web page.

Utility-scale solar

A utility-scale solar power plant, using either photovoltaic [PV] or concentrating solar thermal technology, that sells its electricity to wholesale utility buyers. Often, utility-scale solar projects are described as being "in front of the meter" as opposed to small distributed generation systems, which tend to be "behind the meter."

Vehicle-grid integration

The term vehicle-grid integration or VGI, encompasses the ways EVs can provide grid services, including coordinating the timing of vehicle charging with grid conditions. To that end, EVs must have capabilities to manage charging or support two-way interaction between vehicles and the grid.

Western Electricity Coordinating Council (WECC)

The *Western Electricity Coordinating Council*, also known as *WECC*, is a nonprofit organization that works to address risks to the reliability and security of the Western Interconnection's power system. For more information, see the WECC Web page.

Western Energy Imbalance Market (EIM)

The *Western Energy Imbalance Market*, or Western EIM, is a real-time bulk power trading market. The Western EIM's systems automatically find the lowest-cost energy to serve customer demand across a wide geographic area in the western United States. For more information, see the Western Energy Imbalance Market Web page.

Western Governors Association (WGA)

The Western Governors' Association (WGA) is a non-partisan organization of all 22 United States Governors (representing 19 U.S. States and 3 U.S. territories) that are considered to be part of the Western region of the nation. The WGA addresses important policy and governance issues in the West, advances the role of the Western states in the federal system, and strengthens the social and economic fabric of the region. WGA develops policy and carries out programs in the areas of natural resources, the environment, human services, economic development, international relations and state governance. For more information, see the Western Governors Association Web page.

Western Interconnection (WI)

The *Western Interconnection* is a wide area synchronous grid. It is one of the two major alternating current power grids in the continental United States (the other is the Eastern Interconnection). For more information, see the WECC's Western Interconnection Web page.

Western Interconnection Regional Advisory Body (WIRAB)

The Western Interconnection Regional Advisory Body (WIRAB) was created by Western Governors under the Federal Power Act and focuses on electric grid reliability in the Western Interconnection. WIRAB advises the Electric Reliability Organization (North American Electric Reliability Corporation ["NERC"]), the regional entity (Western Electricity Coordinating Council ["WECC"]), and the Federal Energy Regulatory Commission ("FERC") on whether proposed reliability standards within the region, as well as the governance and budgets of NERC and WECC, are just, reasonable, not unduly discriminatory or preferential and in the public interest. WIRAB's membership is composed of member representatives from all states and International provinces that have load within the Western Interconnection. For more information, see the Western Interstate Energy Board's WIRAB Web page.

Western Interstate Energy Board (WIEB)

The *Western Interstate Energy Board* is an organization of 11 western states and three Canadian provinces. The Board promotes energy policy that is developed cooperatively among member states and provinces and with the federal government. For more information, see the Western Interstate Energy Board Web page.

Zero-carbon resource (for modeling purposes)

The joint agencies' interpretation of "zero-carbon resources," as stated in the SB 100 statute, includes generation resources that meet one or both of the following criteria. (This set of criteria is referred to as "RPS+" in SB 100 workshops and documents.)

- Meets the requirements for RPS-eligibility set forth in the most recent RPS Eligibility Guidebook.[176]
- Has zero onsite greenhouse gas emissions.[177]

For more information, see the 2021 Senate Bill 100 (SB 100) Joint-Agency Report Modeling Framework and Scenarios Overview.

Zero-emission vehicles (ZEVs)

There are three types of zero-emission vehicles:

- Battery-electric vehicles (BEVs) that refuel exclusively with electricity.
- Plug-in hybrid electric vehicles (PHEVs) that can refuel with either electricity or another fuel, typically gasoline. BEVs and PHEVs are collectively known as "plug-in electric vehicles," or PEVs.
- Fuel cell electric vehicles (FCEVs) that refuel with hydrogen.

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[176] California Energy Commission. *Renewables Portfolio Standard Eligibility Guidebook, Ninth Edition (Revised)*. Publication Number: CEC-300-2016-006-ED9-CMF-REV. January 2017. https://efiling.energy.ca.gov/getdocument.aspx?tn=217317.

[177] For modeling purposes, this list does not acknowledge *de minimis* emissions associated with included technologies. SB 100 compliance programs would need to establish clear requirements for qualification as a zero-carbon generation resource.

APPENDIX C:
Assumptions and Calculations to Estimate the Social Cost of Carbon in SB 100 Core Scenario

This appendix describes the assumptions and calculations employed to estimate the social cost of carbon associated with the SB 100 core scenario under high electrification demand.

Greenhouse Gas Reductions

The greenhouse gas (GHG) emissions reductions associated with implementation of SB 100 were estimated by taking the emissions difference between the 60 percent RPS and SB 100 core scenarios modeled under high electrification demand. The GHG emissions associated with in-state generation and unspecified imports are summarized in Table C-1 for year 2045.

Table C-1: Avoided GHG Emissions in 2045 from Core Scenario High Electrification Demand

Scenario	In-State, MT CO_2	Unspecified Imports*, MT CO_2	Total, MT CO_2
60% RPS	42,639,193	15,207,098	57,846,291
SB 100 core	18,423,033	6,574,439	24,997,472

*Unspecified imports use the emissions intensity of 0.428 MT CO_2 per MWh.

The total GHG emissions difference between the 60% RPS and SB 100 Core scenario is 32,848,819 MT CO_2.

Social Cost of Carbon Values

As described in Chapter 4, the social cost of carbon (SC-CO_2) estimates the value of damages avoided by reducing an additional ton of carbon dioxide (CO_2). These damages include, but are not limited to, changes in net agricultural productivity, energy use, human health, property damage from increased flood risk, as well as nonmarket damages, such as the services that natural ecosystems provide to society.

In 2009, the Council of Economic Advisors and the Office of Management and Budget convened the Interagency Working Group on the Social Cost of Greenhouse Gases (IWG) to develop a methodology for estimating the SC-CO_2. This methodology relied on a standardized range of assumptions and could be used consistently when estimating the benefits of regulations across agencies and around the world. The IWG, comprised of scientific and economic experts, recommended the use of SC-CO_2 values based on three integrated assessment models developed over decades of global peer-reviewed research, which are summarized in Table C-2.[178]

Table C-2: Social Cost of CO2, 2015-2050 (in 2007 dollars per metric ton CO2)

Year	5% Discount Rate	3% Discount Rate	2.5% Discount Rate
2015	$11	$36	$56
2020	$12	$42	$62
2025	$14	$46	$68
2030	$16	$50	$73
2035	$18	$55	$78
2040	$21	$60	$84
2045	$23	$64	$89
2050	$26	$69	$95

The IWG SC-CO_2 values are in 2007 dollars. These were translated into 2016 dollars using California Department of Finance consumer price index values for California and are shown in Table C-3.[179]

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[178] Additional documents relating to the IWG process, including iterations of the Technical Support Document for the Social Cost of Carbon for Regulatory Impact Analysis under Executive Order 12866 are available at the President Barack Obama White House Office of Management and Budget Social Cost of Greenhouse Gases Web page. https://obamawhitehouse.archives.gov/omb/oira/social-cost-of-carbon.

[179] State of California, Department of Finance. Inflation: Consumer Price Index Web page. See Calendar Year averages: from 1950 available at: http://www.dof.ca.gov/Forecasting/Economics/Indicators/Inflation/ (version last updated January 2021).

Table C-3: Social Cost of CO2, 2015-2050 (in 2016 dollars per metric ton CO2)

Year	5% Discount Rate	3% Discount Rate	2.5% Discount Rate
2015	$12.92	$42.28	$65.76
2020	$14.09	$49.32	$72.81
2025	$16.44	$54.02	$79.85
2030	$18.79	$58.72	$85.73
2035	$21.14	$64.59	$91.60
2040	$24.66	$70.46	$98.64
2045	$27.01	$75.16	$104.52
2050	$30.53	$81.03	$111.56

Avoided Social Costs

The estimated avoided social cost of the SB 100 Core scenario compared to the 60% RPS scenario is calculated by multiplying the IWG SC-CO_2 values in Table C-3 for year 2045 at the 2.5, 3, and 5 percent discount rates by the GHG emissions difference in Table C-1. The social costs using these assumptions are shown in Table C-4 at the various discount rates.

For example, 32,848,819 MT CO_2 x $27.01/MT CO_2 = $887,236,053

Table C-4: Estimated Social Cost (Avoided Economic Damages)

Scenario	Social Cost of Carbon (2016 dollars) 5% Discount Rate	Social Cost of Carbon (2016 dollars) 3% Discount Rate	Social Cost of Carbon (2016 dollars) 2.5% Discount Rate
SB 100 core, high electrification demand	$887,236,053	$2,468,830,755	$3,433,217,769