CALIFORNIA ENERGY COMMISSION

Energy Research and Development Division

FINAL PROJECT REPORT

Utility-Scale Renewable Energy Generation Technology Roadmap

Gavin Newsom, Governor

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The technologies and strategies in this report were selected based on the best available and most recent literature that could be identified. This report is not expected to be an exhaustive list of technology and research options. All estimates are intended for guidance at a high level, and those pertaining to cost, performance, and otherwise should not be misconstrued to infer suitability for an individual project.

PREFACE

The California Energy Commission's (CEC) Energy Research and Development Division supports energy research and development programs to spur innovation in energy efficiency, renewable energy and advanced clean generation, energy-related environmental protection, energy transmission and distribution and transportation.

In 2012, the Electric Program Investment Charge (EPIC) was established by the California Public Utilities Commission to fund public investments in research to create and advance new energy solutions, foster regional innovation and bring ideas from the lab to the marketplace. The CEC and the state's three largest investor-owned utilities—Pacific Gas and Electric Company, San Diego Gas & Electric Company and Southern California Edison Company—were selected to administer the EPIC funds and advance novel technologies, tools, and strategies that provide benefits to their electric ratepayers.

The CEC is committed to ensuring public participation in its research and development programs that promote greater reliability, lower costs, and increase safety for the California electric ratepayer and include:

- Providing societal benefits.
- Reducing greenhouse gas emission in the electricity sector at the lowest possible cost.
- Supporting California's loading order to meet energy needs first with energy efficiency and demand response, next with renewable energy (distributed generation and utility scale), and finally with clean, conventional electricity supply.
- Supporting low-emission vehicles and transportation.
- Providing economic development.
- Using ratepayer funds efficiently.

Utility-Scale Renewable Energy Generation Technology Roadmap is the final report for Contract Number 300-17-005 with Energetics. The information from this project contributes to the Energy Research and Development Division's EPIC Program.

For more information about the Energy Research and Development Division, please visit the CEC's research website (www.energy.ca.gov/research/) or contact the CEC at 916-327-1551.

ABSTRACT

To reach the ambitious goals laid out in Senate Bill 100, California must triple its renewable energy production over the next decade. A broad approach to research across a wide array of renewable energy resource areas will enable California to avoid technology lock-in and drive a diverse approach to meeting its renewable energy goals. This roadmap provides the California Energy Commission (CEC) with 17 recommended initiatives to guide research, development, and demonstration activities across nine technology areas: solar photovoltaic, concentrated solar power, land-based wind, offshore wind, bioenergy, geothermal power, small hydropower, grid integration technologies, and energy storage systems.

A comprehensive roadmapping process was conducted involving literature research, interviews, surveys, and webinars to gather input from experts and the public to identify barriers and research gaps and prioritize near, mid-, and long-term research, development, deployment, and demonstration activities for each topic area.

This roadmap report presents the method and results of the roadmapping process. Each technology area contains the prioritized recommended technology initiatives, supported by background information that includes generation trends, resource assessment, cost and performance metrics, and other considerations that will impact future CEC technology advancement efforts.

Keywords: energy storage, concentrated solar, photovoltaic, geothermal, windpower, geothermal, hydropower, grid integration, renewable energy generation, utility-scale renewables, roadmap.

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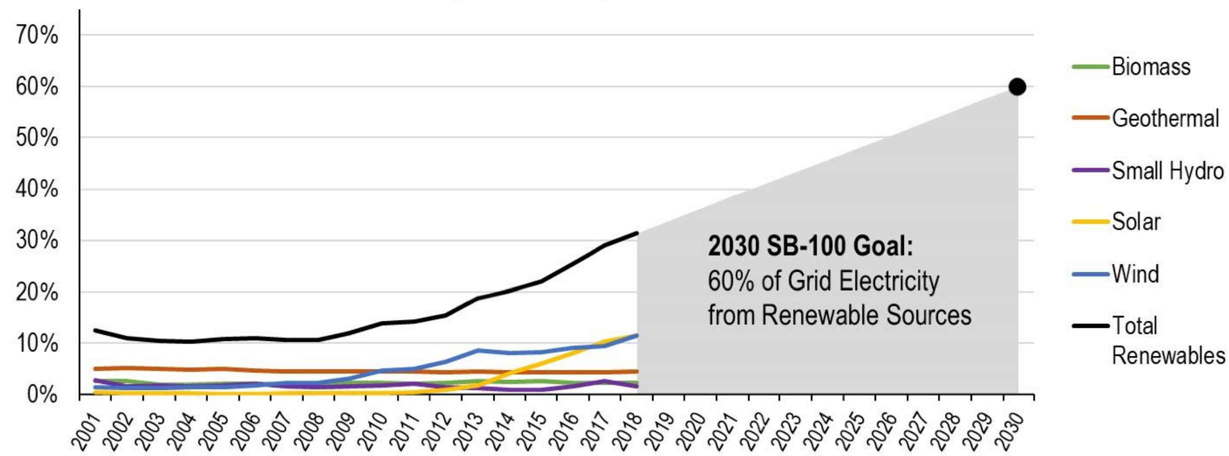
EXECUTIVE SUMMARY

Introduction

In 2018, California increased its aggressive renewable goals: with Senate Bill 100 (De León, Chapter 312), renewable sources must provide 60 percent of electricity by 2030, and renewable and carbon-free sources must provide 100 percent of electricity by 2045. This research roadmap identifies research gaps for utility-scale renewable technologies and prioritizes near-, mid-, and long-term research, development, demonstration, and deployment activities that address those gaps and can help drive California toward its clean energy goals.

Utility-scale renewable generation in California has seen substantial growth since the beginning of the century, increasing from 12 percent of electricity generation in 2001 to more than 31 percent in 2018. SB 100's goals require another doubling of renewable electricity generation over the next decade. Current renewable technologies producing electricity for California's grid can be grouped into the following categories: biomass, solar photovoltaics (PV), concentrated solar power (CSP), geothermal, small hydro, and wind. Past production from these sources in relation to California's 2030 SB 100 goal is shown in Figure ES-1.

Figure ES-1: California Grid Electricity by Renewable Source from 2001 to 2018 Compared to 2030 SB 100 Goal



Source: Energetics

A diverse approach using these and other renewable technologies will enable California to achieve a secure, reliable, and sustainable grid that is powered fully by renewable and carbon-free electricity. This technology roadmap is a fundamental step in planning future CEC efforts to achieve utility-scale energy generation technology improvements.

Project Purpose

To increase renewable electricity for California's grid, current fossil-fuel grid generation must be replaced, and new growth must be supplied with renewable sources. However, there are barriers such as cost and technology challenges that limit renewables adoption. This roadmapping process was designed to identify significant cost and technology-specific challenges and determine solutions.

Some of the key technical barriers can be addressed through funding from the CEC's Electric Program Investment Charge (EPIC), which sponsors research and development (R&D) and technology demonstration. This roadmap identified priority R&D initiatives to target these barriers and will support EPIC portfolio decisions.

This roadmap guides funding decisions that facilitate knowledge transfer and potential market adoption of renewable energy technologies.

This roadmap explores nine technology areas: PV, CSP, land-based wind, offshore wind, bioenergy, geothermal, small hydro, grid integration technologies, and energy storage systems.

Project Approach

This roadmapping project is divided into the technical assessment and the research roadmap. The technical assessment focuses on the current state of renewable energy and storage technologies in California; significant considerations and barriers for future development; and current research efforts in California, other states, and at the national level. The report provides an extensive list of opportunity areas and specific breakthrough technologies for each renewable technology area. This roadmap refines the findings from the technical assessment into recommended initiatives with supporting cost and performance metrics and considerations.

By design, the roadmapping project involved many contributors; stakeholder participation was a priority. Energetics led this roadmap project, supported by a team of subcontractors: Center for Sustainable Energy, DAV Energy Solutions, Renewable Energy Consulting Services, Solar Power Consulting, and TSS Consultants. Energetics provides technology and management services in the fields of energy, manufacturing, sustainable transportation, climate, infrastructure and resilience; Energetics has led multiple technology roadmaps for the CEC over the past 15 years. In addition to the project team, a technical advisory committee was formed at the outset of the project. Technology area experts were engaged through interviews, surveys, and webinars. Two public workshops were held to invite the community to contribute to the refinement process.

Project Results

Using information gathered during the assessment and roadmapping processes, the project team first created an initial list of all renewable energy technologies using information gathered from the technical assessment, surveys, and webinars. To condense to 20 recommendations from the more than 100 technologies, the team developed a set of criteria to qualitatively assess each technology. The criteria included the level of investment in the technology by other organizations, ability to address identified barriers and research gaps, past interest of the CEC, current technology readiness, and potential impact on cost and performance metrics. This evaluation was designed to provide equal coverage for the nine roadmap technology areas; the process resulted in two recommended initiatives for eight of these areas and four recommended initiatives for offshore wind (identified as an area with immense potential in California).

These preliminary 20 recommended initiatives were presented to the public who were given the opportunity to provide feedback on them through written comments or a virtual workshop.

All comments were then organized and considered individually. Ideas with passing ratings were incorporated into the list of initiatives. Out of the 107 comments received, 51 were new ideas.

This decision process resulted in 17 initiatives that were presented again to the public in the final roadmap draft. Another workshop was held, and an opportunity for written comments were provided to encourage public input on these recommendations. Some comments resulted in changes to the scope of the initiative, but no substantial objections were raised to warrant addition or removal of an initiative.

Included in this roadmap are the 17 recommended initiatives, with supporting background information including generation trends, resource assessment, cost and performance metrics, and technology area considerations (Table ES-1). The success timeframe identified in Table ES-1 is related to the technology readiness for commercialization. The near-term timeframe indicates that the technology has to be field tested to reach commercialization in the 1-3 year window. Mid-term projects may recommend a pilot demonstration, but would still require field demonstration to reach commercialization in the 3-5 year window. Long-term projects foresee more research before pilot demonstration or field demonstration can be conducted.

Table ES-1: List of Recommended Initiatives

Technology Area	Initiative	Success Timeframe
Solar Photovoltaics (SPV)	Initiative SPV.1: Field Test Tandem Material PV Cells	Mid-term/long-term
	Initiative SPV.2: Improve Recyclability of PV Modules to Increase Material Recovery	Mid-term
Concentrated Solar Power (CSP)	Initiative CSP.1: Increase Reflectivity of CSP Mirrors with Cleaning Systems or Materials	Near-term
	Initiative CSP.2: Develop Materials and Working Fluids for High Temperature Thermal Energy Storage	Mid-term
Land-Based Wind (LBW)	Initiative LBW.1: Advance Construction Technologies for Land-based Wind Turbines	Near-term/long-term
	Initiative LBW.2: Design Blades that Improve Conversion Efficiency	Mid-term/long-term
Offshore Wind (OSW)	Initiative OSW.1: Develop and Demonstrate Floating Offshore Platform Manufacturing Approaches	Long-term
	Initiative OSW.2: Develop Innovative Solutions for Port Infrastructure Readiness for OSW Deployment	Long-term
	Initiative OSW.3: Develop Solutions for Integrating Wave Energy Systems with Floating Offshore Platforms	Long-term
Bioenergy (BIO)	Initiative BIO.1: Improve Cleaning Methods to Produce High Quality Biomass-Derived Syngas	Mid-term

Technology Area	Initiative	Success Timeframe
	Initiative BIO.2: Demonstrate Thermal Hydrolysis Pretreatment to Increase Biogas Production	Mid-term
Geothermal Power (GEO)	Initiative GEO.1: Improve Materials to Combat Corrosion from Geothermal Brines	Mid-term
	Initiative GEO.2: Improve Mapping and Reservoir Modeling of Potential Enhanced Geothermal System and Traditional Geothermal Sites	Near-term
Grid Integration Technologies (GIT)	Initiative GIT.1: Improve Smart Inverters to Optimize System Communication	Near-term
	Initiative GIT.2: Decrease Line Losses of Underwater High-Voltage Infrastructure for Offshore Energy Interconnection	Long-term
Energy Storage Systems (ESS)	Initiative ESS.1: Lengthen Storage Duration of Energy Storage Systems (8-hour or greater)	Mid-term
	Initiative ESS.2: Optimize Recycling Processes for Lithium-Ion Batteries	Mid-term

Source: Energetics

Benefits to California

The *Utility-Scale Renewable Energy Generation Technology Roadmap* provides an unbiased and thorough process for considering the challenges and opportunities for expanding utility-scale renewable generation technology in California. California ratepayers will benefit from future funding recommended by this roadmap, which could lead to technology breakthroughs that decrease electricity costs while increasing renewable generation.

CHAPTER 1: Introduction

General Objective

California has established one of the most ambitious targets of any local or national government with the passing of Senate Bill 100 (De León, Chapter 312), the California Renewables Portfolio Standard Program: emissions of greenhouse gases. SB 100 sets goals of 60 percent renewable electricity production by 2030 and 100 percent renewable and zero-carbon electricity production by 2045. A diverse investment approach that provides broad, consistent support across all the technology areas is necessary for California to achieve its energy goals. This Research Roadmap project serves as a basis for future CEC's research and development (R&D) efforts, pushing for greater penetration of utility-scale renewable energy generation by identifying and prioritizing research, development, demonstration, and deployment (RDD&D) in a variety of renewable topic areas.

These topic areas include solar photovoltaics (PV), concentrated solar power (CSP), land-based wind, offshore wind (including a supplement on wave power), bioenergy, geothermal power, small hydropower, grid integration technologies, and energy storage. The selections of solar PV, CSP, land-based wind, bioenergy, geothermal, and small hydropower were made because they currently provide a percentage of utility-scale energy generation to California's electric grid. Including offshore wind in possible generation is because of its significant technical potential in California which can contribute to grid and renewable energy goals. A brief supplement on wave energy is also included based on expert and public opinion that it too can contribute significantly to California's renewable energy targets. Wave energy is included in the offshore wind topic area as an adjacent technology that can benefit from the same offshore grid infrastructure development. The electricity sector considers energy storage and grid integration technologies essential enabling technologies that will increase the penetration of renewable energy while providing consistent and reliable utility power.

This roadmapping project is broken into two major reports: A technical assessment (TA) and this research roadmap. The TA summarizes research on the current state of renewable energy generation and storage in California; significant considerations for future development of various renewable technologies; and current research efforts in California, other states, and at the national level. A list of opportunity areas and specific breakthrough technologies for each renewable technology area is also provided in the TA.

The research and interviews used to develop the TA served as inputs into the second phase of the roadmapping process (Chapter 2: Project Approach), The research roadmap. The final result of the roadmapping process is this research roadmap that identifies research gaps and provides a series of recommended initiatives that address those gaps. These prioritized recommendations provide near (1-3 years), mid-term (3-5 years), and long-term (>5 years) RDD&D that can help California advance the commercial status of advanced technologies in a variety of renewable energy technology areas.

Relevant cost and performance targets are provided for each technology area to show the current baseline for the technology area and to serve as a future indicator of success for the recommended initiatives. The metrics demonstrate possible improvements in the technology area that ultimately either reduce cost and/or increase renewable energy production in a way that provides more renewable and zero-carbon energy to investor owned utility (IOU) electric ratepayers in California and advances California toward SB 100 goals.

Current California Energy Mix and Future Expectations for Senate Bill 100

SB-100 sets goals of achieving 60 percent production from renewable energy by 2030 and 100 percent renewable and carbon-free electricity by 2045. Based on the 2018 California energy mix (Table 1), renewables must account for 29 percent more of the energy mix by 2030. Assuming large hydro production remains constant and nuclear production ceases when the last nuclear generator in California is shuttered in 2025, renewable production may need to account for at least 89 percent of the total California energy mix by 2045 to reach SB 100 goals. These future expectations rely on the simplifying assumption that demand stays constant from 2018 to 2045. In the document, *California Energy Demand 2018-2030 Revised Forecast*, the CEC provides estimated 2030 utility-scale electricity demand. See Appendix A for supporting calculations for predicting renewable energy production for 2030 and 2045.

General Method

The roadmapping process began with general research and targeted stakeholder outreach in the nine selected topic areas. The targeted outreach resulted in 37 interviews with experts across all topic areas. Information gathered during this first step served as the basis for the TA.

The Energetics team distributed a series of surveys to a larger list of industry experts and conducted seven webinars to seek input on the topic areas. The focus of these two activities was to prioritize key barriers and considerations for each topic area and to identify the research opportunity areas and technologies that could best address those barriers and drive the commercial deployment of renewable technologies. The output from the surveys and webinars led to development of a diverse set of initial recommended initiatives that were spread equally across the topic areas (two recommended initiatives for all topic areas expect Offshore Wind which featured four). In a Preliminary Draft Roadmap, Energetics summarized these recommended initiatives for the public. Next, the CEC hosted a Public Comment Workshop which gathered feedback on the recommendations.

Energetics' team closely reviewed the feedback received from the Public Comment Workshop and prepared a quantitative decision process to analyze the comments suggesting clarification, additions, or removal of recommended initiatives to finalize the recommendations that are featured in this research roadmap.

Table 1: 2018 Current California Utility-Scale Energy Mix

Type	In-State Generation (GWh)	Percent of Instate Generation	In-State Capacity (MW)	In-State Capacity Factor	Imports (GWh)	CA Energy Mix (GWh)	CA Power Mix
Fossil Fuels	**91,450**	**46.9%**	**41,986**	**24.9%**	**18,101**	**109,551**	**38.4%**
Coal	294	0.2%	55	61.0%	9,139	9,433	3.3%
Natural Gas	90,691*	46.5%	41,491	25.0%	8,953	99,644	34.9%
Oil	35	0.0%	352	1.1%	0	35	0.0%
Other Fossil	430	0.2%	88	55.8%	9	439	0.2%
Renewables	**63,028**	**32.4%**	**23,671**	**30.4%**	**26,474**	**89,502**	**31.4%**
Biomass	5,909	3.0%	1,274	52.9%	798	6,707	2.4%
Geothermal	11,528	5.9%	2,730	48.2%	1,440	12,968	4.5%
Small Hydro	4,248	2.2%	1,756	27.6%	335	4,583	1.6%
Solar	27,265*	14.0%	11,907	26.1%	5,268	32,533	11.4%
Solar PV	*24,698**	*12.7%*	*10,658*	*26.5%*	-	-	-
Solar Thermal	*2,567**	*1.3%*	*1,249*	*23.5%*	-	-	-
Wind	14,078*	7.2%	6,004	26.8%	18,633	32,711	11.5%
Offshore Wind	*0*		*0*		*0*	*0*	
Wave	0		0		0	0	
Other Zero-Carbon Sources	**40,364**	**20.7%**	**14,647**	**31.5%**	**15,976**	**56,340**	**19.7%**
Large Hydro	22,096	11.3%	12,254	20.6%	8,403	30,499	10.7%

Type	In-State Generation (GWh)	Percent of Instate Generation	In-State Capacity (MW)	In-State Capacity Factor	Imports (GWh)	CA Energy Mix (GWh)	CA Power Mix
Nuclear	18,268	9.4%	2,393	87.1%	7,573	25,841	9.0%
Unspecified Sources of Power	**N/A**	**N/A**	**0**		**30,095**	**30,095**	**10.5%**
Total	**194,842***	**100.0%**	**80,304**	**27.7%**	**90,647**	**285,488**	**100.0%**

***Total In-state Generation does not match between the two CEC Sources. The 2019 source was used as the primary source except for Solar PV and Solar Thermal totals which were extrapolated based on the 2020 source.**

Sources: ww2.energy.ca.gov/almanac/electricity_data/electric_generation_capacity.html and ww2.energy.ca.gov/almanac/electricity_data/total_system_power.html.

Opportunities for California Energy Commission Involvement

Through the Electric Program Investment Charge (EPIC) program, the CEC supports emerging technologies and strategies with the potential to grow clean energy in California (CEC 2019b). The EPIC program funds projects that support California's energy policy goals and fit into one of three program areas shown below.

Electric Program Investment Charge Program Areas

- Applied research and development projects center on activities supporting pre-commercial technologies and approaches that are designed to solve specific problems in the electricity sector.
- Technology demonstration and deployment projects aim to evaluate the performance and cost-effectiveness of pre-commercial technologies at or near commercial scale to bring these technologies closer to market.
- Market facilitation projects focus on overcoming non-technical barriers and challenges to help new technologies find early market footholds in investor-owned utility service territories. This category can include procurement and permitting approaches and development of advanced analytical tools.

The recommended technology initiatives presented in this document address the first two areas, applied R&D and technology demonstration and deployment. The team also received comments during the roadmapping process out of the scope of Energy Research and Development Division projects, related to the third program area (market facilitation and educational outreach). This introduction includes a summary of the most applicable non-technical challenges identified in this study and additional out of scope comments are included in Appendix B.

One additional idea for CEC involvement brought up over the course of the roadmapping process was to leverage resources (for example knowledge, funding, facilities, personnel, and intellectual property) from national entities such as the Advanced Research Projects Agency – Energy (ARPA-E), U.S. Department of Energy (DOE) applied research programs, and national laboratories in support of California's renewable generation goals. While only one recommended initiative included in this document specifically encourages partnership with outside organizations, many additional opportunities exist for the Energy Commission to partner with national entities to advance the RDD&D of renewable energy technologies. Energetics researched and considered related national efforts in the roadmapping process, which are included in the TA and in this roadmap in Appendix C and recognizes the benefit of future national collaborations.

Nontechnical Challenges Requiring Broad Stakeholder Involvement

Many of the barriers and considerations brought to light during the roadmapping process require engagement from other California entities or are outside of the CEC's research program scope. These are systemic problems that need to be addressed to allow California's electric system and energy markets to accommodate a high penetration of renewables. The systemic or non-technical challenges facing the increased penetration of utility-scale renewables on California's electric grid require changes to market structures, policy and regulations, or active education and outreach to stakeholders. Three of the most significant barriers are permitting restrictions, resource valuation, and technology lock-in.

Utility-Scale System Permitting

Permitting represents a significant barrier to low-cost utility-scale renewable energy deployments and affects all the aforementioned technology areas, albeit in different capacities. Permitting barriers span local, state, and federal restrictions and therefore may require different tactics across all three levels. Additionally, there may be more than one regulatory body at each level with restrictions that can inhibit system deployment.

In the case of bioenergy, California's air quality standards limit the location and development of bioenergy facilities (Energetics 2019). Bioenergy systems produce air emissions due to the combustion of biomass or through production of syngas or biogas followed by their combustion. However, bioenergy systems can provide innovative, energy-positive solutions for waste management and forest fire mitigation. Although the available alternatives could pose a greater threat to air quality and public health, they provide benefits—waste disposal and reduced fire risk—that permitting decisions do not currently consider.

Wind and solar development also face land use challenges throughout California and on in-state federal lands that have reduced utility-scale investments. Locally, San Bernardino County's Board of Supervisors voted to ban utility-scale solar and wind farms across over a million acres of private land in the county. While the county does have smaller areas designated for renewable energy, this decision greatly restricts the opportunity to develop renewable energy in the Los Angeles metro area (Roth 2019). San Bernardino County is not alone, as Los Angeles, San Diego, Inyo, and Solano counties have voted to approve restrictions on large-scale wind installations (The Times Editorial Board 2019).

The Desert Renewable Energy Conservation Plan (DRECP) is a collaborative effort between multiple Californian stakeholders, including the CEC, approved by the Bureau of Land Management, and plays a significant role in the siting of future renewable energy projects. DRECP set aside 828,000 acres (7.7 percent) out of 10.8 million acres of federal land in Southeastern California for potential renewable energy development with streamlined permitting processes to access 388,000 of those acres. The remaining 440,000 acres available for renewable energy development are defined as general public land or have another designation (DRECP 2016). The 388,000 acres available for streamlined renewable energy development demonstrate the ability of multiple agencies to work together to overcome permitting challenges.

However, there is concern that wind resources in DRECP lands are too limited. Good wind resources are available on 78,779 acres of land covered by DRECP, in which is allowed renewable energy development. However, there is more than 2 million acres of land with ideal wind energy resources covered by DRECP. While the development of DRECP was a collaborative effort, when DRECP was announced, all wind projects being pursued in the region were cancelled, and there has been little to no development in wind power since in southeastern California (CalWEA 2018).

Resource Valuation

Resource valuation emerged as a common theme across all technology areas. Challenges arise because (1) current market structures value the lowest-cost resource at any given time, (2) power availability and other grid services are not part of the valuation, and (3) California's renewable portfolio standard (RPS) tallies credits annually, which does not encourage continuous use of renewables.

Solar PV and land-based wind power currently dominate the renewable energy landscape in California because of their low costs. However, these resources are inherently variable and necessitate the deployment of energy storage systems to allow for a full transition to a decarbonized electric grid. There are alternative renewable power systems that can provide power predictably, reliably, and when required to match grid demand; examples are concentrated solar power with thermal storage, geothermal power, bioenergy, and small hydro. However, the market does not value these benefits when selecting energy sources.

California's current RPS accounting method also favors solar PV and land-based wind by allowing renewable portfolio credits to be counted on an annual basis. This method creates an incentive to over-use these low-cost renewable resources, since they can generate enough portfolio credits during the day to account for a transition back to fossil-based electricity generation at night (CPUC 2019a). In the near term, this keeps energy costs low for consumers. However, in the long term, a different approach must support the grid's transition to be carbon-free at all hours of the day. According to experts and stakeholders, the RPS procedure must also incentivize deployment of non-solar PV and land-based wind renewable energy systems. The electricity sector requires consistent investment across all forms of renewables to maintain institutional knowledge, preserve and grow industry supply chains, and enable cost declines as experience and deployments increase.

The California Public Utilities Commission, California Independent System Operator (California ISO), DOE, and U.S. Energy Information Administration (EIA) recognize these issues and are evaluating new options and market structures. Future market updates could account for the avoided costs of storage or other grid investments, the value of resource availability and dispatchability, and other societal benefits such as energy-positive waste utilization and wildfire mitigation.

Technology Lock-in (Stymied Innovation)

Technology lock-in can pose a significant barrier to innovation because of the scale and nature of investments in the electric grid. Grid infrastructure and generating assets can cost billions of dollars and have useful lives that span decades. Additionally, new technology deployments come with cost and reliability concerns, making utilities, regulators, and customers highly risk-averse. Extensive functional existing infrastructures, combined with concerns associated with new systems, make it difficult for new technologies to transition from pilot studies to full-scale deployment and market commercialization (Energetics 2019).

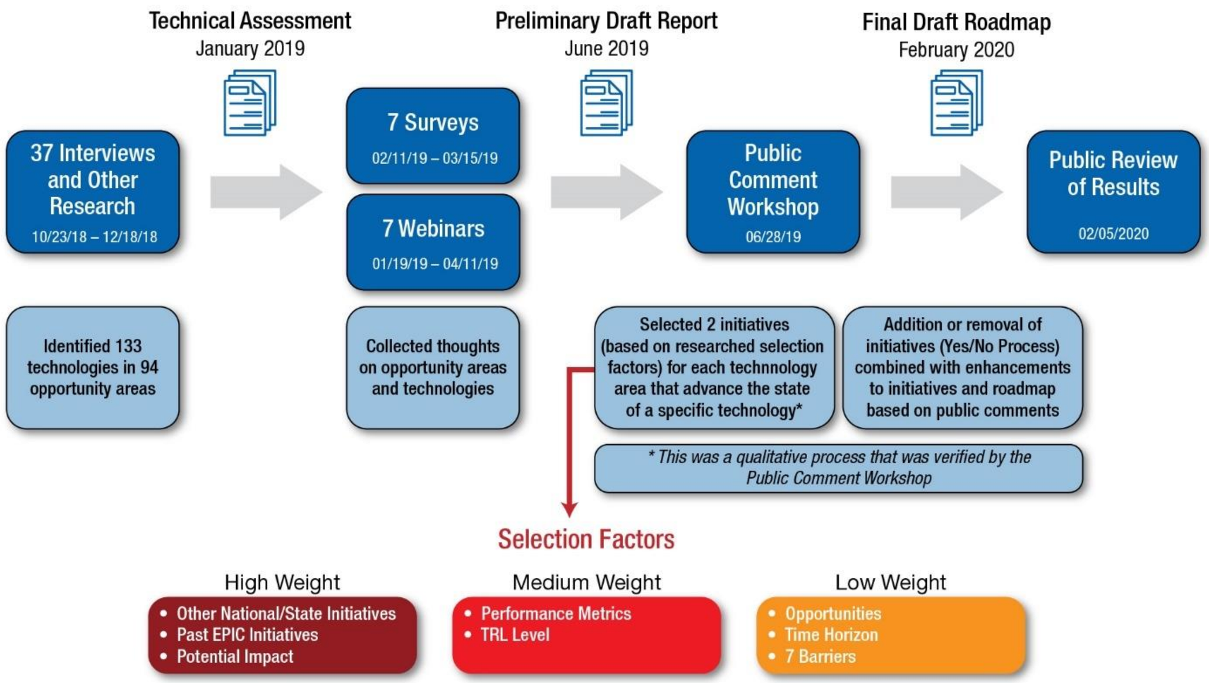
CHAPTER 2: Project Approach

The goal of this project was to develop a research roadmap that identified, described, and prioritized technology RDD&D opportunities with the potential to achieve high-penetration of utility-scale renewable energy into California's electricity grid. Renewable energy includes transmission line connected renewable energy generation technologies and strategies, including energy storage.

Roadmap Project Method

To accomplish the project goals outlined by the CEC, the Energetics team produced two reports: the TA and this research roadmap. The TA informs the research roadmap and can be accessed at the Research Idea Exchange docket (CEC 2019c). Figure 1 shows the timeline and steps that were followed for completion of this project.

Figure 1: Timeline for the Utility-Scale Renewable Energy Generation Technology Roadmap



Source: Energetics

Table 2 shows the number of contributing participants in the roadmapping steps such as the interviews, surveys, and webinars for each topic area.

Table 2: Summary of Participation in Roadmap Project Method

	Solar	Wind and Wave	Bioenergy	Geothermal	Small Hydro	Grid Integration	Energy Storage	Total
Interviews	6	12	6	5	4	8	6	47
Survey Respondents	10	8	12	10	5	11	6	62
Webinar Participants	13	13	8	9	8	10	14	75
Total Roadmapping Participants	19	21	21	17	13	22	18	116 unique invited participants
Public Comment Workshop Participants	108 external public participants (first public workshop) 99 external public participants (second public workshop) excluding CEC and Energetics staff							

Source: Energetics (2020)

Individual Activities in Roadmapping Process

The following section provides a detailed description of the individual activities comprising the roadmapping process.

Interviews

Energetics developed the TA based on a series of expert interviews and related research. The team conducted 37 interviews between October 23, 2018 and December 18, 2018.

Technical Assessment

This document set the stage for specific identification of research gaps in the research roadmap. Targeted research for the TA focused on resource assessments, cost and performance metrics, current capacity in California, current status of technology, RDD&D opportunity areas, and specific emerging and breakthrough RDD&D technologies and strategies for each technology area. In total, the TA identified 94 candidate opportunity areas and 133 emerging and breakthrough technologies. These opportunity areas and technologies served as the basis for the recommended initiatives presented in this roadmap.

Surveys

Energetics used the findings presented in the TA to the develop surveys sent out to experts in each technology area. The surveys asked experts how they would prioritize both RDD&D opportunity areas and emerging and breakthrough technologies. Additionally, experts provided opinions on priority investments in RDD&D opportunity areas or specific technologies in the near-, mid-, and long-term. The team distributed surveys the week of February 11, 2019 and collected 62 responses by March 15, 2019. The survey results allowed Energetics to focus discussion during the next roadmapping activity, the webinars.

Webinars

Energetics facilitated seven webinars between the dates of March 19, 2019 and April 11, 2019 with 75 total webinar participants. The team invited targeted topic area experts to participate in the webinars. To guide discussion during the webinars toward RDD&D advances that could most impact California's grid, moderators asked experts to rank seven different barriers by their level of inhibition on achieving greater renewable energy penetration from respective technology areas. Experts then suggested and discussed R&D projects that the CEC could pursue to address highly ranked barriers. Additionally, the moderators collected key considerations and research gaps identified within the confines of these barriers. The barriers are as follows:

- Cost: Are there high-cost technology development and operations components that drive costs above what the market, financers, and producers will bear?
- Dispatchability: Are technology improvements or strategies needed to ensure that electricity can be used on demand and dispatched at the request of power grid operators, according to market needs?
- Grid Integration and Interconnection: Are there barriers to grid integration or interconnection?

- Performance: Are there barriers pertaining to power output, capacity, energy density, material durability, system degradation/corrosion, efficiency, curtailment, or other performance-related factors?
- Production: Are there issues related to manufacturability, supply chain and logistics, or other factors that limit system production?
- Resource Availability: Is there a clear understanding of geographical locations appropriate for deployment? What regulatory or permitting barriers that may inhibit the development of utility-scale systems? Are forecasting improvements necessary to enhance operations and certainty in power scheduling?
- Resource Valuation Are energy markets appropriately valuing all the benefits that this technology area may bring to the grid or society?

Findings from the surveys and webinars allowed Energetics to prioritize the list of 94 opportunity areas identified in the TA. The selection criterion used to select the most important opportunity areas was their ability to address highly ranked barriers and challenges. Energetics then sorted the emerging and breakthrough technologies identified through expert interviews and research, presented in the TA, and brought up in the webinars into prioritized opportunity areas.

Preliminary Draft Roadmap

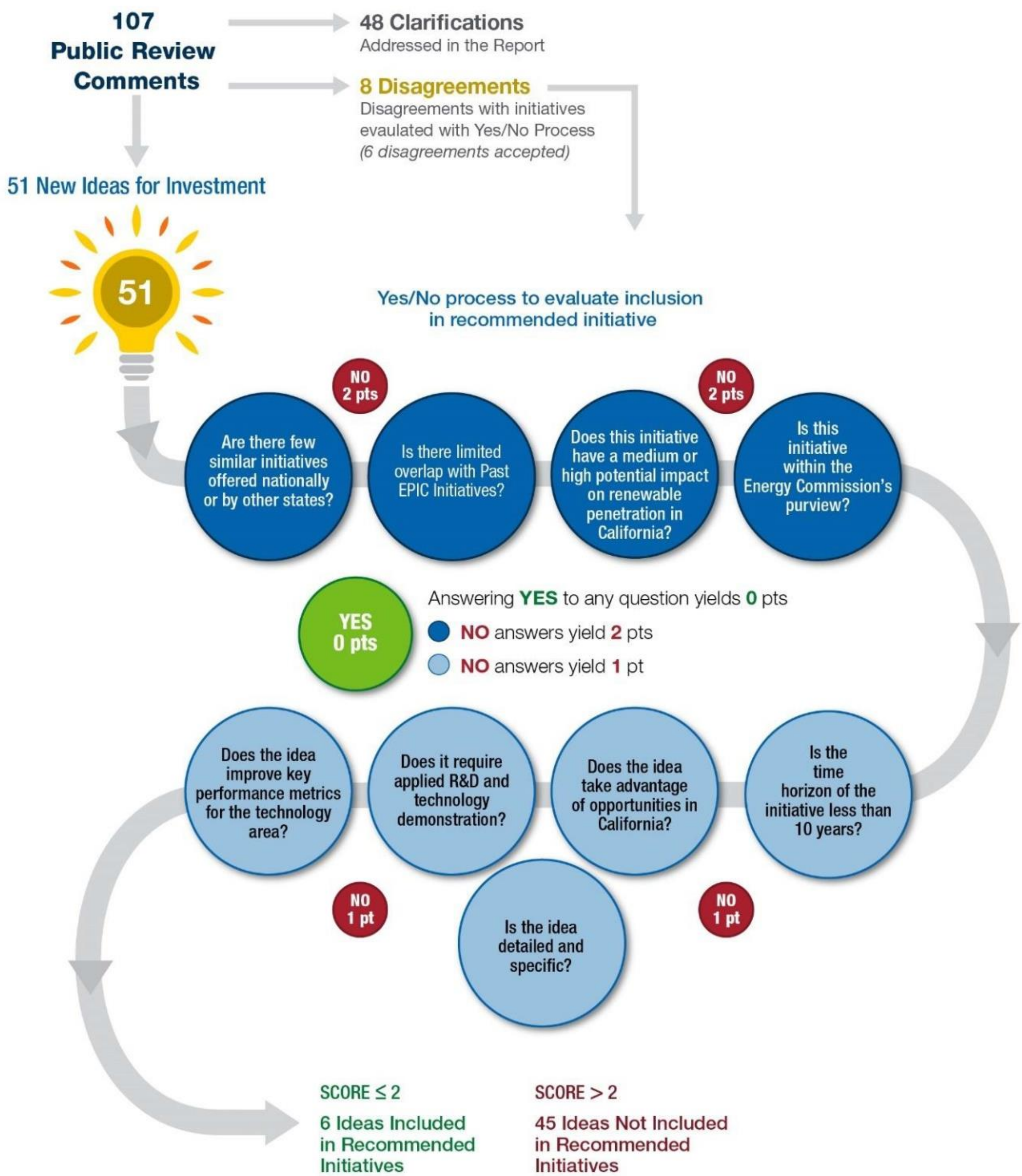
The Preliminary Draft Roadmap outlined 20 recommended initiatives resulting from a qualitative down-selection process. The Energetics team wrote the initial list of preliminary initiatives to contain all relevant emerging and breakthrough technologies that were sorted into prioritized opportunity areas as described above. The criteria considered for down-selecting from the preliminary initiative list included: level of investment in the technology by other organizations, ability to address identified barriers and research gaps, past interest by the CEC, current technology readiness, and potential impact on cost and performance metrics. This qualitative process resulted in two recommended initiatives for each of the nine roadmap technology areas, with the exception of offshore wind which had four recommended initiatives (identified as an area with immense potential in California). In addition to these 20 recommended initiatives, the Preliminary Roadmap Draft contains key barriers and challenges as well as related EPIC and DOE initiatives for each technology area.

Public Comment Workshop

Soon after publishing of the Preliminary Roadmap Draft, the CEC facilitated a public comment workshop on June 28, 2019 to gather feedback on the list of 20 initiatives. The Energetics team conducted the workshop virtually through a webinar; 108 people attended the workshop and comments were collected during the webinar and through an CEC public comment portal. Following the workshop, the CEC held a public comment period to solicit written feedback on the preliminary roadmap draft and its given initiatives that lasted until July 12, 2019.

Energetics sorted comments recorded during the webinar and submitted electronically into four categories: new ideas, initiative disagreements, gaps and/or clarifications, and other. Figure 2 presents the number of comments received, and the resulting actions taken by Energetics. The number of submissions during the Public Comment period is not exact because some comments contained multiple ideas. Additionally, the submission total includes verbal feedback recorded during the Public Comment Workshop. Gaps and clarifications and "other" comments were addressed on an individual basis with relevant suggestions being incorporated into this roadmap. Comments that presented new idea for investment or disagreed with initiatives were put through a quantitative initiative decision process to determine if they should result in changes to the 20 initiatives presented in the Preliminary Draft Roadmap.

Figure 2: Public Roadmapping Webinar Initiative Decision Process



Source: Energetics (2020)

Initiative Decision Process

This process involved nine different questions used to evaluate a proposed addition or removal of an initiative. The Energetics team wrote each question so that "yes" was the desired answer to each question. However, a "no" answer to any of the nine variables did not disqualify a proposed action immediately. Four of these questions factored heavily into a pass or fail decision (are there few similar initiatives offered nationally or by other states?; is there limited overlap with past EPIC initiatives?; does this initiative have a medium or high potential impact on renewable penetration in California?; is this initiative within the Energy Commission's purview?).

Overlapping EPIC, DOE, state, and past CEC initiatives were recorded to justify the yes or no decision for the two corresponding questions on past initiatives. Additionally, calculations were made to quantify the impact of an initiative on SB 100 goals to answer the question on medium or high potential impact when this question was the deciding factor for the decision process described below.

For new ideas for initiatives, a "no" to one of the heavily factored questions and another question or three "no" answers to any questions resulted in a failure of the process. The quantitative interpretation of that process is as follows: a score of two points or lower resulted in a passing score. The four heavily weighted questions received a score of two points for each "no" answer while the other five questions resulted in a score of one point for any "no". All "yes" answers resulted in zero points.

Alternatively, if an original recommended initiative was questioned, new information received through the comment resulted in re-evaluation of the original initiative through the decision process. If that initiative failed the process outlined above for new ideas, then the Energetics team removed the original recommendation from the roadmap and the comment passed the process. Researchers and technology experts further evaluated all proposed additions and removals of initiatives that passed the decision process on an individual basis. After expert review, the Energetics team evaluated each suggestion again with the decision process to determine its final pass/fail status.

New ideas for initiatives that passed both rounds of the decision process resulted in either a new initiative or a change to an existing initiative. Those changes involved one or more of the following actions: editing the content of an initiative, changing the technology area of an initiative, and/or combining initiatives.

Research Roadmap

This document presents 17 recommended initiatives that address research gaps in the near-, mid-, and long-term. These initiatives have the opportunity to improve the quality (e.g. better environmental performance) or increase the quantity of utility-scale renewable energy available to California customers. The roadmap also includes the following information for each technology area to give context to the recommended initiatives: a summary of key information from the TA, cost and performance metrics, other key metrics, potential for reaching SB 100 goals, and the most important considerations and barriers identified throughout the roadmapping process.

Public Review of Results

The team presented the results of the roadmap in a final public webinar conducted in the first quarter of 2020.

CHAPTER 3: Project Results

This roadmap offers a diversity of recommendations that span nine topic areas to provide a comprehensive look at RDD&D initiatives that address pressing research gaps in the state of California. In addition to these initiatives, this chapter includes detailed information about each renewable topic area including generation trends, a resource assessment, potential for reaching SB 100 goals, cost and performance metrics, and additional relevant research findings including key technology area considerations.

The generation trends, resource assessment, and key considerations provide context for the recommended initiatives and demonstrate findings from the roadmapping process. Appendix B includes considerations that were brought up, but were out of scope for this research roadmap.

The resource assessment also serves as a basis for an estimate of the theoretical potential for each renewable technology area to reach the 2045 SB 100 goals. Appendix A contains the calculations used for all of these estimates.

The cost metrics presented throughout this chapter serve as a universal way to judge performance and competitiveness of renewable technologies. Improvements in levelized cost of energy (LCOE) and installed costs are a sign of ongoing progress for each technology area. Therefore, initiatives that lower LCOE contribute to the cost competitiveness of their respective topic area.

Other key metrics presented in each topic area provide additional benchmarks to judge the progress of specific recommended initiatives. These metrics include performance indicators and technology specific costs such as transportation costs.

At the core of this chapter are the recommended initiatives that were fleshed out through this intensive roadmapping process. These initiatives provide specific RDD&D funding opportunities for the research programs of the CEC that will allow California to move toward SB 100 and climate change goals in the short, mid, and long term, and provide unique benefits to California ratepayers. The SB 100 aims to power this grid with 60 percent of eligible renewable resources by 2030 and 100 percent of zero-carbon resources by 2045.

Recommended Initiatives

Based on results obtained using the methodology described in Chapter 2, Table 3 lists the recommended initiatives for the nine renewable technology area included in the roadmap. Small hydropower has no recommended initiatives.

Table 3: List of Recommended Initiatives

Technology Area	Initiative	Success Timeframe
Solar Photovoltaics (SPV)	Initiative SPV.1: Field Test Tandem Material PV Cells	Mid-term/long-term
	Initiative SPV.2: Improve Recyclability of PV Modules to Increase Material Recovery	Mid-term
Concentrated Solar Power (CSP)	Initiative CSP.1: Increase Reflectivity of CSP Mirrors with Cleaning Systems or Materials	Near-term
	Initiative CSP.2: Develop Materials and Working Fluids for High Temperature Thermal Energy Storage	Mid-term
Land-Based Wind (LBW)	Initiative LBW.1: Advance Construction Technologies for Land-based Wind Turbines	Near-term/long-term
	Initiative LBW.2: Design Blades that Improve Conversion Efficiency	Mid-term/long-term
Offshore Wind (OSW)	Initiative OSW.1: Develop and Demonstrate Floating Offshore Platform Manufacturing Approaches	Long-term
	Initiative OSW.2: Develop Innovative Solutions for Port Infrastructure Readiness for OSW Deployment	Long-term
	Initiative OSW.3: Develop Solutions for Integrating Wave Energy Systems with Floating Offshore Platforms	Long-term
Bioenergy (BIO)	Initiative BIO.1: Improve Cleaning Methods to Produce High Quality Biomass-Derived Syngas	Mid-term
	Initiative BIO.2: Demonstrate Thermal Hydrolysis Pretreatment to Increase Biogas Production	Mid-term
Geothermal Power (GEO)	Initiative GEO.1: Improve Materials to Combat Corrosion from Geothermal Brines	Mid-term
	Initiative GEO.2: Improve Mapping and Reservoir Modeling of Potential Enhanced Geothermal Systems and Traditional Geothermal Sites	Near-term
Grid Integration Technologies (GIT)	Initiative GIT.1: Improve Smart Inverters to Optimize System Communication	Near-term
	Initiative GIT.2: Decrease Line Losses of Underwater High-Voltage Infrastructure for Offshore Energy Interconnection	Long-term
Energy Storage Systems (ESS)	Initiative ESS.1: Lengthen Storage Duration of Energy Storage Systems (8-hour or greater)	Mid-term
	Initiative ESS.2: Optimize Recycling Processes for Lithium-Ion Batteries	Mid-term

Source: Energetics (2020)

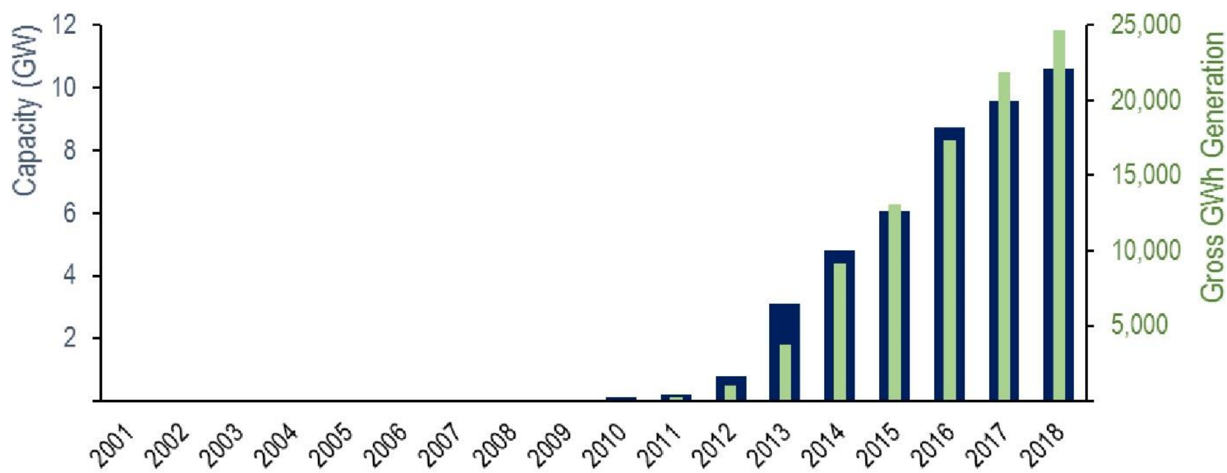
Solar Photovoltaic

Solar PV has largest technical potential of any renewable energy type in California and can be installed feasibly across the entire state. The primary limitations to solar PV installations are rough geography and permitting laws. Currently, Solar PV systems generate more electricity than any other renewable energy sources within the state and will remain an integral part of California's energy mix. California has furthered its commitment to solar energy with its updated Title 24 building standards which requires rooftop solar generation for all new buildings constructed after January 1, 2020. Continued development in solar cell technology will enable further increases in solar energy efficiency and generation while decreasing costs.

Generation Trends

Solar energy is the largest source of renewable energy in the state. Beneficial policies have supported the growth of PV power systems across California. PV has gone from being a small percentage of California's total renewable generation to the largest source of renewable energy generation in the state over the past decade. Figure 3 shows the quantity of utility-scale solar PV generation in California from 2001 to 2018.

Figure 3: Solar Photovoltaic Energy Generation in California from 2001 to 2018



Source: CEC (2019c). Graphic by Energetics.

Resource Assessment

California contains some of highest solar irradiance levels of any state, making the state ideal for large scale solar energy development. While southern deserts have been an area of focus, northern regions of the state are also suitable for solar development. The technical potential capacity of rural and urban utility-scale solar PV in the state is estimated at 4,010 gigawatts (GW) and 111 GW respectively (Lopez et al. 2012).

Potential for Reaching Senate Bill 100 Goals

If all 4,100 GW of solar PV resource potential were captured at the current statewide capacity factor (26.2 percent), solar PV systems would provide roughly 93,700,000 GWh of additional renewable power or 29 times as much renewable production as required to reach 2045 SB 100 goals (supporting calculations in Appendix A). This represents by far the largest potential for any renewable resource in the state.

Solar PV however is a variable renewable resource and needs to be paired with other forms of renewable energy or energy storage to provide power at night when the sun is not shining. The future growth of Solar PV is tied to increases in energy storage capacity more than any other renewable technology presented in this roadmap.

Cost Metrics

The LCOE for utility-scale PV solar systems ranges from $0.036/kilowatt-hour (kWh) to 0.044/kWh, unsubsidized. Installed costs for photovoltaic systems range from $950/kilowatt (kW) to $1,250/kW (Lazard 2018). The LCOE and installed costs have large ranges because they represent the cost of systems installed at a variety of locations globally. Additional current and future estimates of LCOE are provided below from a variety of sources to capture a diversity of cost projections for utility-scale PV. Solar PV power is still poised to lead the field in new renewable development based on these estimates, as it will remain the cheapest form of renewable energy. Table 4 shows the estimate the PV solar energy cost target is an unsubsidized cost of energy at utility-scale and the solar-plus-energy storage cost target is an unsubsidized cost of energy at utility-scale array with 4 hours of battery storage, with actual installed costs in Watts direct current (Wdc). Solar-plus-storage model assumptions are based on NREL analysis: 2017 NREL PV Benchmark Report, the Annual Technology Baseline, and PV-plus-storage analysis. Table 4 provides three solar PV cost estimated by the DOE, CEC, and the International Renewable Energy Agency (IRENA).

Table 4: Solar Photovoltaic Cost Performance Targets

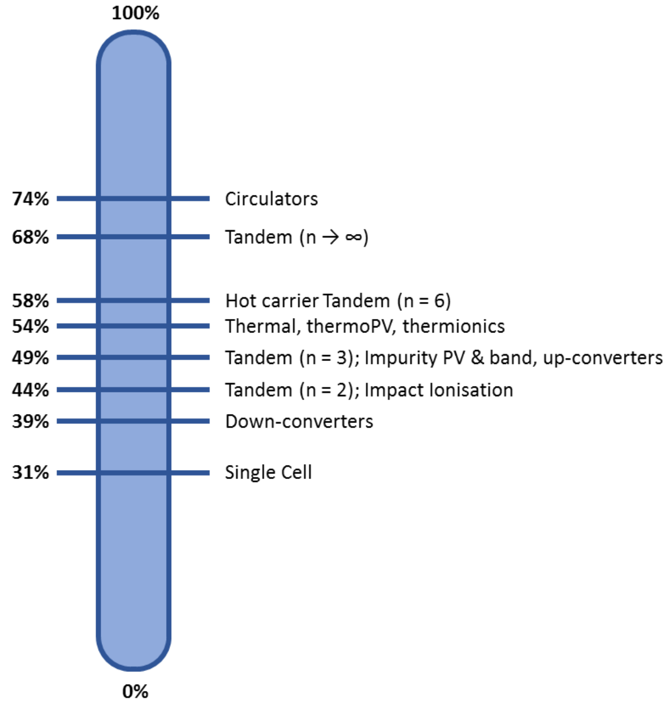
U.S. Department of Energy 2018 Budget Request				
	FY 2017	**FY 2018**	**FY 2019**	**Endpoint Target**
Photovoltaic (PV)	7 cents/kWh (exceeded, 6)	6 cents/kWh	5.5 cents/kWh	3 cents/kWh by 2030
Solar + Storage	$1.96/Wdc	n/a	$1.65/Wdc	$1.45/Wdc by 2030
CEC 2018 Update				
	2017	**2018**	**2019**	**2030**
Photovoltaic (PV)	N/A	4.7 cents/kWh	4.5 cents/kWh	3.5 cents/kWh
IRENA Renewable Power Generation Costs				
	FY 2017	**2018**	**2019**	**2020**
Photovoltaic (PV)	9.7 cents/kWh	8.5 cents/kWh	5.1 cents/kWh	4.7 cents/kWh

Source: DOE (2018a), Neff (2019), IRENA (2019)

Other Key Metrics

- Conversion Efficiency – As Figure 4 shows, there is significant room for increased conversion efficiency beyond silicon single-junction cell technology, which sits just below the maximum of 31 percent for the optimum material. In particular, multijunction ("tandem") technologies range upward of 50 percent in theory and they have achieved nearly 50 percent in the laboratory to date (Green et al. 2018).

Figure 4: Comparison of Theoretical Solar Energy Conversion Efficiencies



Source: (Green 2012) adapted by Energetics

- Recycling Costs – Estimates show that recycling costs for PV modules fall between $10 and $30 per module, net of the recovered materials' market value (Libby and Shaw 2019). This cost currently represents 15 percent of the cost of a solar module, but without significant future reductions this fraction will increase with continued decreases in solar module costs.
- Module Mass Recovery – Current recycling processes are able to recover over 90 percent of a PV module's glass and metal mass into essentially two useful streams. The principal issues for improving upon this relate to the still-small quantities of intimately mingled materials of different types, including metal framing, glass and plastic covers, solar cells, and wiring components. All of these can be recycled, but only after complex separations, which are not generally employed to date because of the small quantities involved (Marsh 2018). The European market is ahead of the U.S. because of recycling and antipollution regulations, but some U.S. manufactures (e.g., First Solar and Sunpower) have initiated recycling programs for their products. (Komoto and Lee 2018)

Recommended Initiatives

The following tables describe the two recommended initiatives selected for solar PV technologies. Regardless of investment, Solar PV will continue to grow and maintain its status as the largest provider of utility-scale renewable electricity. The below initiatives can improve that growth by lowering LCOE and decreasing the amount of land required for solar installations.

Table 5: Initiative SPV.1: Field Test Tandem Material PV Cells

RDD&D Phase	Demonstration
Description and Characteristics	Present-day commercial crystalline silicon PV modules have narrowed the gap between their practical and theoretical performance limits, such that future gains in their LCOE will come only from further economies of larger-scale manufacturing and deployment. Tandem-junction PV technologies, which have two or more active p-n junctions in optical series, offer significantly higher efficiency potential than crystalline silicon single-junction PV. Such tandem-junction devices can be realized via deposition of single-junction thin-film devices on top of conventional silicon cells or in all-thin-film form using many layers of semiconductors deposited sequentially. However, transitioning today's promising tandem cell laboratory results to commercial module practice will require substantial field experience. This initiative will establish field-testing programs to accelerate acquisition of real-world experience in promising novel technologies, such as recent laboratory demonstrations of perovskite thin-film cells on top of crystalline silicon cells. This experience is vital for transferring laboratory advances to commercial products. A 1970s government program provided much of the core knowledge that made crystalline silicon modules a durable success. Lack of similar experience has been a major barrier to tandem PV technologies entering the market in recent decades.
Impacts	Tandem-junction PV technologies, utilizing materials such as perovskite and cadmium telluride, have substantially higher theoretical efficiency limits than crystalline silicon's. Higher ceilings allow for more energy production in a smaller area and can translate into significantly lower energy costs. Field testing will proof the designs in real-world environments and provide information about degradation and failure mechanisms, leading to commercially viable module lifetimes of more than 20 years.
Estimated Potential Impact on SB 100	Augmenting the conversion efficiency of solar PV panels would increase electrical output per installation. While a noticeable increase in conversion efficiency of solar PV panels is not expected until 2030, this initiative has the potential to increase electrical production from installations after that time. This increase in electricity is equivalent to adding125 new solar installations between 2030 and 2045. Assuming current solar PV capacity factors and 25 megawatts (MW) average per installation, 125 installations would provide 2.2 percent of California's 2045 SB 100 goals (2045 SB 100 goals discussed in Current California Energy Mix and Future Expectations for SB 100 in Chapter 1).

RDD&D Phase	Demonstration
Areas for Advancement	Tandem-cell modules must show higher sustained efficiencies in field tests to demonstrate long-term cost-competitiveness with crystalline silicon devices. While development of all semiconductor material types is encouraged, perovskite tandem cells are increasingly popular because they can be made using abundant raw materials and have shown a great increase in conversion efficiency in the laboratory over the past decade. Real-world durability has been an issue in all nascent thin-film technologies, but recent progress in perovskite cell lifetimes shows good promise of stability. However, degradation rates must continue to improve. Several companies are trying to commercialize perovskite technology.
Technology Baseline, Best in Class	Silicon single-junction PV has a maximum theoretical solar conversion efficiency of about 31 percent in unconcentrated sunlight, with the best commercial silicon PV modules today performing at about 23 percent. Tandem-junction PV cells theoretically can exceed 50 percent conversion efficiency, and laboratory thin-film tandem devices in very early development have exceeded 22 percent to date.
Metrics and/or Performance Indicators	Demonstrate a conversion efficiency greater than the 31 percent limit of single-junction PV cells. Tandem cells with a future LCOE of at least 3 cents per kWh in utility-scale applications.
Success Timeframe	Mid-term for field testing of prototypes (3–5 years) Long-term for commercial deployment (>5 years)
Key Published References	Green et al. (2018), Khenkin et al. (2020)
Correlated National Efforts to Leverage	DOE Solar Energy Technologies Office (SETO) – Photovoltaics DOE – SunShot 2030
Correlated CEC Efforts	EPIC 2018–2020 Investment Plan – Initiative 4.1.1: Advance the Material Science, Manufacturing Process, and In Situ Maintenance of Thin-Film PV Technologies GFO-18-303: Cost Reductions, Advanced Technology for Solar Modules (CREATE Solar): EPC-19-002 with UCLA, EPC-19-003 with Tandem PV, EPC-19-004 with UCSD, EPC-16-050.

Source: Energetics (2020)

Table 6: Initiative SPV.2: Improve Recyclability of PV Modules to Increase Material Recovery

RDD&D Phase	Applied Research and Demonstration
Description and Characteristics	Current commercial PV modules have expected service lives longer than first-generation PV products deployed in California. As such, end-of-life issues have not been given major emphasis, and there is currently little incentive to focus on those issues. However, challenges facing disposal of PV modules will inevitably arise as the larger-scale systems reach retirement. Commercial crystalline silicon PV modules typically contain some amount of potentially hazardous materials such as copper, lead, silver, and heavy metals, as well as significant quantities of plastic and glass contaminated with metals and organic compounds. Cost-effectively separating these materials into viable recycling streams is an unmet challenge. This initiative proposes addressing that challenge by helping develop innovative module designs that aim to reduce the cost and complexity of end-of-life recycling and material recovery. Designs should focus on increasing recovery of all module components, with a focus on high-value materials from solar modules (silver, silicon, aluminum). The initiative may also include more durable, less toxic components to aid in end-of-life reclamation economics.
Impacts	This initiative will safeguard the environment from hazardous material disposal while substantially reducing PV decommissioning costs that adversely affect PV lifetime electricity prices.
Areas for Advancement	For silicon modules, the current practice, designed to meet European Union legal requirements, is to separate the metal framing parts from the glass/plastic cell package and send the metal into existing metal-recycling operations while the cell package is generally crushed and fed into existing low-quality glass feed streams. This achieves "high recovery" of module material mass but loses minor amounts of potentially valuable copper and silver, as well as admixing some lead into the glass melt. A minority of cases so far attempt to recover copper and silver from the cells by chemical solution.

RDD&D Phase	Applied Research and Demonstration
Estimated Potential Impact on SB-100	Solar PV module lifespans can reach 25 years. The cost of retiring and recycling a module is therefore outside the window in which associated costs would factor into initial financing. As such, this initiative will have a limited impact in lowering PV costs and increasing the number of new PV installations. However, SB 100 and other California solar PV initiatives will continue to drive the number of installations in the state. By 2030 and 2045, retirements of solar PV modules will increase at the same rate as installations seen 25 years earlier. This initiative will improve environmental performance and decrease waste associated with solar PV installations. This initiative will affect the 45 GW of solar PV installations that are expected between 2030 and 2045 in California. That 45 GW of California solar PV comprises 150 million solar modules. Because of the large role solar PV installations are expected to play in reaching SB 100 goals, this initiative is estimated to enable as much as $2.2 billion in cost savings.
Technology Baseline, Best in Class	The Electric Power Research Institute (EPRI) has determined that current recycling cost is approximately $10 to $30 per module, which represents about 15 percent of the module's price. This fraction of the cost will grow as PV costs decline. First Solar's process for handling the company's cadmium telluride thin-film modules at end of life is said to recover 90 percent of the glass and 95 percent of the semiconductor, which can then be reused in new modules. Other useful metrics for this initiative include estimates of reduced impacts on landfills due to improved recovery of spent materials.
Metrics and/or Performance Indicators	Net recycling costs should be lower than 10 percent of the initial capital cost. Module mass recovery rates should increase to 98–99 percent (to minimize net cost and landfill impacts), and target recovery rates for high-value materials (silver, aluminum, silicon) are over 95 percent.
Success Timeframe	Mid-term for market readiness (3–5 years)
Key Published References	EPRI et al. (2017), Veolia (2018), EPRI (2018), Deng et al. (2019) SEIA (2019), Butler (2019), Libby and Shaw (2019), Komoto and Lee (2018)
Correlated National Efforts to Leverage	DOE Solar Energy Technologies Office (SETO) – Photovoltaics

RDD&D Phase	Applied Research and Demonstration
Correlated CEC Efforts	Related Idea: EPIC 2018–2020 Investment Plan – Initiative 7.3.3: Improve Lifecycle Environmental Performance in the Entire Supply Chain for the Electricity System Interagency Effort to Discuss End-of-Life of PV Panels, EV Batteries, and Energy Storage Systems.

Source: Energetics (2020)

Solar Photovoltaic Considerations

Provided, in no particular order, are some of the notable considerations aligned with the solar PV technology area. These considerations include opportunities, barriers, and potential related technologies for future advancement.

- Peak generation from PV solar systems does not match peak load. Dispatchability is a key challenge for PV systems. Solar power relies on the sun, creating a roughly 6-hour window when solar energy can be maximally produced. While it is possible to forecast solar energy production throughout the day, energy storage is required to offset solar PV generation to match grid demand. Developing technologies that can capture sunlight for more hours of the day or pairing solar PV systems with energy storage can make solar energy more reliable, consistent, and dispatchable.
- The drop off of solar energy in the evening requires additional installations to provide ramping power. Due to the disparity between peak load and peak solar generation in California, the daily net load in the state forms what is known as the “duck curve”. Solar power generation reduces the need for power from other resources during the day, but then solar production decreases as evening demand peaks. This decrease in production necessitates a large ramp up of power that strains the electric grid. This problem will be exacerbated with additional solar installations.
- Pairing solar PV with energy storage systems will increase the grid-value of future installations. When combined with energy storage, solar PV systems are fast ramping and able to meet demand throughout the day. Deployment of storage systems also allows all produced energy to be stored instead of curtailed when overgeneration occurs, which prevents waste of renewable energy production.
- PV solar technologies have lower efficiencies and capacity factors than other forms of renewable power. There are several solar PV technologies that can improve these metrics, but most demonstrations of high efficiency materials have only been done in labs. Field testing of these panels is required to bring them closer to commercialization. For existing technologies, weather, dust, soiling, and maintenance contribute to lower capacity factors.
- Solar PV is currently the least expensive option for renewable development in California. To maintain their status as the lowest cost renewable energy, solar PV systems must navigate upcoming cost challenges such as upgrading T&D infrastructure and incorporating energy storage. Both of these challenges will become more prevalent as solar PV development moves to more rural locations.

- Most current PV modules are built in China where manufacturing costs are much lower. However, newer PV technologies, which require less materials and labor to produce, are developed in the United States. Many solar cell technologies also require rare earth metals, which are primarily mined overseas.
- Variable renewable resources are favored by developers due to how the market values power generation. The electric grid currently pays the lowest cost producers first regardless of their ability to provide power consistently and reliably, which benefits PV operators. However, this structure has to be adapted to continue to increase the amount of renewable power on the grid while still meeting fluctuating demand. Non-variable renewable sources or variable sources paired with energy storage are a necessary part of a fully carbon-free grid.
- Hardware resiliency is important for solar PV arrays in preparation for fire storms, seismic events, and other severe weather events which are occurring with increasing frequency. Environmental hazards can cause physical damage to PV arrays and the transmission systems connected to PV facilities. Hardware that is resistant to environmental hazards and grid events caused by environmental disturbances minimizes maintenance costs and limits power outages due to damage.
- Light-induced degradation needs to be characterized both to predict electricity production and to enable business transactions. Light-induced degradation reduces the energy production of solar panels overtime, but the amount of degradation is difficult to quantify due to varying rates of solar panel decay. Better understanding of the lifetime performance of solar systems will help accurately predict future production and ensure fair pricing.
- Module cleaning of PV systems differs from cleaning CSP mirrors. Both PV modules and CSP reflectors require regular cleaning to remove dust and soil accumulation. Deionized water is a popular method for cleaning both systems. However, better systems with lower water use exist but are specifically designed for either PV or CSP systems. Mechanical methods such as brushing are more useful for cleaning PV systems, while ultrasonic and vibrational methods are better suited for CSP mirror cleaning.
- Recycling and reuse of older solar panels can be driven through policy. Old panels do not necessarily need to be recycled or dismantled. Modules can be resold at a reduced price and continue to produce power. Policy levers can be employed to encourage reuse and proper recycling of panels. In addition, there are several PV testing and certification labs in California that can test older panels, certify their performance, and allow them to be used and/or deployed confidently for more years of service.

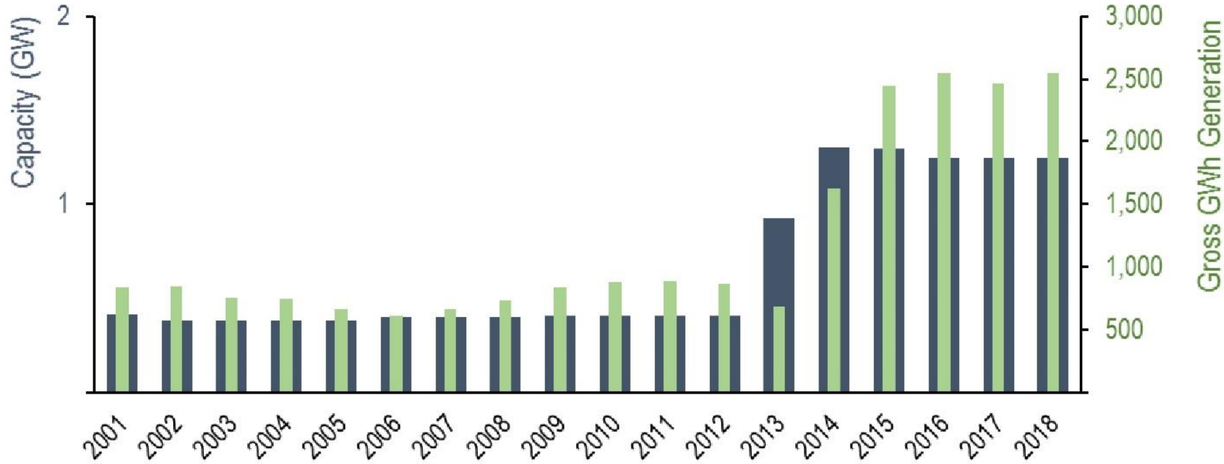
Concentrated Solar Power

CSP represented a small but growing share of California’s renewable generation since the 1980s. Parabolic troughs and solar power towers are the two most common forms of CSP with the former being the most mature technology. Solar towers have the potential to provide a significant upgrade in system efficiency. Continued efforts to increase CSP efficiency and integrate thermal energy storage (TES) can lead towards the development of CSP as a reliable, dispatchable source of renewable energy necessary to meeting SB 100 goals.

Generation Trends

After capacity from CSP systems remained relatively constant for over a decade, CSP capacity saw a recent expansion with the introduction of three new California facilities from 2012 to 2014 (Ivanpah, Mohave Solar, and Genesis Solar). Although solar central-receiver "power tower" designs are gaining worldwide acceptance, the Ivanpah Solar Power Facility is the only one currently operating in California. The remaining CSP facilities use parabolic trough designs. The trends in electricity generation from CSP can be seen in Figure 5.

Figure 5: Solar Concentrating Solar Power Energy Generation in California from 2001 to 2018



Source: CEC (2019d). Graphic by Energetics.

Resource Assessment

The high solar irradiance levels in California that make PV so desirable, also make the state ideal for utility-scale CSP development. California, Arizona, Nevada, and Florida are the only four states that currently have operational CSP deployments and look most attractive for future development. The southeastern part of California remains the best target for CSP development because that is where irradiance levels are the highest. The technical potential capacity of CSP in the state is around 2,700 GW (Lopez et al. 2012).

Potential for Reaching SB-100 Goals

If all 2,700 GW of potential Solar CSP was captured at the current CSP capacity factor of 23.3 percent, Solar CSP systems would provide an additional 5,500,000 GWh of electricity. This total would be enough to provide around 17 times as much renewable production as required to reach 2045 SB-100 goals (supporting calculations in Appendix A).

The availability of resources for Solar CSP and its non-variable nature when paired with TES make it an attractive renewable source for California. New CSP systems have included up to 10 hours of TES which would provide a significant boost to energy storage capacity throughout the state. However, heavy land use, environmental concerns, and high costs are barriers to increasing the number of CSP installations.

Cost Metrics

The LCOE for CSP systems with thermal storage, assuming a 35-year plant life, ranges from $0.098/kWh to $0.181/kWh while installed costs range from $3,850/kW to $10,000/kW (Lazard 2018). These capital costs are higher than those of CSP installations that lack thermal storage, but the LCOE can actually be lower because thermal storage increases the capacity factor of the plants which increases revenue that offsets additional plant capital investment. Table 7 shows the CSP cost targets estimated by the DOE, CEC, and IRENA.

Table 7: Solar CSP Cost Performance Targets

U.S. Department of Energy 2018 Budget Request				
	FY 2017	FY 2018	FY 2019	Endpoint Target
Concentrating Solar Power	10 cents/kWh	n/a	8 cents/kWh	5 cents/kWh by 2030
CEC 2018 Update				
	2017	2018	2019	2030
Concentrating Solar Power	N/A	15 cents/kWh	14 cents/kWh	13 cents/kWh
IRENA Renewable Power Generation Costs				
	2017	2018	2019	2020
Concentrating Solar Power	25 cents/kWh	19 cents/kWh	16 cents/kWh	8.3 cents/kWh

Concentrating Solar Power: The CSP energy cost target is an unsubsidized cost of energy at utility-scale including 14 hours of thermal storage in the U.S. Southwest.

Sources: DOE (2018a), NEFF (2019), IRENA (2019)

Other Key Metrics

Mirror Reflectivity

The solar mirrors, which reflect light toward the receiver to heat the working fluid, are prone to soiling from environmental exposure. Reflectors can lose around 0.5 percent of their reflectivity per day due to natural dust accumulation eventually resulting in more than 50 percent loss in production. Improvements to cleaning methods to maintain reflectivity can increase system energy production by 10 to 15 percent (Griffith et al. 2014).

Cycle Efficiency

Improvements in system efficiency will be necessary to make CSP a cost competitive renewable resource. Current system thermal-to-electric efficiencies are around 30 percent. Reaching efficiencies of over 50 percent will require solar tower systems to increase their operating temperature to above 700°C, much higher than is able to be withstood by current system components.

Operating Temperature

Current tower CSP systems with thermal storage run at an operating temperature of 565°C. Achieving higher temperatures will require improvements in materials and systems processes throughout the CSP cycle. Higher operating temperature solar towers are capable of improved system efficiency and greater storage energy density. CSP systems do have an optimal operating temperature however; as higher operating temperatures do lead to larger thermal loses (Glatzmaier 2011). This temperature is just above 700°C.

Recommended Initiatives

The following tables describe the two recommended initiatives selected for solar CSP technologies. Recent large-scale Solar CSP installations have encountered significant obstacles with several failing to meet cost targets. The following initiatives provide a pathway to increasing production from CSP systems while lowering their LCOE.

Table 8: Initiative CSP.1: Increase Reflectivity of CSP Mirrors with Cleaning Systems or Materials

RDD&D Phase	Demonstration
Description and Characteristics	CSP systems have large mirrors used to concentrate sunlight onto their receivers. In contrast with flat-plate PV systems, which can tolerate soiling with relatively little impact, CSP mirrors quickly lose effectiveness with dust accumulation. The mirrors need high average reflectivity for good performance, but they are easily soiled with wind-blown sand and dust. Mirror soiling can reduce plant energy production substantially (more than 50 percent), so frequent cleaning is necessary. Today's CSP systems use combinations of mechanized and manual cleaning techniques, but even the best systems have difficulty maintaining peak mirror performance. Additionally, the costs of current cleaning methods limit their economical application to approximately once a month on each mirror. Current cleaning methods are time-consuming, expensive, prone to causing mirror breakage, and can be water-intensive. This initiative recommends advancing two techniques to improve reflectivity: upgrading cleaning methods and using new mirror coatings or materials. Improving the methods used for cleaning requires a diverse approach because of the different shapes and sizes of CSP mirrors. Additionally, methods that limit water use would provide additional value to California. Deployment of new mirror materials and coatings are an alternative way to improve overall reflectivity. These materials help by reducing abrasion and dust accumulation.
Impacts	Reducing the cost per unit area cleaned and the frequency of cleaning would be a cost-effective way for plant operators to increase CSP power production and reliability. Improving mirror reflectivity maintenance would raise plant production by at least 10 to 15 percent over current practices, and improved mechanized cleaning would lower costs and reduce water consumption.

RDD&D Phase	Demonstration
Estimated Potential Impact on SB-100	A 15 percent increase in plant production would provide an additional 381 GWh annually (current solar CSP production discussed in Current California Energy Mix and Future Expectations for SB 100 in Chapter 1). The power increase would contribute 0.5 percent of the electricity required to reach 2030 SB 100 goals. Additionally, lower costs and higher outputs of future CSP systems would make them more attractive for future installations.
Areas for Advancement	Improved electronic control systems used for better mechanization could have broad applications, for example reduced-cost building window cleaning. There is an opportunity to build upon international experience in CSP mirror cleaning.
Technology Baseline, Best in Class	Natural dust accumulation can cause reflectors to lose around 0.5 percent of their reflectivity per day. Experience shows that, in normal California desert weather, wind-born soiling degrades reflectivity to below 80 percent within a few months if aggressive cleaning campaigns are not used. Furthermore, occasional high-dust storms can reduce reflectivity to below 50 percent overnight, and without a means of rapidly cleaning the mirrors, plants may have to shut down completely for days or weeks.
Metrics and/or Performance Indicators	Average mirror reflectivity of above 90 percent.
Success Timeframe	Near-term (1–3 years)
Key Published References	Griffith et al. (2014), Ilse et al. (2019)
Correlated National Efforts to Leverage	DOE Solar Energy Technologies Office (SETO) – Concentrating Solar–Thermal Power
Correlated CEC Efforts	2018–2020 EPIC Investment Plan – Initiative 4.3.1: Making Flexible-Peaking Concentrating Solar Power with Thermal Energy Storage Cost-Competitive

Source: Energetics (2020)

Table 9: Initiative CSP.2: Develop Materials and Working Fluids for High Temperature TES

RDD&D Phase	Research and Development
Description and Characteristics	Achieving the DOE CSP endpoint cost target of 5 cents/kWh will require an increase in system efficiency. Current ideas for improved systems involve central-receiver (tower) systems with power-block cycle conversion efficiencies of more than 50 percent. Such efficiencies will require the high-temperature side of the cycle to exceed 700°C (1300°F), which is higher than current system plumbing components and heat-transfer and heat-storage materials can handle. Today's CSP system power cycles have high-temperature reservoirs at up to about 565°C (1050°F). This temperature is limited by fluid stability and containment plumbing durability. Known materials durable at such high temperatures are very costly, and using them would largely negate efficiency gains. DOE is working to achieve the endpoint cost target of 5 cents/kWh by 2030; however, its CSP program is perennially constrained by budget limitations, and its progress is hampered by political forces that make multiyear budgets uncertain. Therefore, having California investment will help to increase progress by providing more overall resources and greater financial stability for the program.
Impacts	Raising the upper temperature in the power cycle from 565°C to 700°C would increase CSP conversion efficiency from about 30 to 50 percent, with LCOE reduction in nearly inverse proportion if the materials involved are not prohibitively expensive. A further benefit of the higher temperature is that the storage system's energy density would be proportionately higher, so each cubic meter of storage medium can contain significantly more megawatt-hours (MWh) of usable heat. Other thermal power systems would also benefit from development of less expensive high-temperature materials to increase efficiency and lower costs. Materials research can be time-consuming, so increased funding toward development in this area can provide a needed boost to RDD&D. Similarly, advances in working fluids may be accomplished sooner and can done in conjunction with advances in materials.
Technology Baseline, Best in Class	CSP systems can currently operate at 565°C.

RDD&D Phase	Research and Development
Estimated Potential Impact on SB-100	If DOE 2030 targets of 5 cents/kWh are met, solar CSP will be cost-competitive with current fossil sources. Future installations can therefore be expected between 2030 and 2045. One additional power-tower-type CSP plant similar to the Ivanpah plant would provide additional in-state capacity of 400 MW. This plant would supply 0.6 percent of electricity toward 2030 SB-100 goals and 0.3 percent of SB-100 2045 goals (2030 and 2045 SB-100 goals discussed in Current California Energy Mix and Future Expectations for SB 100 in Chapter 1). Additionally, a 400 MW installation could be paired with as much as 400 MW of 10-hour storage (4,000 MWh), which would provide a significant boost to storage capacity throughout the state (400 MW is around 10 percent of current storage capacity).
Areas for Advancement	This initiative addresses the key challenges involved in finding low-cost containment materials that have sufficient high-temperature strength and corrosion resistance to contain molten salt at 700°C and/or low-cost noncorrosive fluids that are stable at such high temperatures, together permitting CSP power cycles with more than 50 percent efficiency.
Metrics and/or Performance Indicators	Corrosion-resistant materials that can withstand 700°C while achieving the 5 cents/kWh goal for CSP systems. Material strength and corrosion rate versus temperature (to determine the fluid service life and material amounts needed for fluid containment and, therefore, the cost of the containers and systems).
Success Timeframe	Mid-term (3–5 years)
Key Published References	Glatzmaier (2011), DOE (2019a)
Correlated National Efforts to Leverage	DOE Solar Energy Technologies Office (SETO) – CSP DOE – Gen3 CSP DOE – SunShot 2030
Correlated CEC Efforts	2018–2020 EPIC Investment Plan – Initiative 4.3.1: Making Flexible-Peaking Concentrating Solar Power with Thermal Energy Storage Cost-Competitive GFO-18-902 – Cost Share for Federal Funding Opportunities for Energy Research, Development, and Demonstration

Source: Energetics (2020)

Concentrated Solar Power Considerations

Provided, in no particular order, are some of the notable considerations aligned with the CSP technology area. These considerations include opportunities, barriers, and potential related technologies for future advancement.

- CSP can match peak load and provide ramping power due to its ties to TES. Dispatchability is a major feature of CSP when paired with TES. Additionally, TES systems typically have a longer duration of storage (>8 hours) and higher capacity than lithium-ion batteries combined with utility-scale solar PV. CSP systems designed with TES have the ability to generate, store, and dispatch energy when it is needed making solar power more reliable and consistent.
- CSP systems require energy storage to be competitive with other renewable sources. Current CSP deployments with TES already provide more dispatchability and better ramping performance than other renewable sources. These additional services increase the value of CSP systems to the grid giving CSP a better value proposition than other lower cost renewable technologies.
- The high costs of CSP systems are often prohibitive when compared directly to PV. CSP and solar PV are easily linked because they have the same source of power, but PV systems can produce similar amounts of energy at lower costs. Even with the additional flexibility and dispatchability offered when paired with TES, CSP is typically not valuable enough to outcompete solar PV. Since CSP vies for the same resources as solar PV, CSP may lose valuable land to lower cost solar PV projects.
- The current market structure values variable PV over dispatchable CSP. While CSP provides the type of reliable and dispatchable energy that will be necessary for a fully low-carbon grid, the energy marketplace currently pays the lowest cost producers first. Until CSP's ancillary capabilities are valued, it will struggle to compete against wind, PV, and other low-cost renewables.
- The Low Carbon Fuel Standard (LCFS) offers CSP systems a pathway to commercialization. Renewable power that is shown to directly power electric vehicles (EVs) may be eligible for LCFS credits. Creating these direct charging networks would provide a way for more expensive renewable sources such as CSP to reach profitability faster. However, creating a structure that feeds energy from CSP systems directly to EVs would divert power from the electric grid.
- PV can help drive down the price of CSP with hybrid systems. The blended LCOE of hybrid plants would be lower than that of CSP alone. However, in most cases, no significant technological synergy is considered. Instead, the two portions of the plants operate entirely separately.
- Hybrid systems may also provide co-benefits to both PV and CSP. This concept is being tested at the first commercial CSP-PV hybrid contract. This contract was signed by Morocco's MASEN in early 2019 for an "800 MW" plant (approximately half PV and half CSP) called Noor Midelt, which is scheduled to begin operation in 2022 (NS Energy 2019). This project hopes that unspecified synergies will lower the overall LCOE of both systems.

- California siting restriction have an outsized impact on CSP installations. CSP systems are more economical when installed at a large-scale. These large systems can only be constructed at sites with a lot of land and the ability to handle CSP infrastructure. These sites are uncommon, and future CSP installations may be limited if too many ideal sites for CSP systems are restricted to development.
- Environmental concerns tied to land-use and concentrated sunlight impact CSP installations. Since CSP systems take up a lot of land in remote locations, there is a high chance these systems impact wildlife. Most recently, the Ivanpah facility in California ultimately had to be scaled back to avoid further disturbing the habitat of the desert tortoise (Woody 2010). Land-use and the effect of concentrated sunlight on avian life will always be considerations for new CSP systems.
- California has an opportunity to work with the World Bank, CSP industry, and grid experts to expand CSP development. Convening a symposium and deciding on the potential value and importance of CSP in California and southwestern United States would be a useful activity. CSP systems require large capital investments but have a wide range of interested parties around the globe that can be leveraged for both capital and expertise.
- Focus on developing incremental technologies that improve CSP performance. The best way to evaluate next generation CSP is to continue to test the components of these systems. While an entire CSP system may not be able to be built in the next few years, the internal components can be improved, and the system concepts tested to continue to advance CSP industry experience.

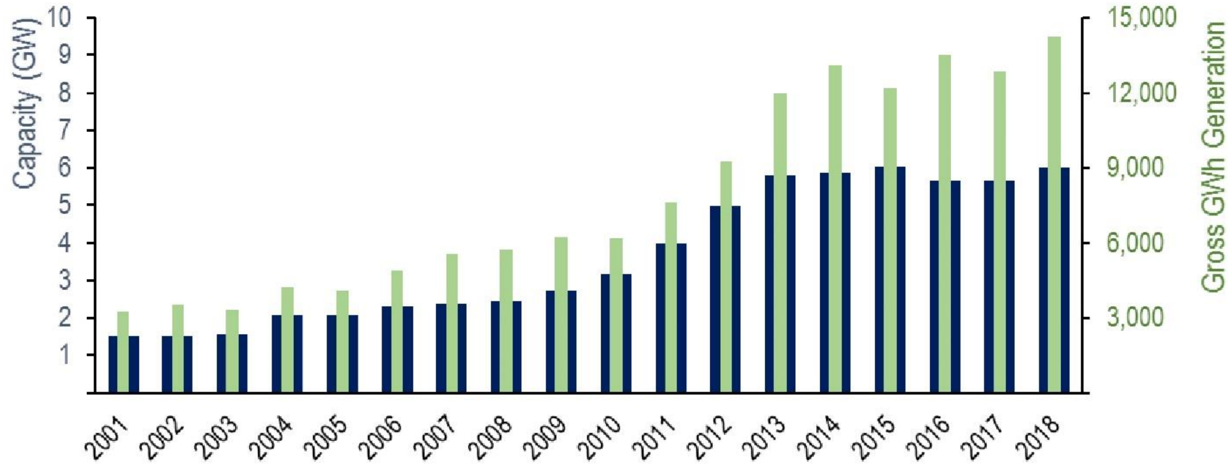
Land-Based Wind

Land-based wind represents one of the more established forms of renewable energy generation in the state. The majority of land-based Wind Resource Areas (WRAs) are currently saturated by wind turbines. To restart growth of California's wind production, new resource areas located in regions with treacherous terrain and/or lower winds speeds must be accessed. Larger turbines that can reach higher elevations are a prominent technology that can achieve growth in undeveloped regions. Emerging manufacturing, transportation, and installation technologies offer a pathway to overcoming barriers preventing developers from building larger turbines in more remote areas.

Generation Trends

Starting in the 1980s, the first wind energy projects were installed in California. Like solar, wind has benefited from policies that have supported its continued development in the state. For instance, since California's RPS law was adopted in 2002, California's wind energy generation has more than tripled. Figure 6 shows the trends in wind energy prdouction since 2001. After a steady increase from the beginning of the century to 2013, the installed capacity of wind turbines has not significantly increased over the past several years despite changes in RPS goals.

Figure 6: Wind Energy Generation in California from 2001 to 2018



Source: CEC (2019e). Graphic by Energetics.

Resource Assessment

California's existing wind fleet primarily occupies six designated WRAs where both wind speed and grid access are ideal. However, these WRAs do not represent the only possible developments sites in the state. The California Wind Energy Association estimates that the state's near-term additional developable potential is approximately 2,000 MW (Rader 2016). Another opportunity exists at higher hub heights that can be accessed in the mid- to long-term with the taller towers and larger blades of advanced wind technologies. The National Renewable Energy Laboratory (NREL) estimates that at a 140-meter hub height, California's wind energy potential can be increased by almost 25,000 square miles to unlock an additional capacity of 128 GW (WINDExchange 2019).

Potential for Reaching SB-100 Goals

Using NREL's estimates at 140-meter hub heights, California has an estimated 301,000 GWh of electricity available from wind power if all potential capacity in the state was captured at 2018 capacity factors (supporting calculations in Appendix A). That amount of energy would fall just short of the total anticipated new renewable electricity requirement for 2045 based on SB 100 goals (326,000 GWh).

However, wind installations at 140-meter hub heights would provide electricity at much higher capacity factors (>40 percent) than current California installations and can be expected to raise the capacity factor seen throughout the state. Additionally, wind turbines are an attractive addition to the California grid because of their ability to generate power at times when solar panels cannot.

Cost Metrics

Wind is one of the cheapest forms of renewable energy, as it is a technologically mature form of renewable energy that has benefitted from incentivized development over the past decade. The LCOE for land-based wind from \$0.029/kWh to \$0.056/kWh unsubsidized, assuming a 20-year system life (Lazard 2018). Installed costs for onshore wind systems range from \$1,150/kW to \$1,550/kW (Lazard 2018). Table 10 includes the land-based wind cost target estimated by the DOE, CEC, and IRENA.

Table 10: Land-Based Wind Power Cost Performance Targets

U.S. Department of Energy 2018 Budget Request				
	FY 2017	**FY 2018**	**FY 2019**	**Endpoint Target**
Land-Based Target	5.5 cents/kWh (exceeded at 5.2)	5.4 cents/kWh	5 cents/kWh	3.1 cents/kWh by 2030
Capacity Factor Target	TBD	TBD	TBD	TBD
CEC 2018 Update				
	2017	**2018**	**2019**	**2030**
Land-Based Wind	N/A	5.3 cents/kWh	6.3 cents/kWh	6.7 cents/kWh
IRENA Renewable Power Generation Costs				
	2017	**2018**	**2019**	**2020**
Land-Based Wind	6.3 cents/kWh	5.5 cents/kWh	4.6 cents/kWh	4.4 cents/kWh

Land-based assumptions: The land-based wind energy cost target is an unsubsidized cost of energy at utility-scale. Real market weighted average cost of capital of 5.6 percent; national capacity weighted average installed capital expenditures and operating expense values; 7.25 meter/second wind speed @50 meter hub height; and 25-year plant life.

Sources: DOE (2018a), Neff (2019), IRENA (2019)

Other Key Metrics

Onsite Installation Time and Cost

The costs of system installation often determine if a wind turbine is feasible for a developer to pursue. The installation of a wind turbine can take one to five days even after building the initial foundations and having all of the components on site. The total construction time varies based on a number of factors including vehicle availability and weather conditions. New technologies can consistently enable a shorter installation time by reducing the number of vehicles and labor hours required (Infinity Renewables 2016).

Capacity Factor

Based on 2018 generation data, the Capacity Factor for land-based wind turbines in California was 27 percent (see Table 1). In the U.S., new projects built between 2014 and 2016 achieved a capacity factor of 42 percent on average while projects build from 2004 to 2011 had an average capacity factor of 32 percent (IRENA 2019). These new projects have raised the total overall capacity factor in the United States to 34.6 percent in 2018 (EIA 2020). The lower capacity factors seen in California can be attributed to the use of older turbines and less productive wind resources than other regions of the United States.

Conversion Efficiency

Potential locations for new wind developments in California have lower wind speeds than the ideal sites for wind farms in the state which are already occupied by wind turbines. Larger turbines with higher conversion efficiencies are able to make development in the new potential areas feasible and economical. The average efficiency of current utility-scale wind turbine is between 35 percent and 45 percent which is higher than legacy systems in California.

Continued improvements to wind technologies can enable more turbines to achieve efficiencies of 50 percent.

Recommended Initiatives

The following tables describe the two recommended initiatives selected for land-based wind technologies. These initiatives focus on pathways to increasing deployment of larger turbines on rugged terrain by increasing conversion efficiency and lowering installation costs. Both initiatives drive down the LCOE of land-based wind energy and provide a way to increase the capacity factor which would also decrease variability.

Table 11: Initiative LBW.1: Advance Construction Solutions for Land-based Wind Turbines

RDD&D Phase	Research and Development
Description and Characteristics	Since California's preferred wind resource areas are already filled with wind turbines, new installations will have to occupy treacherous terrain in more remote locations, which presents installation challenges. In addition, the new wind turbines have larger, wider, longer, and heavier components that are particularly difficult to transport to remote sites. Onsite assembly and manufacturing allow for wind components to be broken up and transported in more manageable pieces. However, once they are transported to the site, assembling the wind components remains a challenge. Several advanced construction technologies and techniques offer a way to facilitate onsite construction of tower structures and to lift and assemble turbine and blades in difficult settings. These technologies include advanced crane technologies, additive manufacturing (AM) techniques, and modified spiral welding. New crane technologies have the shortest timeframe to commercial deployment. Two examples of potential new designs are cranes that can attach to the turbine towers and designs that can reach turbine locations and fit in small construction and installation areas. Other solutions that may be available in the long term include telescopic towers and spiral welding techniques. These technologies would reduce the need for large site equipment by enabling the incremental addition of new tower segments. AM is a technology that changes the process of producing concrete components by removing the need for larger preset equipment and materials.

RDD&D Phase	Research and Development
Impacts	Advanced construction technologies and techniques can enable wind turbine installation in areas not previously accessible or financially viable. This can unlock new wind resource areas in California. Additionally, reducing the time it takes to assemble wind turbines can lower installation costs. AM is advocated for its reduced tooling cost and reduction in waste and energy.
Estimated Potential Impact on SB 100	This initiative focuses on enabling technologies that decrease installation costs, allowing for larger wind turbine installations in more remote locations. To reach SB 100 goals with the same energy mix seen in California today, land-based wind will need to continue to play a large role in renewable energy production in the state (2030 and 2045 SB 100 goals discussed in Current California Energy Mix and Future Expectations for SB 100 in Chapter 1). This initiative will enable access to areas with higher wind speeds, which can allow turbines to produce at higher capacity factors than seen today in California. If wind continues to play a large role in renewable production in California, 2,600 new turbines would be expected by 2030, and 6,000 turbines would be expected by 2045. At maximum, this initiative can provide installation savings of $160,000 per turbine, resulting in $416 million in savings by 2030 and $960 million in savings by 2045.
Areas for Advancement	Technologies and techniques that can improve onsite manufacturing and assembly include rough-terrain cranes, turbine tower attached cranes, self-erecting tower/turbines (telescopic towers), AM (3D printing) techniques using concrete, and automated spiral welding.
Technology Baseline, Best in Class	A crane rental costs $80,000 a day. Onsite installation time can range from one to five days per turbine. Assembly approaches depend heavily on location, the number of pieces to lift, and the turbine's size.
Metrics and/or Performance Indicators	Save one to two days for onsite assembly ($80,000 to $160,000 cost reduction). Wind energy with a future LCOE of at least 3.1 cents per kWh in utility-scale applications.
Success Timeframe	Near-term for crane technologies (1–3 years) Long-term for other advanced technologies (>5 years) (AM, telescopic towers, onsite welding)

RDD&D Phase	Research and Development
Key Published References	Mammoet (2019a), Mammoet (2019b), ForConstructionPros.com (2019), Langnau (2019)
Correlated National Efforts to Leverage	DOE – Atmosphere to Electrons (A2e) Initiative
Correlated CEC Efforts	EPIC 2018–2020 Investment Plan – Initiative 4.2.1: Advanced Manufacturing and Installation Approach for Utility-Scale Land-Based Wind Turbine Components. EPC-17-023: High Performance, Ultra-Tall, Low Cost Concrete Wind Turbine Towers Additively Manufactured On-Site GFO-19-302 – Advanced to Next-Generation Wind Energy Technology (Next Wind). EPC-19-007: On-site 3D Concrete Printing for Next-Generation Low-Cost Wind

Source: Energetics (2020)

Table 12: Initiative LBW.2: Design Blades that Improve Conversion Efficiency

RDD&D Phase	Research, Development, and Demonstration
Description and Characteristics	Unlike on-land wind development in any other state, the industry in California has been ongoing for decades. As a result, most high-wind, attractive development areas are already occupied by less efficient machines with lower capacity factors and more variable operation than modern wind turbines. For land-based wind development in California to continue to grow, greenfield project locations might be in low-wind-speed areas. Larger turbines with taller towers provide one way to access higher and more consistent wind speeds. These larger turbines will ideally generate electricity with less variability than current wind installations in the state. New blade materials can also decrease the variability of output from low-wind regions while increasing overall power output. These materials can reduce stress and extend the lifetime of blades, which are becoming physically longer and are being attached to larger rotors. Blades that are flexible and adaptable, yet sturdy, can increase economical production from wind in California, especially when combined with larger turbines. This initiative focuses on developing better blades for new turbine infrastructure as opposed to retrofits. A subset of these blades are flexible blades that can handle variations in high wind speeds, thanks to their ability to bend and twist passively to adapt to wind forces. These blades have a longer timeframe for development, but a German company is already conducting the first testing of passively adapting blades in Colorado. There is room for R&D from U.S. counterparts as these designs are developed further.
Impacts	Adaptable and flexible blade materials can operate in a wider range of wind conditions and dampen peak loads during times with highly variable wind speeds. The use of these blades will also increase blade lifespans and reduce maintenance costs. Since flexible blades increase power production, they may also make smaller-capacity turbines more economical.

RDD&D Phase	Research, Development, and Demonstration
Estimated Potential Impact on SB 100	An increase in converted energy for wind turbines can have two major impacts: higher-capacity turbines or greater capacity factors. There is a negative correlation between these two metrics, so only one can be increased. In California, the variability of renewable energy production is expected to be a large problem, so improving capacity factors will provide a greater benefit. A 35 percent increase in capacity factor for wind turbines would raise the in-state capacity factor to 36.2 percent. Since this initiative has a long-term outlook, it will affect only 2045 SB 100 goals (2045 SB-100 goals discussed in Current California Energy Mix and Future Expectations for SB 100 in Chapter 1). If wind maintains its same percentage of California renewable energy production by 2045, over 17,500 MW of new wind energy capacity will be required between 2030 and 2045.This large increase in capacity factor would lower this requirement to 13,000 MW. The difference in electricity production enabled by better blade materials in that scenario would be 10,700 GWh, or 3.3 percent of SB-100 2045 goals.
Areas for Advancement	This initiative seeks to develop improved blade materials that are more durable and can stand higher local stresses, as well as helping to advance flexible blades that can bend and twist passively to adapt and produce more power.
Technology Baseline, Best in Class	The average capacity factor of California wind energy farms in 2018 was 27 percent (Table 1). The converted energy of a utility-scale turbine is between 35 and 45 percent.
Metrics and/or Performance Indicators	Increased capacity factor of individual turbines of 35–50 percent. Increased statewide capacity factor in California of above 30 percent on average. For flexible blades in the long-term, increased converted energy rate of near 50 percent. (Preliminary modeling shows these blades can increase converted energy by 35 percent over current designs.)
Success Timeframe	Mid-term for improved blade materials (3–5 years) Long-term for flexible blades with significant material and design changes (>5 years)
Key Published References	Cognet et al. (2017), Yirka (2017), Fraunhofer IWES (2019), Richard (2018), Hingtgen et al. (2019)

RDD&D Phase	Research, Development, and Demonstration
Correlated National Efforts to Leverage	DOE – Design and Manufacturing of Low Specific Power Rotors (Large Swept Area) for Tall Wind Applications
Correlated CEC Efforts	EPIC 2018–2020 Investment Plan – Initiative 4.2.1: Advanced Manufacturing and Installation Approach for Utility-Scale Land-Based Wind Turbine Components GFO-19-302 – Advanced to Next-Generation Wind Energy Technology (Next Wind)

Source: Energetics (2020)

Land-Based Wind Considerations

Provided, in no particular order, are some of the notable considerations aligned with the land-based wind technology area. These considerations include opportunities, barriers, and potential related technologies for future advancement.

- Existing turbines limit accessibility to land-based wind resources in California. As previously mentioned, California has installed wind energy systems for multiple decades. While this has been great for the maturation of the wind industry, it has resulted in a significant amount of space already being filled by wind turbines.
- Permitting and land use restrictions are limiting further development. Multiple municipalities have banned the development of wind turbine projects due to environmental, community, and scenic aesthetic concerns. National plans such as the DCREP limited potential locations for wind resource development as well and added more permitting challenges. These additional barriers are both limiting locations for development as well as making development more time consuming in areas where wind development is allowed.
- The environmental impact of wind turbines is heavily scrutinized. Average fatality rates for birds due to wind turbines range from three to six birds per MW per year nationwide. With California's wind capacity being around 5,500 MW, an estimated 17,000 to 34,000 birds are killed in the state by wind turbines per year. The amount of fatalities by turbine varies with turbine age, height, and blade length. However, the exact effects of turbine design and fatality mitigation strategies on bird and bat fatality numbers are currently uncertain. (AWWI 2018).
- There are social concerns such as sound and aesthetics that hamper wind development. The social impacts of wind turbines center around community concerns. Locals living near old model wind turbines have complained about sound and vibrations disrupting their living. Adding in complaints about aesthetics, backlash against wind turbines has led to several California counties banning their development within municipal borders (Roth 2019). Working with communities on limiting the potential community impacts of wind turbines with proper siting and continuing research on this impact is necessary to ensure communities have the best information accessible so they can work with developers.

- Manufacturing of many wind components is not local to California. Limited local production of wind turbine components in California is causing the cost of system development to rise. While California is currently home to 12 utility-scale wind component manufacturing facilities, larger components such as blades and towers must be transported into the state which increases the capital costs. A commitment to developing more utility-scale wind projects in-state could potentially attract new manufacturing growth.
- New wind resource areas for development are not grid interconnection. Ideal wind resources in California can still be limited by the cost of grid integration, especially if the development site is far from currently existing transmission lines. Due to California's WRAs being saturated, new potential sites without wind development will require infrastructure to connect to the grid.
- Future advances in wind energy will require taller towers and larger blades. Component sizes will increase as wind turbines are designed with higher hub-heights to access faster wind speeds and unlock higher capacity factors. The transportation cost of these components will rise with turbine size increases as well. These cost increases will raise the LCOE of wind energy systems, which are currently among the lowest from all renewable sources.
- Energy storage as well as advanced system design can increase the dispatchability of wind resources. New wind turbines are designed to operate at higher capacity factors with a lower rated capacity than technically possible to maximize energy output and reduce variability on the grid. Additional adaptations such as combination with energy storage and use of generators that can double as spinning reserves can increase the flexibility and dispatchability of wind energy systems to increase the overall value of wind energy to the grid.
- Radar and other technologies for wildlife mitigation has been funded in the past and should continue to be advanced. Wind energy farms negatively impact wildlife directly through fatal collisions and indirectly through the loss of a species' normal habitats or migration paths. However, the positive impact wind turbines play in addressing climate change should be balanced with their other environmental impacts. Climate change poses a greater threat to birds and other wildlife in the long-term (Audubon 2019). Careful siting and specific location guidelines can help direct turbine installations into optimal areas. Additionally, radar systems, imaging technologies, geofences, tracking devices, artificial intelligence data processing, and other tools exist that can detect birds and bats within several miles of wind turbines. Further advancement of this technology and coupling with wind turbine operations can protect wildlife.

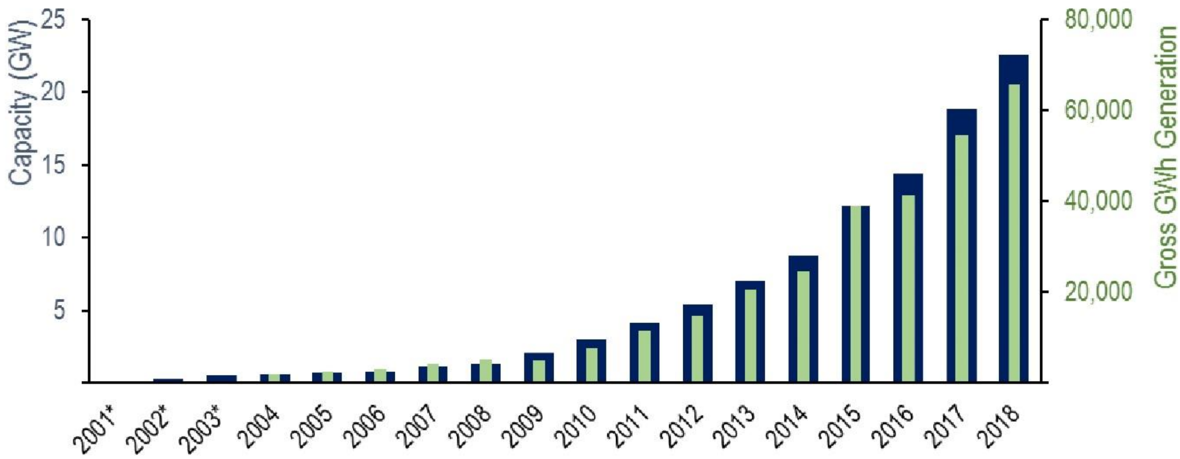
Offshore Wind

Developing offshore wind would provide a new resource for California to meet SB 100 goals. Offshore wind is in the early stages of growth along the eastern coast of the United States. Expanding the offshore wind industry in California requires investments in new port infrastructure, manufacturing hubs, vessels to install and maintain offshore wind systems. An added benefit of this investment would be numerous jobs that span the industry's supply chains and support services.

Generation Trends

Recently, offshore wind has seen its first deployments in the United States on the east coast. However, deploying wind energy on California's coast offers more challenges. On top of the cost and environmental factors, production challenges for California's coast are unique due to its deep-water coasts and need to adapt port infrastructure to deal with offshore turbine manufacturing and deployment. Potential deep-water locations will require the use of floating platforms, which have yet to be demonstrated in the United States and have limited deployments in the world. However, with global manufacturing and deployment infrastructure for offshore turbines in early stages, there is a unique opportunity for California to become a global leader in the emerging floating offshore wind industry. Figure 7 depicts the global offshore wind generation and installed capacity from 2001 to 2018.

Figure 7: Global Offshore Wind Energy Generation from 2001 to 2018



*** Unknown Value for Gross GWh Generation**

Sources: Musial et al. (2019), EWEA (2011), IEA (2019). Graphic by Energetics.

Resource Assessment

While land-based wind energy is well established in the state of California, offshore wind systems present a new opportunity for renewable energy development. Offshore wind energy has a high potential for development in California as the coast has many ideal wind resources. It is projected the technical capacity of wind resources off the coast of California is 160 GW (Musial 2016). Only 9 GW of that total is located in areas with water depths that are suited for fixed bottom deployments (<60 meters). Deep and shallow water potential can be unlocked if the right stakeholders are involved from the outset. These stakeholders include state and federal agencies, port managers, wind developers, grid operators, and the military.

Potential for Reaching Senate Bill 100 Goals

If the entire technical capacity of offshore wind was captured, California could produce an estimated 561,000 GWh of electricity which is 180 percent of 2045 SB 100 goals. The estimate assumes an overall capacity factor of 40 percent for all offshore wind production. If just areas where fixed bottom deployments could be used are considered, 32,000 GWh of electricity could be produced or roughly 10 percent of anticipated 2045 SB 100 renewable electricity goals (supporting calculations in Appendix A). Offshore wind installations would feature high capacity and high capacity factor wind turbines that are able to produce energy that complements solar installations.

Cost Metrics

For offshore wind, assuming a 20-year system life, current LCOE ranges from $0.062/kWh to $0.121/kWh while installed costs range from $2,250/kW to $3,800/kW (Lazard 2018). Fixed-bottom structures currently cost less than any floating platform designs at this point. Like Solar PV, these cost estimates sit below the estimates from IRENA and DOE. There is a large uncertainty in offshore wind pricing due to limited deployments globally and a low overall level of technical maturity. This puts offshore wind in the bracket of more expensive forms of renewable energy. However, offshore wind is a valuable resource due to higher wind speeds, leading to higher capacity factors. Table 13 depicts the cost targets of offshore wind energy estimated by the DOE and IRENA.

Table 13: Offshore Wind Power Cost Performance Targets

U.S. Department of Energy 2018 Budget Request				
	FY 2017	**FY 2018**	**FY 2019**	**Endpoint Target**
Offshore Target	17.2 cents/kWh (target met)	16.2 cents/kWh	15.7 cents/kWh	14.9 cents/kWh by 2020 7.0 cents/kWh by 2030
IRENA Renewable Power Generation Costs				
	2017	**2018**	**2019**	**2020**
Offshore Wind	12.7 cents/kWh	12.6 cents/kWh	17.2 cents/kWh	15.1 cents/kWh

Sources: DOE (2018a), IRENA (2019)

Other Key Metrics

Offshore Vessel and Barge Costs:

Table 14 shows the offshore wind vessel and barge rental costs based on daily rates.

Table 14: Offshore Wind Turbine Vessel Rental Cost

Vessel Type	Daily Rate ($)
Turbine Installation Vessel	150,000 – 250,000
Jack-up Barge	100,000 – 180,000
Crane Barge	80,000 – 100,000
Cargo Barge	30,000 – 50,000
Tugboat	1,000 – 5,000

Source: Lacal-Arántegui et al. (2018)

The average time in vessel days for foundation construction for projects between 2014 and 2017 is 2.56 days, leading to an average total vessel cost of $362,560 – $592,800 per foundation (Lacal-Arántegui et al. 2018).

Floating technologies have different associated transportation and installation costs than fixed-bottom offshore deployments because they do not require construction of a foundation. A tugboat along with one other vessel to attach mooring lines may be all that is required to deploy a floating system (Douglas Westwood 2013).

Floating platform design also impacts the type of vessels required for installation. The spar-buoy design can be assembled offshore and requires heavy lift cranes and stabilization vessels for construction. Semi-submersible designs such as WindFloat (Portugal) can be assembled quayside and towed to project sites.

Onland Transportation:

The transportation of various wind turbine components is limited due to their size, which makes it more difficult to navigate through certain areas. Industry leaders have adopted limits in component size to attempt to facilitate easier travel, shown in Table 15. Port infrastructure would need to be able to receive components of this size or be able to manufacture components of this size or larger for offshore development.

Table 15:. Wind Turbine Transportation Sizing Limits

Component	Conventional Size Limit	System Barriers due to Limit
Tower	Length: 52 to 63m	No Effect
	Width: 4.3 to 4.6m Diameter	80 – 160m Turbines Turbines larger than 1.9 MW
	Weight: 80,000 lbs (truck)	No Effect
Blade	Length: 52 to 63m	2.2 – 3.8 MW
	Width: 4.3 to 4.6m Diameter	4.3 – 7.3 MW
	Weight: 80,000 lbs (truck)	No Effect
Nacelle	Length: 11.7m	No Effect
	Width/Height: 4.3 to 4.6m	No Effect
	Weight: 80,000 lbs (truck) 225,000 (rail)	3 – 5 MW

Source: Mooney and Maclaurin (2016)

Supplement: Wave Energy

One additional source of renewable energy that could contribute at the utility-scale in California is hydrokinetic technologies capturing wave energy. There is some debate on the technical maturity of wave energy conversion technologies due to limited global demonstrations and no current utility-scale deployment. With a number of possible designs still being tested, the future of wave energy is promising but unclear.

There is an opportunity from wave energy systems to benefit from hybrid deployments with other offshore technologies because all offshore energy technologies require similar vessels for installation and infrastructure for interconnection to the grid on-land. Additionally, wave energy faces many of the same environmental and permitting concerns as floating wind power such as impact on shipping lanes and military activities. A hybrid floating offshore wind turbine and wave energy system provides a pathway to faster deployment and lower LCOE for wave energy systems.

Wave Energy Resource Assessment

Along California's 1,200 kilometers of coastline, it is estimated that on the inner and outer shelfs of California, there is a theoretical recoverable potential of 498 TWh (terawatt-hours) (EPRI 2011). The technically recoverable potential if wave energy converters are packed at a density of 20 MW per km is 295.2 TWh which is enough available energy to supply 91 percent of SB 100 2045 goals (supporting calculations in Appendix A). Based on a general literature assessment, a 30 percent capacity factor is an appropriate assumption for wave energy systems (Previsic et al 2012, Lewis, A. et al 2011, Chozas 2015, and Rusu and Onea 2018). These estimates are highly uncertain since few assessments are available for California's wave resource and few existing systems are available to demonstrate actual performance capabilities.

Wave Energy Cost Metrics

In 2014, IRENA offshore wave energy demonstration projects of 10 MW systems produced energy at a cost between 0.330 and 0.630 Euros/kWh (roughly 36.6 – 69.9 cents/kWh). The projected LCOE at that time for a 2030 system deployed at a 2 GW scale was between 0.113 and 0.226 Euros/kWh (12.5 – 25.1 cents/kWh). The cost of installation, operation, maintenance, and mooring is 41 percent of lifetime costs for wave energy systems (IRENA 2014).

Recommended Initiatives

Tables 16-18 describe the two recommended initiatives selected for offshore wind technologies. These initiatives focus on pathways to develop and deploy floating offshore wind technologies. All three initiatives take advantage of research and development occurring throughout the world on floating system designs and emphasize scale-up. The first two initiatives are necessary to enable California to have an in-state presence in manufacturing and deployment. The last initiative positions California to pursue early stage development of wave energy systems.

Table 16: Initiative OSW.1: Develop and Demonstrate Floating Offshore Platform Manufacturing Approaches

RDD&D Phase	Demonstration
Description and Characteristics	Floating offshore wind turbines place a wind turbine on a floating platform that is anchored to the seabed with cables. These systems are necessary to access wind resources in areas with water depths greater than 60 meters. Fixed bottom structures that are most commonly used for offshore wind development cannot be used in greater than 50-meter water depths due to the engineering complexity and cost. About 96 percent of California's offshore wind resources are located in deep waters (>60 meters) off the California coastline and are therefore best suited for floating platforms. Large-scale and long-term development of offshore wind resources in California will therefore require use of floating platforms. There are currently many demonstrations of floating offshore turbines in progress globally including one in Scotland (Hywind) and another funded in Portugal (WindFloat). The early-stage development of floating offshore wind technology means there may be an opportunity to become a global leader in large-scale manufacturing and production of floating offshore turbines. This initiative recommends that California demonstrate manufacturing techniques and process locally to show large-scale deployment of a floating offshore wind structure is possible. It should be noted that one potential roadblock to this initiative is the high cost of labor in California. The selection of a specific floating offshore design depends on the corresponding port location selected for assembly and deployment of these systems. The scale-up, siting, and logistics of such a manufacturing operation requires significant R&D.
Impacts	California has an opportunity to become one of the first global manufacturing centers for offshore floating wind infrastructure. The selection of demonstrated floating offshore designs eliminates risk associated with new testing and can attract established companies in the floating offshore market to move their operations to California or partner with California manufacturers. Developing an offshore wind manufacturing industry in state will decrease the costs of transportation of wind turbine components and create jobs within the state. California is also positioned to become a leader in floating platform development across the Pacific Ocean.

RDD&D Phase	Demonstration
Estimated Potential Impact on SB 100	In 2018, the Bureau of Ocean Energy Management opened up Call Areas in central and northern California that can support 8.4 GW of wind power. Multiple reports have indicated it is feasibly possible to reach this total in California by 2045. This initiative will be necessary to enable this scale of installation in California. At estimated capacity factors for offshore wind turbines of 40 percent, this initiative can unlock 29,400 GWh of new renewable electricity. 8.4 GW of offshore wind energy would provide 9 percent of electricity needed to reach SB 100 2045 goals (2045 SB 100 goals discussed in Current California Energy Mix and Future Expectations for SB 100 in Chapter 1).
Areas for Advancement	This initiative can advance the California market readiness of demonstrated floating platform designs. However, selection and manufacturing of floating platforms will have to be done with heavy consideration given to the size of the port, the location of the manufacturing plant, and the transportation infrastructure. There is an opportunity to pair port development with manufacturing infrastructure as well.
Technology Baseline, Best in Class	Non-local manufacturing can add several more days of vessel transportation time resulting in hundreds of thousands of dollars of extra expenditure per floating turbine.
Metrics and/or Performance Indicators	Vessel transportation time less than one day for floating offshore California installations. Reduction in cost of floating foundations and anchors to lower overall LCOE (7 cents/kWh).
Success Timeframe	Long-term (>5 Years)
Key Published References	Gerdes (2018), IRENA (2016), James and Ros (2015), Musial et al. (2017), Collier et al. (2019), American Jobs Project (2019), Speer et al. (2016),
Correlated National Efforts to Leverage	DOE – Offshore Wind Resource Characterization and Technology Demonstration New York State Offshore Wind Master Plan National Offshore Wind Research and Development Consortium
Correlated CEC Efforts	The Bureau of Ocean Management-California Intergovernmental Renewable Energy Task Force

Source: Energetics (2020)

Table 17: Initiative OSW.2: Develop Innovative Solutions for Port Infrastructure Readiness for OSW Deployment

RDD&D Phase	Research and Development
Description and Characteristics	Due to the large size of offshore wind turbines, large cranes and ample space are required at ports to construct, pre-assemble, and eventually tow turbines into the ocean. Currently, no port in California can assemble offshore turbine components and few ports are able to accommodate the necessary equipment. Of the ports in California, Humboldt Bay is considered the most promising location. Locating and retrofitting a port so it can load an offshore wind turbine will be necessary to install any offshore wind turbines in California. Once a port is selected, development of port infrastructure is required to enable the deployment of floating platform(s) in California. Design considerations include the location and type of floating platform used. Different assembly, staging, and processes are required to construct and assemble different types of floating platforms. Infrastructure may be necessary to manufacture components onsite, assemble larger turbine structures at the port, and to transfer structures to the water. Certain designs may not be possible to be deployed at certain ports as well due to water depths and other logistics. If possible, ports should not be designed to only handle a single offshore design to limit technology lock-in.
Impacts	Port infrastructure development is necessary to unlock the potential of local manufacturing by providing an outlet to assemble and transport turbine components to offshore locations. Without a local port, offshore development will depend on the availability of parts from other states or countries which would introduce economic and logistic challenges to offshore projects. Additionally, upgrading a port would provide a bevy of jobs and a stimulus to the local economy.
Estimated Potential Impact on SB-100	This initiative is tied directly to initiative OSW.1. Without each other, these initiatives will not be able to enable the 8.4 GW of offshore wind energy declared feasible for California. The Estimated Potential on SB 100 is identical for this initiative and OSW.1
Areas for Advancement	This initiative involves designing port infrastructure to be able to deploy floating offshore platforms that can be constructed locally. It is a critical enabling step to unlock production from offshore wind turbines. Improvements to these ports could include specially designed cranes and quayside space customization. Other improvements will be necessary based on the specific transportation and assembly requirements of the port.

RDD&D Phase	Research and Development
Technology Baseline, Best in Class	Even with local manufacturing, a well-designed port is necessary to deploy floating offshore wind turbines. Without an acceptable in-state port, turbine installation requires several more days of vessel transportation time resulting in hundreds of thousands of dollars of extra expenditure per turbine.
Metrics and/or Performance Indicators	Vessel transportation time less than one day for floating offshore California installations. Reduction in cost of floating foundations and anchors to lower LCOE (7 cents/kWh).
Success Timeframe	Long-term (>5 Years)
Key Published References	Musial et al. (2019), Porter and Phillips (2016), Collier et al. (2019), American Jobs Project (2019), Speer et al. (2016)
Correlated National Efforts to Leverage	New York State Offshore Wind Master Plan National Offshore Wind Research and Development Consortium
Correlated CEC Efforts	The Bureau of Ocean Management-California Intergovernmental Renewable Energy Task Force

Source: Energetics (2020)

Table 18: Initiative OSW.3: Develop Solutions for Integrating Wave Energy Systems with Floating Offshore Platforms

RDD&D Phase	Demonstration
Description and Characteristics	Wave energy technologies (hydrokinetic) harness the potential energy from waves to generate power. The development of wave energy technologies has advanced to a point where devices are being commercially field tested around the world. While the cost of electricity from wave power remains high, a specific synergy exists between floating offshore wind systems and wave energy devices. Both technologies use similar infrastructure for deployment and eventual transmission of offshore power. Installing wave energy devices at the same location as floating substructures offers a path to faster deployment and lower costs for wave power systems.
Impacts	Combined siting of wave and wind systems will lower the overall cost of deployment of the hybrid system and will therefore drive down the combined cost of electricity. Further testing and deployment will help advance the wave industry. Synergy between the devices can help address environmental concerns, offshore transmission and integration concerns, and offshore infrastructure concerns for both technology areas.
Estimated Potential Impact on SB-100	Wave energy could provide a limited amount of electricity along with deployment of offshore wind. Wave energy systems vary in their installed capacity (and anticipated capacity factors) due to a lack of consensus and development of commercial systems. Sizes from 500 kW to 7 MW have been proposed. For this estimate, each 1 MW of wave power will be collocated with each offshore turbine with an assumed 30 percent capacity factor for the wave system. Additionally, the same feasible potential of 8.4 GW of Offshore Wind Energy that is possible in California by 2045 will be used. The last assumption is the average Offshore Wind Turbine capacity is 8 MW. The resulting estimated impact of hybrid wave energy systems is an increase of 2,800 GWh or 0.8 percent of SB 100 2045 goals (2045 SB-100 goals discussed in Current California Energy Mix and Future Expectations for SB 100 in Chapter 1).
Areas for Advancement	For this initiative, wave systems will have to be flexible and adaptable to allow for colocation with floating wind substructure which will be the primary concern in the eventual deployment. This initiative will also involve offshore interconnection and integration of electrical energy from separate devices.

RDD&D Phase	Demonstration
Technology Baseline, Best in Class	LCOE estimated at 30-40 cents/kWh for wave energy systems and 17.5 to 10 cents/kWh for floating offshore wind turbines. Installation, operation, maintenance, and mooring costs represent 41 percent of lifetime costs.
Metrics and/or Performance Indicators	LCOE less than 20 cents/kWh for wave energy systems that are co-located with offshore floating wind structures. Floating offshore wind systems should achieve costs around 7 cents/kWh.
Success Timeframe	Long-term (>5 years)
Key Published References	IRENA (2014), OES (2018), Musial (2019)
Correlated National Efforts to Leverage	New York State Offshore Wind Master Plan National Offshore Wind Research and Development Consortium
Correlated CEC Efforts	The Bureau of Ocean Management-California Intergovernmental Renewable Energy Task Force

Source: Energetics (2020)

Offshore Wind Considerations

Provided, in no particular order, are some of the notable considerations aligned with the offshore wind technology area. These considerations include opportunities, barriers, and potential related technologies for future advancement.

- Offshore wind turbine is one of the most expensive forms of renewable energy. These installations are so expensive due to the high capital costs of transportation and the lack of offshore systems in development. The operational and maintenance costs of these systems are also high due to their offshore location.
- California needs to develop the infrastructure to manufacture an entire offshore turbine in state. Due to the size of the structures necessary for offshore wind turbines, it is typically prohibitively expensive or logistically impossible to transport turbine components from manufacturing locations that are not next to a deployment port. An in-state supply chain near a California port that can deploy offshore turbines would enable an offshore wind industry and eliminate the need to ship turbines from other states or countries.
- High labor costs in California may limit the feasibility of local manufacturing and construction. Factors such as job creation and economic stimulus must also be weighed when considering any major actions related manufacture and assembly of offshore wind turbines. A full cost-benefit analysis of local manufacturing that considers other economic factors, such as avoided transportation costs, and social factors, such as job

creation, will help determine the best way to set up an offshore wind turbine industry in California.

- Various different groups and entities will challenge the development of offshore wind systems when they are ready for demonstration. The effect of these systems on marine life as well as their aesthetic impact could pose limits on development locations. Cooperation with the military on developments will also be necessary to ensure that wind turbines do not interfere with their operations and goals in the region.
- Offshore resources are closer in proximity to California's largest load generating areas than their land-based counterparts. This limits the amount of transmission infrastructure required to reach high load areas which improves the expected economics of offshore developments. However, some of the benefits of less infrastructure are offset by the high cost and safety concerns associated with water-based electrical systems.
- The 2020 BOEM Auction is important for seeing future of Offshore Wind Energy. The Bureau of Ocean Energy Management (BOEM) is a government agency responsible for leasing areas within the U.S. Outer Continental Shelf for energy development. According to the BOEM's Budget Justifications for Fiscal Year 2020, there will be two leases sales conducted in FY 2020, one in the Atlantic offshore New York and one in the Pacific offshore California. Additionally, the BOEM has requested budgetary funding in order to hold one additional renewable energy lease auction per year (DOI 2019). In 2016, the BOEM published a report on the offshore wind potential in California (Musial et al. 2016). The agency found six locations in California that are best suited for an offshore wind farm, including Channel Islands, Morro Bay, and Humboldt Bay. The six sites have the potential to produce more than 16 GW of wind power.
- Fabrication and installation studies should be conducted in conjunction with develop of existing floating structures. Research into the unique challenges of fabricating, installing, and maintaining floating offshore wind turbines is necessary for taking advantage of the state's large offshore wind power potential. Unlike the shallow-water wind farms located on the East Coast, future wind farm sites in California will likely be located in depths of up to 500 meters. The DOE published the National Offshore Wind Research and Development Consortium in 2018, which detailed the areas of research necessary for developing offshore wind farms in the Pacific (NYSERDA 2018). The report also suggests that offshore wind technology presents an opportunity for previous employees of the offshore oil and gas sector to provide their unique knowledge to this growing sector. There is precedent for taking examples from the offshore oil and gas sector, as demonstrated by the vertical floating buoy turbines developed by the Norwegian company Equinor (Equinor 2019).
- Fixed-bottom deployments should not be overlooked in California. Opportunities to develop fixed-bottom offshore wind farms in California should be considered due to its potential to increase the state's wind power production. While there is great potential for offshore wind farms in California, all prospective projects involve floating technologies due to the nature of California's coast, which exhibits a sharp plunge in the continental shelf relatively close to California's shore (NRDC et al. 2019). As an example, the sites under consideration by the BOEM to be leased to offshore wind

farms are all located in deep water. The Humboldt Bay area ranges in depth from approximately 500 m to 1100 m and the Morro Bay ranges from 800 m to 1000 m (Trident Winds LLC 2016).

- Artificial Intelligence systems can improve locating and siting deployments. Artificial intelligence systems can be effectively utilized during the planning process for offshore wind farm projects. A research project sponsored by the Engineering and Physical Sciences Research Council in the United Kingdom is currently testing the use of robotics and artificial intelligence technologies for mapping, surveying, and inspecting of offshore wind farms (ORCA Hub 2019). The goal of the project is to lower the operation and maintenance costs associated with offshore wind, the majority of which is due to the cost of transporting engineers and technicians to the wind farm site safely.
- As Offshore wind systems are developed, deep water storage systems should be considered to further improve integration of offshore wind onto the grid. Integrating offshore wind farms with energy storage would help overcome the hurdle of intermittent energy supply, an issue that exists with many forms of renewable energy. According to the Journal of Physics, on-board energy storage would increase the monetary value of a wind turbine as a result of the increase in overall power quality and reliability (Buhagiar 2019). One possible method of energy storage includes a system designed by Buoyant Energy which consists of a floating reservoir that sinks and floats to charge & discharge, although the project is currently still in the theoretical phase (Klar et al. 2019). Other methods include a Compressed Air Energy Storage System, several of which are currently in operation (Manwell and McGowan 2018), and hydrogen storage. The traditional Pumped Hydro Storage System method, typically used on land and in mountainous regions, has been proposed by several countries for use in offshore wind farms. There is currently only one offshore example, a 30 MW capacity system located in Japan.
- Monitoring of birds and other marine life needs to occur for offshore wind projects. A major concern of offshore wind farms is the risk of birds and bats colliding with the turbines or the indirect consequences of wind farm construction taking place within their migratory path. The BOEM is conducting research with the University of Rhode Island at the nation's first offshore wind farm. The study involves tracking the movement of birds and bats fitted with nanotags. The tracking devices are installed on the foundations of the wind turbines (BOEM 2019). The goal of the project is to understand how the animals respond to the presence of the operating wind turbines. The data will be used for future offshore wind farm project planning and risk assessment conducted by the BOEM.
- Offshore wind projects can maximize output by incorporating big data, artificial intelligence research, and hydrogen production. The CEC can research ways to build upon DOE and NREL's present programs in developing commercially efficient ways to electrolyze saltwater near floating offshore wind turbines powered by its generated electricity. Another potential action is to determine the cost-effective supply chain for offshore wind produced hydrogen to reach the State's existing hydrogen users. Big Data and the Internet of things (IoT) can be used to record more data and affordably capture, process, store, manage and report useful findings from the data. Further, artificial intelligence is able to detect 'patterns' and to enhance the data in a manner

that is far more sophisticated than humans. Big Data is being discussed in Europe in nearly all aspects of the offshore wind arena along with claims that it could enhance efficiency and offshore wind farm power output by an additional 20 percent. This is the time to understand how Big Data, IoT and artificial intelligence can be incorporated into California's offshore wind sector. This long-term project affects grid operators, offshore wind developers/owners, utilities, and California ISO operators.

- Remote monitoring via drone inspection will save money and increase efficiency after installation of systems. Operations and maintenance account for 25-30 percent of the total lifecycle costs for offshore wind farms and represents a major hurdle for the offshore wind industry (Röckmann, Christine et al 2017). A study published in the Netherlands, where several offshore farms are currently operating, estimates that operations and maintenance technological advancements will reduce the number of required site visits from five per year to three per year (Röckmann, Christine et al 2017). Offshore turbine site visits are not only costly but can be hazardous for technicians working in rough weather conditions. Drones were successfully used to inspect the support structures and welds at the US's only wind farm on Block Island, Rhode Island in 2018 (Lillian 2018).
- Projections for Offshore Wind Costs may be erroneous due to a lack of consideration for rapid advancement. The CEC could play an important role in funding studies to evaluate potential sites, port infrastructure and manufacturing needs, and the environmental impacts of offshore wind deployment. Additionally, public outreach and stakeholder engagement are critical to ensure that local communities will encourage new development. With consistent support and investments, it is very likely that the necessary supporting infrastructures and supply chains will be developed and that the overall cost-competitiveness of offshore wind power will improve.

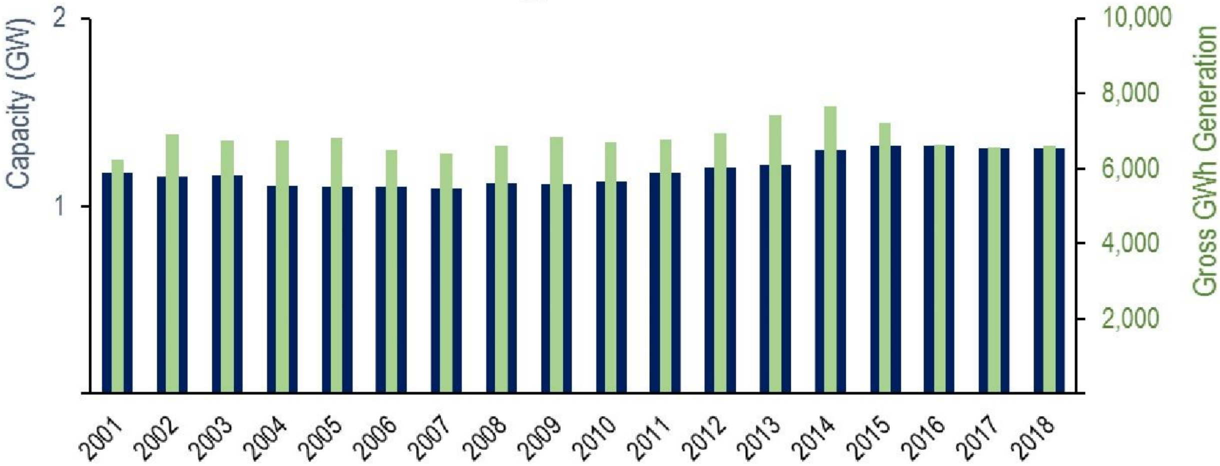
Bioenergy

Bioenergy generation uses existing waste as a form of electricity production. Common sources of biomass feedstock come from either municipal waste, agricultural waste and residue, and forest residue and thinnings, which produce energy by burning them directly or by using them to produce biogas and syngas. By focusing initiatives on improving the yield and quality of biogas and syngas, these two fuels can achieve greater market acceptance and integration into the California energy mix.

Generation Trends

Bioenergy in California is one of the older operating renewable sources in the state and has a wide variety of associated technologies and feedstocks. The diversity of bioenergy is a challenge to integrate into systems and an opportunity for expansion. Traditionally the most used feedstock for bioenergy plants is municipal solid waste (MSW) which is burned for power production. The decommissioning of several biomass plants with woody feedstocks has counteracted a number of new landfill gas and digester gas facilities to keep the production in the state relatively even over the last decade. Figure 8 shows the electricity production from bioenergy in California that produces less than three percent of the in-state generation and its share has decreased over the last years.

Figure 8: Biomass Energy Generation in California from 2001 to 2018



Source: CEC (2019f). Graphic by Energetics.

Resource Assessment

Feedstocks for bioenergy systems are very diverse and come primarily from agriculture, forestry, and municipal solid waste (MSW). The technical electricity potential of these products is 35,000 GWh or enough to support 4,650 MW of capacity (Williams et al. 2015).

Potential for Reaching Senate Bill 100 Goals

The preceding assessments anticipate a capacity factor of 85.9 percent. This estimate is much higher than the 52.9 percent capacity factor seen in California in 2018. A more conservative estimate can be calculated by multiplying the 2018 capacity factor by the technical electrical capacity (4,650 MW) provided above. The resulting electricity generation possible from bioenergy if the entire technical capacity is captured is then 21,500 GWh which would be enough electricity to provide 6.6 percent of 2045 SB100 goals (supporting calculations in Appendix A).

While bioenergy has one of the lower technical potentials of the renewable resources presented in this roadmap, it is uniquely positioned to offset fossil fuel usage with biogas and combustion products that can be dropped into fossil fuel setups. The 21,500 GWh of electrical potential would offset roughly 24 percent of 2018 natural gas usage and provide many of the same fast ramping capabilities as natural gas systems.

Cost Metrics

There are a variety of bioenergy technologies that fall into two major pathways for production: direct combustion of biomass and combustion of biomass derived gases. One of those gases, biogas, is generated from digesters and landfills among other sources. Producer gas can be generated through pathways such as gasification and pyrolysis. Biogas and other producer gases can be upgraded to renewable natural gas (RNG) which has a high methane content. The cost of some of the most common bioenergy technologies are provided in Table 19.

Table 19: Cost Range and Estimated Range for Common Bioenergy Conversion Systems

NREL Annual Technology Baseline Projection				
	2017	2018	2019	2030
Bioenergy (unspecified technology)	11.3 cents/kWh	11.8 cents/kWh	12.1 cents/kWh	12.1 cents/kWh
CEC 2018 Update				
	2017	2018	2019	2030
Bioenergy (combustion)	N/A	15.9 cents/kwh	15.9 cents/kWh	16.6 cents/ kWh

*** NREL Annual Technology Baseline does not factor in costs of building new lines for transmission and interconnection.**

Sources: NREL (2019), Neff (2019)

Other Key Metrics

Cost of Syngas Production

While producer gas is readily producible using existing biomass processing methods, it is generated with varying degrees of quality due to contaminants in the conversion process. The cost of producing syngas (cleaning producer gas) to meet fuel purity standards for electricity generation is 23 cents/kWh. Lower costs syngas production should approach a price range between 6-20 cents/kWh.

Biogas Production from Feedstock

Biogas is primarily produced as biomass decomposes into a gaseous form. It is a natural process that is driven by technologies and processes to increase efficiency and the amount of biogas produced. Feedstocks used to produce biogas include food waste, waste water treatment plant (WWTP) sludges, dairy waste, and other organics. Food waste in particular has around three times the potential for methane production when compared to biosolids. Yields from anerobic digestion of raw food waste can be as high as 3,200 standard cubic feet of methane per ton (Kuo and Dow 2017). However, this conversion efficiency can vary higher or lower depending on the feedstock and its moisture content. New processes to pretreat feedstocks prior to biogas production can increase yield by 75-80 percent.

Sludge Disposal Costs

Waste sludges remain as a byproduct from biogas production which need to be disposed of. Tipping fees can vary widely based on time of year and the weather but can be estimated at between $20 and $50 a ton (Castellon 2015). New technologies to treat feedstocks before production can reduce sludge disposal costs by 25 percent.

Recommended Initiatives

Tables 20 and 21 describe the two recommended initiatives selected for bioenergy technologies. These initiatives focus on pathways to increase production of biogas and syngas which can be converted into electricity. As a plug-in replacement for natural gas, these biomass-derived gases serve a unique purpose in providing a bridge fuel as California transitions to a renewable economy. Additionally, using this gas in existing natural gas infrastructure allows for the same fast ramping capabilities which are so important to handle rapid load changes associated with mass variable renewable deployments.

Table 20: Initiative BIO.1: Improve Cleaning Methods to Produce High Quality Biomass-Derived Syngas

RDD&D Phase	Demonstration
Description and Characteristics	Synthesis gas (syngas) derived from biomass feedstocks is a potential source of clean, renewable fuel for electricity generation. Syngas can be produced from wet and/or dry biomass via thermochemical processes such as gasification (traditional, supercritical water gasification, steam hydrogasification, etc.); pyrolysis (fast/slow, catalytic, torrefaction at lower temperatures, etc.); and hydrothermal processing. The yields and purity of syngas produced by these methods varies considerably; some produce valuable oil or solid products in addition to gas. The raw gas contains varying amounts/types of contaminants (e.g., particulates, tar, alkali metals, and chlorine, nitrogen, sulfur compounds) depending on the biomass feedstock, process used, operating temperatures, and other parameters. Regardless of technology, raw biomass producer gas must be cleaned to meet fuel purity requirements for electricity generation. Producer gas cleaning has significant technical and economic challenges. While advances have been made, removing contaminants remains expensive and can require multiple techniques, depending on end use. Tar and ammonia removal are most problematic; catalytic removal has been promising but suffers from high cost, catalyst accessibility and fouling/deactivation. Catalytic cleanup applications have scale-up issues related to temperature and pressure, impurities, fly ash, and catalyst destruction. Research areas could include lower-temperature catalysts, biomass ash catalysts, reduction of tar reformation, resolving scale-up issues, and exploring pretreatment processes such as thermal hydrolysis to reduce downstream product contaminants.
Impacts	Potential for higher yields and heating value of syngas; higher purity, lower-cost syngas with greater market acceptance for fuel gas production.

RDD&D Phase	Demonstration
Estimated Potential Impact on SB-100	Syngas does not currently supply utility-scale energy to the California grid. This initiative is meant to spur development of syngas systems and enable conversion of new biomass. The assumption for this estimate is that syngas systems are positioned to increase electricity production specifically from forestry waste. Gasification and pyrolysis technologies are suited well for these dryer feedstocks. While agricultural residues are also available for gasification and pyrolysis, the inclusion of animal manure in this category makes it difficult to estimate impacts of agricultural residue conversion to syngas technologies. Most animal manure is typically processed through anaerobic digestion to produce biogas. The technical potential of forestry waste in California is estimated at 1.9 GW. Assuming a high capture percentage of 50 percent of all forestry residue, this initiative could enable syngas installations with the potential to provide 8,800 GWh of electricity to the grid. This much electricity would contribute 1.4 percent to SB 100 2045 goals (2045 SB 100 goals discussed in Current California Energy Mix and Future Expectations for SB-100 in Chapter 1).
Areas for Advancement	Catalytic cracking (nickel-based); biomass ash or natural catalysts for tar and contaminant removal; physical or in situ upstream tar removal. Competitive small-scale syngas production; fouling/deactivation of catalysts; operating parameters and trade-offs for syngas purity versus yield; clean up in extreme environments.
Technology Baseline, Best in Class	Baseline processes: Tar removal during gasification (for example small particle feedstock) or downstream methods such as wet gas cleaning, dry gas cleaning, thermal cracking, catalytic cracking (such as nickel, non-nickel, alkali metal, acid catalysts, carbon-based). (2014) 23 cent/kWh for biomass gasification electricity production. Ammonia removal efficiencies for nickel catalysts 88-92 percent (high cost).
Metrics and/or Performance Indicators	Lower-cost syngas production: (2025) 6 cents/kWh – 20 cents/kWh. 20 percent or more syngas yield increase.
Success Timeframe	Mid-term (3-5 years). Gas cleanup requires cheaper, better catalysts and integrated processes for multiple producer gas contaminants.
Key Published References	Abdoulmoumine et al. (2015), Luo et al. (2018), Yang et al. (2017), Park et al. (2017), Woolcock and Brown (2013)

RDD&D Phase	Demonstration
Correlated National Efforts to Leverage	DOE – Conversion Research and Development
Correlated CEC Efforts	EPIC 2018-2020 Investment Plan – Initiative 4.4.1: Tackling Tar and Other Impurities: Addressing the Achilles Heel of Gasification

Source: Energetics (2020)

Table 21: Initiative BIO.2: Demonstrate Thermal Hydrolysis Pretreatment to Increase Biogas Production

RDD&D Phase	Demonstration
Description and Characteristics	Thermal hydrolysis pretreatment (THP) can be used as a precursor to Anaerobic Digestion (AD) to increase biogas production and improve the breakdown of organic material. THP is used worldwide today in wastewater treatment. It combines high-pressure boiling of waste/sludge followed by a rapid decompression to sterilize and make the waste more biodegradable, improving digestion performance. THP also alters rheology so that loading rates to the digester can be nearly doubled, with improved dewatering. The use of AD is growing for converting MSW, food processing and other agricultural wastes into biogas. Increasing the volume of waste that can be treated (degradation capacity) and output of biogas would enhance the viability of AD for gas production across feedstocks. Applying pre-treatments such as THP is one promising approach to increasing the yields of AD. Pretreatment of combined sludge/MSW streams is also a promising strategy. THP can also be applied to high pressure hydrothermal biomass conversion to improve biogas output. More research is needed to optimize the use of THP specifically for biogas production from mixed/diverse biomass streams.
Impacts	THP can potentially improve cake dewaterability, increase methane production, increase digester loading rates and produce bio-solids ready for land disposal. These improvements will lead to increases in energy output from feedstocks and potential cost reductions for waste treatment and conversion.
Estimated Potential Impact on SB-100	An increase in gas production at current California bioenergy plants would impact 295 MW of in-state capacity that relies on digester gas, landfill gas, and biogas. Assuming this initiative leads to a 75 percent increase in gas production at those facilities, 1,030 GWh of additional renewable electricity can be available to the grid. This much electricity would contribute 0.7 percent to 2030 SB-100 goals (2030 SB-100 goals discussed in Current California Energy Mix and Future Expectations for SB-100 in Chapter 1).
Areas for Advancement	Thermo-pressure hydrolysis, high pressure thermal hydrolysis. Studied primarily for wastewater pretreatment to reduce sludge; some exploration for algae digestion and MSW/food processing wastes. Increased ammonia production and generation of soluble inert materials. Uncertain impacts of THP and operating conditions on feedstock microbial population (adverse or positive).

RDD&D Phase	Demonstration
Technology Baseline, Best in Class	Sludge disposal rates estimated between $20 and $50 per ton. Yields from AD as high as 3,200 standard cubic feet of methane per ton of raw food waste. Current systems in use include: wet AD systems (high-moisture-content feedstock types) such as covered lagoon and complete mix digester; dry AD systems for low-moisture-content feedstock (e.g., yard and green waste); and plug flow digesters. THP used successfully for wastewater treatment to produce biogas and sanitized sludge.
Metrics and/or Performance Indicators	Implementation of full-scale thermo-pressure hydrolysis shown to provide higher anaerobic degradation efficiency. Increased biogas production (+75-80 percent) from waste activated sludge. Enhanced degradation of organic matter and improved cake solids content from 25.2 to 32.7 percent. Reduced total suspended solids lowers sludge disposal costs about 25 percent.
Success Timeframe	Mid-term (3-5 years); available for wastewater pretreatment, requires study and adaptation to biomass/dairy/diverted organic waste AD operations, MSW, and other waste streams.
Key Published References	Ahuja (2015), Meegoda et al. (2018), Oladejo et al. (2018), Keymer et al. (2013), Skinner et al. (2015), Westerholm et al. (2019)
Correlated National Efforts to Leverage	DOE – Conversion Research and Development
Correlated CEC Efforts	EPIC 2018-2020 Investment Plan – Initiative 4.4.3: Demonstrate Improved Performance and Reduced Air Pollution Emissions of Biogas or Low-Quality Biogas Power Generation Technologies

Source: Energetics (2020)

Bioenergy Considerations

Provided, in no particular order, are some of the notable considerations aligned with the bioenergy technology area. These considerations include opportunities, barriers, and potential related technologies for future advancement.

- RNG has a lower energy content than traditional natural gas. RNG can be upgraded or combined with traditional natural gas to increase its energy content so it can serve as a direct replacement for natural gas. While these practices are effective, waste must be available in large quantities and from consistent sources to be able to generate enough RNG for grid-scale electricity production.

- The source and security of feedstock delivery is important to ensure consistent production from bioenergy sources. Ensuring this stability is critical especially for new sources of bioenergy. Load serving entities are reluctant to embrace new source of bioenergy due to the potential for inconsistent supply. An updated assessment on the sources and security of feedstock delivery would provide a better look at the overall potential for bioenergy production and could help attract additional investment to the state.
- A lack of education on RNG and its potential integration into existing gas streams may be preventing its adoption. Coupled with a limited understanding of bioenergy is a breakdown in recycling programs which is limiting the availability of resources. Better public education and valuing of recycled material should allow bioenergy sources to operate more effectively.
- The introduction of RNG and co-products into energy and other markets will have a disruptive affect. Both RNG and other bioenergy co-products will displace incumbents such as natural gas and traditional fertilizer. Longer term supply agreements are required to ensure that shorter term economic shifts tied to changing markets do not affect the revenue of a bioenergy plant detrimentally.
- Markets for byproducts of bioenergy production is required. To provide value to bioenergy systems, coproducts need a revenue streams that can be predictable for producers. The idea of consistent supply and generation of resources is a worry throughout the bioenergy supply chain.
- Without co-products, certain thermochemical processes are not economically feasible. A higher performance for these systems is required. Similarly, bioproducts often require further processing to be ready for sale. Increases in production or quality of bioproducts can increase the overall revenue of bioenergy systems.
- Not all waste is currently accepted into the bioenergy supply chain. To enable more waste to energy systems, WWTPs and MSW systems must be willing to accept more wastes that can be converted into gaseous bioenergy sources. One major example of this is the rejection of food waste by WWTP operators. Food waste is not valued for despite its ability to increase biogas production through co-digestion due to the perception that it could introduce risks to wastewater treatment which is the main goal of WWTPs. A value tied to accepting food waste or a mandate for WWTPs to accept more waste streams would solve this problem.
- Forest fire prevention through bioenergy systems is limited by cost. While wood residue and thinning collection is one of the most noticeable and currently relevant aspects of bioenergy conversion, the cost of collecting and delivering distributed wood resources remains prohibitively expensive. In general, woody biomass generation has a higher cost compared to other renewables even without accounting for collection of the types of wood resources that most often lead to wildfires.
- The societal and environmental benefits of using excess wood for a beneficial purpose are not captured in the market today. While residual wood waste is difficult and expensive to collect, a price that encapsulates the benefit of avoiding forest fires would

go a long way to making the production of bioenergy from these sources more appealing.

- A market for carbon accounting would make RNG attractive. Monetizing GHG benefits would provide a path to greater profitability of RNG systems. To do this, a greater understanding of how waste diversion reduces GHG emissions is first required. A barrier to this analysis is that these GHG pathways are not currently well understood. There is a carbon negative potential for Bioenergy which does not exist for other products
- Inconsistent power purchase prices and few agreements with utilities are a major barrier for bioenergy systems. When producers cannot expect revenue from their production, it makes it difficult to accurately value the systems which reduces the chance for financing projects. A long-term commitment to bioenergy by load serving entities would help reduce risks for financing bioenergy systems by increasing the value of their resource.
- The costs of feedstocks are highly variable and dependent on the amount of waste created and used throughout the entire bioenergy systems. While bioenergy producers may currently receive money for taking waste that can be converted to energy, as more producers enter the market and convert waste, the value of that waste increases. The cost of feedstocks will vary due to availability, and with the volume of future wastes uncertain, there are long term risks tied to market growth.
- Assessments of feedstock logistics from forestry and agriculture would help improve understanding of a key issue facing bioenergy systems. Collecting waste feedstock for power generation provides an alternative to landfill disposal or leaving it onsite after development. The cost and availability of feedstock collection and transportation limits the potential of using biomass for power generation. Assessments of this resource can clarify the potential and viability of waste feedstock as a reliable fuel for biomass.
- Interconnection costs tied to plant siting must be considered for bioenergy facilities. This has to be balanced with a location that limits the costs associated with feedstock delivery and co-product dispatch. Typically, interconnection costs make small-scale bioenergy systems unideal in the marketplace.
- Bioenergy plants provide a greater degree of flexibility and dispatchability when compared to other renewable resources. Any new bioenergy plants may benefit from siting themselves in an area that benefits most from a dispatchable resource both in grid value and revenue received at the plant. Studies and tools that identify the best locations could be useful in this matter.
- Waste-to-energy systems have difficulty incorporating multiple waste streams. Within waste-to-energy facilities, it is difficult to separate small scale food and organic waste to the point the feedstock stream is usable for bioenergy production. While incorporating multiple waste streams diverts waste from landfills and increases sources for bioenergy production, separation challenges must be addressed before scale-up can occur.
- Certain biopower plants are limited by air district regulations mandating the number of particulates and impurities that can emitted by a plant. It is important that bioenergy plants are not unjustly punished for their emissions to the point they cannot operate. Bioenergy plants provide a useful service by diverting waste from a worse environmental fate.

- The organic component of waste to energy MSW systems must be as clean as possible as mandated by SB1383. This process needs to be done economically and efficiently to support profitable energy production.
- There is a need to reduce unwanted byproducts at all waste and bioenergy facilities. WWTPs in particular need to avoid increasing the amount of sludge that may be introduced with additional feedstocks. Sludge can threaten the performance of bioenergy production systems and requires disposal which increases cost and complexity of systems.
- Odors are an issue for any bioenergy plant using a waste or aggregate resource. This issue is particularly detrimental when bioenergy plants are sited close to residential areas.
- Waste to energy systems such as microbial fuel cells offer a way to increase renewable energy generation. Microbial fuel cells (MFCs) can treat wastewater directly with microbial activity and use this waste to produce energy and pure water. Bacteria used for MFCs can thrive on sewage in wastewater and can filter it out, limiting the amount of waste that has to be sent to landfills. Another alternative to directly producing electricity is to use MFCs to produce biogas which can be used to produce heat and energy.

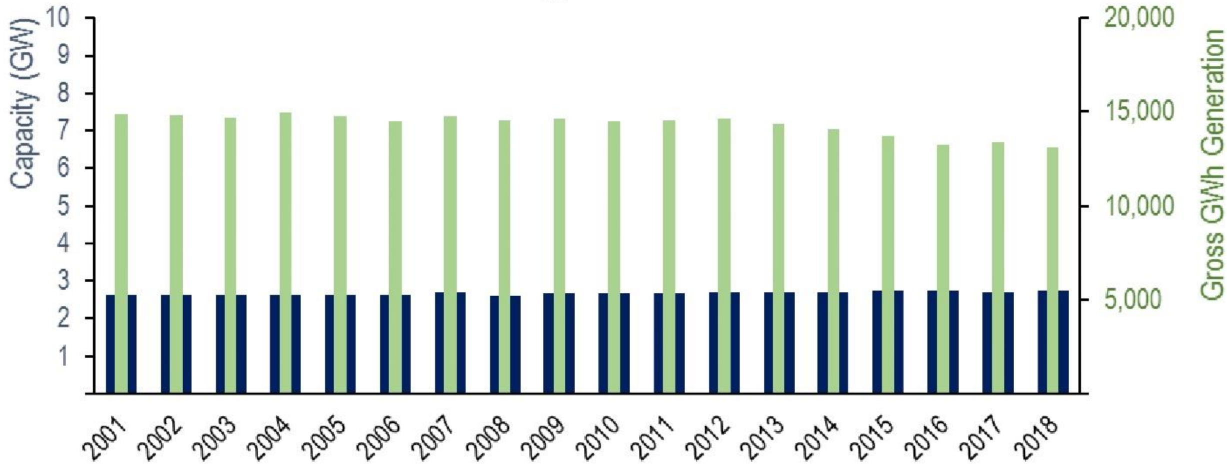
Geothermal

Geothermal systems have been a mainstay in the California energy mix since the 1960s. Geothermal plants use natural heat generated underground to produce steam and electricity. As the largest non-variable renewable resource in the state, increased geothermal development can increase California's renewable baseload energy. New technologies which can limit corrosion and access new areas for geothermal development will enable geothermal energy to provide increasing amounts of constant reliable energy while developing its capabilities as a flexible resource. Additionally, enhanced geothermal systems (EGS) provide a pathway to dramatically increase geothermal production in California.

Generation Trends

Geothermal power is the largest source of non-variable renewable power in the state of California and has been a major part of its energy mix for the past several decades. However, high costs of new systems combined with depleted production of existing resources has led to a stagnant geothermal capacity in the state, as shown in Figure 9.

Figure 9: Geothermal Energy Generation in California from 2001 to 2018



Source: CEC (2019g). Graphic by Energetics.

Resource Assessment

Estimates of additional capacity in California range from 5,000 MW–35,000 MW for conventional geothermal generation and estimates as high as 68,000 MW with the inclusion of EGS (Williams et al. 2008, USGS 2018). California has 25 known geothermal resource areas (KGRAs), of which 14 have temperatures above 300°F. Currently, geothermal capacity in California is concentrated in five regions around the state, but future development is planned in the northeast of the state for the first time. EGS demonstration plants have been developed, and commercial facilities are targeted for deployment in 2030.

Potential for Reaching Senate Bill 100 Goals

Looking at technical capacities of 5.4 GW for conventional geothermal power and 48.1 GW potential for EGS (mean estimates of geothermal capacity in California according to 2008 USGS source), the total possible production from geothermal sources can be estimated at 226,000 GWh or 69 percent of 2045 SB 100 goals. This estimate assumes the 2018 statewide capacity factor for geothermal power continues at 48.2 percent (supporting calculations in Appendix A).

Since geothermal systems typically operate in a baseload configuration, limited curtailment would be expected from geothermal production. New geothermal installations would be in a unique position to offset the decommissioning of remaining nuclear capacity in California at Diablo Canyon by providing a carbon-free replacement to this consistent source of baseload power. Flexible operating modes have also been considered for geothermal systems which would allow them to provide necessary ramping capabilities for the grid.

Cost Metrics

The LCOE for geothermal designs ranges from $0.04/kWh to $0.14/kWh, assuming a 25-year plant life (IRENA 2017). The estimated costs for EGSs range from $0.10/kWh to $0.30/kWh (IEA 2011). Table 22 depicts the geothermal energy cost target at energy at utility-scale estimated by DOE, CEC, and IRENA.

Table 22: Geothermal Power Cost Performance Targets

U.S. Department of Energy 2018 Budget Request				
	FY 2017	**FY 2018**	**FY 2019**	**Endpoint Target**
Geothermal Systems	22 cents/kWh (target met)	21.8 cents/kWh	21.7 cents/kWh	6 cents/kWh by 2030
CEC 2018 Update				
	2017	**2018**	**2019**	**2030**
Geothermal System (Flash)	N/A	13 cents/kWh	13 cents/kWh	14 cents/kWh
IRENA Renewable Power Generation Costs				
	2017	**2018**	**2019**	**2020**
Geothermal Systems	7.3 cents/kWh	7.2 cents/kWh	6.7 cents/kWh	7.6 cents/kWh

The Geothermal Electricity Technology Evaluation Model (GETEM) estimates the representative costs of generating electrical power from geothermal energy. The estimated costs are dependent upon several factors specific to the scenario being evaluated, with most of these factors defined by inputs provided.

Sources: DOE (2018a), Neff (2019), IRENA (2019)

Other Key Metrics

Maintenance Intervals

Geothermal plants produce power around 90 percent of the time from when they are commissioned and are capable of producing power on a near constant basis. Running the plant for longer periods of time can increase maintenance costs by stressing system components. Standard maintenance costs for geothermal plants are between $0.01 and $0.03 per kWh (DOE 2019b).

Discovery of EGS sites

EGS systems can be developed in any location where the subsurface rock is hot enough for a geothermal plant. California has not tapped half of its known potential geothermal resource, and potentially has only discovered 50 percent of the geothermal resource in the state (Matek and Gawell 2014).

Recommended Initiatives

Tables 23 and 24 describe the two recommended initiatives selected for geothermal technologies. These initiatives focus on the two major types of geothermal technologies: conventional and EGS. As a developed technology group, conventional geothermal systems need to reduce their cost and find ways to operate in difficult environments. On the other side, EGS are not at a stage of commercial development and must reduce risk while increasing understanding of the subsurface.

Table 23: Initiative GEO.1: Improve Materials to Combat Corrosion from Geothermal Brines

RDD&D Phase	Research and Development
Description and Characteristics	The high salinity of geothermal brines, especially in the Salton Sea region of California, degrades metal used in power production equipment and infrastructure. As a result, expensive titanium-alloys are often used to prevent corrosion and reduce necessary maintenance. Maintenance trips increase down-time for the systems and increase operations and maintenance cost. Since titanium is one of the most expensive metals, finding an alternative offers a path to cost savings if the selected material is also corrosion resistant. New materials made from base metals such as nickel have been tested but still lack the durability of titanium-alloys. However, further advancement and testing of metal alloys may lead to lower cost and more corrosion-resistant materials.
Impacts	Corrosion resistant materials reduce maintenance and operating costs for geothermal systems and make high-salinity areas more attractive for deployment in California. The use of alternative materials other than titanium-alloys would provide cost savings and lower LCOE for geothermal production.
Estimated Potential Impact on SB-100	The most visible known geothermal resource area with high salinity brines is the Salton Sea. This region has an estimated development potential of 1.8 GW but has seen limited additional capacity installed in recent years. This initiative can lower costs while keeping capacity factors high for traditional geothermal installations in the region. At maximum, this initiative will allow all 1.8 GW of Salton Sea capacity to be utilized providing an additional 7,600 GWh to the California grid. This much electricity would contribute 2.3 percent to 2045 SB-100 goals (2045 SB-100 goals discussed in Current California Energy Mix and Future Expectations for SB 100 in Chapter 1).
Areas for Advancement	Titanium-alloys are currently the preferred material for high corrosion geothermal deployments. This material is unlikely to decrease in cost, so the development of cheaper corrosion-resistant base metals is needed to improve system economics.
Technology Baseline, Best in Class	Geothermal plants operate 90 percent of the time. Maintenance costs for geothermal plants ranges between 1 to 3 cents per kWh

RDD&D Phase	Research and Development
Metrics and/or Performance Indicators	Achieve geothermal operation uptime in high salinity zones above 90 percent. Achieve maintenance costs at low end of normal range in high salinity zones (~1 cent per kWh) The corrosion rates of different metals are also an important factor for this initiative.
Success Timeframe	Mid-term (3-5 years)
Key Published References	Larsen (2019), Gagne et al. (2015)
Correlated National Efforts to Leverage	None
Correlated CEC Efforts	EPIC 2018-2020 Investment Plan – Initiative 4.3.2: Geothermal Energy Advancement for a Reliable Renewable Electricity System Geothermal Grant and Loan Program

Source: Energetics (2020)

Table 24: Initiative GEO.2: Improve Mapping and Reservoir Modeling of Potential EGS and Traditional Geothermal Sites

RDD&D Phase	Demonstration
Description and Characteristics	As geothermal development continues in California, more resources in known Geothermal areas will be occupied. Future growth of the industry relies on identification and development of low-risk sites. Improved mapping and reservoir modeling systems will increase understanding of the subsurface which will reduce the financial risks tied to geothermal development. Research and development of advanced mapping and modeling techniques will help identify both traditional geothermal sites and EGS sites. EGS allows production of geothermal power without siting at a traditional geothermal resource with natural steam or hot water production. These systems involve artificially creating a subsurface pathway where a heat transfer medium (usually water) is pumped underground into an injection well and collected in a separate production well where it returns heated at the surface. There are several concerns with EGS that are prevalent in California. To achieve the required permeability underground for the heat transfer medium to go from the injection well to the production well, hydraulic fracturing (commonly known as "fracking") is required. Concerns over seismic activity and the impact of chemicals and substances used for hydraulic fracturing on natural systems, including surface water resources, are particularly pronounced in California. While the technique is used with limited issues in Southern California oil production, any new use will be heavily scrutinized. All geothermal development involves drilling through hard rock which can drastically increase cost and threaten the potential financial viability of geothermal systems. While all the techniques to create an EGS well exist, the two areas that could provide the most benefit to California are improved assessment and characterization of underground geothermal reservoirs and adaptation of production methods for EGS systems. Improving and using assessment techniques would provide more benefit to EGS systems at this point as potential operators will have to be as informed as possible about potential development sites to receive permission to proceed with EGS developments.
Impacts	Assessment of subsurface geothermal resources in specific areas of California will help pinpoint areas for geothermal production that have limited environmental concerns, reduce or eliminate the need for hydraulic fracturing, and reduce drilling costs.

RDD&D Phase	Demonstration
Estimated Potential Impact on SB-100	EGS will be necessary to reach SB 100 2030 and 2045 goals if geothermal power maintains its same percentage of renewable energy production. If only 50 percent of available EGS sites are currently known, this initiative is estimated to lead to the discovery of 12 GW of additional EGS capacity. At current California geothermal power capacity factors, that resource could provide, at maximum, 16 percent of SB 100 2045 goals (2045 SB 100 goals discussed in Current California Energy Mix and Future Expectations for SB 100 in Chapter 1).
Areas for Advancement	Accuracy of sub-surface assessments can be improved with Artificial Intelligence techniques as well as improved data collection and analysis.
Technology Baseline, Best in Class	Estimated that only 50 percent of the geothermal resource in California has been identified.
Metrics and/or Performance Indicators	Assessment of new geothermal resources such that estimates of discovered geothermal resources in California can be increased to 75 percent.
Success Timeframe	Near-term (1-3 years)
Key Published References	DOE (2019c)
Correlated National Efforts to Leverage	DOE – Frontier Observatory for Research in Geothermal Energy (FORGE)
Correlated CEC Efforts	Geothermal Grant and Loan Program EPC-14-002, EPC-16-021, EPC-16-022, EPC-19-019

Source: Energetics (2020)

Geothermal Considerations

Provided, in no particular order, are some of the notable considerations aligned with the geothermal technology area. These considerations include opportunities, barriers, and potential related technologies for future advancement.

- The most substantial cost tied to geothermal production is for initial exploration and production. While borrowing heavily from practices employed in oil and gas exploration, the drilling practices for geothermal production focus on different rock formations. Hard rock increases the time it takes to drill and entails time-consuming maintenance. The high cost of exploration, which can account for over 50 percent of total project cost, remains one of the largest barriers to reducing the ultimate consumer-facing price of geothermal energy. Finding rigs that are available close to geothermal sites, developing drilling bits made for dealing with high temperature and pressure geothermal rock formations, and using techniques that can reduce the amount of time required to drill a well in general would all help lower exploration costs.

- Associated with the drilling cost is the added risk of drilling unproductive wells. This risk is well known by financing institutions and limits the number of willing financiers. Better modeling and surveying technologies and techniques and knowledge gained through unsuccessful explorations can help lower drilling risks. However, assessing the accuracy of these techniques requires that wells be drilled. Another way to improve the outlook for financiers would be to value plants over longer time frames more consistent with their actual lifespan.
- Lowering well field costs would increase deployments. Because the highest costs associated with geothermal resources are well exploration and drilling, cost decreases would likely result from improved geothermal reservoir discovery and accessibility. Further work in analysis and modeling of potential reservoirs can improve the likelihood of drilling successfully. By improving the certainty of reaching viable reservoirs, developers can decrease costs by minimizing the number of drilling attempts necessary. Improving methods to reach geothermal reservoirs would encourage more developers to drill and develop new power facilities by adding more certainty and reliability to the process.
- While geothermal resources are located at KGRAs, the exact siting of wells can still be improved. New assessment methods have come about in recent years with the advent of new modeling and exploration techniques. Utilizing and improving these methods will help access the best resources and could reduce costs associated with subsurface exploration and resource characterization.
- Once a well is developed and productive in a KGRA, maintenance and material costs can continue to hamper geothermal profitability. Geothermal brines found in likely areas of new development, such as the Salton Sea, contain large concentrations of corrosive impurities that degrade equipment and require constant maintenance.
- Extraction and sale of co-product impurities such as lithium present in the brines can help increase total revenue from geothermal systems. The development of lithium collection technologies can also support lithium-ion battery development in California. This additional revenue stream may attract financing to geothermal systems that would not be financed based on energy production alone.
- Development of new geothermal wells is affected by limited availability of both skilled drilling crews (especially with geothermal experience) and oil and gas rigs. A number of rigs are currently being used for policy-mandated plugging and abandoning of old oil and gas wells, which ties up resources. Some policy relief would help free up rig resources.
- One aspect of geothermal energy that is especially relevant to California is the water requirement for geothermal systems. New installations increasingly require water injection in hot formations to generate the steam required for power production. The constrained nature of California’s water resources threatens geothermal plants’ ability to operate consistently in the future. Moreover, requirements for cooling water for

geothermal power production further compound the issues surrounding water use. Possible solutions involve bringing water to constrained locations, but these approaches are area-specific and add another ongoing cost to geothermal power production. For example, transporting treated wastewater by pipeline to the power plant was a solution for the Geysers. At other geothermal sites, using desalinated water or disposed or treated water is a potential solution.

- Geothermal power is typically run in a baseload configuration. Geothermal power is one of the only reliable and consistent forms of renewable energy available in the energy market today. However, increases in variable solar power installations at a lower price point threaten to push out new geothermal generation and have led to curtailments of this renewable resource.
- Geothermal resources also have the potential to provide black start capabilities and ramping flexibility services. However, to provide these services for the grid, flexible geothermal operations must be fully developed. These ancillary services will require a higher value in the market to incentivize geothermal producers to change their operating mode from baseload to flexible generation.
- Methods of flexible generation, including controlling steam release and shutting in wells and equipment, put wear on equipment and introduce risks to normal system operation. New technologies and testbeds are required to address problems with flexible generation. In addition to system risks, there are cascading effects tied to flexible generation, including byproduct development. These risks may be viewed as an unnecessary by system operators.
- The California Public Utilities Commission's current structure provides incentives for solar production while leaving little incentive for new geothermal installations. A proper valuing of reliable baseload generation and potential flexibility of geothermal will promote further installations. However, this valuation would require a holistic grid design that looks at the specific value that all types of renewable generation provide.
- Geothermal systems more than 50 MW have burdensome permitting requirements which is changing the face of geothermal generation in the state. On the regulatory side, the Warren-Alquist Act requires that all thermal power projects more than 50 MW be licensed by the CEC. Operators are opting to install smaller systems to avoid the licensing process. Streamlining this process would help reduce the high risk already present at the outset of a geothermal project and encourage larger project proposals.
- The degree of difficulty connecting new geothermal wells and KGRAs to the grid depends on existing infrastructure and load locations, which cannot be controlled. The lack of developed transmission in new geothermal resource areas is problematic, as is the cumbersome interconnection process to access utilities. The cost of connecting geothermal facilities to transmission networks should be accounted for as a part of system development as well. Even existing systems have integration problems. For example, the Geysers have had curtailment issues due to transmission congestion.
- The Imperial Valley is a strategically important place for geothermal development. Expansion of geothermal energy in the Imperial Valley would help overall geothermal development as a strategically important element of a balanced renewable portfolio.

Capital costs are higher in this area for geothermal energy. Would help reach goal of 500 MW of energy in Imperial by 2030.

- California needs an updated resource assessment. Improved models and techniques are needed to identify zones of subsurface permeability as well. This would improve well success for both exploration, development, and drilling. Improved reservoir models and field monitoring methods (such as microseismic monitoring systems and the use of geochemical tracers) will enable operators to better manage the usen of geothermal resources as well.

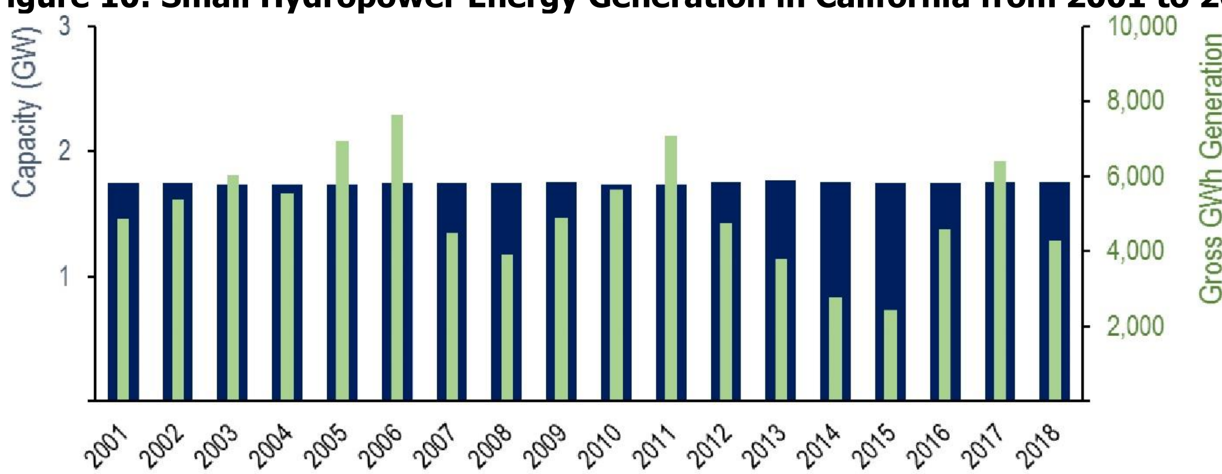
Small-Scale Hydroelectric

Small Hydropower systems (less than 30 megawatts) use existing water infrastructure by adding turbines in locations feasible for small amount of power generation. With California's large water infrastructure, there are multiple areas across the state where small hydropower systems can be installed. Developing technologies to make these systems feasible for developers can support continued development and provide benefits to water purveyors and ratepayers.

Generation Trends

The primary types of small hydropower that exist are new stream development, powering non-powered damns, and in-conduit hydropower. The capacity and energy generation of small hydropower in California is shown in Figure 10. Of the total small hydro energy capacity in California, 320 MW is in-conduit hydropower (Samu et al. 2016).

Figure 10: Small Hydropower Energy Generation in California from 2001 to 2018



Source: CEC (2019h). Graphic by Energetics.

Resource Assessment

The capacity of small hydropower has not changed significantly since 2001. Rainier years tend to produce more hydroelectric energy, while dry years produce less energy (note that periods of decline all occurred during droughts).

Potential for Reaching Senate Bill 100 Goals

Based on current understanding of small hydropower resources in California, the current maximum technical potential is 2.5 GW. At a 2018 California capacity factor for small hydropower of 27.6 percent, this technical potential can provide 6,040 GWh of total electricity or 1.8 percent of 2045 SB 100 goals (supporting calculations in Appendix A). The majority of the technical potential in California is estimated to be from existing waterways.

Cost Metrics

The LCOE of small hydropower projects in North America ranges from $0.05/kWh to around $0.18/kWh, assuming a system life span of 30 years (IRENA 2018). Installed costs can vary highly among systems, ranging from $2500/kW to $5000/kW (O'Conner 2015). Hydrology and civil construction required prior to turbine installation play a significant role in total costs. DOE has looked at streams as having promise, and cost targets for this form of hydropower are shown in Table 25.

Table 25: Small Hydro Cost Performance Targets

U.S. Department of Energy 2018 Budget Request				
	FY 2017	FY 2018	FY 2019	Endpoint Target
Small Hydro (streams)[1]	11.5 cents/kWh (target met)	11.4 cents/kWh	11.15 cents/kWh	10.9 cents/kWh by 2020 8.9 cents/kWh by 2030
NREL Annual Technology Baseline Projection				
	2017	2018	2019	2030
Small Hydro (non powered dams)	5 cents/kWh	• 5.7 cents/kWh	6 cents/kWh	6.1 cents/kWh
Small Hydro (streams)	5.8 cents/kWh	6.6 cents/kWh	7 cents/kWh	7 cents/kWh

1. The new stream development energy cost target is an unsubsidized cost of energy at utility-scale. The target is for small, low-head developments.

2. NREL Annual Technology Baseline does not factor in costs of building new lines for transmission and interconnection.

Sources: DOE (2018a), NREL (2019)

Other Key Metrics

Permitting Time for Interconnection

FERC permitting approval for small hydro projects has been shortened following the passage of the Hydropower Regulatory Efficiency Act in 2013, which allows small hydro projects in conduits that are smaller than 5 MW in capacity to be exempt from FERC permitting if there are no objections to development during a 45-day public notice period (Johnson 2013). Permitting at the state level can still take many months however.

Recommended Initiatives

There are no recommended initiatives for small-scale hydroelectric in this roadmap. However, there were a number of ideas brought up throughout the roadmapping process that are worthy of mention here as future considerations. Presented in no particular order, they are:

- Advanced assessment of velocity and head of small hydropower resources. The current resource assessment for small hydropower systems has it pegged as a small resource for California. One type of small hydropower that was brought up in the roadmapping process was hydrokinetic technologies. These technologies rely on the velocity of water to produce power instead of water height. While these technologies are attractive generally, there is no comprehensive assessment of hydrokinetic resource for California. To better understand the potential for hydrokinetic technologies, an assessment of velocity of head of canals, streams, and other water ways in California is recommended.
- Modular systems for hydropower. Modular systems are adaptable to different waterways and limit the need for site specific design which limits installation and maintenance costs. Development of these standardized systems was originally included as an initiative. However, modular systems exist already and have shown little impact on small hydropower in the state.
- Improved interconnection. Removing obstacles to interconnection of spatially isolated and small devices would lower risks for new small hydropower installations. However, it is difficult to identify a specific process or technology that would universally help small hydropower technologies. Smart inverters exist that can be adapted to each small hydropower device to ease with this process, but these are already developed and on the market.
- Additive manufacturing for small hydropower systems. AM would enable manufacturing based on site specific needs and characteristics. However, as a fledgling technology, it is difficult to pinpoint a specific element or component of small hydropower systems that would benefit significantly from AM. The lack of clarity surrounding AM makes it difficult to recommend a specific initiative related to small hydropower.

Small-Scale Hydroelectric Considerations

Provided, in no particular order, are some of the notable considerations aligned with the small-scale hydroelectric technology area. These considerations include opportunities, barriers, and potential related technologies for future advancement.

- System development costs are high enough that they often prohibit small hydropower development. These costs stem from a variety of factors. Each site is custom engineered, as a site's hydrology and structure contributes to a unique (and therefore expensive) design. As with site development, hydropower components and additional civil structures required for deployment are also custom engineered which again increases upfront costs.
- Smaller system designs face high soft costs for permitting and grid integration. Small hydropower systems deal with similar permitting and interconnection costs as larger projects but produce less energy. Regulatory changes at both the national and state levels have sought to mitigate permitting costs, but challenges remain at local levels. Soft costs associated with grid integration are harder to address, as many locations are far from existing transmission lines.
- The total amount of energy that can be produced from small hydropower in California is uncertain. The last hydropower resource assessment for the state was conducted in 2006 and was limited in scope (Navigant 2006). California experienced many changes

to water availability and flow since that time. The 2018 National Climate Assessment highlighted increasing temperatures and climate change as reasons for decreased winter snowpacks and amplified droughts in California (U.S. Global Change Research Program 2018). Additional assessments can increase current understanding of and future expectations for water flows.

- The performance of in-conduit systems is tied to area hydrology and water flows. When water is available, hydropower systems have high capacity factors at their rated power outputs. However, climate change impacts are reducing the amount of water available in California. Limited water availability prevents maximum performance of in-conduit and other hydropower systems, decreasing the potential impact hydropower systems can have on state energy goals.
- California places tight controls on water use to meet farming and municipal needs. Small hydro systems cannot control how much water flows through them at any given time because changes in water flow affect downstream water distribution. This lack of control prevents small hydropower from providing dispatchable and reliable energy and makes it a more variable resource.
- Hydropower systems are not typically paired with energy storage. Traditional hydropower systems can control the flow of upstream water and use this water as a form of energy storage which makes pairing with other energy storage systems unnecessary. However, with unpredictable water flows in California, using storage would mitigate production risk and ensure small hydropower stays a non-variable resource. But, costs for small hydropower increase when energy storage is added which limits the feasibility of paired systems.
- In-conduit hydropower provides several services which are known but not valued by the marketplace. Small hydro projects can help defer grid upgrades by providing ancillary services such as frequency and voltage control. Policy changes that value these grid services can allow small hydro to flourish and maintain necessary cash flows. Separately, in-conduit hydropower can be used as a revenue generating replacement for pressure reduction valves, which are used to control water pressure in the state.
- Hydro projects are heavily governed by Rule 21. The need for generating units to install smart meters that communicate with the grid affects small hydropower more than other systems due to remote and undeveloped location of these resources. Finding ways to decrease the burden of Rule 21 on small hydropower systems can reduce financing and installation risks.

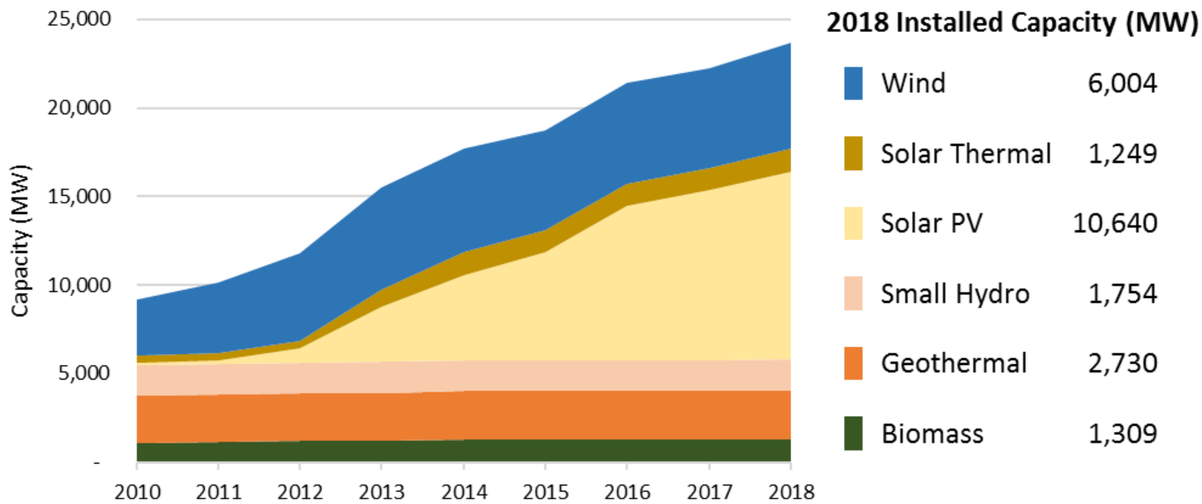
Grid Integration Technologies

A flexible grid which can incorporate multiple points of generation and consumption is necessary for California to meet SB 100 goals. Grid integration and infrastructure upgrades will support the continued implementation of variable renewable resources into the state grid through and create a more resilient, reliable electric grid.

Generation Trends

In 2017, California’s electricity system generated more than 292,000 gigawatt hours (GWh) of energy, with over half of that total being provided by low carbon (nuclear and large hydropower) and zero-carbon sources. Zero-carbon sources include the many large-scale renewable energy sources discussed in this roadmap. The profile of cumulative installed capacity of these renewable resources is shown in Figure 11. The total installed large-scale renewable capacity does not include the 6,800 megawatts (MW) of renewable energy generated from homes and businesses across the state.

Figure 11: Cumulative Installed Large-Scale Renewable Energy Capacity from 2010 to 2018



Source: CEC (2019a). Graphic by Energetics.

Resource Assessment

To handle all electric load in the state, California has more than 4,400 miles of high-voltage (>230 kV) transmission lines and more than 10,300 miles of low-voltage (<230 kV) transmission lines (DOE 2015). However, the energy grid of California requires a new type of grid infrastructure development to balance the growing number renewable energy resources with the decreasing number of conventional energy resources. Inefficiencies in the system lead to problems like curtailment. In 2015, the California ISO was forced to curtail over 187,000 MWh of solar and wind generation. In 2016, that total rose to more than 300,000 MWh (California ISO 2017).

Effective planning can help California achieve 100 percent zero-carbon energy by 2045 by optimizing the existing transmission system and installing new state-of-the-art transmission infrastructure. Both types of improvements will be necessary to handle new electric flows and increases in power generation from renewable sources.

Improvements are required in the four main technology areas within grid integration: transmission and distribution; devices, measurement, and system controls; design, modeling, and resource planning; and grid resilience. All four of these systems coexist to ensure electricity is reliably transferred from generation sources to load sources.

Reaching Senate Bill 100 Goals

Expanding the electric grid either through line capacity upgrades or construction of new electric lines is essential to reaching SB 100 goals. For 2030, an increase in consumption of 54,500 GWh coupled with additional offsets of fossil fuel generation leads to a 2030 SB 100 goal of 141,000 GWh in new capacity on the grid (all renewable). Similarly, for 2045, SB 100 goals require 326,000 GWh in new electricity from renewable sources compared to 2018 generation (supporting calculations in Appendix A).

While renewable energy expansion is expected in some areas that are already grid connected, any development of new resource areas (most noticeably offshore resources) will necessitate new power lines. The high costs of power lines, substations, and other grid equipment must be accounted for in financial planning and serve as a barrier to entry for many new systems. Tables 26-28 provide the baseline costs of transmission lines, substation, and high-voltage direct current (HVDC) bipole submarine cable.

Cost Metrics

Table 26: Baseline Transmission Line Costs

Type of Transmission Line	New Line Cost ($/Mile)
230 kV Single Circuit	$959,700
230 kV Double Circuit	$1,536,400
345 kV Single Circuit	$1,343,800
345 kV Double Circuit	$2,150,300
500 kV Single Circuit	$1,919,450
500 kV Double Circuit	$3,071,750
500 kV HVDC Bi-pole	$1,536,400
600 kV HVDC Bi-pole	$1,613,200

Source: Black and Veatch (2014)

Table 27: Baseline Substation Costs

Substation	Baseline Cost
230 kV Substation	$1,706,250
345 kV Substation	$2,132,700
500 kV Substation	$2,559,250

Source: Black and Veatch (2014)

Table 28: Baseline HVDC Bipole Submarine Cable Cost

Voltage	Power (MW)	Cost (Million $/mile)
150 kV	352	2.52
300 kV	704	2.64
300 kV	1,306	5.02

Source: Liun (2015)

Other Key Metrics

Curtailed Energy

The curtailment of renewable energy is when renewable energy sources are ordered by grid operators to stop producing energy as a result of grid conditions, such as line congestion or overgeneration in the system. The California ISO curtailed 401,492 MWhs of electricity in 2017 and 461,000 MWhs in 2018 (California ISO 2019). Decreasing the amount of energy curtailed will further enable California to meet is SB 100 goals.

Interconnection Energy Losses

As electricity travels from points of generation to points of consumption, up to 15 percent of it is lost through line resistance. In 2017, California lost an estimated 14 million MWh of electricity from losses. Using HVDC lines instead of high-voltage alternating current (HVAC) lines where appropriate can decreases losses by 30-50 percent where implemented (Siemens 2014).

Cyber Attacks

Between 2013 and 2015, the US energy sector experienced more than 250 cyber incidents, more than any other sector, with cybercrime costing the sector $27.62 million in 2015. Meanwhile, spending on security systems for the electric grid totaled between $150 to $800 million dollars in 2015 (DOE 2018b).

Recommended Initiatives

Tables 29-30 describe the two recommended initiatives selected for grid integration technologies. These initiatives focus on two separate but important aspects of the grid: security and offshore integration. Cybersecurity is a constant threat to the grid and diligence will be required to prevent any future attacks as massive amounts of new capacity comes into California's grid at both the utility and distributed levels. Additionally, as land-based resources become more stressed, expanding energy production to offshore sources (mainly wind and wave power) will provide a new pathway to growing utility-scale renewable production. These systems present unique challenges that must be addressed to transport energy efficiently to shore.

Table 29: Initiative GIT.1: Improve Smart Inverters to Optimize System Communication

RDD&D Phase	Demonstration
Description and Characteristics	The electricity grid is transitioning to a system with multiple points of generation and consumption. The grid must integrate variable energy systems, large scale energy storage, and net metering along with enabling the development of thousands of distributed energy systems. In order to maintain grid stability, grid operators must be able to access data in real-time and communicate with multiple inverters on the grid. To integrate the power from many renewable sources onto the grid, the electricity produced by renewables must be passed through an inverter to match the voltage and frequency of power on the grid. Smart inverters can allow data to be transferred faster which allows the grid to monitor early warnings of grid events and behavior, identify failing equipment, and develop improved system models among other capabilities. California is already transitioning away from traditional (non-smart) inverters due to the implementation of Rule 21. However, not all smart inverters that fulfill Rule 21’s requirements have the level of responsiveness and security required for optimal and secure grid operation. To increase the speed that data is available from smart inverters, the devices must be internet connected and able to access grid monitoring and control systems directly. However, the increased amount of data and frequency of data transfer requires careful management and standards of practice to ensure security. Cyberattacks in particular have become a point of focus for new smart inverter technologies.
Impacts	Inverters will be able to transfer data securely and be remotely controlled. The advancement of smart inverters at the grid will require an accepted standard for data transfer as well. An increase in smart inverters on the grid will enable more efficient transmission and distribution of electricity and will improve integration of renewable energy sources. The quicker and safer data can be transferred, the more efficient the system can be.

RDD&D Phase	Demonstration
Estimated Potential Impact on SB-100	This initiative will impact the safety and security of all existing electrical transmission. Additionally, smart inverters will protect 141,000 GWh of new renewable energy generation by 2030 and 326,000 GWh by 2045. This will require protection of 55,000 MW of capacity by 2030 and 129,000 MW by 2045 (2030 and 2045 SB-100 goals discussed in Current California Energy Mix and Future Expectations for SB-100 in Chapter 1). Due to low capacity factors associated with renewable energy technologies, the capacity put onto the grid will surpass the current capacity required for similar amount of electricity.
Areas for Advancement	Synchrophasor technology can collect 30 to 60 samples per second to provide grid performance data; Encryption of transferred data; Virtual Oscillator Control.
Technology Baseline, Best in Class	250 cyber incidents on the U.S. electricity sector between 2013 and 2015
Metrics and/or Performance Indicators	No successful cyber incidents in California.
Success Timeframe	Near-term (1-3 Years)
Key Published References	Brown (2019), Microgrid Knowledge (2018), CPUC (2019b), GTM (2018)
Correlated National Efforts to Leverage	DOE – Advanced Systems Integration for Solar Technologies (ASSIST) DOE – Wind Energy Grid Integration and Grid Infrastructure Modernization Challenges DOE – Grid Modernization Initiative (GMI)
Correlated CEC Efforts	EPIC 2018-2020 Investment Plan – Initiative 3.3.1: Optimize and Coordinate Smart Inverters Using Advanced Communication and Control Capabilities EPIC 2018-2020 Investment Plan – Initiative 3.3.2: Advance Distribution Planning Tools to Reduce the Cost and Time Needed for Interconnection to the Grid and Improve Interoperability

Source: Energetics (2020)

Table 30: Initiative GIT.2: Decrease Line Losses of Underwater High-Voltage Infrastructure for Offshore Energy Interconnection

RDD&D Phase	Demonstration
Description and Characteristics	To connect offshore resources to the onshore grid, extensive cabling and interconnection systems are required. Additionally, underwater cabling represents a very high upfront cost for offshore systems, so optimal design and management of cables, interconnections, and substations is important. Also, the type, structure, and location of cables should minimize electrical losses for the system. Currently, HVAC cables are used most commonly to transmit power for the grid. For specific on-land and offshore transmission where there is a long transmission distance, HVDC transmission lines have been implemented. The ideal offshore wind resource in California exist in areas with large enough transmission distances to warrant the use of HVDC infrastructure. There is a need to understand the design and location of HVDC systems to optimize costs and ensure proper connection to on-land grid infrastructure. In addition, there is room for improvement in HVDC infrastructure in terms of cost and efficiency. Infrastructure that can use improvement include the substations and converter stations that collect energy from multiple devices and switch between AC and DC power in addition to the HVDC lines themselves. As a starting point, Europe's sub-sea cable development provide a blueprint for optimal locations where HVDC should be deployed to bring offshore wind generated electricity to high load areas. Additionally, Massachusetts has undertaken HVDC transmission studies for their proposed wind farms that can serve as a template for California.
Impacts	HVDC cable infrastructure will decrease power losses and enable more efficient connections especially to resources located further from the shore. HVDC also require a smaller amount of material since they have smaller cross-section which limits cable cost and reduces the complexity of installation. Development of HVDC cables and interconnection infrastructure can also be applied to on-land transmission to lower line losses.
Estimated Potential Impact on SB-100	HVDC cable infrastructure will reduce line losses for offshore infrastructure. By 2045, it is feasible that 8.4 GW of offshore wind power will be put on the California grid. Typical line losses seen when integrating offshore systems are around 15 percent for high voltage AC systems. A reduction in line losses using HVDC infrastructure would save 2,200 GWh of electricity or 0.7 percent of total 2045 SB 100 goals (2045 SB 100 goals discussed in Current California Energy Mix and Future Expectations for SB 100 in Chapter 1).

RDD&D Phase	Demonstration
Areas for Advancement	HVDC Cables are commercial but have limited demonstration for offshore use. Successful deployment of offshore infrastructure will also require offshore interconnection and substations to couple energy from separate turbines before transmission to shore. There is room for improvement in costs, availability, and transmission for HVDC infrastructure. The location and on-land interconnection of HVDC transmission into the grid also requires an understanding of load centers and interconnection processes.
Technology Baseline, Best in Class	Submarine HVDC cable cost: 150 kV and 352 MW: $2.52 million per mile 300 kV and 704 MW: $2.64 million per mile 300 kV and 1,306 MW: $5.02 million per mile
Metrics and/or Performance Indicators	Future deployment of HVDC systems below current estimated costs. Estimated reduction in line losses of 30-50 percent over comparable HVAC system.
Success Timeframe	Long-term (>5 Years)
Key Published References	Baring-Gould (2014), Apostolaki-Iosifidou et al. (2019), Collier et al. (2019)
Correlated National Efforts to Leverage	None
Correlated CEC Efforts	No correlated Energy Commission efforts currently

Source: Energetics (2020)

Grid Integration Considerations

Provided, in no particular order, are some of the notable considerations aligned with the grid integration technology area. These considerations include opportunities, barriers, and potential related technologies for future advancement.

- Grid infrastructure does not produce revenue with ratepayers left to pick up the costs of integrating new power lines and grid devices into the energy system. Therefore, the value of these upgrades must be justified to support the upfront capital costs of new transmission lines, smart devices, and other grid management components. The California Public Utilities Commission has oversight of the state’s electric infrastructure and has a significant role to play in future activities related to grid infrastructure as well.
- Renewable resources tend to be concentrated in centralized areas. This leads to large amounts of power coming from multiple facilities located all in the same place. This can

create overloading on the grid as a result of overgeneration of renewables in these areas. Increases in line capacity of existing infrastructure or deployment of additional power lines are two ways to address centralization issues.

- Distributed resources have increased the complexity of integrating renewables. The advent of distributed energy resources, net metering, and energy storage systems require advanced grid systems and control to deal with multiple directions of power flow. With new sources of electricity being introduced to the grid at an increasing rate, distributed systems will heavily shape future grid designs.
- The benefits of new grid infrastructure are not all captured. Grid upgrades can mitigate wildfire hazards, improve system cyber security, and increase energy flow from generation sources to load sources. It is important to demonstrate all the ways a specific upgrade improves the grid so that each benefit can be properly valued.
- Sensors and communications systems will be required to interpret measurements from across the grid. The transition from a conventional grid to a flexible grid with more dispatchable resources requires the development of smart grid devices. With constantly changing loads due to variable generation, distributed energy resources, and energy storage systems, all grid inputs and outputs must be connected to ensure that grid operators can maintain a balanced system.
- Operators are hesitant to install new grid integration technologies due to technology lock in and high costs. One example of a technology that is unlikely to be upgraded is transformers. Because transformers are a critical component for grid reliability and have a high initial cost of replacement, IOUs are unwilling to stray from traditional designs. This technology lock in occurs even though upgrading grid components is an easy way to improve grid performance.
- Developing new infrastructure that increases accessibility to new resources is often more expensive than upgrading current infrastructure. Many projects go undeveloped because of their distance from existing grid infrastructure and the associated cost of interconnection. The preference for easier to connect resources with lower upfront costs limits the number of renewable projects that can be brought online. To reach SB-100 goals, new development sites and grid infrastructure will eventually be required.
- Transactive energy systems have the potential to integrate more renewables and improve load factors on the grid. Transactive energy systems facilitate communication between grid operators, power producers, and consumers. With access to information about real-time electricity costs, consumers have the option to alter their consumption to lower their energy bills. Anticipated changes in behavior include increasing energy usage when renewable energy production is at its peak in the afternoon and decreasing usage in the evening as solar energy goes offline and fossil fuels ramp up generation.
- The growing development of smart devices is allowing for the transformation of the electricity system. Smart devices allow consumers to automatically control their behavior by adjusting consumption to energy pricing signals (such as charging cars at night when prices are low or running appliances in the middle of the day when there is an excess in energy). Consumers are also able to participate in demand response programs with the use of smart devices. This automated behavior will gain importance as California increases its reliance on renewable energy resources. Grid operators can

allow consumers to help change electric flow patterns and reduce consumption through their smart devices which can defer the need for grid upgrades.

- Advanced power electronics and system controls can help increase penetration of renewables in the electric grid and improve reliability. Improved resource forecasting and modeling efforts can reduce renewable energy curtailment and optimize supply- and demand-side resources. Smart devices can also help increase understanding of how the system can operate most efficiently as the deployment of distributed energy resources, in addition to utility-scale systems, increases.

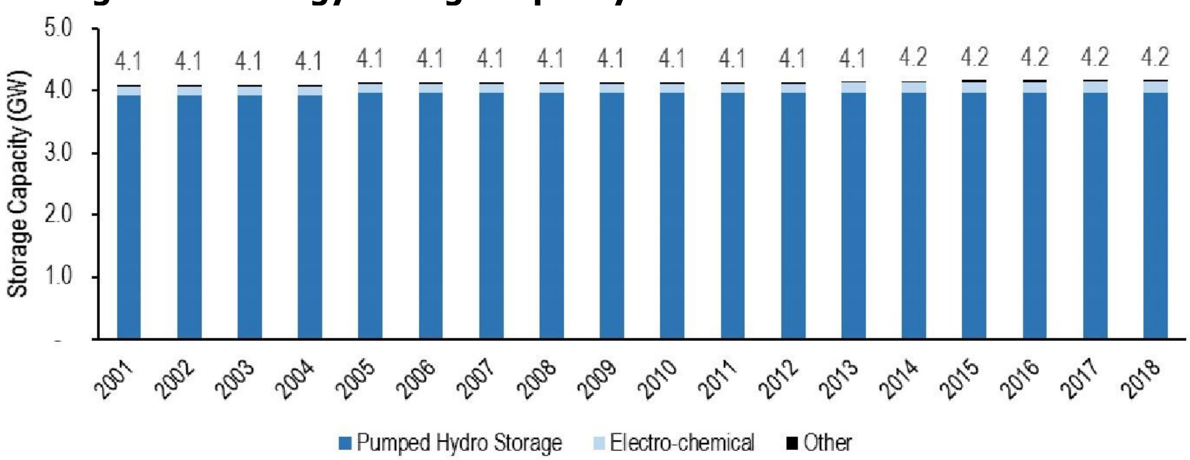
Energy Storage Systems

As the California grid incorporates increasing amounts of variable resources, continued incorporation of storage systems into the grid will be necessary to ensure reliability while minimizing curtailment of energy sources. Low-cost, high-performing energy storage systems are essential to enabling a greater penetration of renewable energy on California's electric grid. Incentive programs and the California legislature have made development and installation of energy storage systems a priority, and the CEC can play a key role in the development, testing, demonstration, and deployment of new systems (Energetics 2019).

Generation Trends

The value of energy storage lies in its ability to increase the penetration of inexpensive variable renewable sources and to provide ancillary services that stabilize the grid. While traditionally, storage in California has been provided by pumped storage hydropower (PSH) systems, decreasing prices of lithium-ion batteries and the continued emergence of other forms of thermal, mechanical, and electrochemical storage are leading to an increase in energy storage capacity in the state for the first time in decades. These trends are visualized in Figure 12.

Figure 12: Energy Storage Capacity in California from 2001 to 2017



Source: DOE (2019d). Graphic by Energetics

Resource Assessment

PSH plants require specific sites with a low- and a high-height water reservoir nearby. DOE's Hydropower Vision report conservatively estimates that 650–1,075 MW of additional pumped hydropower capacity is available in California (DOE 2016). Other types of storage systems have a bevy of capacity available since they can be flexibly located and have few locational and legislative limitations, although installing storage systems near transmission lines and junctions has the benefits of limiting losses and easing system integration.

Potential for Reaching Senate Bill 100 Goals

Energy storage is a necessary asset to achieve SB-100 electricity goals. Since the most plentiful resources in California, Solar and Wind, are variable, renewables will be unable to provide enough supply to meet demand without installing renewable systems at a capacity level massively over California's requirements. Energy Storage Systems allow renewables to smooth generation and to provide electricity to the grid even when renewable assets are not generating.

Renewables are currently able to provide 10-20 percent of generation throughout the day with maximums greater than 40 percent during peak daylight hours. A rough future 2045 estimate assumes that for 6 hours a day, renewables are able to provide 100 percent of electricity while for the remaining 18 hours, renewables average 20 percent of total grid production. Applying these values to 2045 SB 100 targets, yields a requirement of 247,000 GWh of storage available throughout the year. If storage systems on average operate at maximum for 8 hours, a high-end estimate for necessary storage installations is 85 GW of 8-hour storage by 2045 (supporting calculations in Appendix A).

Cost Metrics

The cost of storage systems other than PSH has decreased in the last several years. Looking forward, the DOE FY 2019 budget request establishes cost performance targets for grid-scale energy storage technologies, summarized in Tables 31 and 32. Aqueous soluble organic electrolyte batteries (redox flow battery systems) currently represent DOE's choice for the chemistry of a utility-scale battery.

Table 31: Energy Storage Cost Performance Targets

	FY 2017	FY 2019	Endpoint Target
Grid-scale (>1 MW) aqueous soluble organic electrolyte (redox flow battery system)	\$350/kWh for a 4-hour aqueous soluble organic flow system	\$225/kWh for a 4-hour aqueous soluble organic flow system; projected 1 MW/4 MWh system operating at 150 mA/cm^2	\$100/kWh for a prototype redox flow battery system by the end of FY 2025

Source: DOE (2018a)

Table 32: Current and Projected Energy Storage Capital Costs

Energy Storage System	2018	2025
Lithium Ion Battery	271 $/kWh	189 $/kWh
Flow Battery	555 $/kWh	393 $/kWh
Lead Acid Battery	260 $/kWh	220 $/kWh
Pumped Hydro	2,638 $/kW	2,638 $/kW
Compressed Air	1,669 $/kW	1,669 $/kW
Flywheel	2,880 $/kW	2,880 $/kW

Source: Mongird et al. (2019)

Other Key Metrics

Table 33 shows some of the metrics of energy storage systems, such as maximum discharge duration, lifetime, energy density, and conversion efficiency.

Table 33: Energy Storage Metrics

System	Max Discharge Duration	Max Cycles /Lifetime	Energy Density(wH/L)	Conversion Efficiency
Lithium Ion Battery	8 hours	1,000 – 10,000 Cycles	200 – 400	85 – 95%
Flow Battery	8 Hours	12,000 – 14,000 Cycles	2 – 6	60 – 85%
Lead Acid Battery	8 Hours	6 – 40 Years	50 – 80	80 – 90%
Hydrogen	1 Week	5 – 30 Years	600 (at 200bar)	25 – 45%
Molten Salt	Hours	30 Years	70 – 210	80 – 90%
Pumped Hydro	16 Hours	30 – 60 Years	0.2 – 2	70 – 85%
Compressed Air	30 Hours	20 – 40 Years	2 – 6	40 – 70%
Flywheel	Minutes	20,000 – 100,000 Cycles	20 - 80	70 – 95%

Source: EESI (2019)

Recycled Batteries

Currently, less than 5 percent of Lithium-ion batteries in the United States are recycled. Since the majority of key Lithium-ion battery materials are only accessible overseas, DOE has made it a priority to develop the battery recycling industry within the US and seeks to recycle 90 percent of domestic lithium battery technologies (DOE 2019e). Furthermore, to address this issue the California Environmental Protection Agency created the Lithium-ion Car Battery Recycling Advisory Group to advise the legislature on the recovery and recycling of lithium-ion vehicle batteries sold with motor vehicles in the state. The group, which convenes quarterly, was formed in 2019 in response to Assembly Bill 2832, and consults with universities and research institutions with experience in battery recycling, manufacturers of electric and hybrid vehicles, and the recycling industry to inform California lawmakers on appropriate policies.

Recommended Initiatives

Tables 34 and 35 describe the two recommended initiatives selected for energy storage technologies. These initiatives recognize that lithium-ion batteries are the dominant technology type while seeking to diversify energy storage technology deployments. At the utility-scale, all energy storage technologies offer more value if they are able to provide longer durations of storage. However, in the short-term, lithium-ion batteries are expected to dominate deployments of energy storage systems and addressing their environmental and supply chain impacts can reduce LCOE for these battery systems.

Table 34: Initiative ESS.1: Lengthen Storage Duration of Energy Storage Systems (8-hour or greater)

RDD&D Phase	Demonstration
Description and Characteristics	Energy storage systems are limited by the amount of time they can store and discharge energy. Most storage systems have storage capabilities which last from minutes to a few hours. Longer duration storage systems are necessary to mitigate the future effects of increased penetration in variable renewable resources such as solar power. Utility-scale long duration storage systems can be both behind and in front of the meter. There is a great demand for systems that can be paired with solar power in particular to ease variability and provide a baseload power. Energy storage systems also serve a valuable function when not paired with a specific generating asset as they can provide a variety of services from voltage control to instantaneous black-start power. The increasing need for fast start energy due to massive solar PV installations will require large amounts of available power on stand-by which can be provided by long duration storage. Current solar PV installations are not likely to be retrofitted with behind the meter storage, so separate storage installations fill a specific utility need. The increase in storage time above 8 hours would ensure the constant availability of excess energy. A push toward days-long storage would ensure energy availability even during prolonged times of decreased renewable output. Problems with variability and potential low renewable production will be exacerbated as additional renewable power comes online to meet SB 100 goals.
Impacts	Longer duration storage could help reduce renewable generation curtailment, reduce natural gas ramping requirements to meet evening peak demand, and even shift excess renewable generation to days and/or seasons that have less generation. Additionally, long duration storage will alleviate concerns surrounding increased renewable integration on the grid.

RDD&D Phase	Demonstration
Estimated Potential Impact on SB 100	An estimated 85 GW of energy storage capacity will be required by 2045 to support the electric grid. An increase from 8 hours to 10 hours of energy storage capability on average would reduce the necessary energy storage capacity by 17 GW for 2045 (2045 SB 100 goals discussed in Current California Energy Mix and Future Expectations for SB 100 in Chapter 1).
Areas for Advancement	The following energy storage technologies are capable of providing greater than 8-hours of economic energy storage: Lithium-ion Battery Improvements, Small-Scale Pumped Hydro Storage, TES (with mediums such as molten salt and liquid aluminum), Hydrogen, Compressed Air Energy Storage, Flow Batteries. Any energy storage technology that can achieve long-term energy storage should be supported.
Technology Baseline, Best in Class	Maximum duration of many energy storage technologies shown in Table 33.
Metrics and/or Performance Indicators	Utility-scale energy storage systems should be able to provide 10-12 hours of storage.
Success Timeframe	Mid-term (3-5 years)
Key Published References	Navigant (2018), Dyer (2018)
Correlated National Efforts to Leverage	DOE – Office of Electricity's Energy Storage Systems Program
Correlated CEC Efforts	EPIC 2018-2020 Investment Plan – Initiative 3.4.1: Assessment and Simulation Study of the California Grid with Optimized Grid-Level Energy Storage. EPIC 2018-2020 Investment Plan – Initiative 4.3.1: Making Flexible-Peaking Concentrating Solar Power with Thermal Energy Storage Cost Competitive GFO-18-305: Developing Lessons Learned, Best Practices, Training Materials and Guidebooks for Customer Side of the Meter Energy Storage – EPC-19-026 GFO-19-305: Developing non-Lithium Ion Energy Storage Technologies to Support California's Clean Energy Goals

Source: Energetics (2020)

Table 35: Initiative ESS.2: Optimize Recycling Processes for Lithium-Ion Batteries

RDD&D Phase	Demonstration
Description and Characteristics	In the coming decades there is expected to be terawatt hours of used electric vehicle (EV) batteries in addition to the gigawatt hours of stationary battery storage, nearly all of which are currently lithium-ion technologies. However, there is currently a dearth of lithium-ion battery recycling programs in California. Without recycling programs, these batteries will either be thrown away or routed out of state or out of country. There is a substantial lost opportunity without recycling since many materials in lithium-ion batteries are expensive and primarily sourced outside of the United States. Keeping the battery materials in-state could create new markets for recycled battery materials and components and spur California's battery manufacturing industry. Lithium-ion batteries also potentially pose a serious environmental hazard if recycling is not done properly.
Impacts	Battery recycling in California represents a huge economic opportunity which could help create new markets for battery manufacturing and ultimately reduce the costs of batteries using materials recycled in California. Many materials in lithium-ion batteries, such as cobalt, are expensive and sourced almost entirely out of the US. Keeping these materials in California through battery recycling would open opportunities to reuse these materials in battery manufacturing, helping to lower the costs of battery manufacturing. California needs targeted market and business drivers to encourage in-state battery recycling in order to capture this economic opportunity. Additionally, this initiative would reduce environmental impacts of discarded or improperly dismantled batteries.
Estimated Potential Impact on SB-100	This initiative will improve environmental outcomes associated with lithium-ion energy storage. With lithium-ion batteries slated to be the primary type of energy storage system installed over the next 25 years, the proper disposal of these systems will be necessary. Recycling of lithium-ion batteries will impact system installation costs due to shorter lifespans (10-15 years). Reduction in recycling costs can therefore help spur new installations and financing. This initiative will impact 100 MW of lithium-ion batteries currently operating in California and an additional 600 MW of contracted and announced lithium-ion installations. Any future installations between now and 2030 would also be impacted by before the end of SB 100's timeframe in 2045.

RDD&D Phase	Demonstration
Areas for Advancement	Streamlined recycling processes; metal and material extraction processes; battery manufacturing from recycled materials. Battery disposal; battery manufacturing; material recycling/repurposing.
Technology Baseline, Best in Class	Less than 5 percent of Lithium-ion batteries in the United States are recycled
Metrics and/or Performance Indicators	DOE target of 90 percent rate of recycling for lithium-ion batteries
Success Timeframe	Mid-term (3-5 years)
Key Published References	Engel et al. (2019), Battery University (2019), Duesenfeld (2019), Walton (2019)
Correlated National Efforts to Leverage	None
Correlated CEC Efforts	EPIC 2018-2020 Investment Plan – Initiative 3.2.2: Battery Second Use EPIC 2018-2020 Investment Plan – Initiative 7.3.3: Improve Lifecycle Environmental Performance in the Entire Supply Chain for the Electricity System GFO-19-310: Validating Capability of Second-life Batteries to Cost-Effectively Integrate Solar Power for Small-Medium Commercial Building Applications Interagency Effort to Discuss End-of-Life of PV Panels, EV Batteries, and Energy Storage Systems.

Source: Energetics (2020)

Energy Storage Considerations

Provided, in no particular order, are some of the notable considerations aligned with the energy storage technology area. These considerations include opportunities, barriers, and potential related technologies for future advancement.

- The most important performance characteristics are site- and use-dependent for energy storage systems. Energy storage performance can be judged by a variety of factors including power output, energy density, and efficiency. The relative importance of these factors is determined by the specific use case of energy storage systems. Focusing on developing systems that are customizable and modularizable would make them more attractive to a variety of customers with diverse use cases. System performance across the board will improve as technologies continue to be demonstrated and funded.

- A standardized way to judge energy storage system performance would be beneficial. In California, the grid requires technologies that can store and deliver power quickly to adequately handle the variability created by solar and wind installations. The performance characteristics that are most important to the California grid should be communicated and incentivized properly by California's energy markets.
- Recommend a focus on application and performance attributes that are needed for a decarbonized electric grid. Improvements are needed in systems and performance across multiple areas to develop a decarbonized grid. Performance standards for a decarbonized grid need to be discussed and modeled in order to discover the best route towards decarbonization. Multi-day and seasonal system modeling of renewable energy generation, storage capabilities, and grid technologies can provide insights on which performance improvements provide the greatest benefit towards decarbonization.
- A focus on improving the round-trip efficiency of batteries would help improve economics. This is especially true for flow batteries. Batteries are incapable of releasing all their stored energy, as some is lost in the process of storing and discharging it. Improving round trip battery efficiency will decrease the amount of energy that is lost, maximizing energy storage system capabilities.
- Storage duration needs to be longer. Storage duration is becoming an increasingly important feature of energy storage projects as more variable generation is introduced on the grid. While short-duration storage has shown viability to shave peak demand during high-stress hours on the grid and provide other ancillary services, to deal with long-term lulls of renewable production, longer-duration storage is required.
- Energy storage must avoid technology lock-in to prevent new technologies with potentially better performance for certain applications from entering the market. The increased penetration and manufacturing of lithium-ion batteries is threatening the viability of other types of storage. Lithium-ion batteries suffer from poor performance in certain areas, such as a high degradation of cycle life over time. Other types of energy storage, such as flow batteries, thermal batteries, and mechanical storage, have characteristics that make them more attractive for applications such as voltage regulation, long-duration storage, and heating and cooling. New technologies cannot improve without moving from the laboratory scale to pilot projects and full-scale demonstrations. The true value and cost of a technology cannot be determined accurately until it is demonstrated.
- The costs associated with energy storage can be broken into two categories: the cost of capacity ($/kW) and the cost of electricity ($/kWh). Based on the application, these two costs should be considered separately when evaluating a system's long-term viability and profitability. While the cost of capacity remains high for underdeveloped systems, these systems have the potential to operate for many years. Underdeveloped systems include compressed air energy storage (CAES), flywheels, and molten salt storage. As energy storage systems work to provide long-duration storage, the cost of electricity will be a more effective way to determine technologies' value to the grid than the cost of capacity.
- Energy storage technologies can provide a bevy of valuable services, but it is difficult to decide which use is the most valuable for the operator and the grid at any given time.

The value stacking of energy storage services will be better understood as energy storage systems continue to be deployed. However, the outlook for value stacking is currently focused on the short term. While one operation mode may best serve the grid today, an understanding of the changing nature of the electricity grid will prevent these systems from losing their value in the future.

- Energy storage systems can also be used for distributed generation and utility-scale generation. A contract and market structure that values energy storage services in a way that unlocks their full value for the grid is in California's best interest but must be researched further. It is possible that distributed energy storage systems provide a greater value to the grid, and resources and investment should be focused on those technology scales. Distributed advancements still have the potential to help increase the performance and cost characteristics of utility-scale systems, and the CEC should pursue overlapping research opportunities.
- The market structure in California has a harder time capturing the true value of ancillary services provided by energy storage. While some ancillary services such as grid regulation and system and local capacity are currently valued appropriately, flexibility and avoiding curtailment are not. Grid operators should determine which energy storage capabilities are most useful to the grid so storage providers can be incentivized to provide those services.
- Challenges with grid integration and interconnection are driven primarily by the type of energy storage technology. Pumped hydropower and CAES systems have many more environmental and permitting challenges than smaller lithium-ion or other battery systems that can be sited flexibly to avoid these issues. These challenges must be considered when accounting for the time and cost of a larger energy storage project. Some standardized processes could help reduce the costs of interconnection and address some of the complexity presented by a specific site and technology. Avoiding a long wait time for interconnection will reduce risks and potential costs associated with grid interconnection.
- The true amount of energy storage capacity needed on the grid is unknown. Energy storage smooths variability, but without adequate long-duration storage, long periods of sun or wind deprivation will limit the amount of renewable energy available to the grid and increase the need for fast-start energy and non-variable renewable production. A greater understanding of how often these deficit scenarios occur and predictions of population, electrical load, and renewable energy production are necessary to accurately estimate the need for energy storage. If more non-variable renewable sources are integrated into the grid, the amount of energy storage needed to ensure grid reliability will be less.
- The expectation that smaller behind-the-meter systems will contribute grid services also creates several complicated integration considerations. The integration of behind-the-meter energy storage as a utility-scale asset requires advanced meters that can respond to price signals. It will is more difficult for grid operators to utilize behind-the-meter systems for ancillary services than energy storage systems connected directly to the grid.

- California is currently reliant on imports of batteries, mainly from China. The materials and manufacturing of energy storage technologies are not significant barriers to deployment due to a current abundance of manufacturing capability in China. However, California can increase its control of the supply chain for energy storage devices by domestically procuring lithium through geothermal brines in the Salton Sea and recycling retired batteries. Additionally, California can learn from the example set in Nevada with the development of the Tesla Gigafactory to create its own in-state manufacturing capabilities.
- Local manufacturing and lithium production would reduce transportation costs. In state manufacturing and recycling would also limit environmental impacts due to creation, transport, and recycling of lithium-ion batteries. California also has an opportunity to become a manufacturing and production leader in new thermal, electrochemical, and mechanical energy storage devices that will soon be demonstrated at scale.
- Despite providing most grid storage capacity, Pumped Hydro Storage has limitations. Pumped hydro storage systems are limited by site selection. A feasible location must have the capability to maintain two large reservoirs of water with a significant elevation difference between them. The efficiency of pumped hydro power systems is limited due to it being a mechanical form of energy storage. There are battery systems which have higher efficiencies than pumped hydro systems. Pumped hydro systems also have environmental issues such as requiring large amounts of water which could lower plant efficiency when droughts occur.
- TES will benefit California by providing flexible, dispatchable energy generation. TES provides a method to store larger amounts of energy for longer timescales than many other current storage technologies. TES systems integrated with concentrated solar power or geothermal can maintain high efficiency by storing the heat transfer fluid produced during the day and releasing it to produce energy when the grid requires it. TES can also be provided by concrete materials which are readily available and can withstand the high temperatures that are used for CSP. Concrete TES can also reheat compressed air required for efficient operation of CSP systems by reusing heat of compression avoiding the need to burn natural gas to generate heat.
- Green Hydrogen has applications in bioenergy, CSP, and geothermal production and along with renewable natural gas can provide long-term storage options While current methods of hydrogen production often require the use of fossil fuels to split water, there are multiple alternatives which do not require processes that emit carbon dioxide. These processes include splitting water using the same solar concentrators used for CSP as well as producing biohydrogen using biomass and waste. Hydrogen is readily storable as a molecule and can be stored for long periods of time without having energy dissipate.
- Finding ways to reduce the need for energy storage can be just as valuable as installing new storage. Non-variable renewable energy systems with an avoided spend on storage provide value to the grid. Additionally, any reduction in storage needs also lowers the need for new transmission lines and interconnection. The incorporation of this avoided cost into the LCOE for non-variable systems would improve their economics and possible reduce the overall cost required to reach SB 100 goals.

CHAPTER 4: Technology/Knowledge/Market Transfer Activities

Energetics' Team included experts in solar energy, wind energy, geothermal energy, bioenergy, energy storage, and grid integration. A diverse team of experts was engaged to conduct the initial research and outreach, identifying barriers and opportunity areas in the various technology areas of study. This foundational multi-disciplinary teamwork served as the baseline for establishing the recommended initiatives. The project team went on to impart their individual expertise by providing commentary, review and verification.

Knowledge transfer and supporting market adoption was the rationale for involving outside project contributors. Experts in California and beyond were engaged through interviews during the TA research phase of the project to expand the scope of analysis and experience. Roadmapping webinars and surveys were conducted to further engage selected subject matter experts to verify and solidify the barriers and opportunity areas identified.

The knowledge transfer was expanded to include the general public through two public webinars. These webinars shared information and collected feedback from the public on the recommended initiatives. The first public webinar took place on June 28, 2019, and provided an opportunity to share and gather feedback on the preliminary roadmap draft, including the initial 20 initiatives. During the public webinar and comment submittal process 107 comments were collected. A second public webinar presentation will take place in the beginning of 2020 to present the final results of the roadmap and the final recommended initiatives developed for the CEC.

CHAPTER 5: Conclusions and Recommendations

Using a broad approach of research across multiple renewable energy technology areas will enable California to avoid technology lock-in and advance a diverse approach to meeting SB 100 goals. This Utility-Scale Renewable Generation Technology Roadmap provides the CEC a selection of initiatives to guide future RDD&D activities across nine technology areas: solar photovoltaic, concentrated solar power, land-based wind, offshore wind, bioenergy, geothermal power, small hydropower, grid integration technologies, and energy storage systems.

Through a literature review, expert interviews and surveys, and multiple expert and public webinars, the roadmapping project has produced both a TA and this research roadmap. While the TA focused on the current state of renewable energy resources and research efforts in both California and nationally, the research roadmap pinpoints recommended initiatives which fill current technology gaps. Accompanying the initiatives are performance baselines and targets to show both the current state of each technology area as well as the anticipated impact on the technology type. These recommended initiatives can all also reduce the cost of renewable energy systems and increase renewable energy produced for electric ratepayers in California. The following sections are a high-level summary of recommendations for each technology area.

Solar PV

Solar photovoltaics remain in an ideal position to continue being deployed as a renewable energy resource in the state. Already the largest source of renewable energy, low costs and a large technical capacity continue to make it an attractive option. Testing new solar cells in the field will enable the acceleration of real-world experience for new solar technologies, providing valuable information and increasing future reliability. As PV modules continue to be deployed in increasing quantities, methods of cell recycling can decrease PV decommissioning costs and lower system capital costs by creating a revenue stream for modules at the end of their lifespan.

Concentrated Solar Power

CSP systems are proven to be effective in California and the state remains attractive for future deployments. Methods to improve dust cleaning will enable CSP power outputs to be reliably maintained over time, increasing energy generation. The development of corrosion resistant materials and heat transfer mediums will enable CSP systems to operate at higher temperatures, increasing system efficiency while decreasing system costs.

Land-Based Wind

California’s ideal wind resources are saturated with older wind turbines, limiting the potential for future system development across the state. New construction technologies and methods are required to increase the accessibility of the remaining wind resources that are available to harvest. New technologies and onsite manufacturing methods can decrease build time and enable taller wind turbines that can benefit from a higher wind resource. New blade technology can also enable access to lower wind resources by improving turbine efficiency. New blades deployed in low wind areas can produce electricity with less variability than older counterparts in higher wind resource, improving power output and system reliability.

Offshore Wind

Offshore wind represents one of the greatest opportunities for California because it's an undeveloped resource. Areas ideal for offshore wind are closer to California's largest load generating areas than other forms of power generation, which will decrease the amount of transmission infrastructure required and the losses due to transmission as a result. Due to California's deep shelf, the state is ideally positioned to utilize floating turbines. California can lead on this front, since there are limited demonstrations of other floating wind turbine systems globally. California port infrastructure must also be able to handle wind turbine components so turbines do not have to be shipped from out of state. Another technology type that is undeveloped in California is wave energy. Co-deployment with offshore wind systems will allow this technology to benefit from synergies in transmission and platform use.

Bioenergy

Biomass provides the opportunity to convert waste into energy. The amount of waste available for energy production in California represents a high technical capacity, with most of the feedstock coming from agricultural, forestry, and municipal solid waste. Opportunities exist to expand bioenergy production by improving pre-treatment of waste used to produce biogas and the post-production cleaning of syngas. By improving pretreatment and cleaning respectively, production yields can increase, producing more gas for energy while reducing costs.

Geothermal

While geothermal has been a key part of California's energy mix since the 1960s, just under 3,000 MW out of the known 20,000 MW available has been tapped for energy production, making it a widely available resource for new development. Despite its availability, geothermal systems are costly due to the process of siting and drilling for geothermal resources. Water requirements and availability also make some sites unfeasible. Improvements in site assessment can reduce upfront costs for traditional and potential enhanced geothermal sites. New materials for geothermal systems, which reduce the amount of corrosion caused by brines, can reduce maintenance time and cost, enabling plants to produce more energy and minimize time offline.

Small Hydro

Small hydropower uses California's existing water supply and infrastructure to generate smaller amounts of power than a typical hydropower facility. Multiple opportunities exist for small hydropower in new stream developments, powering non-powered dams, and installing in-conduit systems in existing aqueducts and pipes. The cost of small hydropower is variable as every development site has unique hydrology, leading to projects that can either be competitively priced or too expensive for their power output. Methods to standardize interconnection of small hydro systems can reduce system costs and complexity.

Grid Infrastructure

Grid infrastructure improvements will be necessary to handle the shifting loads that result from an reliance on variable renewable energy and ever-expanding renewable installations. Implementing more smart inverters across the grid can enable more communication between grid systems and system operators, mitigating potential hazardous grid events. Separately, the development of offshore high voltage cables will enable offshore wind resources to be incorporated into the state grid more efficiently.

Energy Storage

Energy storage enables a shift in renewable energy from peak generation to peak load, which is necessary to meet SB 100 goals while ensuring grid reliability. Future energy storage systems must be able to store and discharge energy on time scales longer than currently available from most energy storage technologies. Long duration storage will support renewable energy growth by reducing energy curtailment and decreasing the amount of natural gas ramping required in the evenings. However, continued deployment of battery storage systems will also necessitate the development of disposal methods. Developing a recycling industry provides a new opportunity for California to limit costs of importing materials necessary for lithium-ion battery production, often from other nations.

LIST OF ACRONYMS

Term/Acronym	Definition
AD	Anaerobic Digestion
AM	Additive Manufacturing
ARPA-E	Advanced Research Projects Agency – Energy
BIO	Bioenergy
BOEM	The Bureau of Ocean Energy Management
CAES	Compressed Air Energy Storage
CEC	California Energy Commission
CSP	Concentrated Solar Power
DOE	U.S. Department of Energy
DRECP	Desert Renewable Energy Conservation Plan
EGS	Enhanced Geothermal System
EIA	Energy Information Administration
EPIC	Electric Program Investment Charge
ESS	Energy Storage Systems
EV	Electric Vehicles
GEO	Geothermal Power
GIT	Grid Integration Technologies
GW	Gigawatt
GWh	Gigawatt-hour
HVAC	High Voltage Alternating Current
HVDC	High Voltage Direct Current
IoT	Internet of Things
IOU	Investor Owned Utility
ISO	Independent Systems Operator
KGRA	Known Geothermal Resource Areas
KW	Kilowatt
KWh	Kilowatt-hour
LBW	Land-Based Wind
LCFS	Low Carbon Fuel Standard
LCOE	Levelized Cost of Energy
MFC	Microbial Fuel Cell
MSW	Municipal Solid Waste
MW	Megawatt

Term/Acronym	Definition
MWh	Megawatt-hour
NREL	National Renewable Energy Laboratory
OSW	Offshore Wind
PSH	Pumped Storage Hydropower
PV	Photovoltaics
R&D	Research and Development
RDD&D	Research, Development, Demonstration, and Deployment
RNG	Renewable Natural Gas
RPS	Renewable Portfolio Standard
SB-100	Senate Bill 100
SHP	Small Hydropower
SPV	Solar PV
TES	Thermal Energy Storage
THP	Thermal Hydrolysis Pretreatment
TWh	Terawatt-hours
Wdc	Watts direct current
WRA	Wind Resource Area
WWTP	Waste Water Treatment Plants

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APPENDIX A: Calculations Related to SB 100

Included here are the calculations that support estimates provided throughout this roadmap. These estimates center around predictions for 2030 and 2045 renewable production and the relationship to SB 100 goals.

Current California Energy Mix and Future Expectations for Senate Bill 100

2030 Consumption Estimate: 340,000 GWh (Rounded from 339,160)

This mid-range estimate from the model predicts an increase of 1.27 percent annually from 2016 onward. Applying this to the 2030 estimate yields:

$$340{,}000\ GWh\,(1\ +\ 0.0127)^{15} =\ 411{,}000\ GWh$$

Goal for 2045 estimated at 411,000 GWh

Renewable Targets

Both calculations for SB 100 Goals assume constant electricity generation from Large Hydro in the future.

Nuclear production is expected to decrease to zero by 2045 due to the last remaining nuclear generators in the state (both at Diablo Canyon) scheduled to be retired in 2024 and 2025 (Walton 2018).

SB-100 2030 Renewable Targets: 60%.

$$340{,}000\ GWh * 60\%\ Renewable\ Target\ =\ 204{,}000\ GWh$$

$$\begin{aligned}204{,}000\ GWh\ 2030\ Target - 63{,}028\ GWh\ 2018\ Instate\ Renewable\ Generation \\ = 141{,}000\ GWh\ new\ renewable\ generation\ required\ for\ 2030\end{aligned}$$

SB-100 2045 Low Carbon Sources Target: 100%.

$$411{,}000\ GWh * 100\%\ Clean\ Energy\ Target\ =\ 411{,}000\ GWh$$

$$\begin{aligned}411{,}000\ GWh\ 2045\ Target - 63{,}028\ GWh\ Instate\ Renewable\ Generation \\ - 22{,}096\ Large\ Hydropower \\ = 326{,}000\ GWh\ new\ renewable\ generation\ required\ for\ 2045\end{aligned}$$

For the purpose of this roadmap, the anticipated 2030 and 2045 Renewable Energy Mix is as follows. Capacity factors held constant.

$$\frac{204{,}000\ GWh\ 2030\ Renewable\ Target}{63{,}028\ GWh\ 2018\ Renewable\ Generation} = 324\%\ Higher\ for\ 2030$$

$$\frac{388{,}904\ GWh\ 2045\ Renewable\ Target}{63{,}028\ GWh\ 2018\ Renewable\ Generation} = 617\%\ Higher\ for\ 2045$$

Table A-1: Projection of Renewable Generation and Capacity in 2030 and 2045

Renewables	2018 Total (GWh)	2030 Projection (GWh)	2045 Projection (GWh)	2018 Total (MW)	2030 Projection (MW)	2045 Projection (MW)
Biomass	5,909	10,784*	10,784*	1,274	2,325*	2,325*
Geothermal	11,528	37,312	71,132	2,730	8,836	16,845
Small Hydro	4,248	7,272**	7,272**	1,756	3,006**	3,006**
Solar PV	24,488	94,829	197,147	10,658	41,273	85,805
Solar Thermal	2,545	8,237	15,704	1,249	4,043	7,707
Wind	14,078	45,566	86,866	6,004	19,433	37,047
Total	63,028	204,000	388,904	23,671	78,915	152,735

***Biomass maximum theoretical potential given below is 4.65 GW. 2030 and 2045 totals have been set to a maximum of 50% of the recoverable potential (2.33 GW). Solar PV given balance of generation to reach SB-100 goals.**

****Small hydropower undeveloped theoretical potential given below is 2.5 GW. 2030 and 2045 totals have been set to reflect an increase that is 50% of that theoretical potential (1.25 GW). Solar PV given balance of generation to reach SB-100 goals.**

Sources: CEC (2019a), CEC (2018)

Renewable Technology Area Maximum Technical Potential in Relation to SB-100 Goals

All Maximum Potential Estimates use the estimated resource availability of the technology area. This GW total is multiplied by the number of hours in the year to give the maximum theoretical energy production from the technology area in GWh. This GWh total is then multiplied by the 2018 Statewide Capacity Factor to provide an estimate of total available electricity from each technology area.

The GWh estimate for total available electricity is divided by the 2030 and 2045 renewable targets provided above to demonstrate how much each resource can theoretically contribute to SB 100 goals at full statewide installation.

While these totals are not expected to every reach 100 percent installation, higher totals indicate that it will be easier to access resources in the short-term.

Solar PV: Potential for Reaching Senate Bill 100 Goals

Capacity Factor: 26.2 percent

Estimated Maximum In-state Resource: 4,100 GW

$$4{,}100\ GW * \frac{8760\ Hours}{1\ Year} * 26.2\%\ Capacity\ Factor = 9{,}410{,}000\ GWh$$

$$\frac{9{,}410{,}000\ GWh}{326{,}000\ GWh\ 2045\ SB100\ Goal} = 2{,}900\%$$

Solar CSP: Potential for Reaching SB-100 Goals

Capacity Factor: 23.3 percent

Estimated Maximum In-state Resource: 2,700 GW

$$2{,}700\ GW * \frac{8760\ Hours}{1\ Year} * 23.3\%\ Capacity\ Factor = 5{,}510{,}000\ GWh$$

$$\frac{5{,}510{,}000\ GWh}{326{,}000\ GWh\ 2045\ SB100\ Goal} = 1{,}700\%$$

Land-Based Wind: Potential for Reaching SB-100 Goals

Capacity Factor: 26.8 percent

Estimated Maximum In-state Resource: 128 GW

$$128\ GW * \frac{8760\ Hours}{1\ Year} * 26.8\%\ Capacity\ Factor = 301{,}000\ GWh$$

$$\frac{301{,}000\ GWh}{326{,}000\ GWh\ 2045\ SB100\ Goal} = 92\%$$

Offshore Wind Potential: Potential for Reaching Senate Bill 100 Goals

Anticipated Capacity Factor: 40 percent

Estimated Maximum In-state Resource: 160 GW

$$160\ GW * \frac{8760\ Hours}{1\ Year} * 40\%\ Capacity\ Factor = 561{,}000\ GWh$$

$$\frac{561{,}000\ GWh}{326{,}000\ GWh\ 2045\ SB100\ Goal} = 180\%$$

Offshore fixed bottom potential

Anticipated Capacity Factor: 40 percent

Estimated Maximum In-state Resource: 9 GW

$$9\ GW * \frac{8760\ Hours}{1\ Year} * 40\%\ Capacity\ Factor = 31{,}500\ GWh$$

$$\frac{31{,}500\ GWh}{326{,}000\ GWh\ 2045\ SB100\ Goal} = 10\%$$

Wave Energy Resource Assessment

Anticipated Capacity Factor: 30 percent

Theoretically Available Wave Energy Resource in California (EPRI 2011):

- Outer Shelf: 293 TWh
- Inner Shelf: 205 TWh
- Total: 498 TWh

Recoverable wave resource with a packing density of 20 MW per km (highest given in EPRI report):

- Outer Shelf: 166.2 TWh

- Inner Shelf: 129 TWh
- Total: 295.2 TWh

Relationship to SB-100 goals:

$$\frac{295{,}200\ GWh}{326{,}000\ GWh\ 2045\ SB100\ Goal} = 91\%$$

Bioenergy: Potential for Reaching Senate Bill 100 Goals

Capacity Factor: 52.9 percent

Estimated Maximum In-state Resource: 4.65 GW

$$4.65\ GW * \frac{8760\ Hours}{1\ Year} * 52.9\%\ Capacity\ Factor = 21{,}500\ GWh$$

$$\frac{21{,}500\ GWh}{326{,}000\ GWh\ 2045\ SB100\ Goal} = 6.6\%$$

Bioenergy (specifically biogas or renewable natural gas) can be a direct replacement for Natural Gas making it an ideal renewable energy source to use in existing infrastructure. Below is an estimate of the amount of Natural Gas that can theoretically be replaced with bioenergy.

$$\frac{21{,}500\ GWh}{90{,}691\ GWh\ 2018\ Natural\ Gas\ Electricity\ Generation} = 23.7\%$$

Geothermal: Potential for Reaching Senate Bill 100 Goals

Capacity Factor: 48.2 percent

Estimated Maximum In-state Resource: 5.4 GW Conventional + 48.1 GW EGS = 53.5 GW

$$(5.4\ GW\ Conventional\ Geothermal + 48.1\ GW\ EGS) * \frac{8760\ Hours}{1\ Year} * 48.2\%\ Capacity\ Factor = 226{,}000\ GWh$$

$$\frac{226{,}000\ GWh}{326{,}000\ GWh\ 2045\ SB100\ Goal} = 69\%$$

Small Hydro: Potential for Reaching Senate Bill 100 Goals

Capacity Factor: 27.6 percent

Estimated Maximum In-state Resource: 2.5 GW

$$2.5\ GW * \frac{8760\ Hours}{1\ Year} * 27.6\%\ Capacity\ Factor = 6{,}040\ GWh$$

$$\frac{6{,}040\ GWh}{326{,}000\ GWh\ 2045\ SB100\ Goal} = 1.8\%$$

Energy Storage: Potential for Reaching Senate Bill 100 Goals

Rough assumption of 20 percent of power provided by renewables for 18 hours a day and 100% of power provided by renewables for 6 hours a day (estimated time with direct sunlight) would yield:

$$411{,}000\ GWh\ 2045\ Target * \frac{18\ hours}{24\ hours} * 20\%\ of\ Power\ from\ Renewable$$
$$+\ 411{,}000\ GWh\ 2045\ Target * \frac{6\ hours}{24\ hours} * 100\%\ of\ Power\ from\ Renewable$$
$$= 164{,}400\ GWh\ from\ Renewables\ direct\ to\ Grid$$

$$411{,}000\ GWh\ 2045\ Target - 164{,}400\ GWh\ from\ Renewable\ direct\ to\ Grid$$
$$= 246{,}600\ GWh\ in\ Storage\ Required$$

Assumption is average grid storage length will be 8 hours by 2045. This would provide an overall capacity factor of 33 percent.

$$\frac{246{,}600\ GWh}{8760\ hours} * \frac{1}{33\%\ Capacity\ Factor} = 85\ GW\ of\ 8\ Hour\ Storage$$

Calculations of Initiatives' Potential for Reaching SB 100 Goals

Initiative SPV.1

Estimates for increases in Solar PV capacity for this roadmap between 2030 and 2045 are 44,532 MW.

Last Five Years average MW of new installation was 25 MW.

Increase of conversion efficiency from current levels 23 percent to 30 percent would yield a 7 percent increase in capacity for the same surface area.

$$\frac{44{,}532\ MW\ by\ 2030}{25\ MW\ Average\ MW\ per\ Installation} = 1{,}780\ new\ installations\ between\ 2030\ and\ 2045$$

This initiative is expected to have a long-term horizon. Its impact can be estimates by increase in capacity by 7 percent per year for installations between 2030 and 2045:

$$1{,}780\ Installations * 7\% = 125\ Fewer\ Installations$$

At 25 MW per installation, this contribution of this initiative to SB-100 goals assuming 2018 capacity factors is:

$125\ Fewer\ Installations * 25\ MW\ per\ Installation * 26.2\%\ Capacity\ Factor * 8760\ hrs =$
$7{,}200\ GWh$

$$For\ 2045\text{:}\ \frac{7{,}200\ Additional\ GWh}{326{,}000\ GWh\ 2045\ Goal} = 2.2\%\ of\ SB100\ 2045\ Goals$$

Initiative SPV.2:

44.5 GW of Capacity expansion expected between 2030 and 2045 in California.

Assuming 300 Watts per module.

$$\frac{44.5\ GW}{300\ Watts\ per\ module} = 148\ Million\ modules$$

It is estimated that the recycling cost of a module is 15 percent per module.

The following is a high-end estimate for cost savings enabled by this initiative:

At a rough cost of $1 per Watt for installed Solar PV (within range of source used for roadmap), recycling costs are:

$$300\ Watts\ per\ Module * \$1\ per\ Watt * 15\% = \$45\ per\ module$$

This is higher than EPRI's estimates of ($10-$30) given in the roadmap but is unknown how many Watts are in the modules used for EPRI's estimates.

The goal of this initiative is to reduce recycling costs from 15 percent of capital costs for each module to 10 percent. A reduction of 5 percent would save:

$$300\ Watts\ per\ Module * \$1\ per\ Watt * 5\% = \$15\ per\ module$$

$$\$15\ per\ module * 148\ million\ modules = \$2.2\ billion\ in\ recycling\ savings\ by\ 2045$$

Initiative CSP.1

This initiative is expected to increase plant production 15 percent more than current totals.

Increase in Capacity Factor:

$$\begin{aligned}23.3\%\ 2018\ CSP\ Capacity\ Factor * 15\%\ Increase\ in\ output\ due\ to\ Mirror\ Cleaning \\ = 26.8\%\ Capacity\ Factor\ after\ Improved\ Mirror\ Cleaning\end{aligned}$$

2018 Production from CSP: 2,544 GWh

$$\begin{aligned}2{,}544\ GWh * 15\%\ Increase\ in\ output\ due\ to\ Mirror\ Cleaning \\ = 382\ GWh\ Increase\ in\ CSP\ Electricity\end{aligned}$$

Potential of SB-100 Goals for 2030:

$$For\ 2030\text{:}\ \frac{382\ Additional\ GWh}{141{,}000\ GWh\ 2030\ Goal} = 0.3\%\ of\ SB100\ 2030\ Goals$$

Initiative CSP.2

A reduction in CSP cost could drive new installation. Even a single new power tower design CSP plant identical to the Ivanpah facility would increase capacity by roughly 400 MW. At current CSP capacity factors, this would equate to an increase in production of:

$$400\ MW * 23.3\%\ 2018\ Solar\ PV\ Capacity\ Factor * 8760\ hours = 816\ Additional\ GWh$$

Percentage of SB-100 Goals for 2030 and 2045

$$For\ 2030\text{:}\ \frac{816\ Additional\ GWh}{141{,}000\ GWh\ 2030\ Goal} = 0.6\%\ of\ SB100\ 2030\ Goals$$

$$For\ 2045\text{:}\ \frac{816\ Additional\ GWh}{326{,}000\ GWh\ 2045\ Goal} = 0.3\%\ of\ SB100\ 2045\ Goals$$

Initiative LBW.1

Expected increases in wind energy based on above projections are:

$$For\ 2030\text{:}\ 19{,}433\ MW - 6{,}004\ MW = 13{,}429\ MW\ Increased\ Wind\ Capacity$$

$$For\ 2045\text{:}\ 37{,}047\ MW - 6{,}004\ MW = 31{,}043\ MW\ Increased\ Wind\ Capacity$$

Advanced cranes are an enabling technology unlocking higher capacity factors. This can reduce the amount of required capacity from wind to reach SB-100 electricity goals.

If California achieves closer to national capacity factors for wind of 34.6 percent, that will reduce expected requirements of wind capacity by:

$$13{,}429\ MW\ Increased\ Wind\ Capacity * \left(\frac{26.8\%\ 2018\ CA\ Wind\ Capacity\ Factor}{34.6\%\ Anticapted\ Capacity\ Factor}\right)$$
$$= 10{,}400\ MW\ Adjusted\ Wind\ Capacity\ Requirement\ for\ 2030$$

$$31{,}043\ MW\ Increased\ Wind\ Capacity * \left(\frac{26.8\%\ 2018\ CA\ Wind\ Capacity\ Factor}{34.6\%\ Anticapted\ Capacity\ Factor}\right)$$
$$= 24{,}000\ MW\ Adjusted\ Wind\ Capacity\ Requirement\ for\ 2045$$

This initiative could save between $80,000 and $160,000 in crane rental costs per turbine.

Financially, assuming an average of 4 MW per turbine for these new, larger turbines, this initiative has the following estimated impacts:

$$\frac{10{,}400\ MW\ of\ New\ Capacity\ Expected\ Instate\ by\ 2030}{4\ MW\ Assumed\ Capacity\ per\ Turbine} = 2{,}600\ New\ Turbines\ by\ 2030$$

$$\frac{24{,}000\ MW\ of\ New\ Capacity\ Expected\ Instate\ by\ 2045}{4\ MW\ Assumed\ Capacity\ per\ Turbine} = 6{,}000\ New\ Turbines\ by\ 2045$$

$$For\ 2030\text{: } 2{,}600\ New\ Turbines * \$160{,}000 = \$416\ Million$$

$$For\ 2045\text{: } 6{,}000\ New\ Turbines * \$160{,}000 = \$960\ Million$$

Initiative LBW.2

Increasing converted energy of Wind Turbines can either result in an increase in their rated capacity on average or an increase in their capacity factor if rated capacity is kept the same.

The assumption in this case is that rated capacity is unchanged. An increase in capacity factor of 35 percent would result in a state-wide capacity factor increase from:

$$26.8\%\ 2018\ CA\ Wind\ Capacity\ Factor * 135\% = \ 36.2\%\ Estimated\ Capacity\ Factor$$

Since this initiative has a long-term outlook, the change in capacity factor is anticipated for 2030. Between 2030 and 2045, based on above projections:

$$For\ 2045\text{: } 37{,}047\ MW - 19{,}433\ MW$$
$$= 17{,}614\ MW\ Increased\ Wind\ Capacity\ between\ 2030\ and\ 2045$$

The 35 percent increase in converted energy would reduce the required MW to:

$$17{,}614\ MW * \frac{26.8\%}{36.2\%} = 13{,}000\ MW$$

This would account for an increase of GWh toward SB-100 goals of:

$$13{,}000\ MW * (36.2\% - 26.8\%) * 8760\ Hours = 10{,}700\ GWh$$

$$For\ 2045\text{: } \frac{10{,}700\ Additional\ GWh}{326{,}000\ GWh\ 2045\ Goal} = 3.3\%\ of\ SB100\ 2045\ Goals$$

Initiative OSW.1

This initiative is viewed as an enabling technology necessary to open deployment of Offshore Wind systems in California.

No Utility Scale Offshore Wind currently exists. Manufacturing would enable the state to set up Port Infrastructure (OSW.2) and move forward with specific offshore wind platform designs.

As an enabling technology, this initiative would open up development of offshore wind power in California. It is feasible that California could support 8.4 GW of Offshore Wind energy by 2045. The indirect impact of this initiative could therefore be as high as:

$$8{,}400\ MW * 40\%\ Estimated\ Offshore\ Wind\ Capacity\ Factor * 8760\ Hours = 29{,}400\ GWh$$

$$For\ 2045\text{: } \frac{29{,}400\ GWh}{326{,}000\ GWh\ 2045\ Goal} = 9.0\%\ of\ SB100\ 2045\ Goals$$

Initiative OSW.2

This initiative is viewed as an enabling technology necessary to open deployment of Offshore Wind systems in California.

No Utility Scale Offshore Wind currently exists. Port Infrastructure is required to scale-up deployment of offshore wind in-state. This initiative is linked to manufacturing of Floating Offshore Wind structures in state (OSW.1) as well.

Port infrastructure would unlock potential floating offshore wind and eliminate potential barriers to deployment. A necessary step in creating a feasible offshore wind industry in the long-term.

As an enabling technology, this initiative would open up development of offshore wind power in California. It is feasible that California could support 8.4 GW of Offshore Wind energy by 2045. The indirect impact of this initiative could therefore be as high as:

$$8{,}400\ MW * 40\%\ Estimated\ Offshore\ Wind\ Capacity\ Factor * 8760\ Hours = 29{,}400\ GWh$$

$$For\ 2045\text{: } \frac{29{,}400\ GWh}{326{,}000\ GWh\ 2045\ Goal} = 9.0\%\ of\ SB100\ 2045\ Goals$$

Initiative OSW.3

Wave energy could provide a limited amount of electricity along with deployment of offshore wind. Wave energy systems vary in their installed capacity (and anticipated capacity factors) due to a lack of consensus and development of commercial systems. Sizes from 500 kW to 7 MW have been proposed.

For this assumption, an average capacity of 1 MW operating at 30 percent capacity factor will be used. Additionally, the same potential of 8.4 GW of Offshore Wind Energy that is possible in California by 2045 will be used. The last assumption is the average Offshore Wind Turbine capacity is 8 MW.

$$\frac{8{,}400\ MW\ of\ Potential\ Offshore\ Wind\ Power}{8\ MW\ per\ Offshore\ Wind\ Turbine} * 1\ MW\ Coupled\ Wave\ Energy\ System\ per\ Turbine * 30\%\ Anticipated\ Capacity\ Factor * 8760\ Hours = 2{,}800\ GWh$$

$$For\ 2045:\ \frac{2{,}800\ GWh}{326{,}000\ GWh\ 2045\ Goal} = 0.8\%\ of\ SB100\ 2045\ Goals$$

Initiative BIO.1

No Utility Scale Syngas production. Would be an enabling.

Assumption that syngas development is positioned to increase electricity production specifically from forestry waste. Gasification and pyrolysis technologies are suited for dryer feedstocks which fits well with forestry wastes. Agricultural residues also are available for gasification and pyrolysis. However, the inclusion of animal manure in this category makes it difficult to attribute syngas advances to increases in agricultural residue conversion. Animal manure is typically processed through anaerobic digestion to produce biogas.

The technical potential of forestry waste is estimated at 1.9 GW. At the capacity factor of 52.9 percent seen for bioenergy throughout California, this translates to enabling:

$$1{,}900\ MW * 52.9\%\ Bioenergy\ Capacity\ Factor * 8760\ Hours = 8{,}800\ GWh$$

High-end assumption that improved syngas production helps capture 50 percent of the technical forestry resource:

$$For\ 2045:\ \frac{8{,}800\ GWh * 50\%\ Capture}{326{,}000\ GWh\ 2045\ Goal} = 1.4\%\ of\ SB100\ 2045\ Goals$$

Initiative BIO.2

This initiative is both an enabling technology and a performance enhancer. For this assumption, the focus is on how this initiative would increase production from current gas facilities.

Landfill and Digester Gas accounts for 295 MW of capacity in state currently. Assumption is that biogas production can be increased 75 percent. A similar 75 percent increase in electricity production is assumed here:

$$295\ MW * 52.9\%\ Bioenergy\ Capacity\ Factor * 8760\ Hours = 1{,}370\ GWh$$

$$1{,}370\ GWh * \ 75\%\ Increase\ in\ Production = 1{,}030\ GWh\ new\ Production$$

$$\frac{1{,}030\ GWh}{141{,}000\ GWh\ 2030\ SB100\ Goal} = 0.7\%\ of\ 2030\ SB100\ 2030\ Goal$$

Initiative GEO.21

This initiative seeks to increase installations in the Salton Sea region and other known geothermal areas with high salinity contents of underground water. Taking just the Salton Sea, there is an estimated additional development potential of 1.8 GW.

While a lack of development in the region cannot be only attributed to high costs, an alternative to titanium would encourage and enable new development in the region.

Assumption here is a new alloy allows for full development of the Salton Sea region at current geothermal capacity factors:

$$1{,}800\ MW * 48.2\%\ Geothermal\ Capacity\ Factor * 8760\ Hours = 7{,}600\ GWh$$

$$\frac{7{,}600\ GWh}{326{,}000\ GWh\ 2045\ SB100\ Goal} = 2.3\%\ of\ 2045\ SB100\ Goal$$

Initiative GEO.2

Enabling technology for EGS. With only 5,400 MW of projected conventional geothermal potential in California, to maintain geothermal's share of the California grid, EGS development is required.

$$For\ 2030{:}\ 8{,}836\ MW - 2{,}730\ MW = 6{,}106\ MW\ Increased\ Geothermal\ Capacity$$

$$For\ 2045{:}\ 15{,}719\ MW - 2{,}730\ MW = 12{,}989\ MW\ Increased\ Geothermal\ Capacity$$

Only 50 percent of geothermal resource in California estimated to be discovered. Initiative expected to increase that percentage to 75 percent:

$$48.1\ GW * 25\%\ Increase\ in\ EGS\ Site\ Discovery * 48.2\%\ Capacity\ Factor\ for\ Geothermal\ Power * 8760\ Hours = 51{,}000\ GWh$$

$$\frac{51{,}000\ GWh}{326{,}000\ GWh\ 2045\ SB100\ Goal} = 16\%\ of\ 2045\ SB100\ Goal$$

Initiative GIT.1

Improve system security and safety of existing and new infrastructure. California will have to handle the following approximate new renewable energy capacity:

$$For\ 2030{:}\ 78{,}915\ MW - 23{,}671\ MW = 55{,}000\ MW\ increase\ from\ 2018\ to\ 2030$$

$$For\ 2045{:}\ 152{,}735\ MW - 23{,}671\ MW = 129{,}000\ MW\ increase\ from\ 2018\ to\ 2045$$

In addition to the following new electrical load from renewables:

$$For\ 2030{:}\ 204{,}000\ GWh - 63{,}028\ GWh = 141{,}000\ GWh\ increase\ from\ 2018\ to\ 2030$$

$$For\ 2045{:}\ 388{,}904\ GWh - 63{,}028\ GWh = 326{,}000\ GWh\ increase\ from\ 2018\ to\ 2045$$

Initiative GIT.2

Reduction in line losses by 30-50 percent. Based on anticipated offshore installations, it is possible to achieve 8.4 GW Offshore Wind Installation by 2045. Line losses can reach 15% for large-scale offshore HVAC systems. A reduction in line losses would yield an increase in power of:

$$8.4\ GW * 40\%\ Expected\ Capacity\ Factorfor\ Offshore\ Wind * 8760\ Hours * 15\%\ Line\ Losses *= 4{,}400\ GWh\ Lost$$

$$4{,}400\ GWh * 50\%\ Line\ Loss\ Reduction = 2{,}200\ GWh\ Saved$$

$$\frac{2{,}200\ GWh}{326{,}000\ GWh\ 2045\ SB100\ Goal} = 0.7\%\ of\ 2045\ SB100\ Goal$$

Initiative ESS.1

Less required Energy Storage capacity lowering overall system costs. An increase in capacity to 10 hours from 8 hours would reduce highest end storage requirements by:

$$85\ GW\ of\ 8\ Hour\ Storage * \frac{8\ Hour\ Storage}{10\ Hour\ Storage} = 68\ GW\ of\ 10\ Hour\ Storage$$

Reduction in storage requirement of:

$$85\ GW - 68\ GW = 17\ GW$$

Initiative ESS.2

Improved environmental outcomes. Recycling of lithium-ion will impact costs due to shorter lifespan of batteries (10-15 years). Reduction in costs can help spur new installations and financing.

This initiative could impact 100 MW of lithium-ion batteries currently operating in California. The 600 MW of contracted and announced lithium-ion installations and any future installations between now and 2030.

APPENDIX B: Considerations for the Energy Commission Outside the Scope of This Roadmap

The following ideas were out of scope for inclusion in the rest of the roadmap but were brought up through the course of the roadmapping process:

1. Tours for public information and education would help spread information on renewables
2. One commenter expressed general concern over shifting away from nuclear and natural gas generation
3. There is a potential to lower cost of energy through taking account of farmland synergies (cheaper land use)
4. One commenter advocated for a focus on technology readiness level advancement
5. Optimize the design and operation of carbon capture and storage systems
6. One commenter recognized this was a utility-scale roadmap but wanted to encourage recognition of direct-use geothermal for its ability to offset conventional electrical consumption. California has significant geothermal potential for direct-use projects.

APPENDIX C: Related Initiatives from the CEC and Other Agencies

Table C1: Projection of Renewable Generation and Capacity in 2030 and 2045

Initiative	Description/Goal	Potential Impact
Solar Initiative		
2018–2020 EPIC Triennial Investment Plan		
Initiative 4.1.1: Advance the Material Science, Manufacturing Process, and In Situ Maintenance of Thin Film PV Technologies	This initiative will advance the materials science associated with emerging thin film PV technologies by exploring the advantages of changes in materials composition, substituting non-toxic and abundant alternatives for toxic and/or rare elements.	Combining advancements in materials science of thin film PV materials, demonstration of high efficiencies, and utilization of abundant and non-toxic materials with effective low-cost encapsulating strategies to increase module lifetime could lead to a greater acceptance and large-scale adoption of thin film PVs.
Initiative 4.3.1: Making Flexible-Peaking Concentrating Solar Power with Thermal Energy Storage Cost-Competitive	This initiative will conduct comprehensive research, technology development and demonstration, and studies that will advance the technology readiness of CSP with thermal energy storage (TES), bring it closer to the market, and make CSP-TES cost-competitive compared to fossil fuel power generation and conventional (battery) energy storage systems.	Financially viable CSP-TES will increase future deployment, which will provide a significant contribution to California's RPS goal while providing a dispatchable form of renewable energy ready to support non-synchronous renewables.
California, Multi-Agency Initiative		
Go Solar California	Go Solar California combines three program components from separate entities in California. The California Public Utilities Commission's (CPUC's) California Solar Initiative (CSI), CEC's New Solar Homes Partnership, and various programs from California's publicly owned utilities (POUs) comprise the Go Solar California program.	
U.S. Department of Energy		

Initiative	Description/Goal	Potential Impact
Advanced Systems Integration for Solar Technologies (ASSIST)	Strengthen the integration of solar on the electricity grid, especially critical infrastructure sites, and improve grid resilience.	Develop tools that enhance the situational awareness of solar systems on both the distribution and transmission grid and validate technologies that improve grid security and resilience.
Solar Energy Technologies Office (SETO): Concentrating Solar-Thermal Power	Advance components found in CSP sub-systems including collectors, power cycles, and thermal transport systems.	Develop new technologies and solutions capable of lowering solar electricity costs for CSP.
Solar Energy Technologies Office (SETO): Photovoltaics	Support early-stage research that increases performance, reduces materials and processing costs, and improves reliability of PV cells, modules, and systems. In addition, develop and test new ways to accelerate the integration of emerging technologies into the solar industry.	Develop new technologies and solutions capable of lowering solar electricity costs for PV.
Solar Energy Technologies Office (SETO): Workforce	Support projects that seek to prepare the solar industry and workforce for a digitized grid. Increase the number of veterans in the solar industry.	Improve workforce training that will manage a modern grid.
Solar Forecasting 2	Support projects that generate tools and knowledge for grid operators to better forecast how much solar energy will be added to the grid.	Improve the management of solar power's variability and uncertainty, enabling more reliable and cost-effective integration onto the grid.
Others: SunShot 2030, SunLAMP		
Wind Initiative		
2018–2020 EPIC Triennial Investment Plan		

Initiative	Description/Goal	Potential Impact
Initiative 4.2.1: Advanced Manufacturing and Installation Approach for Utility-Scale Land-Based Wind Components	Support advanced manufacturing techniques of wind turbine components and introduce new composite material for wind towers and blades.	Improve the performance of wind technology and explore untapped areas with lower wind speeds. Bring new manufacturing facilities and jobs to California that will lower associated transportation costs.
Initiative 4.2.2: Real-Time Monitoring Systems for Wind	Reduce maintenance costs by introducing a proactive maintenance system (preventive approach) that avoids unexpected failures that lead to expensive repair and generation loss, minimizes downtime, and maximizes technology performance.	Provide performance monitoring for operation and condition-based maintenance, with the potential to reduce O&M costs by more than 20% for offshore turbines and more than 10% for land-based turbines.
Initiative 7.3.1: Find Environmental and Land Use Solutions to Facilitate the Transition to a Decarbonized Electricity System	Proactively find solutions to potential environmental issues tied to deployment of renewable energy systems (long permitting delays, post-construction monitoring and mitigation).	Allow deployment of offshore wind in areas with sensitive marine environmental considerations.
U.S. Department of Energy		
Atmosphere to Electrons (A2e) Initiative	Investigate systems-level interactions influenced by atmospheric conditions, variable terrain, and machine-to-machine wake interactions.	Reduce unsubsidized wind energy cost of energy by up to 50% by 2030, compared to a $46/MWh national average in 2015.
Design and Manufacturing of Low Specific Power Rotors (Large Swept Area) for Tall Wind Applications	Strengthen the body of knowledge necessary for industry to mitigate aerodynamic loads, deploy new materials and approaches to structural design, and apply novel methods of fabrication and transportation, including evaluation of the potential for onsite manufacturing.	Overcome barriers to achieving a 10% improvement in wind plant capacity factor.

Initiative	Description/Goal	Potential Impact
Wind Energy Grid Integration and Grid Infrastructure Modernization Challenges	Focus on the tools and technologies to measure, analyze, predict, protect, and control the impacts of wind generation on the grid as it evolves with increasing amounts of wind power.	Enable incorporation of increasing amounts of wind energy into the power system, while maintaining economic and reliable operation of the national transmission grid.
Minimize Radar Interference and Wildlife Impacts from Domestic Wind Energy Development	Support projects that evaluate proof-of-concept mitigation measures in operational settings and ready them for broad deployment.	Address the impacts of wind development on critical radar missions.
Grid Modernization Initiative (GMI)	Evaluate and refine essential reliability services (such as voltage control, frequency response, and ramp rate control) provided by wind power plants.	Utilize renewable integration studies to evaluate various power system scenarios with ever-increasing amounts of wind energy to better understand impacts on reliability of the electric power network.
Beyond Batteries Initiative	Conduct laboratory-based R&D on adaptable, wind-based, energy storage alternatives. Focus on advances in controllable loads, hybrid systems incorporating generation from all sources, and new approaches to energy storage.	Develop advances that allow for loads to be combined with generation from all sources, optimizing use of existing assets to provide grid services and increasing grid reliability.
Other: Offshore Wind Resource Characterization and Technology Demonstration Funding Opportunity		
NYSERDA		
New York State Offshore Wind Master Plan	Conducted 20 studies and engaged with stakeholders and the public to ensure the responsible and cost-effective development of offshore wind.	Generate 2,400 MW of offshore wind energy generation by 2030.
Cross-Cutting		

Initiative	Description/Goal	Potential Impact
National Offshore Wind Research and Development Consortium	Lead the formation of a nationwide R&D consortium for the offshore wind industry, beginning with a collaboration between DOE, NYSERDA, the Renewable Consulting Group, and the Carbon Trust.	Fill the long-term vision for offshore wind under the current U.S. policy and based on the 2015 DOE Wind Vision Report, which calls for 86 GW of offshore wind capacity, representing 7% of all U.S. electricity generation, by 2050.
Bioenergy Initiative		
2018–2020 EPIC Triennial Investment Plan		
Initiative 4.4.1: Tackling Tar and Other Impurities: Addressing the Achilles Heel of Gasification	The focus is on research to help eliminate the reliability risks of biomass gasification to electricity systems due to problems caused by tars and other impurities produced during the gasification process. Additional R&D is also being conducted on the disposal of wastes that may be derived from the removal of tars and impurities.	Cost-effectively solving the tar and other impurity issues will assist in making biomass gasification to electricity more reliable, mitigating risks to downstream equipment such as the internal combustion engine generator set, and lowering costs of biomass gasification electricity systems.

Initiative	Description/Goal	Potential Impact
Initiative 4.4.2: Demonstrating Modular Bioenergy Systems and Feedstock Densifying and Handling Strategies to Improve Conversion of Accessibility-Challenged Forest Biomass Resources	This demonstration initiative is to generate critical in-field data and address technological challenges needed for broader deployment and commercialization of biomass-to-electricity systems in the forest–urban interface. Challenges include integration of multiple units, feedstock handling and loading, grid interconnection, produced gas quality improvement, air/water emission and waste management, and co-products. This initiative is to advance needed methods and strategies to bring the abundant, yet many times accessibility-challenged, forest biomass waste resources to the power generation facilities in a more economic manner.	The initiative demonstrates improvements to conversion efficiency, emissions, and emissions control, and mitigates solid and liquid waste byproducts to safe environmental levels. Such projects could lead to wider adoption of small-scale biomass electricity facilities using forest biomass that has been removed to reduce catastrophic wildfires. Demonstration projects involving feedstock transportation cost reduction would provide better economics for biopower projects.
Initiative 4.4.3: Demonstrate Improved Performance and Reduced Air Pollution Emissions of Biogas or Low-Quality Biogas Power Generation Technologies	The aim is to reduce the cost of pollution controls for small-scale biogas-to-electricity systems and develop more cost-effective off-the-shelf, low-emission electricity generation technologies that use biogas. There is also a need for new and/or improved technologies to utilize low-quality biogas, such as is generated at landfills and wastewater treatment facilities. More economic cleanup and emissions controls are needed for these low-quality-biogas producing facilities.	Improved air quality would better meet permitting requirements and lead to wider use of biogas that is otherwise emitted or flared.
U.S. Department of Energy		

Initiative	Description/Goal	Potential Impact
Conversion Research and Development	R&D to improve the conversion of biomass to biopower.	Increasing conversion efficiency will lower biomass feedstock costs, a critical cost factor in the production of electricity from biomass.
Feedstock Supply and Logistics	R&D to improve the harvesting, handling/processing, and transportation of biomass feedstocks.	Technology improvements in processing and logistics that enter the market over time can reduce the unit cost of biomass supply.
NYSERDA		
Biomass Heating R&D Program		
Geothermal Initiative		
2018–2020 EPIC Triennial Investment Plan		
Initiative 4.3.2 Geothermal Energy Advancement for a Reliable Renewable Energy System	Addresses flexible generation issues such as corrosive material build-up to allow geothermal to operate in a non-baseload setting. Explores the economic values of capturing build-up from condensates and looks at ways to boost geothermal power from declining or idling geothermal plants.	Will accelerate penetration of total renewable generation on the grid by decreasing reliance of non-renewable generation for ramping and ancillary services. Could make geothermal more attractive to investors as well.
Previous EPIC Investment Plans		

Initiative	Description/Goal	Potential Impact
Previous/Planned/Possible EPIC Investments in Geothermal Technologies	1. Flexible Geothermal Energy Generation a. Comprehensive Physical–Chemical Modeling to Reduce Risks and Costs of Flexible Geothermal Energy Production 2. Exploration, Resource Characterization, and Resource Development a. Improving Performance and Cost-Effectiveness of Small Hydro, Geothermal, and Wind Technologies b. High-Resolution Imaging of Geothermal Flow Paths Using a Cost-Effective Dense Seismic Network 3. Increasing Cost-Effectiveness and Economic Opportunities of Geothermal Power Generation a. Recovery of Lithium from Geothermal Brines	
Other		
Geothermal Grant and Loan Program	Seeks to promote the development of new or existing geothermal technologies. Commonly known as the Geothermal Resources Development Account (GRDA) program (after its funding source).	Provides millions of dollars for funding project developers operating on federal land in California. These grants and loans can provide vital funding to emerging technologies such as lithium recovery.
U.S. Department of Energy		
Frontier Observatory for Research in Geothermal Energy (FORGE)[1]	Dedicated site where scientists and engineers can test, develop, and accelerate breakthroughs in EGS technologies.	Providing a site for EGS development will push the technologies toward commercialization.
Energy Storage Initiative		
2018–2020 EPIC Triennial Investment Plan		
Initiative 2.3.1: Development of Customer's Business Proposition to Accelerate Integrated Distributed Storage Market	Focus energy storage research on new technology development, new use cases, metering and telemetry, streamlined practices, improving cybersecurity, and financing structures.	Provide energy storage system developers with a roadmap of how they can fully maximize and be compensated for the value they provide.

Initiative	Description/Goal	Potential Impact
Initiative 3.1.2: Assess Performance of Load Control System	Develop reliable estimates of performance under different conditions and times with the goal to reduce the need for telemetry on distributed resources and allow different loads to provide demand response.	Demand response technologies and strategies would be more widely adopted.
Initiative 3.2.1: Grid-Friendly PEV Mobility	Demonstrate advanced vehicle-to-grid (VGI) functions to better characterize the business cases for emerging applications.	Accelerate electric vehicle adoption, as there will be more opportunities to make revenue on electric vehicles.
Initiative 3.2.2: Battery Second Use	Develop battery monitoring technologies or test methods to better characterize and assess used EV cell condition to optimize configuration of second-life batteries.	Improve both primary and secondary use of batteries by providing health diagnostics for the batteries.
Initiative 3.4.1: Assessment and Simulation Study of the California Grid with Optimized Grid-Level Energy Storage	Determine future needs for grid-level energy storage connected to the distribution or transmission systems.	Provide information on which combinations and locations of grid-level energy storage will provide the best value. It will also inform energy storage policies and provide regulatory, technical, and institutional knowledge to stakeholders.
Initiative 4.3.1: Making Flexible-Peaking Concentrating Solar Power with Thermal Energy Storage Cost-Competitive	Conduct comprehensive research, technology development and demonstration, and studies that will advance CSP with thermal energy storage and make it more cost-competitive.	Assist in greater renewables integration and grid stabilization. This effort can attract additional investment into this technology.

Initiative	Description/Goal	Potential Impact
Initiative 7.3.3: Improve Lifecycle Environmental Performance in the Entire Supply Chain for the Electricity System	Find substitute materials or processes that can reduce GHG emissions and other environmental impacts of energy technologies.	Assist the state in achieving its GHG and other environmental goals by making the manufacturing, decommissioning, and recycling of energy-related materials more environmentally friendly.
U.S. Department of Energy		
Grid Modernization Initiative (GMI)	GMI develops the concepts, tools, and technologies needed to measure, analyze, predict, protect, and control the grid of the future. The goals are to increase electrical system reliability and security.	Create a more robust, resilient, and reliable electrical grid. Reduce risks of cyber attacks, natural disasters, or physical attacks on the grid.
Beyond Batteries Initiative	As part of the Grid Modernization Initiative, Beyond Batteries focuses on advances in controllable loads, hybrid systems, and new approaches to energy storage to increase the reliability and resilience of our energy systems.	Create innovative types of energy storage that can be used for heating, cooling, electricity, and other energy needs.
Office of Electricity's Energy Storage Systems Program	This program collaborates with utilities and state energy organizations to design, procure, install, and commission pioneering types of energy storage. The program supports analytical, technical, and economic studies on energy storage technologies. It also conducts research into innovative and emerging energy storage technologies.	Foster the growth of energy storage technologies and markets at statewide and national levels. The program can also help in sharing lessons learned across different local, state, and national-level agencies.

Initiative	Description/Goal	Potential Impact
ARPA-E	ARPA-E invests in early-stage high-potential, high-impact energy technologies that are at too early a stage for private-sector investment.	Potentiate radical improvement of our country's prosperity, national security, and environmental well-being. New technologies can greatly transform our energy systems.
Other: Advanced Energy Storage Initiative and FE Energy Storage Technology Research Program		
State Initiatives		
New York Energy Storage Roadmap	This document was developed to give the state a plan to accomplish Governor Cuomo's 1,500 MW by 2025 energy storage target. The roadmap identifies the most promising near-term policies, regulations, and initiatives needed to realize the goal.	Help New York install 1,500 MW of energy storage to help the state meet its renewable energy and environmental goals.
Massachusetts Energy Storage Initiative	This initiative aims to make Massachusetts a national leader in energy storage deployments. The initiative requires the state to procure 200 MWh of energy storage by 2020.	Foster a new energy storage market in the Northeast that can help the state meet its energy and reliability goals.
Maryland Energy Storage Tax Credit Program	The purpose of this tax credit is to encourage energy storage deployment.	Create a customer-sited energy storage market in Maryland.

APPENDIX D: Method Documentation

Included in this Appendix are the backup methodology details that are summarized in the Roadmap Method. This Method Documentation Appendix includes the following:

- Interview Summary
- Survey Results
- Webinar Results
- Public Workshop Comments (1)
- Quantitative Comment Decision Process (Yes/No Process)
- Public Workshop Comments (2)
- CEC Feedback from Closeout Meeting

Interview Summary

Interviews were conducted with representatives from a wide variety of organizations including state and federal government entities, national laboratories, industry trade associations, colleges/universities, utilities, and businesses (Table D-1). Interviewees were assured their interview transcripts would not be published. These assurances allowed interviewees to speak freely and candidly on the associated topics. Feedback from these interviews was used as supplementary information throughout the roadmapping process. The Technical Assessment covers much of the findings from the interviews, includes the names of interviewees, and should be reviewed for further detail and context on the topic areas included in this roadmap.

Table D-1: Number of Interviewees by Topic

Topic	Interviewees
Solar Power	6
Wind Power	10
Biopower	6
Geothermal	5
Small Hydropower	4
Grid Integration	8
Energy Storage	6
Wave Power	2
Total	**47**

Source: Energetics (2020)

Survey Results

Surveys asked experts to rank technology areas, R&D areas, and emerging and breakthrough technologies that were identified for the technical assessment. Results are provided in the tables below. The normalized score for the Technology Areas is an adjustment of the averages of the near-, mid-, and long-term scores to make the maximum value 10 (Tables D-2 though D-8). The normalized score for all other areas is an adjustment to the overall score submitted by the survey participants with the maximum value being 10.

Table D-2: Bioenergy Survey Results

Bioenergy								Number of Respondents: 12
Ranking of Technology Areas								
Technology Area	**Near-term**		**Mid-term**		**Long-Term**		**Average Score**	**Normalized Score**
	# of Ans.	Avg. Score	# of Ans.	Avg. Score	# of Ans.	Avg. Score		
T&D Infrastructure	9	8.3	7	9.0	8	10.1	9.2	6.5
Devices, Measurement, and System Controls	6	10.5	6	10.0	6	9.5	10.0	7.1
Design, Modeling, and Resource Planning	6	10.7	6	10.3	6	7.2	9.4	6.7
Resilience	8	9.9	7	11.7	7	12.1	11.2	8.0
Photovoltaics	8	4.3	7	4.6	7	4.9	4.6	3.3
Concentrated Solar Power	7	3.0	7	2.0	7	2.7	2.6	1.8
Land-Based Wind Power	6	3.2	6	3.0	6	3.0	3.1	2.2
Offshore Wind Power	6	3.7	6	3.8	7	5.7	4.4	3.1
Biopower	10	10.8	8	11.6	7	11.3	11.2	8.0
Geothermal Power	7	7.1	7	7.3	6	5.7	6.7	4.8
Small-Scale Hydroelectric	7	4.1	6	4.8	6	4.5	4.5	3.2
Mechanical Energy Storage	7	8.0	7	8.4	7	8.9	8.4	6.0
Thermal Energy Storage	7	8.6	8	9.8	7	10.1	9.5	6.8
Electrochemical Energy Storage	7	10.7	7	10.7	6	11.7	11.0	7.9

Ranking of R&D Areas									
R&D Area	**Near-term**		**Mid-term**		**Long-Term**		**Overall Score**		**Normalized Score**
	# of Ans.	Avg. Score	# of Ans.	Avg. Score	# of Ans.	Avg. Score	# of Ans.	Avg. Score	
Improved Pyrolysis Processes	9	2.2	8	2.4	9	2.6	10	6.2	4.2
Microbial Fuel Cells	10	2.0	8	2.4	8	2.8	11	5.9	4.6
Modular Gasification Systems	10	2.4	8	2.6	8	2.5	11	5.6	4.9

Bioenergy

Number of Respondents: 12

Integrated Gasification Combined Cycle (IGCC)	9	2.0	8	2.0	8	2.4	9	7.0	3.3
Thermal Hydrolysis at WWTPs	9	2.4	7	2.7	7	2.9	8	5.2	5.3
Bioenergy with Carbon Capture and Storage (BECCS)	9	2.4	8	2.5	9	3.1	9	4.9	5.7
Cleaner Combustion Technologies	9	3.3	8	3.3	8	3.1	8	3.5	7.3
Pipeline Injection	9	3.1	7	3.1	7	3.1	10	3.1	7.7
Food Waste Integration into WWTPs	9	3.6	7	3.6	7	3.6	9	2.5	8.4

Ranking of Emerging and Breakthrough Technologies

Technology Name	**Near-term**		**Mid-term**		**Long-Term**		**Overall Score**		**Normalized Score**
	# of Ans.	Avg. Score	# of Ans.	Avg. Score	# of Ans.	Avg. Score	# of Ans.	Avg. Score	
Convert Direct Combustion Biomass Facilities to Gasification Facilities	9	2.0	8	2.3	8	2.3	4	6.3	6.9
Existing and Idle Biomass Plant Retrofits	8	2.1	7	2.3	7	2.3	5	5.2	5.8
Improved Pressurized Biomass Gasification and Gas Cleaning	9	2.2	8	2.6	8	2.9	3	6.3	7.0
Integrating Biopower into Biorefineries	8	2.4	7	2.9	7	3.0	3	6.3	7.0
Large-Scale Biomass Gasification Systems	9	2.3	8	2.4	8	2.5	3	3.7	4.1
Tar and Other Impurity Management	8	2.8	7	3.0	7	3.1	4	4.3	4.7
Thermochemical Conversion Technologies	9	2.7	8	3.0	8	3.1	2	4.0	4.4
Advanced Wastewater Treatment Plants	10	3.3	8	3.3	8	3.4	8	6.5	7.2
Biochemical Conversion Technologies	8	2.9	8	2.6	7	3.1	3	3.0	3.3
Codigestion of Wastes	10	3.0	8	2.8	8	2.6	7	5.4	6.0
Enhanced Anaerobic Digestion with Enzymes	8	2.5	7	2.6	8	2.5	1	2.0	2.2

Bioenergy									Number of Respondents: 12
Processing of MSW to Economically Remove the Organic Component	9	3.1	7	3.1	7	2.9	7	8.6	9.5
Biogas Power Generation Technologies	9	3.0	7	3.1	8	3.0	5	3.8	4.2
Environmental and Social Benefits Analysis	10	3.5	7	3.9	7	3.6	10	6.1	6.8
Modular Bioenergy Systems	10	3.0	7	3.3	7	3.0	5	5.4	6.0
Pollution and Emissions Controls	10	2.9	7	3.0	7	3.0	6	5.0	5.6
Solar Integration with Bioenergy Systems	8	2.0	8	2.3	7	2.4	5	2.8	3.1
Ultra-Clean Biogas	8	2.3	7	2.7	8	2.6	6	3.3	3.7
Waste-to-Energy Bioenergy Systems	9	2.7	7	3.0	7	3.1	6	5.0	5.6
Other R&D Areas to Consider: Gasification of Agricultural Waste for Biochar Production									

Source: Energetics (2020)

Table D-3: Energy Storage Survey Results

Energy Storage								Number of Respondents: 6
Ranking of Technology Areas								
Technology Area	Near-term		Mid-term		Long-Term		Average Score	Normalized Score
	# of Ans.	Avg. Score	# of Ans.	Avg. Score	# of Ans.	Avg. Score		
T&D Infrastructure	6	9.5	5	9.6	6	11.3	10.1	7.2
Devices, Measurement, and System Controls	6	9.8	5	11.8	5	12.2	11.3	8.1
Design, Modeling, and Resource Planning	6	11.5	5	10.0	5	9.0	10.2	7.3
Resilience	6	7.2	5	7.0	5	8.6	7.6	5.4
Photovoltaics	6	4.8	5	2.4	5	1.8	3.0	2.2
Concentrated Solar Power	6	5.8	5	6.6	5	6.0	6.1	4.4
Land-Based Wind Power	6	9.2	5	9.2	5	7.0	8.5	6.0
Offshore Wind Power	6	6.5	5	7.8	6	9.0	7.8	5.5
Biopower	6	5.7	5	6.6	5	8.2	6.8	4.9
Geothermal Power	6	4.5	5	5.2	5	4.0	4.6	3.3
Small-Scale Hydroelectric	6	3.3	5	3.8	5	3.0	3.4	2.4
Mechanical Energy Storage	6	8.3	5	9.0	6	9.7	9.0	6.4

Energy Storage									Number of Respondents: 6
Thermal Energy Storage	6	11.0	5	10.2	5	10.2	10.5		7.5
Electrochemical Energy Storage	6	7.8	5	6.6	6	8.2	7.5		5.4

Ranking of R&D Areas

R&D Area	**Near-term**		**Mid-term**		**Long-Term**		**Overall Score**		**Normalized Score**
	# of Ans.	Avg. Score	# of Ans.	Avg. Score	# of Ans.	Avg. Score	# of Ans.	Avg. Score	
Compressed Air Energy Storage	4	0.8	4	1.3	4	1.8	4	5.5	3.7
Flywheels	4	1.5	4	1.5	4	1.5	3	7.0	4.7
Small Scale Pumped Hydro Storage	4	1.3	4	1.3	4	2.0	4	7.0	4.7
Battery Improvements	4	2.8	4	2.8	4	2.8	4	12.5	8.3
Battery Second Use	4	2.8	4	2.8	4	2.5	4	9.3	6.2
Recycling of Li-ion Batteries	4	2.5	4	2.5	4	2.5	4	10.0	6.7
Flow Batteries	4	2.5	4	3.0	4	3.0	4	10.3	6.8
CSP Thermal Energy Storage	4	2.5	4	2.5	4	2.8	3	9.7	6.4
Refrigeration and HVAC Based Storage	4	3.3	4	3.0	4	2.8	3	10.3	6.9
Assessment and Simulation	3	2.7	3	3.0	3	3.3	3	8.3	5.6
Innovative Energy Storage Systems	3	3.7	3	4.0	3	4.0	3	13.0	8.7
Lifecycle Environmental Improvements	3	3.7	3	4.0	3	4.0	3	13.0	8.7
Manufacturing	3	2.7	3	2.7	3	3.0	3	7.3	4.9
Virtual Power Plants	3	2.3	3	2.3	3	2.3	3	8.0	5.3
Transactive Energy	3	2.7	3	2.7	3	2.7	3	7.0	4.7

Ranking of Emerging and Breakthrough Technologies

Technology Name	**Near-term**		**Mid-term**		**Long-Term**		**Overall Score**		**Normalized Score**
	# of Ans.	Avg. Score	# of Ans.	Avg. Score	# of Ans.	Avg. Score	# of Ans.	Avg. Score	
Advanced Rail Energy Storage	6	1.2	6	1.2	6	1.2	5	7.2	4.0
Long-Duration Fly Wheel	6	2.2	6	2.2	6	2.2	5	10.8	6.0
Mechanical Energy Storage – Cranes	6	1.8	6	2.5	6	2.5	5	10.4	5.8
Advanced Lithium Extraction	4	1.8	4	2.0	4	2.0	3	8.3	4.6
Alternative Cathode Materials for Lithium-Ion batteries	4	3.0	4	3.0	4	3.0	3	12.3	6.9

Energy Storage									Number of Respondents: 6
Alternatives to Rare Earth Metals	4	3.0	4	3.3	4	3.3	3	11.7	6.5
Flow Battery	4	2.3	4	2.5	4	2.5	3	7.7	4.3
Gaseous Electrolyte	4	2.3	4	2.5	4	2.8	3	8.3	4.6
Lead–Acid Battery	4	1.5	4	1.5	4	2.0	3	5.0	2.8
Lithium Metal Anode	4	2.5	4	3.0	4	2.8	3	13.3	7.4
Silicon Anode	4	2.3	4	2.3	4	2.3	3	8.7	4.8
Sodium Battery	4	2.8	4	3.0	4	3.0	3	12.7	7.0
Solid-State Electrolyte	4	2.5	4	2.5	4	2.8	3	13.0	7.2
Zinc Battery	4	2.0	4	2.0	4	2.0	3	7.0	3.9
Concentrated Solar Power	4	2.5	4	2.5	4	2.5	3	10.3	5.7
Liquid Air Energy Storage	4	2.3	4	2.3	4	2.3	3	8.7	4.8
Pumped Heat Thermal Storage	4	3.0	4	3.0	4	2.8	2	13.0	7.2
Thermal Energy Storage Paired with Solar PV	4	2.0	4	2.0	4	2.3	3	5.7	3.1
Other R&D Areas to Consider: Energy Storage Combined Cycle									

Source: Energetics (2020)

Table D-4: Geothermal Survey Results

Geothermal								Number of Respondents: 10
Ranking of Technology Areas								
Technology Area	**Near-term**		**Mid-term**		**Long-Term**		**Average Score**	**Normalized Score**
	# of Ans.	Avg. Score	# of Ans.	Avg. Score	# of Ans.	Avg. Score		
T&D Infrastructure	7	11.7	6	10.8	6	11.3	11.3	8.1
Devices, Measurement, and System Controls	6	8.7	6	7.7	6	9.3	8.6	6.1
Design, Modeling, and Resource Planning	7	9.1	6	10.0	6	10.0	9.7	6.9
Resilience	7	11.4	6	11.7	6	11.5	11.5	8.2
Photovoltaics	7	6.0	6	4.5	6	4.3	4.9	3.5
Concentrated Solar Power	6	4.0	7	4.4	6	3.5	4.0	2.8
Land-Based Wind Power	7	6.3	6	5.2	6	3.7	5.0	3.6
Offshore Wind Power	6	4.0	8	4.9	6	3.5	4.1	2.9
Biopower	7	5.4	7	5.3	7	4.9	5.2	3.7
Geothermal Power	8	11.4	7	12.3	7	12.4	12.0	8.6
Small-Scale Hydroelectric	7	6.6	6	6.3	6	5.5	6.1	4.4

Geothermal									Number of Respondents: 10
Mechanical Energy Storage	7	7.3	7	6.3	7	6.1	6.6		4.7
Thermal Energy Storage	7	8.7	8	8.4	9	8.9	8.7		6.2
Electrochemical Energy Storage	7	7.1	7	9.6	8	9.9	8.9		6.3

Ranking of R&D Areas

R&D Area	Near-term		Mid-term		Long-Term		Overall Score		Normalized Score
	# of Ans.	Avg. Score	# of Ans.	Avg. Score	# of Ans.	Avg. Score	# of Ans.	Avg. Score	
Corrosive Material Reduction	8	2.6	7	2.9	7	2.9	9	3.7	4.1
Energy Storage Integration	8	3.1	7	3.3	7	3.1	9	6.4	7.2
Enhanced Geothermal Systems	7	3.4	8	3.6	7	3.7	9	6.7	7.4
Exploration, Resource Characterization, and Resource Development	7	3.7	7	3.7	8	3.5	8	6.8	7.5
Flexible Geothermal Energy Generation	8	3.1	7	3.1	7	3.1	9	5.3	5.9
Improving Aging Facilities	8	2.4	7	2.7	7	2.4	9	2.8	3.1
Increasing Cost-Effectiveness	7	2.7	7	2.9	8	3.0	8	4.1	4.6
Innovative Geothermal Systems	8	3.0	7	2.9	7	2.9	9	3.2	3.6
Material Reuse	8	2.6	7	2.6	7	2.7	8	4.9	5.4

Ranking of Emerging and Breakthrough Technologies

Technology Name	Near-term		Mid-term		Long-Term		Overall Score		Normalized Score
	# of Ans.	Avg. Score	# of Ans.	Avg. Score	# of Ans.	Avg. Score	# of Ans.	Avg. Score	
Carbon Dioxide as a Working Fluid	7	2.1	7	2.1	8	2.4	9	4.1	2.7
Characterizing and Modeling EGS Reservoirs	7	3.1	7	3.4	8	3.5	8	9.0	6.0
Combination with Desalination	8	2.8	7	2.7	7	2.6	8	7.6	5.1
Corrosion-Resistant Geothermal Piping	8	2.8	8	2.9	7	2.9	8	7.8	5.2
Downhole Heat Exchangers	8	2.5	8	2.9	7	2.9	9	6.0	4.0
Geophysical Methods	8	3.4	7	3.4	7	3.3	8	10.4	6.9
Heat Recovery	7	2.9	8	2.9	7	2.7	7	7.9	5.2

Geothermal								Number of Respondents: 10	
Improved Fluid Injection	7	2.6	7	3.0	8	3.0	8	6.4	4.3
Improved Well Connectivity in EGS	7	3.0	8	3.3	7	3.3	9	9.3	6.2
Integration with CSP Systems	7	2.0	7	2.0	8	1.9	9	4.4	3.0
Lower Drilling Costs	9	3.7	7	3.7	7	3.7	8	12.8	8.5
Material Recovery from Geothermal Brines	9	3.6	7	3.6	7	3.7	8	11.5	7.7
Modeling for Flexible Generation	7	3.4	7	3.3	8	3.1	9	10.4	7.0
Oil–Gas Well Reuse	7	3.1	7	3.6	8	3.3	9	8.0	5.3
Water Reinjection	7	3.0	8	3.0	7	3.0	8	5.6	3.8

Source: Energetics (2020)

Table D-5: Grid Integration Survey Results

Grid Integration							Number of Respondents: 11	
Ranking of Technology Areas								
Technology Area	**Near-term**		**Mid-term**		**Long-Term**		**Average Score**	**Normalized Score**
	# of Ans.	Avg. Score	# of Ans.	Avg. Score	# of Ans.	Avg. Score		
T&D Infrastructure	10	10.7	10	10.8	10	10.8	10.8	7.69
Devices, Measurement, and System Controls	11	12.3	9	12.9	9	12.1	12.4	8.87
Design, Modeling, and Resource Planning	9	12.0	9	12.9	9	12.0	12.3	8.78
Resilience	9	10.8	9	11.7	10	12.3	11.6	8.27
Photovoltaics	11	10.5	9	8.7	9	8.3	9.2	6.54
Concentrated Solar Power	10	8.2	8	7.9	10	9.0	8.4	5.97
Land-Based Wind Power	10	7.5	8	5.9	10	6.2	6.5	4.66
Offshore Wind Power	9	3.6	9	5.9	9	4.6	4.7	3.33
Biopower	9	3.0	9	4.0	9	3.4	3.5	2.49
Geothermal Power	9	4.0	9	4.8	9	4.3	4.4	3.12
Small-Scale Hydroelectric	9	3.9	9	3.9	9	3.3	3.7	2.65
Mechanical Energy Storage	10	6.9	9	7.4	10	7.6	7.3	5.22
Thermal Energy Storage	11	7.5	9	6.1	10	7.2	6.9	4.94
Electrochemical Energy Storage	11	8.8	9	8.8	9	7.6	8.4	5.99
Ranking of R&D Areas								

Grid Integration										Number of Respondents: 11
R&D Area	**Near-term**		**Mid-term**		**Long-Term**		**Overall Score**		**Normalized Score**
	# of Ans.	Avg. Score	# of Ans.	Avg. Score	# of Ans.	Avg. Score	# of Ans.	Avg. Score	
Climate-Based Risk and Resilience Tools	10	2.9	9	3.1	9	3.4	9	4.6	5.7
Load Control Systems	9	3.0	10	3.2	9	2.8	9	4.9	6.1
Load Models	10	3.0	9	3.0	9	2.8	9	4.7	5.8
Sensors	10	3.0	8	3.1	8	3.0	8	3.6	4.5
Smart Inverters	9	3.7	9	3.4	8	3.0	8	5.6	7.0
Telemetry	9	3.0	9	3.0	9	2.3	9	3.6	4.4
Transmission Architecture	9	2.9	8	3.0	8	3.1	8	4.6	5.8
Weather Models	10	3.3	10	3.1	9	3.1	9	5.3	6.7
Other R&D Areas to Consider: Microgrids/Remote Grid for Wildfire Resilience									

Ranking of Emerging and Breakthrough Technologies

Technology Name	**Near-term**		**Mid-term**		**Long-Term**		**Overall Score**		**Normalized Score**
	# of Ans.	Avg. Score	# of Ans.	Avg. Score	# of Ans.	Avg. Score	# of Ans.	Avg. Score	
Aluminum Conductor Composite Core (ACCC)	3	2.7	3	2.7	3	2.7	3	7.0	5.8
High Voltage DC Grid, Transmission Wires	4	3.5	4	3.5	4	3.3	4	10.3	8.5
Silicon Carbine (SiC) Power Semiconductors	3	3.7	3	3.7	3	3.7	3	9.0	7.5
Transmission Line Reactance (Smart Wires)	5	3.4	5	3.2	5	2.8	5	10.0	8.3
Transmission Towers with Insulating Cross-Arms	3	2.7	3	2.3	3	2.3	3	6.7	5.6
Dynamic Line Rating	5	3.6	5	3.2	5	3.2	5	9.2	7.7
Lidar-Assisted Controls	4	2.3	4	2.3	4	2.0	3	5.0	4.2
High-Fidelity Solar Power Forecasting System	7	3.1	6	3.0	6	2.8	6	8.5	7.1
Improved Net-Load Forecasting	9	3.3	8	3.1	8	3.1	8	6.3	5.2
Satellite Imagery and Data	7	2.4	6	2.5	6	2.2	6	6.3	5.3
Two-Way Coupled Modeling	8	1.6	7	1.7	7	1.9	6	5.5	4.6

Grid Integration								Number of Respondents: 11
Univariate Time Series Prediction of Solar Power	7	2.1	6	2.2	6	2.0	6	5.5	4.6

Source: Energetics (2020)

Table D-6: Small Hydro Survey Results

Small Hydro								Number of Respondents: 5
Ranking of Technology Areas								
Technology Area	**Near-term**		**Mid-term**		**Long-Term**		**Average Score**	**Normalized Score**
	# of Ans.	Avg. Score	# of Ans.	Avg. Score	# of Ans.	Avg. Score		
T&D Infrastructure	3	11.7	4	11.0	4	9.8	10.8	7.7
Devices, Measurement, and System Controls	2	9.5	1	7.0	1	7.0	7.8	5.6
Design, Modeling, and Resource Planning	2	8.5	1	9.0	1	8.0	8.5	6.1
Resilience	4	10.3	1	4.0	1	11.0	8.4	6.0
Photovoltaics	4	6.8	1	1.0	1	1.0	2.9	2.1
Concentrated Solar Power	2	3.5	1	3.0	1	5.0	3.8	2.7
Land-Based Wind Power	2	6.5	1	5.0	1	3.0	4.8	3.5
Offshore Wind Power	2	2.0	1	2.0	1	2.0	2.0	1.4
Biopower	2	10.0	3	13.3	3	12.3	11.9	8.5
Geothermal Power	2	9.0	1	13.0	1	12.0	11.3	8.1
Small-Scale Hydroelectric	5	12.2	1	14.0	1	13.0	13.1	9.3
Mechanical Energy Storage	4	9.8	1	6.0	1	6.0	7.3	5.2
Thermal Energy Storage	2	9.5	1	10.0	1	10.0	9.8	7.0
Electrochemical Energy Storage	4	9.3	3	12.3	3	13.3	11.6	8.3

Ranking of R&D Areas									
R&D Area	**Near-term**		**Mid-term**		**Long-Term**		**Overall Score**		**Normalized Score**
	# of Ans.	Avg. Score	# of Ans.	Avg. Score	# of Ans.	Avg. Score	# of Ans.	Avg. Score	
Alternative Materials for Turbine Components	4	3.3	1	3.0	3	3.0	1	6.0	6.7
Electrical and Control Systems	4	3.3	1	3.0	1	3.0	1	5.0	5.6
Environmental and Societal Improvements	4	2.3	1	1.0	3	2.3	1	0.0	0.0

Small Hydro									Number of Respondents: 5
Forecasting and Assessment	4	3.0	1	3.0	1	3.0	1	3.0	3.3
Integrate Climate Readiness into Electricity System Operations, Tools, and Models	4	2.5	1	2.0	1	2.0	1	1.0	1.1
Low-Head Application	4	3.5	1	4.0	1	4.0	1	7.0	7.8
Real-Time Monitoring Systems	4	2.8	1	2.0	1	2.0	1	2.0	2.2
Site and Energy Assessment of Existing Conduits	4	3.5	1	4.0	1	4.0	1	9.0	10.0
Testing Methods and Facilities	4	2.5	1	2.0	1	2.0	1	0.0	0.0
Turbine Improvements	4	3.0	3	3.0	1	3.0	1	4.0	4.4
Turbine Standardization	4	3.3	3	3.3	1	4.0	1	8.0	8.9

Ranking of Emerging and Breakthrough Technologies

Technology Name	Near-term		Mid-term		Long-Term		Overall Score		Normalized Score
	# of Ans.	Avg. Score	# of Ans.	Avg. Score	# of Ans.	Avg. Score	# of Ans.	Avg. Score	
Cavitation Analysis	3	2.7	2	3.0	1	3.0	1	3.0	3.3
Composite Materials	2	2.0	2	2.5	2	2.5	1	6.0	6.7
Dead Level Turbine Efficiency	0	0.0	1	3.0	0	0.0	1	7.0	7.8
Hydrokinetic Turbines	1	4.0	0	0.0	0	0.0	1	4.0	4.4
Induction Generator	0	0.0	0	0.0	1	3.0	1	5.0	5.6
Inflatable Weirs	0	0.0	0	0.0	1	4.0	1	0.0	0.0
Modular Systems	1	4.0	0	0.0	0	0.0	1	8.0	8.9
Permanent Magnet Generator	0	0.0	1	3.0	0	0.0	1	2.0	2.2
Standardized Site Assessment Tool	1	3.0	0	0.0	0	0.0	1	9.0	10.0
Test Facilities	1	3.0	0	0.0	0	0.0	1	1.0	1.1
Water and Self-Lubricated Turbines	0	0.0	0	0.0	1	3.0	1	0.0	0.0

Other R&D Areas to Consider: The single largest barrier to small hydro development in the US (and California) is reliable pricing programs. There are no other barriers of any significance that are presented in the questionnaire.

Source: Energetics (2020)

Table D-7: Solar Survey Results

Solar									Number of Respondents: 10

Ranking of Technology Areas

Technology Area	Near-term		Mid-term		Long-Term		Average Score	Normalized Score
	# of Ans.	Avg. Score	# of Ans.	Avg. Score	# of Ans.	Avg. Score		
T&D Infrastructure	10	11.2	9	11.7	8	10.3	11.0	7.9
Devices, Measurement, and System Controls	10	9.7	9	10.7	9	9.6	10.0	7.1
Design, Modeling, and Resource Planning	10	9.0	10	9.8	9	10.2	9.7	6.9
Resilience	10	8.4	10	8.3	8	8.4	8.4	6.0
Photovoltaics	9	10.9	9	9.4	10	9.3	9.9	7.1
Concentrated Solar Power	8	4.6	7	5.4	9	7.4	5.8	4.2
Land-Based Wind Power	9	7.8	8	6.9	7	5.3	6.6	4.7
Offshore Wind Power	9	6.0	9	5.9	8	5.8	5.9	4.2
Biopower	7	6.0	7	5.0	7	5.4	5.5	3.9
Geothermal Power	7	5.9	7	5.4	7	4.9	5.4	3.8
Small-Scale Hydroelectric	8	5.1	8	4.8	7	3.4	4.4	3.2
Mechanical Energy Storage	7	9.0	8	8.4	8	9.4	8.9	6.4
Thermal Energy Storage	8	8.8	8	9.4	9	11.3	9.8	7.0
Electrochemical Energy Storage	9	9.9	10	10.8	10	11.7	10.8	7.7

Ranking of R&D Areas

R&D Area	Near-term		Mid-term		Long-Term		Overall Score		Normalized Score
	# of Ans.	Avg. Score	# of Ans.	Avg. Score	# of Ans.	Avg. Score	# of Ans.	Avg. Score	
Building- and Community-Scale PV and Storage	10	3.3	10	3.5	10	3.7	9	10.1	8.4
Innovative Technologies	10	2.3	10	2.6	10	3.4	9	8.8	7.3
Improving, Predicting, and Quantifying PV Durability	10	3.0	10	3.0	10	3.5	8	8.1	6.8
Large-Scale Manufacturing of Emerging Technologies	10	2.9	10	3.3	10	3.4	9	9.6	8.0
Traditional PV Improvements	10	2.9	10	2.9	10	2.6	8	7.4	6.1
Thin Film Technologies	10	2.2	10	2.3	10	2.6	8	5.1	4.3

Solar									Number of Respondents: 10
Alternatives to Conventional CSP	9	1.7	8	1.9	8	2.4	5	3.0	2.5
Efficient Thermal Energy Storage and Heat Transfer Fluid	9	2.9	8	2.9	8	3.0	6	8.0	6.7
Improved Receivers and Absorbers for CSP	9	2.0	8	2.5	8	2.6	5	4.0	3.3
Thermal Energy Storage	9	2.7	8	2.6	8	2.6	5	6.2	5.2
Environmental and Social Improvements	10	2.9	10	3.0	10	2.9	7	6.7	5.6
Testing Methods and Facilities	10	3.0	10	3.0	10	3.1	6	7.5	6.3

Other R&D Areas to Consider: Social engineering to better match solar availability

Ranking of Emerging and Breakthrough Technologies

Technology Name	Near-term		Mid-term		Long-Term		Overall Score		Normalized Score
	# of Ans.	Avg. Score	# of Ans.	Avg. Score	# of Ans.	Avg. Score	# of Ans.	Avg. Score	
Alternative to Rare Earth	9	2.1	9	2.0	9	2.2	5	16.0	8.4
Gallium Arsenide Solar Cells	9	2.1	9	2.0	9	2.3	5	14.0	7.4
Organic Photovoltaics	9	1.7	9	1.7	9	1.9	5	12.2	6.4
Perovskite Solar Cells	9	2.3	9	2.6	9	3.1	7	14.1	7.4
Tandem PV	8	2.8	8	3.0	8	3.4	7	16.7	8.8
Brayton Cycle	7	2.3	7	2.3	7	2.4	4	8.5	4.5
Beam Down CSP	7	1.4	7	1.4	7	1.7	4	7.3	3.8
Direct Solar to Salt Receiver	7	2.1	7	2.1	7	2.3	4	10.5	5.5
Containment Alloys	7	1.9	7	2.0	7	2.3	4	11.3	5.9
Gas Phase Receiver	7	1.7	7	1.7	7	1.9	4	8.8	4.6
Insulation of Molten Salt	7	2.0	7	2.1	7	2.1	4	7.5	3.9
Linear Fresnel	6	1.5	6	1.5	6	1.2	4	5.3	2.8
Molten Salts	6	1.8	6	1.8	6	2.2	4	10.0	5.3
New Materials for Reflection and Absorption	6	1.7	6	1.7	6	1.7	4	7.0	3.7
Particle Receiver System	6	2.0	6	2.0	6	2.0	4	9.3	4.9
Pumps for Molten Salt	6	2.2	6	2.2	6	2.2	5	8.0	4.2
Stirling Dish Engine	6	1.3	6	1.3	6	1.3	4	3.8	2.0
Sensory Systems	7	2.9	7	2.9	7	3.1	5	13.8	7.3
Test Facilities	8	3.0	8	3.3	8	3.4	6	17.2	9.0

Solar	Number of Respondents: 10
Other R&D Areas to Consider: understanding effects of PV components when deployed in a larger system	

Source: Energetics (2020)

Table D-8: Wind Survey Results

Wind								Number of Respondents: 8
Ranking of Technology Areas								
Technology Area	**Near-term**		**Mid-term**		**Long-Term**		**Average Score**	**Normalized Score**
	# of Ans.	Avg. Score	# of Ans.	Avg. Score	# of Ans.	Avg. Score		
T&D Infrastructure	7	11.7	6	10.5	6	11.0	11.1	7.9
Devices, Measurement, and System Controls	7	9.4	6	7.0	6	7.0	7.8	5.6
Design, Modeling, and Resource Planning	6	9.8	6	9.5	6	10.0	9.8	7.0
Resilience	6	8.5	6	8.8	6	9.0	8.8	6.3
Photovoltaics	6	9.3	6	8.8	6	8.2	8.8	6.3
Concentrated Solar Power	6	4.0	6	3.8	6	4.5	4.1	2.9
Land-Based Wind Power	6	9.0	6	7.8	6	7.0	7.9	5.7
Offshore Wind Power	6	8.2	6	10.7	7	11.6	10.1	7.2
Biopower	6	4.0	6	4.5	6	5.7	4.7	3.4
Geothermal Power	6	3.7	6	4.0	6	3.8	3.8	2.7
Small-Scale Hydroelectric	6	4.5	6	3.8	6	3.3	3.9	2.8
Mechanical Energy Storage	6	5.8	7	5.9	6	5.0	5.6	4.0
Thermal Energy Storage	6	6.5	7	9.4	6	8.2	8.0	5.7
Electrochemical Energy Storage	6	11.5	7	12.3	0	11.2	11.7	8.3

Ranking of R&D Areas									
R&D Area	**Near-term**		**Mid-term**		**Long-Term**		**Overall Score**		**Normalized Score**
	# of Ans.	Avg. Score	# of Ans.	Avg. Score	# of Ans.	Avg. Score	# of Ans.	Avg. Score	
Aging Wind Turbines	7	2.1	6	1.8	6	1.8	4	11.3	5.9
High-Elevation Wind	6	2.7	6	2.7	6	2.7	5	14.0	7.4
On-site Manufacturing	7	1.9	6	1.7	6	1.7	3	11.0	5.8
Non-Traditional Wind Energy Designs	6	1.2	6	1.2	6	1.5	4	8.8	4.6

Wind									Number of Respondents: 8
Land-based Tower and Structure Design	6	1.5	6	1.5	6	1.5	3	10.0	5.3
Land-based Turbine Transportation and Assembly	7	2.7	6	2.7	6	2.7	5	13.4	7.1
Floating Wind Turbines	7	3.3	7	3.7	6	3.7	7	17.4	9.2
Off-shore Turbine Manufacturing	7	2.9	6	2.8	6	3.0	5	14.6	7.7
Off-shore Tower and Structure Design	6	2.8	6	3.0	6	3.2	7	14.3	7.5
Off-shore Turbine Transportation and Assembly	7	3.0	7	3.3	6	3.5	7	14.4	7.6
Blade Improvements	6	2.8	6	2.8	6	3.0	5	12.2	6.4
Blade Repair Solutions	7	2.9	6	2.7	6	2.5	3	16.3	8.6
Electrical Systems	6	2.2	6	1.8	6	1.8	2	16.0	8.4
Environmental and Social Improvements	8	2.9	7	2.9	7	2.9	6	15.7	8.2
Forecasting and Assessment	7	2.9	6	2.8	6	2.7	5	14.0	7.4
Real-Time Monitoring Systems	6	2.7	6	2.7	6	2.7	5	12.2	6.4
Testing Methods and Facilities	6	1.7	6	1.8	6	1.8	3	10.0	5.3
Turbine and Nacelle Improvements	6	1.3	6	1.3	6	1.3	2	7.5	3.9
Turbine and System Control	6	2.8	6	2.8	6	2.8	6	12.3	6.5
Other R&D Areas to Consider: Hybrid energy systems; Wind resources providing reliability services and grid forming capability, and forecasting; Advanced materials for blades and tower. New composites with stiffer higher strength blades that allow larger rotors and taller towers at reasonable cost and are recyclable.									

Ranking of Emerging and Breakthrough Technologies

Technology Name	**Near-term**		**Mid-term**		**Long-Term**		**Overall Score**		**Normalized Score**
	# of Ans.	Avg. Score	# of Ans.	Avg. Score	# of Ans.	Avg. Score	# of Ans.	Avg. Score	
Airborne Wind Power Systems	6	0.7	6	0.8	6	1.3	1	8.0	2.9
Onsite Assembly	6	1.8	6	2.2	6	2.5	4	21.0	7.5
Shrouded Horizontal Axis Turbines	6	0.3	6	0.3	6	0.3	1	1.0	0.4
Turbines for Lower-Wind-Speed Sites	7	2.7	7	2.7	7	2.7	5	21.8	7.8
Alternative Underwater Pile Driving Operations	7	1.7	7	1.9	7	1.9	3	16.3	5.8
Floating Installations	7	2.9	7	3.1	7	3.6	6	25.7	9.2

Wind								Number of Respondents: 8
Floating Lidar	5	2.4	5	2.4	5	2.4	1	26.0	9.3
Ice Prevention Systems	5	1.2	5	1.2	5	1.2	1	3.0	1.1
Offshore High-Voltage Inter-Array Cables	6	2.5	6	2.5	6	2.8	3	24.0	8.6
Radar Interference Mitigation	7	2.6	7	2.6	7	2.9	3	25.3	9.0
Substructure Design for Offshore Wind	6	2.3	6	2.5	6	2.8	3	25.3	9.0
Aerodynamic Sensors Along Blade	5	2.2	5	2.2	5	2.2	2	22.0	7.9
Aeroelastic Techniques to Shed Load	5	2.6	5	2.6	5	2.6	3	24.0	8.6
Alternatives to Rare Earth Technologies	5	1.8	5	2.0	5	2.2	2	20.5	7.3
Coatings for Corrosion and Erosion	5	1.4	5	1.4	5	1.6	1	5.0	1.8
Concrete Structure Fabrication	5	1.4	5	1.4	5	1.4	2	11.5	4.1
Flexible Blades	6	2.3	6	2.5	6	2.5	3	24.7	8.8
Flow Control on Grids	5	2.6	5	2.6	5	2.4	3	22.7	8.1
Forecasting of Site-Specific Wind Resources	5	2.2	5	2.4	5	2.4	1	211.0	75.4
High-Temperature Superconducting (HTS) Generators	5	1.4	5	1.6	5	1.6	1	17.0	6.1
Laminate Layouts	5	1.6	5	1.6	5	1.6	1	12.0	4.3
Nondestructive Inspection of Blades	5	2.4	5	2.4	5	2.4	2	21.0	7.5
Permanent Magnet Generators (PMGs)	5	1.8	5	1.8	5	1.8	1	16.0	5.7
Pitch Control	5	1.6	5	1.6	5	1.6	1	10.0	3.6
Power Converters	6	1.8	6	1.8	6	1.8	2	18.0	6.4
Reduce Dependence on Heavy Lift Systems	6	2.2	6	2.2	6	2.2	3	21.0	7.5
Silicon Carbide for Power Conversion Electronics	5	2.0	5	2.0	5	2.0	2	18.0	6.4
Wind Turbine Noise Reduction	5	2.4	5	2.4	5	2.4	1	15.0	5.4
Other R&D Areas to Consider: Development of infrastructure for offshore Installations - Install ships, cable laying ships, crew ships, port infrastructure									

Source: Energetics (2020)

Webinar Results

Webinars were designed to both identify R&D opportunities and to prioritize R&D technologies to incorporate into initiatives.

Grid Integration Technologies and Strategies Webinar: March 19, 2019

Number of Participating Experts: 10

Key Challenges to Grid Infrastructure and Increased RE Penetration in California

What are key barriers that inhibit grid infrastructure technologies from increasing the penetration of utility-scale RE in California?

- Nimby opposition.
- Alignment of the rate structure to motivate best investments; the rate structure will need to continuously change as the investment level increases.
- Conservative utilities are somewhat adverse to trying new technology.
- Future supply constraints on grid-scale energy storage.
- Need for diversity of supply or significant low-cost storage.
- Regulatory restrictions.
- Policy definitions as to what constitutes renewables.
- Monopolist framework - Few entities control big portions of the grid infrastructure.
- Infrastructure will be required which has cost implications and opposition to large facilities.

Discussion on Research Initiatives

Question or instruction for the discussion:

Which R&D initiative can have the greatest impact to increase the penetration of utility-scale renewable energy in California's energy mix?

Click on a tile for a research opportunity and enter your comment in the text box. You can also respond to a previous comment to make a related point.

- CLIMATE-BASED RISK AND RESILIENCE TOOLS to improve planning, operations and better understand risks and resilience.
    - Need better and faster dynamic modelling tools
- LOAD CONTROL SYSTEMS to assess technical system needs (i.e., ancillary services, balancing VRE, etc.) and help manage different loads when available.
- LOAD MODELS to reduce power system operational uncertainty.
    - Need new tools allowing for faster control
- SENSORS designed for solar monitoring applications, including solar power efficiency checks and solar power site selection.
- SMART INVERTERS for improved monitoring and communication with the grid and making autonomous decisions to improve stability, power quality, and ancillary services.
- TELEMETRY to improve the cost and efficiency of high-density ground telemetry.
    - Need to create plug and play smart inverter requirements

- TRANSMISSION ARCHITECTURE hardware and materials to enable greater transmission capacity while reducing energy losses.
  - transmission architecture adequate to RE characteristics - testing
- WEATHER MODELS to predict power production from weather-dependent energy sources.
- MARKET FACILITATION (i.e., regulatory assistance, market analysis, program evaluation, etc.) to support deployment and expand access to clean energy technology and strategies.
  - Motivating investment is foundational
- Suggest an ALTERNATIVE R&D INITIATIVE for consideration
  - Smart inverters absent standardized interfaces will be difficult to integrate easily

Ranking Research Initiatives

Please rank items by impact to increase the penetration of utility-scale renewable energy in California's energy mix (Table D-9 and Figure D-1).

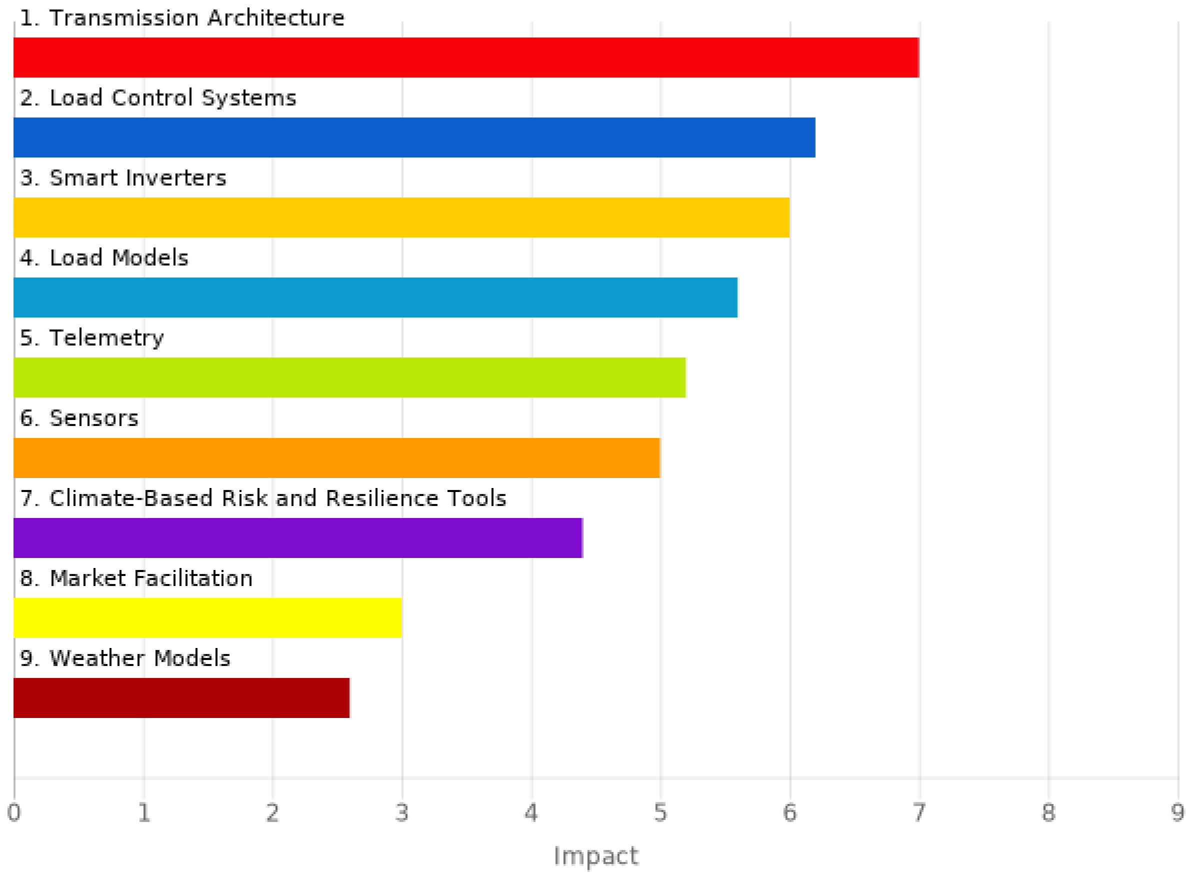
Table D-9: Grid Integration Research Areas Rated during Webinar

Criterion "Impact" sorted by mean
Highest rank of 9 is given 9 points.
Ratings submitted: 5. List of items randomized.

Nr	Item	↓Mean	SD	n
1	Transmission Architecture	7.00	**0.34**	5
2	Load Control Systems	6.20	0.29	5
3	Smart Inverters	6.00	0.22	5
4	Load Models	5.60	0.25	5
5	Telemetry	5.20	0.13	5
6	Sensors	5.00	0.07	5
7	Climate-Based Risk and Resilience Tools	4.40	0.33	5
8	Market Facilitation	3.00	0.27	5
9	Weather Models	2.60	0.09	5

Source: MeetingSphere (2019)

Figure D-1: Rating of Grid Integration Research Areas



Source: MeetingSphere (2019)

Transmission Architecture

Transmission Architecture - Identify key challenges that inhibit the ability of the research initiative in increasing RE penetration on the grid

- Need for a more responsive grid.
- Perhaps creating new standards would help. The utility sector is very fragmented and teaching each single utility is a very expensive challenge.
- Cost and identifying where to upgrade without unnecessarily burdening the rate base.
- Need alignment of policy with mandates, specifically. siting opposition makes deploying utility scale RE problematic.
- Not knowing how much to upgrade at each location. Everything cost money and utilities do not want invest in stranded assets.
- Mandating certain solutions is not the optimal approach.
- Need to have state-wide policy to enable upgrades. China can build these facilities in a fraction of the time that it takes for us here.

Transmission Architecture - Specify activities the Energy Commission can pursue to enable the greatest level of success.

- Getting the metrics right is key - more renewables and lower cost for electricity

- possibly plan a technical meeting where various technologies can be explained by experts.
- Stakeholder outreach and consensus building is key.
- Drive alignment across state agencies.
- Need to identify transmission bottlenecks and then develop solutions to remove those constraints.
- R&D regarding what actually is required to achieve. For example smart inverters without communications and effectively plug and play approach.
- Development of streamlined siting procedures.

Smart Inverters

Smart Inverters - Identify key challenges that inhibit the ability of the research initiative in increasing RE penetration on the grid.

- The smart inverter is a energy conversion device and does not generate energy. So, it is limited by the renewable resources behind it. We can use couple the renewable with storage to address this issue. But that comes with high costs.
- The smart inverter communication requires communication channels which may be an additional cost. But at high penetration levels, it is critical for the grid operator to know how much resources are available at any given time in order to operate the grid properly. The grid operator needs to keep the generation and load balanced in real time, or the grid may collapse.
- In some instances of large facilities there is a need for grid forming capability in order to be able to blackstart.

Smart Inverters - Specify activities the Energy Commission can pursue to enable the greatest level of success.

- The IEEE-1547-2018 required many capabilities to enable the smart inverter to support the grid. But the activation of the capabilities are still dependent on the local jurisdictions. Getting the capabilities activated is an uphill battle sometimes.
- Consistent application of performance characteristics, specifically two inverters should have almost identical performance characteristics and this should not change with manufacturer.
- Continue to support certified inverter posting.
- CTC has had some success explaining how the use of advanced conductors such as ACCC is providing a cost effective means of improving the efficiency, capacity, reliability and resilience of the grid which is also helping access renewables.

Load Control Systems

Load Control Systems - Identify key challenges that inhibit the ability of the research initiative in increasing RE penetration on the grid

- Provide guidance on what is the most cost-effective way to achieve the state's climate goals. The multiple efforts such as RPS and IV are not coordinated. Currently, it is not clear what is the best way to achieve these goals. Some people are pushing for distribution adoption even though DERs cost more on a $/kWh basis. Some are pushing for microgrids and not aware of the fact that microgrid costs are significantly higher than grid energy costs.

- do grid operators have the ability to access and use data on various technologies?
- Coordinating the multiple efforts is a challenge.
- R&D can create an outcome that seems simple but implementation is difficult. For example system modelling efforts for one circuit may not be easily extendable more broadly.
- Not knowing the target penetration and the target location makes identifying what is needed challenging. Different location has different transmission capacity and different needs.

Load Control Systems - Specify activities the Energy Commission can pursue to enable the greatest level of success.

- We need to identify what are the problems that we try to solve and then go from there. Doing a shot gun approach with vague objective may not yield as much benefits.
- Once again, I think they need to better understand each technology - perhaps by holding technical meetings - to fully understand what they offer.
- question: What is the level of cross communication between the CEC and other agencies concerned about efficiency and climate change?
- CEC can provide guidance on how to implement the specific CA objectives. Right now, it is very vague. We do not have any official indication on whether we should encourage the renewables on the transmission or the distribution, or whether we should encourage microgrids. The RPS goals may need to be tweaked to account for the effect of the CCAs.
- Investigation on Demand Side Management as it relates with Load Controls.
- CEC needs to make changes to the Loading Order to avoid the large generators from being shutdown and we lose the frequency support that we are getting from those units, at least until after the synthetic inertia units are being deployed. Not doing so, may have bad consequences to the grid reliability.

Biopower Webinar: March 21, 2019

Number of Participating Experts: 8

Brainstorm question or instruction:

What are key barriers that inhibit bioenergy technologies from increasing the penetration of utility-scale RE in California?

- Availability of pipeline quality renewable gas.
- Cost of woody feedstock.
- Woody biomass generation has relatively high cost compared to wind, solar, and natural gas.
- Logistics and cost of feedstock delivery at quantities and consistencies necessary to achieve utility scale production.

- Power purchase price/agreements appears to be a major inhibitor. Difficulty of obtaining and contracts.
- Acceptance of food waste by WWTP operators.
- New and innovative technologies for co-products from thermochemical processes
- Cost and security of feedstock is a primary variable for viability.
- Siting of facilities to reduce interconnection costs.
- Lack of steam hosts for combined heat and power.
- The costs of woody biomass generation does not take into account societal and environmental benefits.
- Distribution infrastructure exists -- so conversion into pipeline quality is critical.
- Tools to determine best sites for bioenergy projects (fuel availability and interconnection).
- Loan guarantee programs for risk associated with bioenergy projects.
- Lack of means to monetize forest fire mitigation benefits.

Question or instruction for the discussion:

Which R&D initiative can have the greatest impact to increase the penetration of utility-scale renewable energy in California's energy mix?

- BIOENERGY WITH CARBON CAPTURE AND STORAGE (BECCS).
- Carbon policy required to incentivize BECCS but best long-term carbon strategy
- This should include bio-power along with bio-fuels technologies.
- To meet the state's GHG reduction goals, BECCS can produce carbon negative numbers.

CLEANER COMBUSTION TECHNOLOGIES to more effectively produce energy while complying with local air district regulations.

FOOD WASTE INTEGRATION INTO WASTEWATER PROCESSES

IMPROVED PYROLYSIS PROCESSES

- This is a popular research area with DOE. CEC should partner on DOE funding to California companies.
- Research should look at logistics of delivering pyrolytsis bio-oil to refineries.
- Collaborative projects with refineries would be good.
- Mobile and modular systems should be demonstrated at commercial scales.

INTEGRATED GASIFICATION COMBINED CYCLE (IGCC) to improve power plant efficiency and decrease carbon emissions

MICROBIAL FUEL CELLS to take carbon-rich bio-waste and convert it into stored electricity.

MODULAR GASIFICATION system development

- Economic modular small systems would benefit distributed generation initiatives.

PIPELINE INJECTION of biogas into existing natural gas pipelines

- There are technologies to produce RNG using thermal gasification. These should be included in this category or a separate category.
- Gas is critical electric reliability yet Load Serving Entities are reluctant to embrace new gas.
- Market and carbon accounting mechanisms are needed to provide comfort to LSEs to use renewable gas for reliability.
- The long-term commitment by an LSE needs to be backed by assurance of supply -- both feedstock availability and cost.

PROCESSING OF MSW to economically remove the organic component

- Senate Bill 1383 will ultimately require the organic component of MSW to be segregated and be free of contaminants as possible for use in Anaerobic Digestion. This needs to be as efficient and economic as possible.
- I understand that SB1183 (?) will require cities to purchase certain minimum level of organics as construction and demolition wastes. These are large quantities which should be converted to bioenergy.

THERMAL HYDROLYSIS AT WASTEWATER PLANTS as a precursor to anaerobic digestion

MARKET FACILITATION (such as regulatory assistance, market analysis, program evaluation, etc.) to support deployment and expand access to clean energy technology and strategies.

- Greater near-term impact can be realized by facilitating the market access for existing technologies.
- Need to provide incentives for co-products such as biochar that can improve carbon recycling as well as energy generation.
- Collaboration with CARB for development of carbon accounting systems .
- Loan guarantees.

Suggest an ALTERNATIVE R&D INITIATIVE for consideration

- Production of RNG from woody biomass.
- Production of higher value co-products along with Bio-Power and Bio-RNG.

Ranking Research Initiatives

Please rank items by impact to increase the penetration of utility-scale renewable energy in California's energy mix (Table D-10 and Figure D-2).

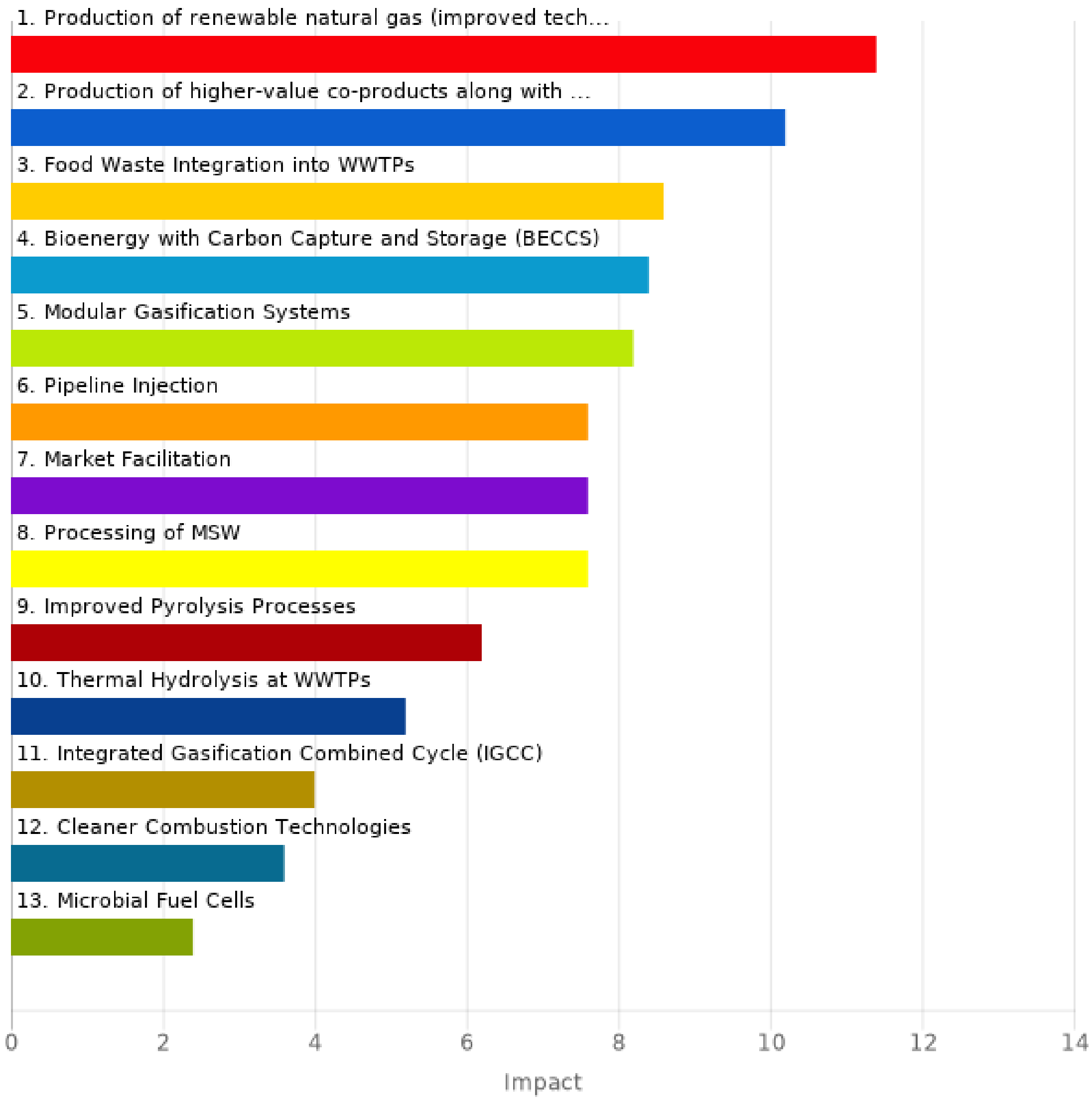
Table D-10: Biopower Research Areas Ranked during Webinar

Criterion "Impact" sorted by mean Highest rank of 13 is given 13 points. Ratings submitted: 5. List of items randomized.				
Nr	**Item**	**↓Mean**	**SD**	**n**
1	Production of renewable natural gas (improved technology development)	11.40	0.08	5

Criterion "Impact" sorted by mean Highest rank of 13 is given 13 points. Ratings submitted: 5. List of items randomized.				
Nr	**Item**	**↓Mean**	**SD**	**n**
2	Production of higher-value co-products along with bio-power and bio-RNG	10.20	0.16	5
3	Food Waste Integration into WWTPs	8.60	0.20	5
4	Bioenergy with Carbon Capture and Storage (BECCS)	8.40	0.32	5
5	Modular Gasification Systems	8.20	0.23	5
6	Processing of MSW	7.60	0.17	5
7	Pipeline Injection	7.60	0.27	5
8	Market Facilitation	7.60	0.34	5
9	Improved Pyrolysis Processes	6.20	0.17	5
10	Thermal Hydrolysis at WWTPs	5.20	0.13	5
11	Integrated Gasification Combined Cycle (IGCC)	4.00	0.25	5
12	Cleaner Combustion Technologies	3.60	0.17	5
13	Microbial Fuel Cells	2.40	0.08	5

Source: MeetingSphere (2019)

Figure D-2: Rating of Biopower Research Areas



Source: MeetingSphere (2019)

Research Opportunity #1 (Challenges and Mitigating Actions)

Technologies to produce RNG - Identify key challenges that inhibit the ability of the research initiative in increasing RE penetration on the grid

- Continued low cost of fossil natural gas.
- Interconnect costs, particularly for smaller projects.
- Long-term price incentives, look at what price would attract investment.
- Cost of feedstock.
- Lower cost of production, capital and operations.
- Co-products that can help the economics.
- Financing projects.
- Utility partnerships.
- Smaller scale systems.
- Economics of small scale systems.

- Process equipment normally benefits from scale, so innovation is needed around modularization.
- Monetizing greenhouse gas benefits.
- Customer education about RNG.
- Variability of feedstock during the year is a challenge. Variability across the state might reduce CEC research impact.
- Cost of front-end development done at risk.

Specify Research and Development Projects the Energy Commission can pursue to enable the greatest level of success.

- Development of conceptual framework (based on ARPA-E), that then allows research proposals to focus on things because the challenges have been clearly identified. Very helpful to getting responsive proposals.
- For BECCS, R&D needed for the carbon capture component.
- Continue advanced technology R&D for RNG production with potential coproducts. Focus on technologies that are economical competing with fossil alternatives.
- Education of the public about the benefits and potential of RNG. State is heavily focused on electrification.
- Focus on consistency of RNG among various technologies.
- R&D on the conversion of woody biomass to lower cost RNG to compete more economically with fossil natural gas.

Research Opportunity #2 (Challenges and Mitigating Actions)

Foodwaste Integration Into WWTPs - Identify key challenges that inhibit the ability of the research initiative in increasing RE penetration

- Efficient and economic separation of organic wastes from MSW.
- Education of WWTP operators to the benefits of co-digestion.
- In light of the breakdown in recycling programs, because of food contamination, maybe new incineration methods should be considered?

Research and Development projects the Energy Commission can pursue (Food Waste Integration in WWTPs)

- Identify the barriers by surveying WWTP operators.
- Technology testing and validation programs.
- Research issues with sludge amounts and disposal, most WWTP's don't want to increase their sludge.
- Small scale food and organic waste separation from MSW technology.
- Develop biosolid to gas capability, leveraging electrolytic hydrogen.
- Impact of variations of food waste on process efficiency.
- Filtrate from the digester should be included in study of sludge impacts.
- Use the CO_2 and electrolytic hydrogen to increase biogas yield and reduce CO_2 emissions.

Research Opportunity #3 (Challenges and Mitigating Actions)

High value Co-Products - Identify key challenges that inhibit the ability of the research initiative in increasing RE penetration on the grid

- Potential market value of the co-products.
- They have to displace other feedstocks that are well characterized with ability to have long term supply agreements.
- Coproducts should cover non-energy products that can compete with fossil counterparts
- Need economy of scale to support capital investment.
- Novel uses of bio-char (not enough of a market).
- Lower nutrient value of AD digestate for fertilizer.
- Advanced catalyst technologies for producing co-products have not been fully developed.

Research and Development activities the Energy Commission can pursue (high-value co-products)

- Research state of the art in U.S. and worldwide.
- Customer markets for biochar.
- Increasing nutrient value of AD digestate.
- Chemicals that can be made from syngas that can compete with fossil counterparts.
- Prove out the impact and benefits of biochar.
- Mitigation of odors from AD digestate.
- Lower capital cost for removing or lowering NH_3 from liquid AD digestate.

Brainstorm question or instruction:

Research and Development Projects the Energy Commission should consider (broadly)

- How to monetize the benefits of bio-energy technologies.
- Take a look at synergy from systems integration in addition to point focused technology.
- R&D work on the carbon capture component of BECCS.
- Longer term incentive programs.
- Research policies that reduce the costs of biomass feedstock (monetize the societal costs of biomass accumulation and disposal - open burning, forest fires, methane emissions, etc).
- Enzyme and biological methods to increase biogas production from AD systems.
- Examine the potential for carbon negative emissions from bioenergy facilities (BECCS and conversion of CO_2 to products).
- Research on long-term incentives for biofuels.

Energy Storage Webinar: March 26, 2019

Number of Participating Experts: 14

Discussion on Energy Storage barriers

Key Challenges inhibiting energy storage systems from increasing utility-scale renewable energy in California

We will briefly discuss each "challenge area" and then will undergo a prioritization exercise. Subsequently, the key barriers will be discussed in greater detail and we will identify potential R&D projects the Energy Commission could pursue to address them.

OST Are there high-cost technology development and operations components that need to be addressed?

- There are so many that it is difficult to know where to start.
- Focus on capital costs in the past, going forward installation, operation, maintenance, and disposal costs should also be a focus.
- Capital amortization charges dominate. In addition to CAPEX, must focus on lifetime and capacity factor. In other words long-duration, long-lifetime systems.
- Moving from lab scale to pilot study to full-scale types of projects require significantly larger investments for all types of technologies.
  - I feel like we need to move away from Pilot projects and just start putting these things in the field.
- Is it effective to focus on technology LCOS? In other words, is the industry standard evaluation methodology flawed?
- Efficiency and duration should also be studied.
  - Yes but this should be an iterative process where we learn through deployment rather than toothless pilot programs.
- The cost of the plant needed to build out the CAES plant that would be needed for the system that PG&E's demonstrated at King Island was very high.
- Life cycle cost?
- Cost of power ($/kW) and energy ($/kWh) need to be separately considered.

RESOURCE VALUATION Are energy markets appropriately valuing all of the benefits that this technology area may bring to the grid or society?

- No.
- No, contract and market structure and control system capability do not allow the full value stack of storage to be compensated.
- This is a key issue - without understanding how rate structures will evolve, it's very difficult to assess the cost targets for storage application.
- Like why can't I install a microgrid that is simultaneously an RA asset but is also a resilience backstop for natural disasters?
- The markets may not be fully developed yet. So, it is difficult to say whether the benefits are fully valued.
  - What market though?
- System flexibility (ramp up and down rates) and volume of storage need to be assessed in evaluating different storage options.
- How does the grid value resiliency?

- Ironically, vertically integrated traditional utility structures are better able to capture value, than the derivatives markets implemented in California.
- Value stacking is in development (multiple-use applications), however we are not considering the 5 year+ value stacking needs.
- The market may not be there until the grid is significantly weakened by intermittent resources.
- RA markets do not value long-duration storage advantageously.
- They are appropriately valuing Energy and Ancillary Services (reg up and reg down), as well as System and Local capacity (RA). However, Flexibility is undervalued, as is ability to avoid curtailment.
- No, benefits to climate of storing and using excess renewable electricity (instead of fossil) are not currently monetized as effectively as cap and trade or low carbon fuel standards are for CCS.

DISPATCHABILITY Are technology improvements or strategies needed to ensure that electricity can be used on demand and dispatched at the request of power grid operators, according to market needs?

- No problems here on the wholesale side. California ISO has a very well documented set of IT requirements for dispatch and our projects are working as initially expected in this regard.
- Is it problematic to have customer-sited generation that can also be controlled by the system operator? Like do we know of any deployed examples where behind the meter assets are effectively dispatched on the wholesale market?
- This is needed, but a key part of doing this is to generate the price signals and projected price signals that will enable the controls to be useful to stabilizing the grid.
- The power system needs to have generation that meets the load demand in real time. Currently, there are sufficient conventional generators to support the grid. But this may not be true at high renewable penetration levels.
- Yes, specifically with hybrids (for example, solar plus storage), it may be worth exploring how if each component will act independently. When will storage be called vs. the solar, and how are these market signals delivered to this system?
- Yes, communication and controls of these systems are an important area for development. Much like the apps on our phones - they need a standard communication platform to be fully utilized.
- Improved and more flexible regional grid would help facilitate more efficient operations.
- Economic dispatch is challenged by the need to schedule charging, and by the cost of the stored energy, which may be far more volatile than fuel.

RESOURCE AVAILABILITY -Clear understanding of geographical locations appropriate for deployment? -Regulatory or permitting barriers that may inhibit the development of utility-scale systems? -Forecasting improvements necessary to enhance operations and certainty in power scheduling?

- This is no better or worse for storage than for other types of generation. Note that this is faint praise, as siting and choosing the substation to connect to is opaque for everyone.

- Space constraints in urban areas - energy density needs to be higher.
- Is there value in having storage located close to power plants?
- This should be based on RFP by the CAISO or system operator. The power system is engineered to supply load at minimal costs with good reliability. The requirements are still the same regardless of the resources.
- Sunrun was working on a really interesting project that used weather data to create a state of charge estimator based on machine learning algorithms. I think the weather to asset behavior relationship is important and it is a precedent set in the capacity expansion modelling field.
- Location of systems tied closely to the market and value the system provides to the grid. Need to be understood together.
- Both charge and dispatch constraints can be geographical, so siting is trickier than for straight capacity.
- Right now inconsistency in fire codes and their interpretation across Authorities Having Jurisdiction is a challenge. Wildly varying requirements from one city/county to the next.
- For CAES in depleted natural gas reservoirs, geographical locations are known, but they each need individual evaluation so one cannot know apriori exactly where the given CAES reservoir(s) could be located. But generally, the location(s) is known, and it is where depleted reservoirs/wells exist.
- Re-contracting of existing assets (hybridizing gas plants with storage, adding storage to utility-scale storage) maybe limited to geography.
- Many people are talking about the geospatial relationship of generation assets here.

GRID INTEGRATION AND INTERCONNECTION Are there barriers to grid integration or interconnection that need to be addressed for this technology area?

- For transmission connected battery storage systems we have had no problem navigating this process and interconnecting projects in a timely fashion.
- Clear policy guidelines in place to direct the installation of energy storage cost effectively.
- There will be environmental and permitting challenges related to siting - these may impact how such systems are integrated into the grid based on locations where energy storage is tied into the grid.
- Long interconnection queues (lengthy process, which could kill a project that cannot wait it out).
- Energy density of prevaling tech is super low.
- Seems like each interconnection is unique. A more standard process would help reduce costs.

PERFORMANCE (including but not limited to: power output; capacity factor; energy density; material durability/corrosion; system degradation; efficiency; and curtailment)

- ASME PTC-53 Performance Test Code for Energy Storage Systems (Draft) will need industry review later this year.
- The ability to store and deliver energy quickly seem to be key aspects for performance.

- Cycle live degradation is pretty terrible for Li-Io. Low energy density presents a land use issue in all storage technologies. Flywheels take up a lot of space but chemical batteries catch on fire.
- Need standard ways to characterize system performance characteristics so that technologies can be matched with grid needs.
- For lithium ion batteries the power output, energy density, and efficiency are already quite good. Improving cycle life and reducing degradation as a function of time and use is the area that could improve the most.
- Duration of storage is a major issue. Also, once discharged, the storage is of no use to the grid. This is contrary to the fuel-based resources where we can just add fuel to prolong the support period.
- System performance continues to improve as technology advances. Each system has pluses and minuses, and are sited according to their best application/use-case. There is still quite a bit of customization, when modularity would accelerate project deployment.
- For CAES in depleted gas reservoirs or aquifer systems, wells and infrastructure are subject to material degradation. Re efficiency, reservoir damage can occur which points to need for reservoir engineering to manage operations. Long-term performance of porous media CAES systems has not been demonstrated (existing systems are in salt caverns).
- Energy storage will have efficiency issue too.
- Variance results in customer uncertainty.
- Recyclability.
- Ditto recyclability.
- Agreed.

PRODUCTION Are there issues related to the manufacturability, supply chain and logistics, or other factors that limit system production?

- System costs may be tied to the ability to have large scale production.
- Cobalt is problematic.
- All this stuff made overseas and that's no good from a market stability standpoint. Also what happens if the Congo dries up of cobalt.
- Are the material available for wide-scale deployment?
- Hybrid thermal-mechanical systems that integrate thermal storage have no such limitations.
- generally I'm pleased with the supply chain, would be nice if more of it was US based, but I honestly wouldn't pay extra for it.
- Could a sustainable recycling process help to support domestic supply and manufacturing?
- Security of raw material .
- Concern over lithium costs rising as EV demand increases.
- Also the inverter market is really weird.

- There may be limited sites where such technologies as pumped energy storage or CAES would be viable.
- Again, recyclability at end of life.
- The viability of depleted natural gas reservoirs in California for use as CAES reservoirs needs to be evaluated. Aspects such as depth, permeability, porosity, state of wells, capacity, etc. need evaluation.

THER BARRIER CATEGORIES Are there other major barrier categories to consider?

- Public acceptance will be important for deployment of some technologies.
  - Yeah like utililities need to come out and be like "yo this technology is chill to deploy."
- For Lithium Ion batteries, no. Costs are good and getting better. They're readily available and straightforward to connect to the grid. Basically, every other category of technology is severely lagging on cost, footprint, etc.
- Building on performance understanding to incorporate into planning and dispatch models.
- Need more more advanced modeling to understand the capabilities of these technologies (IRP).
- First of A Kind (FOAK) risk is the biggest barrier to utility innovation and technology adoption.
- Environmental performance from a life cycle perspective for different technologies.
- This may have been covered, but the market value isn't clear: for example, if I purchase a heat pump for domestic hot water, should I purchase a storage tank. But, I guess you're focused on utility scale.
- Need for performance testing standards (potentially a state-run facility).
- System modelling and ensuring that storage assets can be accurately captured in existing capacity expansion/ IRP models.
- Or standard test procedures for field systems.
- For CAES in depleted gas reservoirs, there are economic barriers related to idea that future gas prices could make the reservoir economic again. Need to establish value of CAES that is greater than projected natural gas value. Or need to find reservoirs with no future producibility.
- Climate change might be a hoax.

Ranking Key Challenges

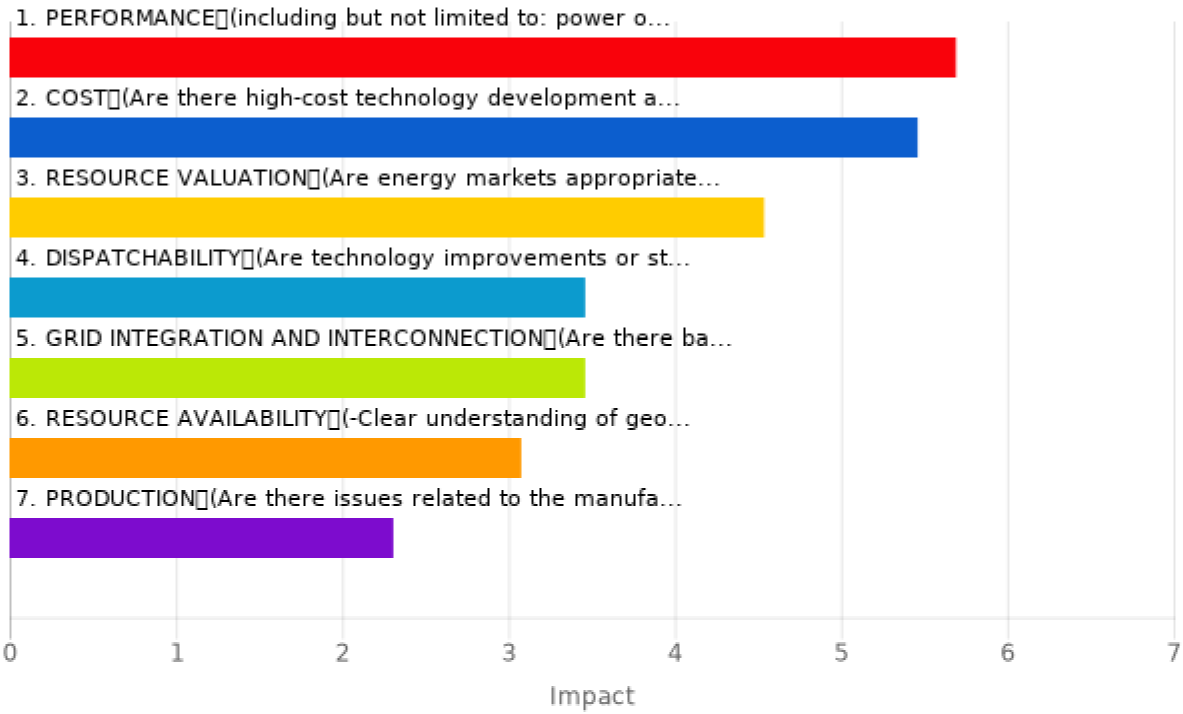
Please rank the Key Challenges inhibiting energy storage systems from increasing utility-scale renewable energy in California (Table D-11 and Figure D-3).

Table D-11: Challenges facing Energy Storage

Criterion "Impact" sorted by mean Highest rank of 7 is given 7 points. Ratings submitted: 13. List of items randomized.				
Nr	**Item**	**↓Mean**	**SD**	**n**
1	PERFORMANCE (including but not limited to: power output; capacity factor; energy density; material durability/corrosion; system degradation; efficiency; and curtailment)	5.69	0.23	13
2	COST (Are there high-cost technology development and operations components that need to be addressed?)	5.46	0.23	13
3	RESOURCE VALUATION (Are energy markets appropriately valuing all of the benefits that this technology area may bring to the grid or society?)	4.54	0.29	13
4	DISPATCHABILITY (Are technology improvements or strategies needed to ensure that electricity can be used on demand and dispatched at the request of power grid operators, according to market needs?)	3.46	0.21	13
5	GRID INTEGRATION AND INTERCONNECTION (Are there barriers to grid integration or interconnection that need to be addressed for this technology area?)	3.46	0.25	13
6	RESOURCE AVAILABILITY (-Clear understanding of geographical locations appropriate for deployment? -Regulatory or permitting barriers that may inhibit the development of utility-scale systems? -Forecasting improvements necessary to enhance operations and certainty in power scheduling?)	3.08	0.16	13
7	PRODUCTION (Are there issues related to the manufacturability, supply chain and logistics, or other factors that limit system production?)	2.31	0.22	13

Source: MeetingSphere (2019)

Figure D-3: Rating of Energy Storage Challenges



Source: MeetingSphere (2019)

R&D Projects to Address Challenge #1

What R&D Projects could the Energy Commission pursue to address the PERFORMANCE CHALLENGES?

Make sure to specify if there is a specific aspect of the Key Challenge the project would address. (Additionally, we'll follow-up by asking who are the required stakeholders, what are the measures of success, and what could inhibit success for the suggested R&D project.)

Unsorted (3)

- As a developer, encourage CEC to focus on materials research, and system design. Focus on basic research. CAISO is already working on communication protocols with developers.
- Definitely a need for basic funding and development. Looking at later TRL stages, that's where technology developers really struggle. If CEC could look across the TRL stage of the technology, look at DOE and DoD and see where CEC can help to bridge the technology gap before things are ready for large-scale deployment or VC funding.
- When looking at bigger picture, tension between focusing on distributed vs utility-scale. Important to look at both. In terms of the efficiency that you get from the storage, it may be possible using thermal storage locally that you get much higher-efficiency centrally. The extent to which CEC should focus on distributed vs utility-scale is very different for storage than for generation.

Comments

- In general the difference in the efficiency has the potential to be even bigger for storage, and difference in cost. Storage tank for heated water per energy stored may be much cheaper than the cost of the battery, how do we reach the CEC's overall goals?

Lithium Ion (3)

- Support materials research for improvements to anode/cathode/electrolye/housing for Lithium Ion.

Comments

- Footprint efficiency, cycle life.
- Improve the charge/discharge cycle efficiency for each of the storage technologies? There are always losses involved associated with storage and we should try to use generated power directly if possible to maximize usage.
- Cycle-life is hugely important.

Unclear requirements (3)

- Need to define the necessary performance requirements first.

Comments

- Yeah but let's see how the assets work in the field and then pick up the slack.
- What are we trying to achieve? Frequency support? Voltage support? Grid capacity offset? Each may have different performance requirements.

Comments

- A Storage asset can step in to fill all those roles simultaneously.
- 13. Will these systems look at seasonal vs. hourly energy storage needs?

Demonstrations (7)

- We want to see assets that operate in as many markets/ dispatch scenarios as possible.
- Support demonstrations to see fielded systems in operation.
- Agree with the need to have field demonstration projects that test the performance of different storage systems.

Comments

- You mean actual deployment followed by data gathering and design iteration? We could do pilots for the next decade and then sink into the sea.
- Demonstration to mitigate First Of A Kind (FOAK) risk.
- Performance testing facility for demonstration projects (help to improve the comparability of technologies).

Comments

- How do we balance the value of a facility versus the value of the integration learning from fielded systems?
- Modeling efforts should be used to help design and evaluate performance of field tests.
- Hybrid systems that integrate thermal energy with generation or cogeneration need demonstration.

Round-Trip Efficiency (2)

- As we use more storage, achieving a high round-trip efficiency will be critical to minimizing the need for installing more and more renewable generation capacity.
- Not sure how the commission would manage life-cycle performance (separate from point-performance). Operational test that is done over the life of the system (installation, quarterly, annually, etc).

Comments

- Lithium Ion has a certain life-time and degradation, when you would reach end of life. Just having a better method and standards to characterize it. Tracking from an operations and maintenance perspective.
- This is something that individually utilities are doing. CEC could play a role standardizing the data that is collected.

CAES (1)

- For CAES in subsurface porous media reservoirs, R&D is needed to (i) evaluate the potential size (capacity) of this approach, (ii) evaluate reservoirs around the state for CAES performance, (iii) evaluate integrity of existing wells to contain compressed air.

Comments

- Huge opportunity in CA to make use of depleted natural gas reservoirs. Studies that evaluate those reservoirs for porous media caves.
- In the performance realm itself, what is the state of that depleted resource. State of the wells such as oil that could muck things up.

System Standardization (4)

- Support development of standardized system characterization methods.
- As communication and controls for these systems are developed - creating standard data measurements that are collected to streamline monitoring and operational management.
- Interested in consistency (CESA), technology can go be evaluated at a standard testing facility. Similar to some of the PV testing fields out there. The thought around that is to help with streamlining and help the customer understand and receive data in some way, easily help them compare.
- (EPRI) standard testing protocols so a utility and a vendor can test and characterize systems using an agreed upon standard. Publicly open group has been working on. CEC has the opportunity to amplify that work.

R&D Projects to Address Challenge #2

What R&D Projects could the Energy Commission pursue to address the COST?

Make sure to specify if there is a specific aspect of the Key Challenge the project would address. (Additionally, we'll follow-up by asking who are the required stakeholders, what are the measures of success, and what could inhibit success for the suggested R&D project.)

Unsorted (0)

Lithium Ion (3)

- Materials research on lithium ion battery components.

Comments

- 4 major component categories (cathode, anode, electrolyte, housing), look at each as closely as you can and find improvement opportunities.
- A lot of groups are putting research efforts into this, DOE programs, how can CEC coordinate or augment research being done in these areas.
- There is a huge Li resource available from Salton Sea geothermal brines - this resource could reduce costs and increase Li availability - but research is needed for Li removal from brines at industrial scale at low costs.
- Understanding end-of-life and system disposal costs. How to support the development of a sustainable recycling infrastructure for batteries and storage systems.

Flywheels (1)

- We need energy density improvement in the flywheel space. This is primarily a material science and manufacturing challenge vis a vis rotor construction.

Comments

- Also cost minimization.

Liquid Air Technology (3)

- Liquid air really increases the efficacy of using waste heat or waste fuel. Couple electrical energy storage with other technologies or developments to utilize waste heat and thermal aspects (maximize efficiency of some of these systems).
- Pintail Power's Cryogenic Combined Cycle (CCC) has similar performance to CAES, with more flexible siting.
- Liquid air has been reported to be a low-cost approach to storage. Are those reports hype or is there a pathway that is useful there? A project that could answer the commercial readiness could be useful and complementary to what others are funding.

Comments

- Challenge = Opportunity. It's cost-effective at large scale (like LNG plants) but the charging process is challenged at small scale.

Off-river Pumped Hydro (gravity storage) (3)

- Off-river pumped hydro is being adopted in a big way in Australia - has the CEC explored whether such a technology would be useful in California?

Comments

- The general idea is that environmental challenges with pumped-hydro are associated with turning a river on and off. Instead of doing that, find a territory. (rugged/mountainous), with low-habitation of people. Create an area that is very high, or use caves as the lower storage volume, can get a high-head pressure in a confided space. Such areas don't typically have transmission lines reaching them.
- With liquid air technology could use an existing coal-plant that is getting shut down.

- Australian government is beginning to invest in billions of dollars in projects (CEC should watch and see the costs they are achieving).
- Additional gravity storage technologies could be promising and worthy of CEC consideration.
- Here is an example of a gravity storage project - [https://www.greentechmedia.com/articles/read/energy-vault-stacks-concrete-blocks-to-store-energy#gs.34azpk.](https://www.greentechmedia.com/articles/read/energy-vault-stacks-concrete-blocks-to-store-energy#gs.34azpk)

CAES (1)

- For CAES, R&D to reduce costs could be directed at (i) evaluating potential reservoirs to avoid those that need extensive remedial work on legacy wells, (ii) to select those that have high-quality reservoirs for CAES (for example injection-withdrawal tests, capacity/compression testing, compositional testing (such as mixing of air with residual CH_4 in the reservoir), and (iii) determination of synergies, e.g., could enhanced gas recovery associated with conditioning the reservoir for CAES be carried to subsidize development costs?

Long Duration (general) (5)

- Long duration by separating power ($/kW) from energy ($/kWh) can reduce overall CAPEX, but also enable much high capacity factor. Together these can drive down cost dramatically.

Comments

- Radically long durations are practical with hybrid integration using fluids such as liquefied or compressed air, or molten salt. They can create techno-economic synergies to improve performance and reduce cost.
- Generally comment that research into long-duration is a high priority. How do we deploy faster, create market demand, remove policy barriers.
- Integration of thermal energy into thermal generation could fit the bill. Could create some technical and economic synergies when combined. Could be deployed at a range of plants. (Demonstration effort).

Comments

- For example, Energy Storage Combined Cycle integrates molten salt with combustion turbine -- improves thermal to electric efficiency of storage and fuel heat rate. Uses proven equipment, at any scale.
- 28. Necessary and required according to all projections for SB 100. Look closely at this area and find opportunities to reduce costs.
- 30. No clear definition for "long duration". Sometimes it is viewed as 4 hours plus, or seasonal, but there is not a consistent definition. Needs to be done by someone at some point.

Comments

- 12+ hours enables higher capacity factor -- opportunity to charge with more low-cost renewable, dispatch longer.

Energy Density (general) (1)

- Focus research on the high energy density storage technologies. Also, identified bottlenecks to maximize returns.

Operating costs (general) (1)

- How to reduce operating costs (as opposed to capex) in wholesale markets: dedicated fiber/IT is expensive, Scheduling Coordinator at the ISO is expensive, meters are expensive and some utilities want more than one. Right now big projects in the tens of MWs can be in the money, but everything smaller is living on grant money or some other type of out of market life support.

Comments

- CEC could work with CAISO, who sets the requirements for this stuff to get them more comfortable with something not as large and hardened as they are used to. Very expensive to be a wholesale market participant.
- Economy of scale will continue to rule, so large-scale, long-duration technologies need to be supported.

Modeling studies (general) (1)

- Modeling studies could help assess the viability of aquifer thermal energy storage and its costs and efficiency.

Soft-Costs and End-of-Life (general) (2)

- Focus on lowering technology costs (all technologies), there are a number of exciting new topics. Is there a role for the CEC in the soft-costs?

Comments

- A decade ago there was significant focus on solar technology which drove down hardware costs, but recently focus on permitting and soft costs around the technology
- Energy Storage Integration Council put out a way to capture soft-costs. Battery system costs can be very different from a full-installed system costs. Each system (safety, communication, housing, power conditioning/inverter, site selection, prepare site, interconnection), think through how to factor in all of those costs. Some of that will come with industry maturity, but CEC could help provide the focus to ensure those are also being considered.
- Follow the system through, processes for dismantling the whole containerized system. Removing refrigerant from cooling systems. Transporting to recycling centers. California recycling groups are thinking about this. Stakeholder coordination could be very important.

R&D Projects to Address Challenge #3

What R&D Projects could the Energy Commission pursue to address RESOURCE VALUATION?

Make sure to specify if there is a specific aspect of the Key Challenge the project would address. (Additionally, we'll follow-up by asking who are the required stakeholders, what are the measures of success, and what could inhibit success for the suggested R&D project.)

- The value of avoided costs (reduced need for additional generation facilities) need to be considered for energy storage projects.

- Given that most storage technologies are anticipated to pay for themselves over multiple years, it's important to identify how rate structures will change over the coming years in order to reduce the risk associated with the large upfront investment.
- For CAES in subsurface depleted gas reservoirs, the main activity is an assessment of the resource capacity in the state. What is the capacity? Where are they located? What will effect on local economy be (new jobs)? What are the optimal properties of reservoirs for CAES?
- Try to use the market to determine the value of the resource instead of using administrative methods to arbitrarily determine the value. For example, check to see if the load customers are willing to pay extra for that improved service.
- Lifecycle greenhouse gas emissions (such as manufacturing, installation, operation, decommission) should be considered for energy storage options - this should be one of the considerations for evaluating energy storage options.
- Quantify the value for the benefits first before offering higher pricing for certain benefits.
- Demonstrating the greater value that a very flexible resource such as energy storage has over slow starting generators with high minimum generation levels would be valuable for informing the Resource Adequacy market, where all generators and storage are treated as similar commodities today.
- Need standardized evaluation criteria -- LMP and WX files for evaluating ESS.

R&D Projects to Address Challenge #4

What R&D Projects could the Energy Commission pursue to address DISPATCHABILITY and INTERCONNECTION?

Make sure to specify if there is a specific aspect of the Key Challenge the project would address. (Additionally, we'll follow-up by asking who are the required stakeholders, what are the measures of success, and what could inhibit success for the suggested R&D project.).

Dispatch (5)

- Identify what grid communication/control upgrades are needed to enable the dispatch signals. Are faster communications links needed?
- Optimization technology to improve dispatching of energy storage and minimization of curtailment.
- Would open source communications and controls help? Could it be done in a way that provided security for the grid but enabled technology development and deployment?
- Improved forecasting of solar and wind future generation levels and anticipated load to determine timing and magnitude of energy storage and delivery needs.
- Development of resilient energy storage systems that can deal with different types of systems interruptions (natural disasters, cyberattacks, etc.).

Comments

- How to capture value of system resiliency versus cost of that resiliency.

Interconnection (5)

- Capture Interconnection Lessons learned from existing supported demonstration projects.

Comments

- Or as part of future supported demonstration projects.
- Storage devices must have the capability to provide essential reliability services.
- For CAES, spatial study of locations of PV and wind generation overlain on transmission lines to look for overlaps with depleted natural gas reservoirs might focus initial reservoir evaluation studies on a tractable subset of proximal reservoirs.
- Identify the storage operating modes to streamline the interconnection requirements. Different operating modes may have different impacts and associated requirements.
- Charging and discharging constraints may be locationally different. Recharging may be impractical for some N-1-1constraints. So self-charging backup (with hybrid systems) can offer additional reliability benefits.

Comments

- Applies to dispatch also -- you can't discharge if you can't get charged.
- The storage locations, size, and operating modes need to be aligned with the local grid needs.

Closing Thoughts

Closing Statement: What is the one thing the Energy Commission should keep in mind as we draft the roadmap?

- Minimizing cost of storage will be most important in the end.
- Need to focus on the grid needs at high renewable penetrations and not simply on renewable adoption at the expense of the grid performance and costs.
- There are many different ways to store energy and the CEC should keep all options on the table and do R&D objectively and transparently and see what technologies (plural) rise to the top.
- Long (and season) and flexible durations will be necessary to mitigate the duck.
- Agreed. Consider how energy storage helps the grid from a system perspective.
- Yes - it's not just the cost of storage but the cost of all electricity in the end.
- Agreed. We need to look at final ratepayer costs.

Geothermal Webinar: March 28, 2019

Number of Participating Experts: 9

Discussion on Key Challenges

Key Challenges inhibiting geothermal systems from increasing utility-scale renewable energy in California.

We will briefly discuss each "challenge area" and then will undergo a prioritization exercise. Subsequently, the key barriers will be discussed in greater detail and we will identify potential R&D projects the Energy Commission could pursue to address them.

COST Are there high-cost technology development and operations components that need to be addressed?

- Drilling costs need to brought down.
- Modular power plants could reduce costs and speed up the timeline for putting systems online.
- Costs should be discounted by time and risk. High-risk and long-duration to positive cash flow issues stand in the way (such as exploration, characterization, and permitting, transmission and interconnection, off-take agreements).
- In the Salton Sea, especially, costs of existing corrosion resistant materials for the drilling and production side need to be reduced - or there needs to be development of entirely new materials and technologies that are more cost effective.
- One way to reduce costs is to reduce drilling of bad wells - this requires improved technologies to site wells through the use of geophysical techniques.

RESOURCE VALUATION Are energy markets appropriately valuing all of the benefits that this technology area may bring to the grid or society?

- The 24/7 availability of geothermal resources need to be valued.
- No, they are not valued for the benefits to the transmission system such as VARS
- No. Ancillary services are not appropriately valued in markets with increasing VRE penetration.
- The potential for flexible generation.
- There are numerous additional value streams that are not currently captured - such as direct use applications (heating, cooling), mineral recovery, etc.
- When I speak to utilities, they are more interested in lowest cost (RECs and market power) over green baseload.
- If the system wants geothermal flexible the resource should be paid for that value to the system. For example, the cost of the battery system to support solar and/or wind.
- potential for value of produced materials from geothermal brines (30 percent of Salton Sea production is solids) - what are the value streams there?
- Hybrid thermal storage might increase value.

DISPATCHABILITY Are technology improvements or strategies needed to ensure that electricity can be used on demand and dispatched at the request of power grid operators, according to market needs?

- Yes. Hybridization with thermal energy storage could enhance flexibility and improve efficiency.
- Aquifer thermal energy storage systems are extensively used in the Europe, but hardly utilized in the US.
- If the resource was paid for this service the technology is there but the plant/field has to be designed to operate this way.
- Contracts need to provide incentives for flexible operation of geothermal resources.
- flexibility can be introduced in two basic ways at geothermal plants - at the wellhead or by plant bypassing (continuous production flows). Flexibility at the wellhead required

hardened materials. Flexibility at the plant requires hybridized technologies and other value streams that can make the economics work - it also presents some technical challenges on the injection side.

- Mitigating thermal stress of turning on and off the resource delivery systems, i.d. wells and pipelines
- Hybrid operations with solar might help optimize dispatchabilty of power systems.

RESOURCE AVAILABILITY -Clear understanding of geographical locations appropriate for deployment? -Regulatory or permitting barriers that may inhibit the development of utility-scale systems? -Forecasting improvements necessary to enhance operations and certainty in power scheduling?

- It takes much longer to permit a project in CA due to CEQA and litigation that comes along with it. Regardless of the land ownership.
- Some KGRA's could be developed but do not have the necessary transmission available at this time (Surprise Valley KGRA).
- Project risk due to associated seismic activity will limit available sites.
- Geothermal resources are restricted to specific geologic conditions - thus their development and utilization depends on having sufficient transmission capabilities - the Salton Sea area is a good example for restricted grid.
- KGRA = Known Geothermal Resource Area a term that used to be used.
- CEQA is broken.
- KGRA = Known Geothermal Resource Area - areas already identified in the state of California as having goethermal resources.
- Preparation of a state-wide programmatic Environmental Impact Report for geothermal development that could help streamline CEQA at the project specific level.

GRID INTEGRATION AND INTERCONNECTION Are there barriers to grid integration or interconnection that need to be addressed for this technology area?

- Some curtailment that occurs at The Geysers is due to transmission congestion.
- They are non-technical and market barriers - full and appropriate valuation of geothermal's ancillary service and essential reliability services to the grid. It’s in part a policy challenge.
- The investor owned utilities have a very cumbersome interconnect process.

PERFORMANCE (including but not limited to: power output; capacity factor; energy density; material durability/corrosion; system degradation; efficiency; and curtailment)

- Availability of water for reservoir recharge is critical for sustainabilty of geothermal reservoirs.
- Geothermal power plants have historically had much higher capacity factors than any other type of generation.
- The oversupply of solar has caused curtailment of geothermal projects.
- Flexible generation may cause thermal cycling of wells, leading to performance issues for casing and cement.

- performance improvements in geothermal can in part come from improved reservoir management which yields improved resource sustainability and improved energy recovery. reduced system degradation.
- Hybrid thermal storage integration can enable improved cycle conditions (as could gas) to reduce $/kW CAPEX and $/MWh operating cost.
- Use of alternative materials that are more resistant to corrosion.
- Improved resource management via injection and production systems.

PRODUCTION Are there issues related to the manufacturability, supply chain and logistics, or other factors that limit system production?

- Availability of skilled drilling crews and rigs important for successful drilling operations - these can be in short supply when oil and gas prices are high.
- rig availability - largely uncontrollable and an artifact of the oil and gas industry. Best way to resolve that problem is to get oil companies back in the geothermal game?
- Long-term mechanical degradation of wells designed for base-load, converted to flexible production.
- Geothermal industry needs new participants for it to be able to grow.
- High NRE (Non-recurring Engineering) costs are a challenge because resource conditions are site-specific.

OTHER BARRIER CATEGORIES Are there other major barrier categories to consider?

- Access to money due to financial markets fears of the risk of geothermal.
- Public awareness and acceptance of geothermal technologies - educating them on its benefits.
- Technical and economic feasibility of recovering minerals and chemicals from geothermal brines.
- The CA Public Utilities Commission continues to review projects as least cost/least cost instead of least cost/best fit.
- Community involvement to assist in gaining support for development and resolve concerns over subsidence and seismic activity.
- State carbon policy enables smoke screens, since utilities can claim carbon neutrality, but not have to deliver carbon-free energy.
- Interconnect costs in rural areas can be excessive.
- The electrical market is changing, and this may impact the abililty of geothermal companies to finance projects. Previously, this was done by having long term power purchase contracts with utilities - these are becoming shorter in length and with different types of organizations.
- Fear by the public of volcanoes and earthquakes associated with geologically active areas. More education and outreach to the public and elected officials.
- Need to educate public about benefits and impacts of geothermal power - it is unknown to many.

Ranking Key Challenges

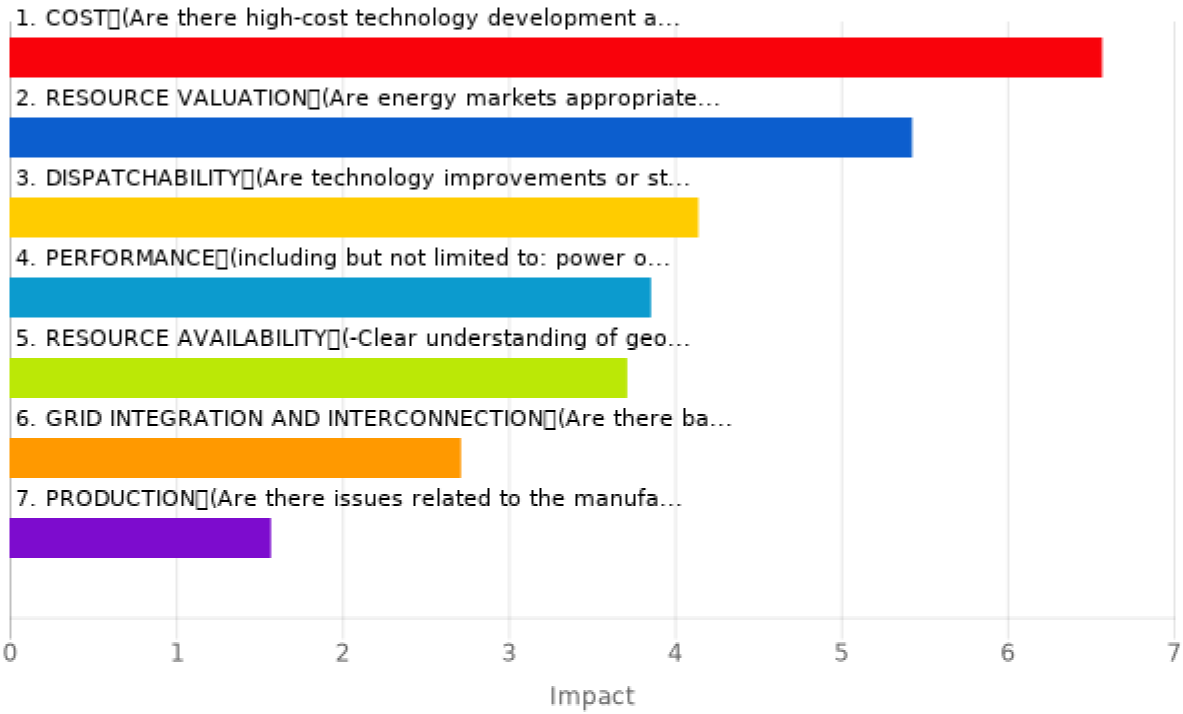
Please rank the Key Challenges inhibiting geothermal systems from increasing utility-scale renewable energy in California Table D-12 and Figure D-4).

Table D-12: Challenges facing Geothermal Power

Criterion "Impact" sorted by mean Highest rank of 7 is given 7 points. Ratings submitted: 7. List of items randomized.				
Nr	**Item**	**↓Mean**	**SD**	**n**
1	COST (Are there high-cost technology development and operations components that need to be addressed?)	6.57	0.10	7
2	RESOURCE VALUATION (Are energy markets appropriately valuing all of the benefits that this technology area may bring to the grid or society?)	5.43	0.27	7
3	DISPATCHABILITY (Are technology improvements or strategies needed to ensure that electricity can be used on demand and dispatched at the request of power grid operators, according to market needs?)	4.14	0.14	7
4	PERFORMANCE (including but not limited to: power output; capacity factor; energy density; material durability/corrosion; system degradation; efficiency; and curtailment)	3.86	0.23	7
5	RESOURCE AVAILABILITY (-Clear understanding of geographical locations appropriate for deployment? -Regulatory or permitting barriers that may inhibit the development of utility-scale systems? -Forecasting improvements necessary to enhance operations and certainty in power scheduling?)	3.71	0.18	7
6	GRID INTEGRATION AND INTERCONNECTION (Are there barriers to grid integration or interconnection that need to be addressed for this technology area?)	2.71	0.18	7
7	PRODUCTION (Are there issues related to the manufacturability, supply chain and logistics, or other factors that limit system production?)	1.57	0.10	7

Sources: MeetingSphere (2019)

Figure D-4: Rating of Geothermal Challenges



Sources: MeetingSphere (2019)

R&D Projects to Address Challenge 1

What R&D Projects could the Energy Commission pursue to address COST?

Make sure to specify if there is a specific aspect of the Key Challenge the project would address. (Additionally, we'll follow-up by asking who are the required stakeholders, what are the measures of success, and what could inhibit success for the suggested R&D project.)

Drilling (17)

- Improved drilling and well completion technologies to reduce cost and time to drill wells
- Drilling fluids and/or materials to address lost circulation.
- Drilling requires technology and skills specific for hot water - which leads to limited availability of contractors.
- Identify O&G best practices from fracking.
- Develop methods to improve permeability on "failed" wells - this could also help with Enhanced Geothermal Systems resources.
- Need to lower the cost of drilling.
- Develop hybrid approaches for utilization of geothermal resources.
- New drilling technologies - laser, high pressure jets, and other potential methods could be explored.
- Drilling new wells is risky financially, because drilling often takes longer and sometimes requires deeper drilling or other unexpected costs.
- Adopt expedited drilling methods developed by the unconventional oil and gas industry (improved procedures, monitoring systems while drilling).

Comments

- Higher rates of penetration and lower downtime. Challenge is the oil and gas majors invest billions of dollars in this. Existing oil and gas operations can help lower costs for geothermal.
- Application of lessons learned from past drilling experiences could lead to improved productivity.
- Harder rock conditions and higher temperatures. Adaptations that need to be made to account for that.
- From the rig perspective, more activity going on on the O&G side and gas storage that has raised concerns about rig availability (new regulations). In general, most of that work is being done with a double instead of a triple. Geothermal is done with a triple instead of a double. Drilling rig can pull two joints of pipe vs three (each joint is about 30 feet), mast height and pulling capacity is different.
- Every gas storage well in CA has to be reworked by 2025. All the gas storage fields in CA are very active about 6 months of the year (injection), other fields have two rigs and are going to three to facilitate meeting the 2025 requirement of tubing and packing on every well.
- Other regulation that got passed (30,000 idle O&G wells in CA). All operators are now required to plug and abandon a certain number of wells each year, or pay a substantial fee for testing requirements. Several thousand wells will be abandoned this year that otherwise wouldn't have been. Permian basis is doing a huge draw down on rig capacity right now too.
- Since mineral recovery from geothermal wells is still in early stages of development, bank investment risk needs to be addressed to assist in supporting this development - probably through succesful demonstration plant(s).
- The market price of minerals that can be extracted is a factor. Lithium, thus far is expected to be profitable. Zinc has been pursued in the past but proved to not be succesful. With better technology development, it may become possible to extract a panel of minerals and make it overall economically feasible.

Exploration (2)

- Subsurface imaging and exploration.
- Greatest potential for geothermal growth in CA is in the Salton Sea. There needs to be a holistic plan that provides value to multiple stakeholders (agricultural, energy, environmental, public, etc.). Geothermal can be central to this and there is a huge potential win for all parties involved where a nexus can be formed that 1) cleans up the sea (desal? water engineering?) 2) provides energy, 3) provides mineral/lithium recovery, etc. The value will come from cost reductions across all parts of that nexus, and they build upon one another. The whole is greater than the sum of the individual parts.

Materials (2)

- Alternative materials to address corrosion and durability.
- Casing and/or piping metallurgy to reduce costs of well workovers due to corrosion and/or scaling.

Modeling (1)

- Utilization of big data and machine learning methods to better integrate diverse data types to develop improved exploration models for geothermal systems.

Water (1)

- improved cooling technology for example hybrid that's efficient in the desert environment to address the water issue.

Byproducts (8)

- Co production of hot water from existing oil wells.
- Development of mineral recovery technologies can create an additional revenue source.
- Lithium extraction from Salton Sea (existing well-field), could meet 1/3 the demand of world lithium.
- Other products: Desalination options, hydrogen recovery, important in enabling flexibility in geothermal plants.
- Move the flexibility away from the well head (don't throttle and then re-open wells), put it at times of low demand to divert power flows to another beneficial use.
- In Hawaii, wells had a turbine bypass so they could operate wells without pulling power (better option is to put through a cascaded use).
- Use geothermal heat for forward osmosis (water being the energy source and fluid).
- Challenge (little growth or development of new geothermal resources in California), not additional resources available (Salton Sea is plentiful), more holistic approach needed to tap into lithium, de-sal, power production.

Integration with Storage (1)

- Integrate with thermal energy storage, charged by renewable power, to establish better power cycle conditions, reduce specific cost of power cycle ($/kW), and potentially gain some scale advantages.

R&D Projects to Address Challenge 2

What R&D Projects could the Energy Commission pursue to address RESOURCE VALUATION?

Make sure to specify if there is a specific aspect of the Key Challenge the project would address. (Additionally, we'll follow-up by asking who are the required stakeholders, what are the measures of success, and what could inhibit success for the suggested R&D project.)

Resource = Generation + Storage (5)

- I've seen cost comparison arguments that suggest geothermal should be compared to solar bundled with storage - which I do not think is how the cost is valued currently
- Load Serving Entities (LSEs) do not assign higher value to 'green baseload' but they will to 'green peak'. So add capacity and flexibility via thermal storage, and maybe help improve power cycle performance and cost at the same time.
- Look for geothermal direct use applications near urban areas - where these are more economically viable.
- Look for options for reservoir thermal energy storage tied to geothermal fields.

- The CEC has not been a strong advocate for geothermal energy.   That would help to have this agency carry the torch.

Ancillary Services (1)

- Geothermal power plants can provide black start capability and other essential reliability services (freq. control, voltage reg) - if compensated to do so - the plants can run flexibly and do fast ramping, something CA and the grid increasingly needs. CEC could do a study examining the historical benefit this has provided when geothermal plants ran this way in the past (geysers) or model the potential value it could provide if plants were operated this way in the future.

Holistic Grid Design (5)

- update on statewide resources expanding on what the USGS has historically done
- Iceland has developed a geothermal cluster approach to the utilization of their resources - for power generation, tourism, heating, aquaculture, and a variety of other uses. This more holisitic approach could help increase the resource valuation.
- Intermittent renewables create costly issues on the grid that they are not required to pay for. More baseload renewables on the grid would decrease the need for intermittent renewables.
- The Renewables Portfolio Standard encourages all renewables, but does not guarantee fair value to the benefits of geothermal generation offering better/more financially secure Power Purchase Agreements from utilities.
- CalISO has seen the benefits of the resource and is valuing that in some of their latest studies (CPUC has not been as helpful)

Byproducts (3)

- Use of hot water that is currently co-produced from oil wells, only to be reinjected with no energy obtained
- Use of deleted oil and gas fields for low or moderate temperature uses beyond electrical generation. For example, direct use or combined heat and power projects.
- Some of the resources in California may have supercritical temperatures at depth (such as the Salton Sea, The Geysers, Coso, and Long Valley) - utilization of these higher temperatures could be beneficial (and could facilitate hydrogen production as a secondary energy product for storage and vehicle transportation).

Comments

- good point - and the upside potential is huge

R&D Projects to Address Challenge 3

What R&D Projects could the Energy Commission pursue to address DISPATCHABILITY?

Make sure to specify if there is a specific aspect of the Key Challenge the project would address. (Additionally, we'll follow-up by asking who are the required stakeholders, what are the measures of success, and what could inhibit success for the suggested R&D project.)

Cascading use schemes and Byproducts (5)

- Flexible production has impacts on performance of wells (casing and cement) - these impacts need to be evaluated to see how geothermal power could be used to follow load rather than be produced as a baseline power source. Physical changes in field operations (such as having a turbine bypass and having more interconnections of steam and brine lines) may be needed to facilitate such operations. If other types of uses for geothermal fluids can be developed when power is not needed due to negative pricing episodes, then geothermal becomes a more viable option.

- It all comes down to figuring out ways to get geothermal operators to run flexibly. They can do this (as has been demonstrated), but they won't do this unless they are compensated for that. Cascaded use schemes, additional hybrid value streams (mineral recovery, desal, etc.) all help with this. The rules of the game are broken for geothermal - as Bill has mentioned. So whatever the CEC can do to change the rules of the game. Perhaps this is an advocacy action? Does/can that fall in CEC's mandate? Are there ways for CEC to support that?
- Curtailment is often viewed as lost revenue - how can this be changed?
- Mineral extraction has been done on small pilot scales - but there is a high cost threshold to demonstrating the viability of such systems at industrial scales - this type of effort could be supported by the state.

Comments

- A number of efforts for very small-scale demonstrations that the technology works. Now need to prove this will work on a field scale level (valley of death for funding).
- The extent to which you are integrating additional value-streams could introduce new risk for both groups (may not improve the economic attractiveness of the product). For example, have to secure a new long-term agreement for someone to take lithium for example. Bank upset that may be reducing the lifetime of the asset).

Comments

- Make sure to be aware of unintended consequences of activities.

Storage (1)

- Add thermal energy storage of renewables that is re-dispatched with the baseload geothermal.

Utility Barriers (1)

- Utilities do not want to pay for baseload, can get cheaper power in the market.

Comments

- Systems will have to adapt or market rules need to change.

R&D Projects to Address Challenge 4

What R&D Projects could the Energy Commission pursue to address PERFORMANCE?

Make sure to specify if there is a specific aspect of the Key Challenge the project would address. (Additionally, we'll follow-up by asking who are the required stakeholders, what are the measures of success, and what could inhibit success for the suggested R&D project.)

Unsorted (3)

- Performance improvement must be in service of profit improvement. Many things that are technically possible, but given that geothermal is project (rather than product) oriented, it's hard to count on an experience curve. So R&D projects must have immediate application.

- Geothermal companies are IPPs, can't pass on costs to ratepayers as the IOUs can. Operate at very slim margins. Any help with R&D is helpful, because the companies don't have that type of resource. Big oil & gas had research centers that helped with existing projects, but those resources are gone now. Anything to evaluate different metallurgies or materials to help expedite advancements would be helpful (collaboration with the national labs). Everything is about economics. Companies are working diligently to reduce costs. Only see a benefit to helping geothermal.

Comments

- Whether it is materials or flexibility, companies are running so slim as it is.
- Induced seismisity in geothermal fields. Trying to reduce impacts on the community. Whether or not this is going to be successful depends on how you manage this type of hazard.

Water Use (cooling and injection) (2)

- Evaluation of sustainability of geothermal resources - this introduction of additional injection water sources at The Geysers was a major success. Coso has had declining production - are there options on how to improve this?

Comments

- City of Santa Rosa were dumping polluted water, now get paid to pump it up to the Geyers
  - The water is tertiary treated in Santa Rosa (the idea of disposing treated wastewater in a river doesn't go over well).
- Not a large WWTP at Ridgecrest to provide water to Coso. Pipeline to bring in freshwater is not enough unfortunately. Some communities don't have those resources. Water coming across from Mexico is such a larger problem than discharge problems at local communities.
- Other water sources that would justify building a pipeline? Some geothermal projects are so remote you don't have that ability.
- Water is also a key issue in the Imperial Valley - most of the binary power plants use air cooled condensers, which are not efficient during the hot summer months. Are there alternative ways to improve performance?

Comments

- Improve cooling tower sustainability results in more water available for re-injection. Energy lost in summer is about half the load.
- Have to be paid for changing the design of the system to accommodate that. Economics have not supported it yet. In CA, power prices have been so low.
- There was a group doing research on reducing water usage on a part of the Geysers not hooked up to the recharge pipelines.
- Nevada at Stilllwater, more solar available in the summer (less efficient geothermal), but complementary effect of other renewable resources at the same facility. Some of that is powerplant contracts as well.

Materials (and corrosivity) (2)

- The Salton Sea brines are highly corrosive due to their high temperatures and salt contents - developing lower cost alloys that can withstand these fluids would improve performance and costs.

Comments

- So corrosive due to pH and high-solids content due to scaling.
- Even a titanium liner only lasts five years. Operators at Salton Sea are investigating other types of materials. This can dramatically affect the O&M costs for the facility. Piping, wells, reworks of wells.
- Changing the composition of the fluid will not be the case in the Salton Sea. Introducing additional water from a pipeline helps.
- Support the development of alternative materials for corrosion control and durability.

Comments

- Some corrosion at the Geysers as well (HCL), change the pH of the steam to try and mitigate that issue in the wells as well.

Surveying (and well monitoring) (3)

- Subsidence surveying could assist in better monitoring of well injection and production - to mitigate and avoid environmental harm.
- There is interest in gathering InSAR (Interferometric synthetic aperture radar) to collect satellite imagery of geothermal fields)
- Improved reservoir models to help optimize system performance (where to have injection and production focused in the field to enhance pressure support without thermal breakthrough)

Hybrid systems (multi-renewable) (2)

- Development of hybrid (solar-geothermal) systems may be advantageous for some systems
- Corrosion are primarily associated with well casings

R&D Projects to Address Challenge 5

What R&D Projects could the Energy Commission pursue to address RESOURCE AVAILABILITY?

Make sure to specify if there is a specific aspect of the Key Challenge the project would address. (Additionally, the team wills follow-up by asking who are the required stakeholders, what are the measures of success, and what could inhibit success for the suggested R&D project.)

- It has been more than a decade since the last review of geothermal resources in California by the USGS. A reevaluation might be timely.
- KGRA's (Known Geothermal Resource Areas) are identified for the state (and available on a map on the CEC website).
- In NV many hidden resources have been discovered as a result of geophysical techniques that either didn't exist or weren't used in geothermal exploration years ago.
- One challenge for exploring for and developing new resources in California has been the increased environmental requirements for systems > 50MW.
- Further examination of co-produced hot water in oil wells.
- Given that there are 30,000 idle oil and gas wells in the state, an evaluation of their viability for extracting heat might be warranted.
- Better geothermal well resource identification and technology is needed - to reduce risk in drilling (location and depth) on a fine scale.

Thank You and Next Steps

Closing Statement: What is the one thing the Energy Commission should keep in mind as we draft the roadmap?

- Geothermal energy projects support the greenhouse goal mandates for the state along with the RPS because any CO2 emissions due not count in the emission inventory.
- Be sure to look at the wide range of value that geothermal might offer - not just power generation (such as heating and cooling using lower grade heat).
- Geothermal potential in urban areas either through co-produced hot water from oil wells, or the drilling of new geothermal wells.
- Carbon benefits are being left unused and untapped because the unique attributes of geothermal are not valued. Research that makes geothermal more valuable would include green peak technology for flexibility.
- Talk with DOE Geothermal Technologies Office - they have developed similar roadmaps, and might provide some helpful suggestions.
- Support of geothermal development is needed - through financing, renewable energy incentive programs, legislation, etc to keep it competitively priced and able to support the grid as a baseload technology.

- Could the CO2 emissions from geothermal projects in Imperial County be used for something? Even CO2 floods in the oil fields?

Solar Webinar: April 4, 2019

Number of Participating Experts: 13

Discussion on Key Challenges

Question or instruction for the discussion:
Key Challenges inhibiting solar power from increasing utility-scale renewable energy in California
We will briefly discuss each "challenge area" and then will undergo a prioritization exercise. Subsequently, the key barriers will be discussed in greater detail and we will identify potential R&D projects the Energy Commission could pursue to address them.

- **COST Are there high-cost technology development and operations components that need to be addressed?**
    - The cost of upgrading the existing T&D infrastructure need to be considered.
    - Need to consider soft costs of permitting and barriers such as environmental issues (avian, glare).
    - The cost of mitigating intermittency, such as coupling with storage, need to be considered in system planning.
    - Hybridization opportunities exist to time-shift over-generation at low cost by integrating thermal storage and thermal generation. Storage could be charged electrically (PV) or thermally (CSP).
    - Installed system cost drives LCOE; higher PV efficiency – such as with new technologies - can drive down system cost
    - Cost of monitoring PV plants in a uniform, meaningful and understandable way seems to be a limiting factor to parties I've spoken to or heard from.
    - Currently, costs are being decreased incrementally in many different categories, enabling, in total, substantial reduction - it is difficult to prioritize a single cost issue - there are still many opportunities
    - Cost of PV recycling
    - Need to look at the needs of local load and match generation to load.
    - Low capacity factor is a challenge -- need to use assets more hours
    - Some costs reported last year of combined PV and batteries in Arizona were reported at less than $0.06/kWh, but this is misleading if the fraction of storage capacity is very small relative to the total capacity of the PV plant.
- **RESOURCE VALUATION Are energy markets appropriately valuing all of the benefits that this technology area may bring to the grid or society?**
    - Thus far the focus has been overly narrow on LCOE.
    - Cost of carbon needs to be included.
    - This is a chicken or egg situation. The market is not mature at this time. But on the other hand, the equipment may not be capable of providing the market needs either.

- The ancillary services that PV can provide (frequency support and grid support) are just beginning to be recognized in some locations.
- Markets are not appropriately valuing CSP's ability to store and dispatch electricity. Compared to PV + batteries, CSP is currently cheaper.
- utilities are not valuing coincidence of low carbon generation with demand, but rely on accounting schemes (RECs).
- There seems to be a lack of understanding by both the public and the media regarding the trade-offs in different renewable (such as solar) technologies. These trade-offs include technical and financial differences between commercial, residential and utility projects. Effective education is essential.
- Cost of maintaining duplicate infrastructure for dispatch is not included.
- The market value of renewables may not be high enough until the system is much weaker by high renewable penetration levels.
- More life cycle assessment beyond GHG emissions.

- **DISPATCHABILITY Are technology improvements or strategies needed to ensure that electricity can be used on demand and dispatched at the request of power grid operators, according to market needs?**
  - Without load, generation has no value or negative value. So, matching generation to load, locally, regionally, and system-wide, is critical.
  - Long duration, large-scale, cost-effective storage is key to supplying demand with low carbon.
  - Focus on capacity availability as well as just electricity generation so that curtailment is economic.
  - Improved accuracy of solar energy forecasting models used by California ISO and utilities .
  - This is an important topic with many parts. It's not clear what EPIC's role should be here.
  - Long-term storage technologies are needed. A metropolitan city like New York or LA needs 10 - 15 GWh of electricity to power the city for just one hour. All of the battery storage demonstration plants amounted to just under 1 GWh as of 2018. Need to consider other options such as thermal energy storage and CSP.
  - Backup generation costs, including increasing O&M, could be important.
  - Need fast ramping energy storage technologies.
  - Size the generation to local load is desirable. For large units, transmission resources may be needed.

- **RESOURCE AVAILABILITY -Clear understanding of geographical locations appropriate for deployment? -Regulatory or permitting barriers that may inhibit the development of utility-scale systems? -Forecasting improvements necessary to enhance operations and certainty in power scheduling?**
  - Need to look at resource availability together with the availability of existing transmission resources.
  - Need to look at both resource availability and variability (currently, the focus is mostly on availability)
  - Understanding the resource availability is foundational. Continued work is needed in this area, though it should not be a dominant investment.
  - Improved dual-use encouragement for deployment on agricultural land
  - Need to consider encroachment of military lands. DoD has expressed significant concerns regarding the impact of solar/wind installations on their training grounds (glare, radar clutter).
  - Better understanding of environmental impacts and regulatory hurdles of existing plants would facilitate future deployments
  - Sharing transmission between intermittent solar and dispatchable generation is needed to just needed transmission investment
  - resource without local load may not be meaningful unless transmission is available to transport the power to load.
  - Resource availability for solar typical concentrates on W/m2 irradiance, but also needs to include factors such a soiling and reliability in a given location.
  - Solar energy installations near airports need to be concerned about glare.
- **GRID INTEGRATION AND INTERCONNECTION Are there barriers to grid integration or interconnection that need to be addressed for this technology area?**
  - With increasing curtailment of over-generation, it may be hard to justify transmission & interconnect investment to take power to load centers
  - The biggest barrier is attempting to install resources wherever available with total disregard to available load or T&D capability. The grid just does not work that way.
  - How do we curtail or use excess energy from renewable energy sources on the grid?
  - Cost will go up if the generation is not matched with local load.
- **PERFORMANCE (including but not limited to: power output; capacity factor; energy density; material durability/corrosion; system degradation; efficiency; and curtailment**)
  - Most PV research on performance historically has been for increased efficiency at STC. More work can be done on improving the field performance
  - Improved conversion efficiency remains a key long-term driver for increased deployments
  - The ramp rate of CSP systems need to be improved to serve as peaker plants.

- The energy payback is best for systems that last a long time. So, investment in long-term reliability will have payback in the long term
- For CSP: optimize system design to meet specific generation needs, rather than overall performance (not just produce the most energy, but produce it at key times)
- Performance may suffer when the generation is not matched with local load. The system operator may need to curtail excess solar ourput to avoid load gen imbalance. California ISO is paying APS to accept excess generation already.
- For PV and CSP, a clear understanding of the interplay between location-specific dust transport, weather, soiling, maintenance (such as cleaning) costs and performance trade-offs needs to be achieved.
- Higher energy density – for example. more efficient PV - facilitates more generation in the built environment – such as on commercial and industrial rooftops, in turn improving the economics of solar generation by minimizing the need for adding transmission to remote sites.
- Capacity factor drives cost of energy, but storage often increase capital expense so much that it can't compete.
- Need to consider hardening PV modules or CSP components as more extreme weather events increasingly occur.
- When there is load gen imbalance, additional losses may occur

- **PRODUCTION Are there issues related to the manufacturability, supply chain and logistics, or other factors that limit system production?**
  - PV and battery materials are difficult to salvage and can be considered hazardous. Need to consider the cost of decommissioning in the supply chain for PV. Nearly all of the material in a CSP plant is salvageable.
  - CSP has not yet gotten an experience curve like PV to drive cost out of collectors.
  - Understanding the equivalence or differences between materials in terms of quality and longevity in the supply chain should be shared amongst the industries involved (including the financial & investment side).
  - New solar PV technologies – for example perovskites - offer pathway to local manufacturing as the infrastructure and cost components are not inherently advantaged by the existing PV industry infrastructure elsewhere. Tandem devices – such as. perovskites on silicon or CIGS - leverage existing industry capacity to deliver capital efficient industry expansion and installed system cost reductions.
  - Most CSP designs are "one offs", rather than modular (like PV), which increases costs and slows the time to install/operation
  - Tariffs have complicated things
  - Increased CSP deployment will require more skilled craftspeople
- **OTHER BARRIER CATEGORIES Are there other major barrier categories to consider?**

- Lack of knowledge of how the power system works and why the power system was designed and operated in the current configuration.
- Lack of freely available data for performing studies on, for example solar forecasting and economic impacts of storage, thereby slowing down overall progress
- Environmental and safety concerns should be considered in the roadmap. Especially in California, avian mortality caused by CSP or PV can be a showstopper. Need to ensure glare from solar energy systems do not pose a safety hazard for aviation and motorists.
- RPS can diverge from CO2 objectives. We need a holistic view, perhaps based on carbon accounting if not a tax.
- Pre-commercial solar technologies – such as perovskite PV - would benefit from demonstration programs and projects as they lack the long field history necessary to be bankable by routine PV project financing.
- Sharing of lessons learned with other states and even other countries is essential to shorten the time crawling up the learning curve(s) for PV and CSP deployment.
- Trying to change an existing engineering system without fully understanding the pros and cons.
- Need to find a way to include long-duration energy storage with renewables to get past ~30 percent penetration.

Ranking Key Challenges

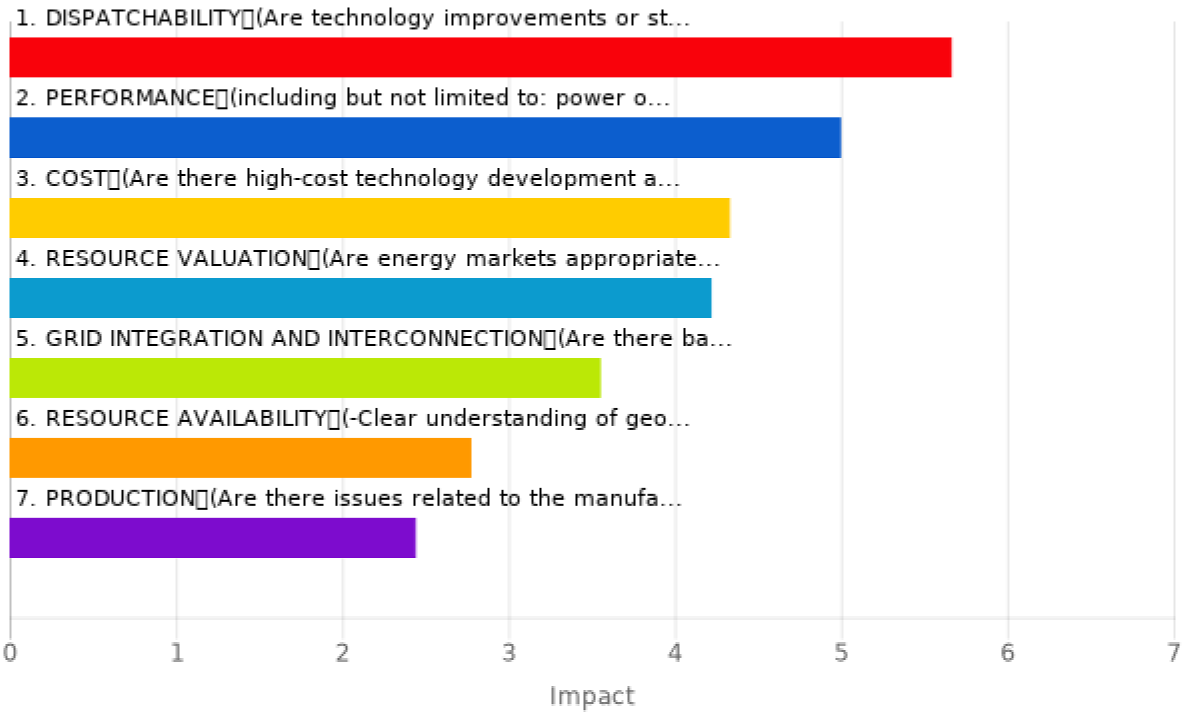
Rating question or instruction:
Please rank the Key Challenges inhibiting solar systems from increasing utility-scale renewable energy in California Table D-13 and Figure D-5).

Table D-13: Challenges facing Solar Power

Nr	Item	Mean	SD	n
	Criterion "Impact" sorted by mean Highest rank of 7 is given 7 points. Ratings submitted: 9. List of items randomized.			
1	DISPATCHABILITY (Are technology improvements or strategies needed to ensure that electricity can be used on demand and dispatched at the request of power grid operators, according to market needs?)	5.67	0.24	9
2	PERFORMANCE (including but not limited to: power output; capacity factor; energy density; material durability/corrosion; system degradation; efficiency; and curtailment)	5.00	0.18	9
3	COST (Are there high-cost technology development and operations components that need to be addressed?)	4.33	0.25	9
4	RESOURCE VALUATION (Are energy markets appropriately valuing all of the benefits that this technology area may bring to the grid or society?)	4.22	0.28	9
5	GRID INTEGRATION AND INTERCONNECTION (Are there barriers to grid integration or interconnection that need to be addressed for this technology area?)	3.56	0.24	9
6	RESOURCE AVAILABILITY (-Clear understanding of geographical locations appropriate for deployment? -Regulatory or permitting barriers that may inhibit the development of utility-scale systems? -Forecasting improvements necessary to enhance operations and certainty in power scheduling?)	2.78	0.23	9
7	PRODUCTION (Are there issues related to the manufacturability, supply chain and logistics, or other factors that limit system production?)	2.44	0.25	9

Sources: MeetingSphere (2019)

Figure D-5: Rating of Solar Challenges



Sources: MeetingSphere (2019)

What R&D Projects could the Energy Commission pursue to address Dispatchability?

Brainstorm question or instruction:
What R&D Projects could the Energy Commission pursue to address Dispatchability? Make sure to specify if there is a specific aspect of the Key Challenge the project would address. (Additionally, the team will follow-up by asking who are the required stakeholders, what are the measures of success, and what could inhibit success for the suggested R&D project.)
CSP - with thermal storage (8)

- Concentrating solar power with thermal energy storage for large-scale (GWh) dispatchable energy.
- Even if only on a short-term (a few hours), e.g., the ability of thermal storage to cover the 4-8pm peak demand period in California with no solar
- Thermal storage is low-cost and can be readily hybridized with thermal generation for low-carbon dispatch. Electric heating can integrate with PV over-generation.
- Integration of large-scale thermal energy-storage combined with curtailed energy from renewables.
- General demonstration for long-duration storage with CSP. Funding a commercial system would be very useful (currently none in the pipeline).
- Long-duration (hours, days, seasonal). Thermochemical energy storage CSP can play a role seasonally. Temperature difference is only hours or perhaps days (insulated tanks)
- CSP plus storage can be made more effective in a hybrid combined cycle. SEGS plants could be repurposed this way to demonstrate long-duration and nighttime dispatch

- Identify how much storage should be added to integrate solar. Where should they be installed considering availability of transmission capacity? How much storage would be cost effective? What would be the rate impact?
- Use of thermochemical storage and/or CSP-produced fuels for long-term storage (days or months).
- Curtailed PV can be instead used to provide additional heat to CSP thermal storage

PV Integration with storage (4)

- Investment in new storage technologies could be very useful to complement PV systems, but the Energy Commission may want to be strategic in funding projects that complement what others are doing.
- Demonstrate a large (GWh) PV plant + battery system for thousands of hours to understand operational and technical challenges.
- Electrical storage - e.g. batteries - would enhance PV economic penetration. Distributed storage - e.g. homes, businesses, vehicles - aggregated into virtual units would be most impactful and might best leverage private consumer investments to augment community benefits
- Could oversize the PV to have more production for a longer period of time (increases capital cost)

Identify dispatchability needs (18)

- Identify the level of dispatchability (time response) needs for different conditions.
- Identify how much intermittent renewables, in MW, are permissible relative to the load values. Identify how much conventional units are needed to maintain system stability and reliability.
- Develop projects to explore vehicle to grid and grid to vehicle for load leveling
- Using CA-specific software tools and models such as those developed by Daniel Kammen's (UC Berkeley) group may be useful to understand dispatchability.
- If we go to very long storage, will we need it most of the time? (4-hours you can use most often) Days storage is useful, but don't use as often. Tradeoffs
- To get to 100% renewable by 2045, could be days if not weeks for below-optimal power conditions. May need days to weeks of storage
- What's the cost of that long-term storage and how often will we use it. Battery could last 10 years, but need to replace it before it is ever used
- Identify R&D for solutions that can be optimal (thermochemical storage). Need to consider losses...
- Consider flow-batteries, but take losses into account. If batteries are cheap enough. Construction of battery vs thermal storage could create a price advantage
- Could use hydrogen, or perhaps some other renewable fuel source that can be kept for a long time
- Efficient long-distance transmission and grid interconnection can help to balance loads across the country
    - Matter of cost

  - Reliable transmission going across the country takes advantage of the ability to generate some sort of energy, somewhere in the country, at any time of day
  - High voltage DC lines have been discussed (one option), if it can be done safely could be good.
  - Need to look at the cost. HVDC is not cheap. Usually used for long-distance transmission. Any time you add a new terminal, you add more cost. It's possible.
  - Have HVDC from Washington and Oregon to southern California for 40 years
  - Regionalization provides benefits. CA provides benefits from connecting to WECC. Even if 100 percent renewable and no synchronous generators, can rely on rest of the system to support the grid
  - Political issues though
- CEC may consider using a standby generator for the 1 percent of the time it's needed, it drastically reduces the cost
- Key is dispatchability with storage. Have to have storage to provide energy at night. Fundamental issue is storage. Dispatchability with storage
- Don't see Lithium Ion having the capacity we need
- Perhaps EVs can provide some energy as needed.
- Flow batteries, research can help to drive down costs. Demonstrate integrated large-scale PV plus long-duration storage would be crucial
- Need to be thinking bigger for the long-duration large capacity systems if we're going to get serious about powering California and major cities with renewables
- Size the generation to load, locally
- Reduces the load on the system dispatchers
- Size the system closer to load and operate that way
- Take away a lot of the duck curve issues, ramping, all of that
- Did not set up system taking existing load needs into account
- Need to also consider shifting demand to match available generation, e.g. social engineering to incentivize consumers to shift demand to daylight hours to reduce storage / back-up generation requirements.
- There is a potential for techno-economic synergy by appropriately combining technologies in hybrids.
  - PV has 23 percent capacity factor, then storage backs it up, then fuel-based system backs that up. Possible for those things to work together in a way that is overall better (measure of economics, carbon, and ability to coordinate operations)
  - Urge CEC to look at opportunities to create synergy and hybridization at appropriate scales
- Need to consider and understand the role of the multitude of smart grid technologies and local community solar projects on dispatchability. This relates to point to point supply and demand.

- Smart grid and local solar projects (what's the role in dispatchability)? Point to point supply and demand issues to be considered.

Notes on distributed systems (3)

- Utilities are not set up to deal with hundreds of thousands of units. Don't have the communications systems. Looking at major upgrades that are required to operate the grid. Using the existing grid to operate DERS, but long term might not work
- DERS could play an increasing role for renewables penetration. There will be a limit as to what can be carried by local systems
  - Analagous to personal computers, and now shifting back to the cloud
  - Always going to need some form of centralized system to complement the distributed system
- Hybridize, so you have one high capacity factor system instead of three (PV, battery, genset)

What R&D Projects could the Energy Commission pursue to address PERFORMANCE?

Brainstorm question or instruction:
What R&D Projects could the Energy Commission pursue to address PERFORMANCE?
Make sure to specify if there is a specific aspect of the Key Challenge the project would address. (Additionally, the team will follow-up by asking who are the required stakeholders, what are the measures of success, and what could inhibit success for the suggested R&D project.)

Unsorted (1)

- PV cat = PVQAT TG12 (an international IEC standards-focused group started by Sarah Kurtz and lead by NREL). There are monthly webinars

PV (8)

- Increasing efficiency of the PV cells would be beneficial. Tandem cells, different material, etc. But the new design needs to have high reliability as well.
- Traditional PV technologies – for example single-junction Si, CIGS, CdTe, etc. - are nearing theoretical efficiency limits, and commercial high-efficiency options – such as multi-junction III-V materials - are prohibitively expensive. New concepts – for example tandem structures combining perovskites and Si - offer much higher efficiencies and in turn manufacturing and operational capital efficiency. The challenge is that these new concepts, perovskites in particular, require significant R&D and demonstration to reach commercial scale.
  - Perovskite performance is on small research cells. Need to scale and prove out their yield performance and product durability. Of particular merit, they can be used in tandem structures to improve their efficiency (thus drive down system costs)
  - This helps with demonstrating the viability of tandem structures. Leverage existing technologies. Burden of endangering the bankability confidence of traditional technologies
  - Do new modules provide compatible voltage and currents compared to existing modules?

    - Power electronics in PV has shifted from the system level to the array level to the string level and now to individual modules. More reliability and allow you to match disimilar modules. Addressable today.
    - Performance of optimizers must be considered as well. Make sure the optimizers themselves are not failing.
- CEC should consider low-reflectance module covers that improve transmittance to the PV cells and mitigate glare. Some companies are considering polymeric materials that have very low reflectance, but soiling is a question. R&D to demonstrate modules with ultra-low reflectance, high transmittance, and low soiling would be useful.
  - Big issue is glare and permitting of PV systems (not only near airports, but in communities). Having a low reflectance module cover is important. Even a few % reflectance is blinding. Have studied deeply textured glass, polymeric module covers (SBD solar), but if you use this, it can impact soiling. Haven't seen any tradeoffs on long-term performance and transmittance vs anti-reflective properties
  - (Greg) deals with PV cat group regarding soiling. No studies out there on this
  - Don't we have anti-reflection coatings? Wavelength specific?
    - Took a bunch (20 different manufacturer models), most had anti-reflection coatings. Didn't matter that much, all within 60 degrees incidence angle. Above 60 degrees it gets bad on glare. Not that different in terms of total specular reflection.
  - Shingle solar cells on some houses that look more like a slate shingle. Very deeply textured.
- Bifacial PV panels are enjoying increased use, activity & production and need to be understood in terms of CA environment(s).
- Quantifying long-term system degradation and sharing performance data to better characterize lifetime
- O&M best practices may become more important at the PV fleet ages
  - Agreed. O&M monitoring platforms are varied and not standardized across that part of the PV industry. This is both a barrier and opportunity for CA.
- Circular economy
  - Different encapsulation materials (poly-olefins), do they have applicability to the end of life? Module materials? How can they recover materials?
  - If you look at PV modules today, 95% are crystalline silicon. Some materials, metals, glass. Everything CAN be recycled. But today it's a problem a lot of people consider in the future in that everything sold has a 25yr lifetime and 33yr warranty. Circular economy is real.
  - New technologies that are coming, perovskites, lower recyclability economics. Overall in a high-value module and in some type of tandem configuration, warrant consideration for circular economy
  - Who should be a full participant in the circle? Ship modules back to the country of origin, or have the full circle in the US. Material reclaim and usage issues for

    manufacturing. If we're not in that part of the value chain, whole idea is a construct for which we're not completing the full circle
  - Don't have the process set up here, what would it take to recycle those modules
  - Some have looked at this, accumulation shipping of the product. Not the viability of recycling the product. Organization issues, but not technology issues.
- Veolia opened European PV recycling plant in Rousset, southern France in 2018. PV recycling is an issue! 1,300 tonnes of PV in 2018.

CSP (6)

- CSP steam plants aspire to be 1950s baseload coal plants, but that's not what the market wants. Need faster startup, flexible load following. Can be achieved by pairing with gas turbines.
- Can CSP plants be used as peaker plants to provide energy when demand is greatest (e.g., in the evenings)? This will require a demonstration of fast-ramping energy production.
- Alternatively, customize the design of CSP plants to meet specific needs (e.g. evening demand, assuming the CSP plant has enough thermal inertia or storage available)
- There are assets in California that could be repurposed and made more valuable, as opposed to dispatching energy against lower cost PV
- The best use of CSP could be in hybrid systems that directly reduce fuel burn in a thermal plant
- Most of the hybrid plants are "lipstick on a pig". Don't integrate enough thermal energy into an optimized combined cycle to make a difference. Did a super critical coal plant and couldn't make a difference. De-optimized the system (when sun was shining burned more fuel than you did before)
- For new plants, unless there is an offtaker to enter into a contract at above market rates, it won't happen
- Can't move the project forward without a buyer. Utilities would rather have too much PV that they curtail, then pay an extra few cents for geothermal that could cover them overnight (that's the economics and the way they are incentivized), and how the RPS is structured
- Doesn't have to be provided round the clock, can meet RPS requirements on an annual true-up. Let it be CAISO's problem to ship the power some place
- CEC may want to look at the value of dispatchability and repurpose these older units.
- Raise temperature of thermal cycles in the power blocks. Receivers, heat transfer medium, and actually new power block components
- Don't see an immediate role for CEC in that effort. Perhaps a cooperative effort with DOE

Location-specific performance (cross-cutting) (1)

- Location-specific PV module and CSP mirror soiling losses (due to particle/dust shading) and related performance losses with and without cleaning could be studied and characterized in demonstration projects in California.

Inertia (3)

- Inverter based systems are only missing real inertia. It would be a big win if they could provide a stiffer grid.
- "stiffer grid" less susceptible to large scale oscillations. Frequency doesn't move around as much
- If a big load drops off, or a new generator drops off or something
- Synthetic inertia design would also be helpful. But these cost more since storage will be required.
- New standards for inverters that capture the new functions, such as synthetic inertia, microgrids, load following, etc, may be needed to help facilitate the development of these new applications.

What R&D Projects could the Energy Commission pursue to address COST?

Brainstorm question or instruction:
What R&D Projects could the Energy Commission pursue to address COST?
Make sure to specify if there is a specific aspect of the Key Challenge the project would address. (Additionally, we'll follow-up by asking who are the required stakeholders, what are the measures of success, and what could inhibit success for the suggested R&D project.)
Integration with storage (6)

- Need to appropriately value the cost of electricity production with storage. Currently, many states' renewable portfolio standards focus on low-bid, which drives the deployment of wind and solar PV. Need appropriate metrics and technoeconomic studies to value dispatchability of electricity when demand is greatest (value is highest).
- Need to reduce costs of battery systems, which includes the battery pack, inverters, etc. The cell cost is typically only half of the battery system cost.
- Hybrid integration of renewable plus thermal storage plus thermal generation can be low risk (interest) long life (tenor) high capacity factor, and lower cost than battery
- To reduce costs of curtailed electricity, develop R&D to utilize excess energy at a utility scale. One option is to use the otherwise curtailed electricity to heat media for thermal storage and pumped thermal storage.
- Pumped thermal storage utilizes a heat pump to separate a hot reservoir from a cold reservoir. The larger temperature difference increases the efficiency of the heat engine (power cycle).
- Storage LCOE calculations (Lazard) assume 100 percent duty cycle. Four hour battery discharges 4 hours per day. But economic dispatch is different. Need some realistic assumptions and models.
- Need new low-cost materials and manufacturing methods for high-temperature heat exchangers for CSP (>700 C) operating at high pressures to enable next-generation power cycles like supercritical CO_2 Brayton cycles.

Size to load (3)

- Size the DERs to the local load so that there are no excess generation to cause distribution problems and miminize mitigation costs.
- Size the transmission renewable generation to local transmission loads and minimize transmission flows and associated losses.
- Look into integrating PV into building material, such as roofing tiles, or building wall material, to minimize costs of structural support requirements.

Additional system costs (4)

- Capital amortizaton dominates. 1. reduce CAPEX. 2. reduce interest rate 3. increase capacity factor 4. increase tenor (lifetime) 5. lobby for tax credit
- PV modules are a relatively low fraction of installed PV system cost, for example 20-45 percent depending on residential, commercial, utility, etc. application and system design. More-efficient PV modules amortize non-module system costs to drive down overall installed system cost, especially in area-constrained installations. New concepts – such as perovskite / silicon tandems - provide a path significantly increasing PV module efficiency with no substantive change in module design, ergo within the existing PV system design, installation and operation ecosystem.
- Reduce PV decommissioning costs and establish procedures in CA
- Cost vs durability vs reliability
- Perhaps CA can support the interrelationship between bill of materials and how long the system will last in a particular environment

Standardization (1)

- Reduce (LCOE) costs by standardizing software platforms used for monitoring of, for example, solar resource and/or O&M and performance monitoring (data collection). Each solar asset manager and O&M provider seems to use their own. There is very little sharing of learning or common aspects. Hard to compare. Uncertainty leads to lower confidence from funding agencies (such as banks and investors).

Closing Statement: What is the one thing the Energy Commission should keep in mind as we draft the roadmap?

Brainstorm question or instruction:

Closing Statement: What is the one thing the Energy Commission should keep in mind as we draft the roadmap?

- Economical, long-term, large-capacity energy storage will be required for increased penetration of renewables. Thermal energy storage is an option that is often overlooked.
- We need multi-disciplinary, holistic systems view of not just the goal (summit of the mountain) but the path (up the shear cliff face or taking the switchbacks)
- Base policy decisions on power system needs and not simply GHG reduction. The electric grid is critical to CA economy and we need to maintain the safety and reliability in a cost effective manner.

- We need comprehensive models to not only define capacity expansion needs, but also to integrate and control a multitude of diverse energy generating sources to provide reliability and resilience.
- Renewable energy technologies are the only solution to climate change, which is the existential issue of our time. Don't drop the ball.
- The Energy commission should reach out to both more national and international leaders and experts as it formulates a plan. This could be via PVQAT groups or IEC standards groups or European Commission solar groups.
- Consider complementary goals that are likely to become further coupled in the future (e.g. energy generation, climate change, and water usage)
- Look into using existing conventional units as spinning reserve for system support in addition to deploying storage since storage comes at high costs. The existing units may not burn that much fuel when used in this mode.
- Existing technologies – such as Si PV - provide a foundation for a clean, reliable, California energy ecosystem. But existing technologies are reaching technological and cost limits short of those needed for transformational change to sustainable energy. New technologies - e.g. tandem PV devices based on new materials - are a key avenue for CEC to deliver on a future of sustainable low-carbon energy in California.
- Thermal storage is cheap and can improve ramp rate of thermal units while cutting GHGs dramatically

Wind Webinar: April 9, 2019

Number of Participating Experts: 13

Discussion on Key Challenges

Key Challenges inhibiting Wind Power from increasing utility-scale renewable energy in California

We will briefly discuss each "challenge area" and then will undergo a prioritization exercise. Subsequently, the key barriers will be discussed in greater detail and we will identify potential R&D projects the Energy Commission could pursue to address them.

COST Are there high-cost technology development and operations components that need to be addressed?

- Ultra tall wind turbine towers and offshore wind offer huge energy potential increases for CA, but capital cost reductions in both technologies are needed in the towers for land based wind and foundations for offshore wind.
- floating foundations for offshore
- Capital and operational cost reductions for floating offshore wind is greatest opportunity area for CEC, in my view
- Taller towers must increase the thickness of the steel in the tower, making the technology no cost effective.
- Research and development of wildlife detection, deterrent, and smart curtailment technologies have a significant gap to bridge from R&D to commercialization. Evaluation studies of a technology's effectiveness is costly but necessary (both offshore and onshore applicability)

- Port infrastructure needs upgrading -- take best practices from Europe.
- On-shore infrastructure for offshore wind
- Hard to know what CEC can uniquely do to reduce cost of land-based wind, that is CA specific. Floating offshore has greater CA potential it seems

RESOURCE VALUATION Are energy markets appropriately valuing all of the benefits that this technology area may bring to the grid or society?

- Valuation should include benefits in mitigating for the duck curve growth due to PV generation.
- Clean-air and -water benefits are not adequately valued
- The CPUC's Integrated Resource Planning process is doing a good job at valuing the portfolio benefits of wind, and will be improving valuation for out-of-state and offshore wind in the current IRP cycle.
- CAISO rules to enable wind/solar participation in AS markets would be a net gain, but wind/solar unlikely to be low-cost providers of AS generally. Nonetheless, as very high VRE penetrations are reached, will need to increasingly extract available flexibility from wind and solar
- Non-coincidence of wind and solar generation is enormously valuable to grid, but LSEs (Load Serving Entities) are not valuing renewable power -- just renewable energy.
- Only if they consider the entire life-cycle of infrastructure (from development to eventual dismantling). Lessons could be learnt from European examples or even from offshore oil/gas on how to incorporate "end of life."
- The low carbon energy sources is not sufficiently valued by the market.
- The climate mitigation benefits for wildlife have not been adequately compared to the impacts on birds and bats
- comparative assessment of renewables benefits, relative to direct environmental impacts.
- CPUC IRP will be enforced on all LSEs, based on a proposed decision that will be voted on soon.

DISPATCHABILITY Are technology improvements or strategies needed to ensure that electricity can be used on demand and dispatched at the request of power grid operators, according to market needs?

- Let's not lose sight of the importance of demand management in discussing dispatchability.
- What are the options for storage of electricity produced off-shore if it is generated at low-demand times?
- need to use all of the capabilities that wind plants already offer
- Isn't that the point of the CAISO?
- There are novel vertical axis concepts that might be more flexible -- multiple units could be independently dispatched.
- Same comment as on previous question: need to enable wind/solar to provide ancillary services, though that will not be a panacea. May also require technical standards for advanced grid interaction functionality as CAISO loses inertial response and fast

frequency response from thermal plants as VRE increases. Need to address grid-forming inverters more rapidly in CA than in other states, so a possible increased CEC role in this space-- not only for wind.

RESOURCE AVAILABILITY -Clear understanding of geographical locations appropriate for deployment? -Regulatory or permitting barriers that may inhibit the development of utility-scale systems? -Forecasting improvements necessary to enhance operations and certainty in power scheduling?

- By far the factor that has most dramatically limited onshore wind development in CA is permitting barriers. (The same is likely to be true of offshore development.) In San Diego County presently, proposed projects are being effectively opposed on the basis of health impacts, despite a favorable meta-study by the county health department. Perceived environmental impacts have also led to zoning prohibitions or restrictions. These areas deserve a substantial focus of public research dollars.
- There is a need to determine areas with high shear value. California is unique and the shear values vary from region to region and throughout the day.
- inability to access otherwise appropriate sites due to permitting and siting regulations
- regions in southern CA have been taken off the table for wind development for reasons that may be flawed
- Some novel concepts have potential to better use existing resources, including less land area and bird kill
- A counter to the tendency for stakeholder groups to develop go/no go maps with intent to make siting decisions easier but rarely do these tools accomplish this goal.
- There is a need to have more information generated on hourly site-specific resource.

GRID INTEGRATION AND INTERCONNECTION Are there barriers to grid integration or interconnection that need to be addressed for this technology area?

- Allocation of the costs of interconnection of projects needs to be considered. European models of sharing the cost with an ISO are worth a look here.
- see earlier comments vis a vis AS and grid forming inverters
- enhanced cooperation with utilities beyond the state boundaries would assist higher wind penetrations
- Cost of integration and interconnection remains a barrier and often prevents us from mitigating grid issues
- CAISO process is expensive, but that is how serious projects are differentiated from speculative ones.
- Robustness of the system to be able to handle varying input into the grid from offshore. This include awareness of and agreements about reliance on the state of "older" parts (and maintenance thereof) of the electrical grid.
- The cable to shore routing can be and issue - cost and permitting, as well as the interconnection point for large offshore wind farms.

PERFORMANCE (including but not limited to: power output; capacity factor; energy density; material durability/corrosion; system degradation; efficiency; and curtailment)

- Novel concepts need demonstration

- Material and system deterioration and durability issues in offshore structures. Difficult to monitor and detect damage.
- Higher hub heights in some regions could offer increased energy production.
- The offshore capacity factors are already quite high for offshore wind so this is probably not an issue.
- Continuous monitoring is extremely important to improve safety, minimize down time, provide reliable power generation, and lower costs related to maintenance and logistics, especially that the turbine price increases with larger capacity.
- Impacts to production due to wildlife impact risk reduction measures (e.g., curtailment) could be reduced with commercialization of smart or informed curtailment strategies.
- Research into lessons learnt from other infrastructure which has been subject to harsh marine environments (to identify performance SWOTs)
- Need tougher, more durable, and more damage tolerant materials for tower, foundation and blades
- Taller towers with soft-soft designs show promise
- CA offshore wind could provide a very significant boost to its secure its clean energy future
- Bigger rotors and taller towers can increase energy capture performance especially in land constrained or NIMBY constrained areas.

PRODUCTION Are there issues related to the manufacturability, supply chain and logistics, or other factors that limit system production?

- Transportation and manufacturing challenges related to tall towers and offshore foundations
- port facilities supporting offshore wind equipment production offer a significant economic opportunity for CA
- Access to materials and reliance on trade systems, a.o., to gain (affordable) access to those materials during certain times/periods
- Need activities to encourage growth of in-state component manufacturing.
- Limited availability of large capacity ports, need to build maritime skills and infrastructure
- The big issue in the U.S. is deployment vessels and O&M vessels and large floating cranes on the West Coast.
- Manufacturing in CA is just costly and the resulting high cost to transport very large systems from out of state drive up the cost of wind energy or make it just too difficult. Often easier low cost solutions available.
- California is a very long state that makes transportation of conventional tower and blade technologies prohibitively epensive across regions. On site or near site manufacturing can help address this issue.
- Confidence in durability/reliability of 3rd party equipment (deterrents, detection systems, etc.) installed on wind platforms is a market barrier for such technologies. Realizing actual O&M costs for employing such technologies is a related area of interest.
- Onsite and nearsite manfacturing

OTHER BARRIER CATEGORIES Are there other major barrier categories to consider?

- Environmental risks and impact analysis
- Reconsider exclusion of regions of southeast CA
- Wildlife interactions will likely be a major barrier for permitting - birds, bats and marine mammals.
- Agree with all above -- siting and permitting are the biggest barriers in CA.
- upgrade port infrastructure
- How do activities impact marine environments near and far? As well as directly coast ecosystems?
- Life cycle environmental impacts of wind turbine structures
- More accurate and faster wind production forecasting tools - onshore (complex terrain) and offshore.
- wildlife deterrent technologies
- Small companies tend to develop more high risk innovative technologies. But capital needed to develop them is large. Bridging this funding valley of death is challenging.
- Waste recycling
- long term environmental impacts examined as well
- Developer risk is huge, given Coastal Commission, CEQA, federal permitting, permitting of on-shore facilities, technical risk of floating towers, lack of transmission infrastructure to land the power and then connect it. Should target specific locations like Morro where infrastructure exists

Ranking Key Challenges

Please rank the Key Challenges inhibiting Wind Power systems from increasing utility-scale renewable energy in California (Table D-14 and Figure D-6).

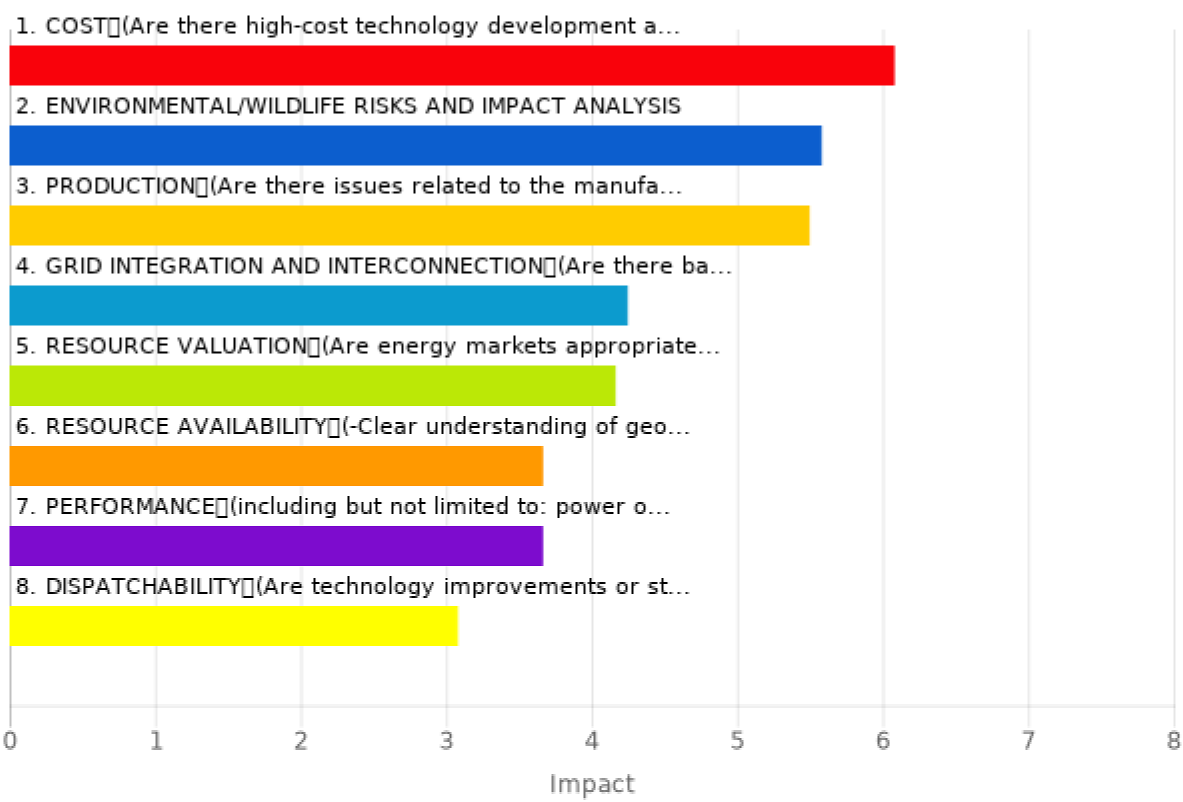
Table D14: Challenges facing Energy Wind Power

Criterion "Impact" sorted by mean				
Highest rank of 8 is given 8 points. Ratings submitted: 12. List of items randomized.				
Nr	**Item**	**↓Mean**	**SD**	**n**
1	COST (Are there high-cost technology development and operations components that need to be addressed?)	6.08	0.27	12
2	ENVIRONMENTAL/WILDLIFE RISKS AND IMPACT ANALYSIS	5.58	0.27	12
3	PRODUCTION (Are there issues related to the manufacturability, supply chain and logistics, or other factors that limit system production?)	5.50	0.20	12
4	GRID INTEGRATION AND INTERCONNECTION (Are there barriers to grid integration or interconnection that need to be addressed for this technology area?)	4.25	0.26	12
5	RESOURCE VALUATION (Are energy markets appropriately valuing all of the benefits that this technology area may bring to the grid or society?)	4.17	0.24	12
6	PERFORMANCE (including but not limited to: power output; capacity factor; energy density; material durability/corrosion; system degradation; efficiency; and curtailment)	3.67	0.27	12
7	RESOURCE AVAILABILITY (-Clear understanding of geographical locations appropriate for deployment? -Regulatory or permitting barriers that may inhibit the development of utility-scale systems? -Forecasting improvements necessary to enhance operations and certainty in power scheduling?)	3.67	0.32	12
8	DISPATCHABILITY (Are technology improvements or strategies needed to ensure that electricity can be used on demand and	3.08	0.21	12

Criterion "Impact" sorted by mean Highest rank of 8 is given 8 points. Ratings submitted: 12. List of items randomized.				
Nr	**Item**	**↓Mean**	**SD**	**n**
	dispatched at the request of power grid operators, according to market needs?)			

Source: MeetingSphere (2019)

Figure D-6: Rating of Wind Challenges



Source: MeetingSphere (2019)

R&D Projects to Address Challenge 1

What R&D Projects could the Energy Commission pursue to address COST?

Make sure to specify if there is a specific aspect of the Key Challenge the project would address. (Additionally, we'll follow-up by asking who are the required stakeholders, what are the measures of success, and what could inhibit success for the suggested R&D project.)

Unsorted (0)

Land-Based (4)

- consider novel approaches to taller towers such as soft towers (more flexible) with advanced controls to mitigate resonances
- Co-fund a big turbine demonstration with a tall tower and big rotor.
- Primary issue with land-based (excluding wildlife), resource areas are not great, need infrastructure, need bigger turbines to capture lower-wind speeds. Hard to put land-based wind in due to permitting and visual issues.
- Transportation issues for large-turbines as well

Off-shore (8)

- Focus on maritime infrastructure development
- Get California Universities and small companies engaged in offshore wind R&D in a more substantial way by providing fund opportunities for them. Also educate CA investors about the offshore opportunities.
- For offshore, reduce developer risk by resolving environmental issues upfront to create more certainty about mitigation requirements.
- Do this exercise again with European-based off-shore experts.
- Provide support for tailored CA support vessel development of offshore wind.
- Infrastructure requirements are going to be so huge. The state needs to commit to investing in this (like high-speed rail), build the infrastructure, university programs, and other supporting activities to move this forward. Energy Commission can help to develop the plan on how to do this.

Comments

- It takes an eco-system of supply chains, universities, and other supporting agencies to make this happen. If west-coast universities have a chance to get involved it will benefit California and the rest of the country as well.
- For offshore develop innovative foundations and anchoring systems.
- No vessels suitable for installation on the west coast. Need to get them from Europe and bring them over. Deployment costs are huge. Whole infrastructure missing. Cable laying, need a vessel but there are none there.

Wildlife issues (cross-cutting) (4)

- Put to bed some of the wildlife issues for land based and offshore
- cross-cutting cost concern, related to wildlife risk reduction technologies, are unknown O&M costs associated with employing the technology. While evaluation tests may indicate effectiveness sufficient to respond to market demand, a remaining hurdle for technology developers is clearly specifying what the costs are to operate and maintain the systems as well as durability and reliability over time (i.e., shelf life).
- Typically this is a big time delay. Insufficient baseline data for permitting offshore installations. The permitting agencies are worried about fisheries, marine mammals, sea-floor disturbance, noise from boats going back and forth. Not a good understanding of where whale's go. It takes a long time to satisfy the agencies.
- Valley of death for wildlife technologies can be an issue. Commercialization of it and ramping up to meet market demand. Disconnect between the need of investment and a

clear market signal (from regulator community) that technology would be viewed in a favorable light to meet permitting requirements.

Innovation (cross-cutting) (5)

- Research innovation can lead to high-performance and low-cost solutions
- Whatever the CEC can contribute to reduce uncertainty in project development, resource verification/quantification, forecasting of wind, etc. Uncertainty drives up cost of wind energy
- *Comments*
- Uncertainty. Production rate of off-shore wind systems. At least 100 turbines, each 10 MW machines. Developers want to know if they can meet production rate needs. Manufacturing, site preparation, the entire supply chain basically
- Work to reduce the fixed project costs. The variable costs are easier to address by projects.
- Develop onsite manufacturing approaches for larger wind technologies to help reduce installation and logistics costs for both land-based and offshore

Comments

- Includes alternative crane designs
- Developing on-site and near-site manufacturing systems for both land-based and off shore systems. Off-shore is actually easier in some regards, build components at the dock. Land-based using additive manufacturing technologies.
- Offshore - wind resource verification

Infrastructure (4)

- The State needs to take the lead and commit to infrastructure, probably in the Morro Bay area where there will be unused transmission
- Infrastructure investments should help all wind projects.
- R&D can target upgrading the points of connection on the grid, onshore and offshore.
- "Crane availability". Taller turbines and taller rotors require bigger cranes. And now there are not enough cranes (or approaching that). In the future, tower climbing cranes, or self-erecting cranes could help to enable the industry

Comments

- Alternative crane technology
- Could also be particularly important for off-shore

R&D Projects to Address Challenge 2

What R&D Projects could the Energy Commission pursue to address ENVIRONMENTAL/WILDLIFE RISKS and IMPACT ANALYSIS?

Make sure to specify if there is a specific aspect of the Key Challenge the project would address. (Additionally, we'll follow-up by asking who are the required stakeholders, what are the measures of success, and what could inhibit success for the suggested R&D project.)

Unsorted (8)

- Bird and bat concerns (will continue with climate change both land-based and off-shore). Been working on deterrents but don't have a fool-proof solution. Curtailment (not great), but there is room for research.
- A lot of room for research in this area (Radar camera systems and otherwise). Opportunities to partner with DOE.
- Smart curtailment modeling vs active modeling. For CA areas of concern, "eagles" (generally).

Comments

- Need preliminary data on activity. Video footage, SCADA, etc. Co-variates such as weather patterns. Develop predictors of activity. Better models
- There is generally a trend away from eagles in general (across the country, focus on bats). CEC can fill that gap
- CEC has done an excellent job dealing with/documenting/studying the avian issue in Altamont and in the process developed significant leadership in this area. The CEC should pursue similar leadership in risk reduction for offshore avian and aquatic animals for offshore wind
- Collect a lot of data that pertains to the usage of an area

Comments

- Developer on a development timeline, but there is a certain amount of due dilligence to indicate what may be present on a site. Accumulation of data that could be leveraged by developers to look approximately at a site they have interest in. Fill in gaps, as opposed requiring developers to do all of the data collection on their own.
- California jobs study relating to land-based or off-shore wind. Potential for near-site or on-site manufacturing technologies.
- Education regarding the benefits of wind

Comments

- Communities that are putting up permitting barriers. Can the Energy Commission help to promote the facts?
- National lab surveys on people who are near turbines. (on a national scale). Vocal minority, but most people are supportive.
- Some concerns are real and others are perception. Local decisions may be impacted by a very small number of people with either real or perceived issues.
- Continued conveyance of the silent majority of people in support could help enable development in these communities.
- This occurs in both on-shore and off-shore
- Opposition is extraordinarily vocal. Advocates and developers are not vocal.
- There is a lot of misinformation on wind. Energy commission can help to counter this.

Land-based (5)

- Conduct studies on wind impacts on health and environment where the existing research is thin. This will hopefully translate to greater social acceptance (or at least policymakers overruling unreasonable public commentary).
- demonstrate emerging technologies for wildlife deterrence
- Ensure that we have a complete understanding of the environmental benefits of wind energy -- e.g., air and water quality, GHG reduction -- and that markets recognize those benefits.

Comments

- These positive impacts need to be factored into the CEQA (and NEPA) process.
- Studies of the economic benefits of wind projects.
- Counter misinformation about impacts of wind. Disseminate factual info that already exists. Lots of good info is available and just needs to be actively shared.

Comments

- Agreed. The CEC could compile existing information on health and other wind impacts and lend its backing that, to help influence local siting decisions.

Off shore (4)

- Conduct studies on marine impacts ASAP to help resolve uncertainties.
- Sea-floor surface impacts. Whale movement and migration. Impact on fisheries. We don't have a good understanding of marine life and avian use of the ocean. Need baseline data to satisfy some concerns by permitting agencies.
- Now you need a NEPA permit (fishing, wildlife), NOAA, not just CA permitting. Hurdles are a lot higher.
- General lack of knowledge

R&D Projects to Address Challenge 3

What R&D Projects could the Energy Commission pursue to address PRODUCTION?

Make sure to specify if there is a specific aspect of the Key Challenge the project would address. (Additionally, we'll follow-up by asking who are the required stakeholders, what are the measures of success, and what could inhibit success for the suggested R&D project.)

Unsorted (1)

- Key to make anything happen is economics. Solar is well suited to RPS targets (can true up production, no incentive to provide power 100% of the time). Near time, legislative structure is a problem

Land-based (3)

- Often land-based is the low hanging fruit. It takes more than one energy source. It's important to not give up on land-based wind. Many of the same companies supporting land-based wind are the same as those supporting off-shore. More a matter of prioritization.
- The Germans have a very poor wind environment inland. They have gone to 140m towers and large rotors. From a study point of view, it might be reasonable (in the near

term want more onshore) to look at areas where you could do that. Get's into wildlife issues and visual problems. Multi-dimensional.

- Hypothesis - CA market could evolve similarly the way the German market has evolved. Could be some value in exploring that

Off shore - demonstration (3)

- Support a major offshore demo in the state -- e.g., off Morro Bay
- More support for technology demonstration projects. Of course that involves funds but are there ways for CEC to have teams of experts to provide more support for these demonstration projects (land-based as well as offshore) - help answer questions/solve issues/connect with agencies/etc.

Comments

- Ideally want to see fairly big installations. There is a 30MW system in Scotland. Ideally, would want something much bigger to cover O&M costs, transport out.
- Biggest turbine now is 12 MW (GE Haliadae X)
- Suspect in the next few years we'll see 100 MW turbines, maybe larger. To pay for the platform, have to get the rotor size up
- Ideally, 1/2 GW wind farm to cover costs for all support equipment, maintenance, crew ships. Lots of investment in infrastructure.
- An offshore demo requires participation by many players -- state, federal, industry, etc. -- but some organization needs to ride point. CEC could be that lead organization.

Off shore - studies (2)

- The on site manufacturing comments made earlier apply to production by enabling taller towers and bigger rotors to be built and installed. For offshore, a port infrastructure study would be helpful. MA had a good example. Also, documentation of the necessary supply chain elements would be helpful.
- For off-shore, we still need to identify the infrastructure needs: ports, ships, fabrication yards, skills)

Off shore - platform development (4)

- A major cost for offshore floating wind systems is the platform and this still an area open for research for turbine stability and much lower costs to fabricate and install.

Comments

- There is only one floating system installed globally
- Wide open area for research. Give a stable platform that doesn't screw up the turbine.
- There is currently one floating wind farm that operating globally of 5 turbines.
- Consider starting with a lower risk fix bottom prototype in California now.
- Concrete offers a low cost solution to offshore floating foundations, but uncertainties exist in its ability to resist dynamic loads.

Off shore - supply chain (3)

- Leverage existing related manufacturing in the state to develop additional manufacturing of components used in wind projects. ? IT hardware, electronics?

- Booming off shore opportunity now on the east coast. Not sure if there are any CA companies (unclear). Need to get CA universities involved. Are there companies that can be developed? Can companies get established to participate, or learn from the east coast or global activity.
- Poise to be advocates for the industry and provide the supply chain that will be needed, takes time to grow.

R&D Projects to Address Challenge 4

What R&D Projects could the Energy Commission pursue to address GRID INTEGRATION AND INTERCONNECTION?

Make sure to specify if there is a specific aspect of the Key Challenge the project would address. (Additionally, we'll follow-up by asking who are the required stakeholders, what are the measures of success, and what could inhibit success for the suggested R&D project.)

Unsorted (6)

- Examine cost sharing between project owners and the grid operator.
- The CAISO's Deliverability Assessment Methodology will create a big barrier for the interconnection of offshore wind. It uses a dispatch assumption that maximally stresses the transmission system and a worst case multiple transmission system contingency. These highly unrealistic assumptions will assure a need for significant network delivery upgrades at a high cost to developers and, ultimately, to consumers. A research effort could investigate this methodology and encourage a more reasonable one.
- Technical and operational needs to manage grid systems with lower amounts of inertia and fast frequency response, including options for wind in delivering these services,
- Identify transmission paths for off-shore wind connection as first step to siting maritime infrastructure
- Objectively evaluate the pros and cons of accessing wind energy from other states
- How offshore wind affects grid integration in California remains an important question.

Thank You and Next Steps

Closing Statement: What is the one thing the Energy Commission should keep in mind as we draft the roadmap?

- Policy decisions are more important to wind deployment than technology issues, which the market can address. Research should help to inform major policy decisions that are necessary to advance onshore and offshore wind development.
- The CA offshore potential and opportunity is almost entirely unexplored and undeveloped. It's the elephant in the room.
- Wind is, in general, a mature and global industry. There are many areas of possible research, but far fewer that are unique to California. Focus on aspects that are reasonably unique to California, which most obviously would include floating offshore wind.
- cross-cutting and with respect to wildlife risk impact and reduction technologies and strategies, there is no short path to these solutions. CEC should consider a multi-year strategic plan for EPIC focus.

- In the roadmap, try to focus on just 2 or 3 areas where then the CEC can provide national/international leadership when it comes to issues facing wind energy. Likely in the area of offshore wind.
- Off-shore is key to long-term decarbonization because it helps balance solar. But it is very long-term, and the planning needs to be undertaken, followed by legislation to support the infrastructure development, probably a bond issue also, and then a mandate for Load Serving Entities to participate in energy procurement.
- Consider all regions of the state with good wind resources, even some that have already been excluded, unless there is very solid objective reasoning behind exclusion.

Small-Scale Hydroelectric Webinar: April 11, 2019

Number of Participating Experts: 8

Discussion on Key Challenges

Key Challenges inhibiting Small-Hydro from increasing renewable energy in California

We will briefly discuss each "challenge area" and then will undergo a prioritization exercise. Subsequently, the key barriers will be discussed in greater detail and we will identify potential R&D projects the Energy Commission could pursue to address them.

COST Are there high-cost technology development and operations components that need to be addressed

- Remote operation through automation
- Prime Movers
- Civil works for installation of conduit hydro can be expensive
- Site-specific nature inflates non-recurring engineering and manufacturing costs. Standardization efforts might be useful
- Civil works

RESOURCE VALUATION Are energy markets appropriately valuing all of the benefits that this technology area may bring to the grid or society?

- Ancillary services
- Still low importance given to grid regulation, storage capability, response time
- NHA is currently pursuing research on exactly this issue
- Operation at different power outputs according to grid demand
- Startup time to create power on grid better than other renewable technologies

DISPATCHABILITY Are technology improvements or strategies needed to ensure that electricity can be used on demand and dispatched at the request of power grid operators, according to market needs?

- Opportunities to make small hydro more dispatchable/flexible by combining with energy storage
- Technology already in place and effective at addressing these challenges
- It would be worth exploring the extent to which storage could be usefully paired with small hydro

- Remote sensing and communication for enhanced controls

RESOURCE AVAILABILITY -Clear understanding of geographical locations appropriate for deployment? -Regulatory or permitting barriers that may inhibit the development of utility-scale systems? -Forecasting improvements necessary to enhance operations and certainty in power scheduling?

- No assessment of conduit potential has been done in CA
- There is a good understanding of the potential locations where small hydro can be deployed
- Additional siting and resource assessment needed
- Better resource evaluation is needed for conduit systems: there is a pending proposal at DOE for Oak Ridge National Lab to complete that next year
- Regulatory barriers are associated with time required to obtain
- Permitting barriers are a huge problem but that is a federal issue which NHA has been pursuing for decades
- Lots of efforts to facilitate the permitting in progress

GRID INTEGRATION AND INTERCONNECTION Are there barriers to grid integration or interconnection that need to be addressed for this technology area?

- High costs of interconnection - need for streamlining the interconnect process
- Connection to existing transmission lines to reduce overall costs
- Interconnection costs for small hydro can be very high
- Huge incentive to size systems below CAISO dispatching threshhold
- Remoteness of some small hydro sites can be a challenge for interconnections

PERFORMANCE (including but not limited to: power output; capacity factor; energy density; material durability/corrosion; system degradation; efficiency; and curtailment)

- Multiple options available that are dependent on site specific conditions
- Not a problem when water is available; the big variable is annual hydrology variation
- Some technology can be cost prohibitive for small hydro

PRODUCTION Are there issues related to the manufacturability, supply chain and logistics, or other factors that limit system production?

- Smaller size generally lowers the manufacturing cycle
- Site-specific design and manufacturing lead to higher costs. Opportunities exist to standardize design and components.
- Right now the market is now so tiny that per-unit costs are relatively high since all systems are typically custom engineered and manufactured
- Increased standardization of systems across equipment vendors
- Possibility of standardization to reduce overall time and cost

OTHER BARRIER CATEGORIES Are there other major barrier categories to consider?

- Lack of government incentives similar to solar and wind technologies

- Particularly for very small systems, there can be information barriers, i.e. folks not being aware of 2013 federal regulatory reforms
- Better understanding of where small hydro fits in the energy grid (role, functions)
- Public perception of hydroelectric systems
- Supporting infrastructure resilience, particularly with regards to wildfires.
- Capital investments

Ranking Key Challenges

Please rank the Key Challenges inhibiting Small-Hydro from increasing renewable energy in California (Table D-15 and Figure D-7).

Table D-15: Challenges facing Small Hydro Power

Criterion "Impact" sorted by mean

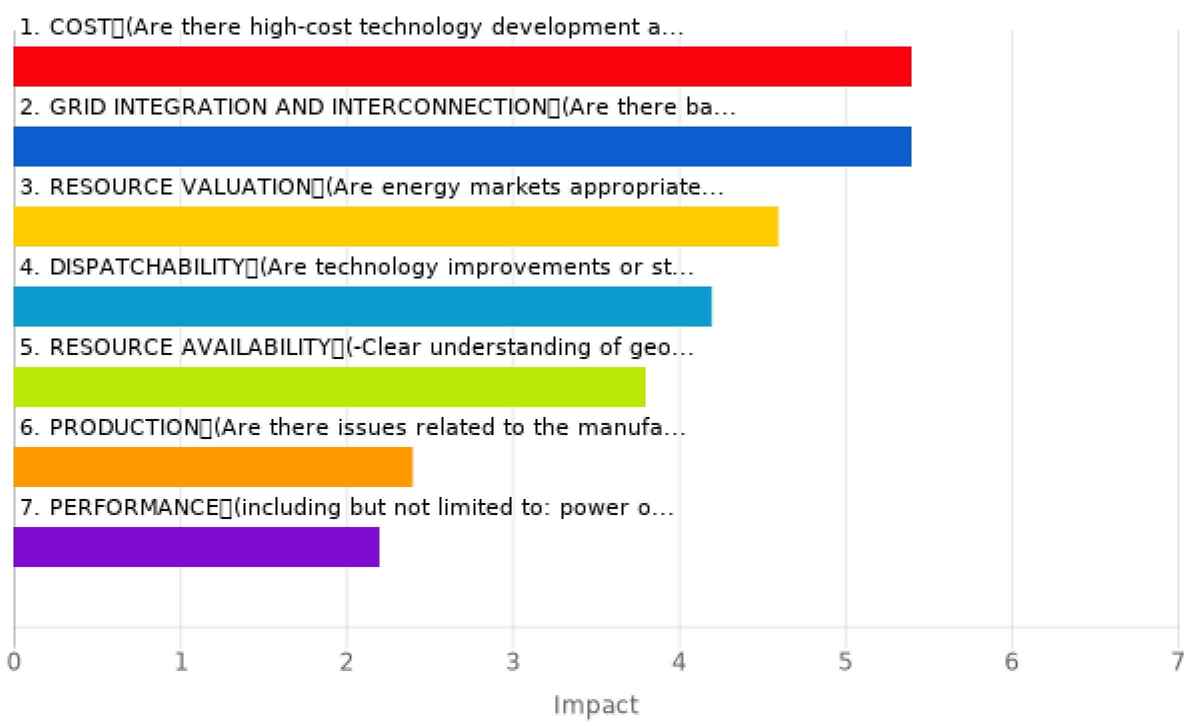
Highest rank of 7 is given 7 points.
Ratings submitted: 5. List of items randomized.

Nr	Item	↓Mean	SD	n
1	GRID INTEGRATION AND INTERCONNECTION (Are there barriers to grid integration or interconnection that need to be addressed for this technology area?)	5.40	0.19	5
2	COST (Are there high-cost technology development and operations components that need to be addressed?)	5.40	0.32	5
3	RESOURCE VALUATION (Are energy markets appropriately valuing all of the benefits that this technology area may bring to the grid or society?)	4.60	0.21	5
4	DISPATCHABILITY (Are technology improvements or strategies needed to ensure that electricity can be used on demand and dispatched at the request of power grid operators, according to market needs?)	4.20	0.17	5
5	RESOURCE AVAILABILITY (-Clear understanding of geographical locations appropriate for deployment? -Regulatory or permitting barriers that may inhibit the development of utility-scale systems? -Forecasting improvements necessary to enhance operations and certainty in power scheduling?)	3.80	0.31	5

Criterion "Impact" sorted by mean Highest rank of 7 is given 7 points. Ratings submitted: 5. List of items randomized.				
Nr	**Item**	**↓Mean**	**SD**	**n**
6	PRODUCTION (Are there issues related to the manufacturability, supply chain and logistics, or other factors that limit system production?)	2.40	0.19	5
7	PERFORMANCE (including but not limited to: power output; capacity factor; energy density; material durability/corrosion; system degradation; efficiency; and curtailment)	2.20	0.14	5

Source: MeetingSphere (2019)

Figure D-7: Rating of Small Hydro Challenges



Source: MeetingSphere (2019)

R&D Projects to Address Challenge 1

What R&D Projects could the Energy Commission pursue to address COST?

Make sure to specify if there is a specific aspect of the Key Challenge the project would address. (Additionally, we'll follow-up by asking who are the required stakeholders, what are the measures of success, and what could inhibit success for the suggested R&D project.)

Unsorted (0)

Operations (3)

- Insofar as operational costs (particularly personnel) can be substantial, could be worth exploring extent to which operational costs can be lowered through modernization to install remote operational capability -- may help keep existing old small hydro systems on line

Comments

- If look at the fleet of existing utilities (PG&E), much of it is dated. That has higher operational costs because the equipment is so old.
- If you look at what's actually happening, combination of high operational cost driven by old equipment, high re-licensing costs, staring into the teeth of wholesale market environment. PG&E is forfeiting small-hydro because there are high operational costs and energy is much higher cost than what's available on wholesale market
- Remote operation could decrease the operational cost, and that could decrease the de-commissioning being experienced by the industry
    - But right now it's expensive to operate remotely.
    - Needs to be understood politically/socially as well. Are you going to fire an operator?
    - Development of low maintenance or maintenance-free equipment that can operate over a longer time period could help improve the return on investment on small hydro units.

Comments

- Larger topic on maintenance. For R&D, still some possibility of improvement, specifically in small-hydro turbines, to put in place equipment that will require little to no human interface over a long-period of time to minimize operational costs.
- When you look at some of the other technology (solar/wind), not a lot of interaction required by humans over the time period it generates energy. Hydro (maybe less with new systems), but old systems have a significant amount of time required to make sure systems stay operational and effective.
- Regular outages of 2 weeks to 2 months per year, per unit
- Bearings, bushings (always come first in failure). Generator and electrical equipment needs to be inspected regularly (need to minimize this).
- Echo of agreement. Want to get to a world where small-conduit hydro is like rooftop solar, plug and play. Challenge with a hydro system if something goes wrong water might flow where it shouldn't. But small systems in particular, could become as operator free as small solar and wind
- In-conduit - If everyone explored replacing a PRV (pressure reduction valve)with a small-hydro system, huge opportunity. Not additional cost when needing to replace a PRV anyways, replace with small hydro

Standardization (2)

- I'm somewhat of an outsider to small hydro, but I can see how there might be challenges with economies of scale? Is there an opportunity to improve production costs through economies of scale?
- Standardization of small hydro solutions for a certain range of head & flow could help optimize costs and schedule for major equipment

Integration (1)

- Grid integration - Experience on utility scale wind, not just small-hydro that experiences high-costs of grid interconnection.

Comments

- Modeling requirements, dealing with regulations and code standards (drafted for synchronus generators and being adopted for asynchronous generation).
- Messy, rules are complex, vary place to place, electrical models always a challenge, people who know how to run those models are few and far between.
- Required to demonstrate how stable the new generating source can be to the surrounding grid.

Civil Works (1)

- Civil works is typically a high cost item in small hydro. Addressing ways to potentially reduce and streamline the excavation and erection of water conveyances would be beneficial.

Comments

- A lot of the cost involved with small hydro is associated with making sure that the location of the job-site is ready to receive small hydro equipment
    - A lot of time and cost associated with finding the best way to bring water to the small hydro system
- Would benefit the industry to have quicker ways to go through this. Standardize based on certain range of head or flow so units can be installed more rapidly
- Agreement. Specifically the rationale that led to DOE's small hydro modular research effort

R&D Projects to Address Challenge 2

What R&D Projects could the Energy Commission pursue to address GRID INTEGRATION AND INTERCONNECTION?

Make sure to specify if there is a specific aspect of the Key Challenge the project would address. (Additionally, we'll follow-up by asking who are the required stakeholders, what are the measures of success, and what could inhibit success for the suggested R&D project.)

- Is the correct information with regards to electrical performance of the systems made available by the OEMs? Do operators need help interpreting P-Q charts, FRT profiles, etc.?

- Small hydro, by definition, has a smaller output potential that can be detrimental in the assessment of the required capital investment. Unless there is an existing transmission line nearby, this can become a "show stopper" for the overall project.

Comments

- Not so much in-conduit. Run of the river type small hydro
- As long as the utilities have a transmission line nearby or within reasonable distance, it's not that complicated to connect additional power sources to the line. (Actually help the grid)
- As you get more remote this becomes a problem (requires more cost). Severe hinderance to make a project possible
- Right now there is mapping done (what will wind resource be, people bid in according to that estimate), not sure if anyone has really studied the hydrology data

Comments

- Some small hydro systems in northern California, may only run in high-intensity rain events (particularly in the winter). How does that hydrology profile compare to what's actually happening on the electrical system?
- On an analytical basis it would be interesting to compare that
- Unclear if someone has looked at what the CA fleet does now as a function of hydrology and how that compares to the needs of CA's electricity system?

7. Generally speaking, gird integration is not a hindrance to small hydro. Most owners have this under control. The divesting of older small hydro assets is associated with the operating costs not warranting continuous operation.

R&D Projects to Address Challenge 3

What R&D Projects could the Energy Commission pursue to address RESOURCE VALUATION?

Make sure to specify if there is a specific aspect of the Key Challenge the project would address. (Additionally, we'll follow-up by asking who are the required stakeholders, what are the measures of success, and what could inhibit success for the suggested R&D project.)

- The resource valuation analysis which NHA is pursuing now is more related to the ancillary benefits which big pieces of small spinning metal can provide to the grid; this benefit is less likely to apply to smaller systems
- There is a "resilience" benefit of all small systems which is not yet fully understood

Comments

- Would be interesting to do a study to understand what reserve power systems (and ancillary systems) current people use. Compare to small hydro backed up with storage. Can we explore whether this a small hydro resource that could provide some resilience.
- Hydroelectricity is no longer required to perform only base loading for energy production with the surplus coming from other renewables. Small hydro units are now better used to regulate the grid, provide storage possibilities, work as frequency control for the grid... these ancillary services are not currently priced differently from normal generation.

- There is nascent research aimed at aggregating and coordinating small hydropower assets to provide firm energy and firmer ancillary servicies, but few/no real-world examples.

Comments

- Could remote sensing further this purpose? Compared to wind at least, hydro could be considered a firmer resource. How would this be quantified and how could it be signaled to ISOs?
- Contrary to other renewables (wind/solar), can't accumulate solar energy and wind energy without a battery. Need other methods of accumulating energy to do this. Difference with small hydro (and pumped storage) is you can store the energy itself in the form of water.
- Need an idea if there is an additional cost associated with providing services (not just producing energy like everyone else)
- In general, the increasing penetration of renewables and electrification is driving a change to services markets instead of capacity markets. Small scale hydro benefits from the acceleration of this transition as well.

R&D Projects to Address Challenge 4

What R&D Projects could the Energy Commission pursue to address DISPATCHABILITY?

Make sure to specify if there is a specific aspect of the Key Challenge the project would address. (Additionally, we'll follow-up by asking who are the required stakeholders, what are the measures of success, and what could inhibit success for the suggested R&D project.)

- Projects are frequently subject to license flow regime requirements which can limit the ability to more flexible to serve dispatchability needs

Comments

- Typically there is a flow requirement for a given stream. There are flow minimums that need to be maintained, water limits, assumptions about availability of water for rafters/fisherman or what have you. Those cannot be changed to suit the power market.
- All depends on the limitations on a particular stretch of river.
- Hydroelectric units have the potential to provide energy over a larger operating range, which can be beneficial to the overall grid.

Comments

- Ramping speed is actually in term of seconds to move operating points up or down, which makes hydroelectricity ideal for grid regulation
- As we lose solar baseload (clouds coming in), other form of energy need to replace that. Hydro has that potential.
- Desire for ramping, particularly for small-hydro, allows for research on water fluctuations. Mechanically this opportunity might be there. But does the physical hydrology of the system allow for ramping and modulating hydro systems?
- Can we show where it is and is not feasible to ramp small hydro?

- Dispatchability may be possible through coordinated control of multiple small hydropower assets over a range of time scales.

Comments

- Do not know of third-party commercial interests doing this yet. Considerable research is needed to show that this is economically feasible. Idaho National Lab and NREL are collaborating on some of this research
- Generation shifting for peak response, Primary Frequency Response, inertia, blackstart reserve etc..What improvements in communication are needed with other small scale hydro operators and grid operators to aggregate a meaningful shift? And how are the participating entities remunerated?

R&D Projects to Address Challenge 5

What R&D Projects could the Energy Commission pursue to address RESOURCE AVAILABILITY?

Make sure to specify if there is a specific aspect of the Key Challenge the project would address. (Additionally, we'll follow-up by asking who are the required stakeholders, what are the measures of success, and what could inhibit success for the suggested R&D project.)

- Essentially, all existing dams have the potential to be equipped with hydro units.
- Oak Ridge has a pending proposal to DOE to complete a resource assessment based on actual water system flows in CA and nationwide. Hopefully it will be funded during the upcoming fiscal year.
- Oak Ridge did a natural stream flow assessment. The latest assessment would be water supply and conduit opportunities (not natural streams). Likelihood of this, not sure. Need to wait until the next fiscal year.
- Not aware of specific industry investigation on most likely locations for installing small hydro in California... can only speak to individual feasibility-level efforts performed locally by different owners.
- Hydrology/flows (potential power output) compared to power market needs. Potential need for research. National labs have been more focused on the resource availability, less focused on the cost of implementation and deployment and market value of the power.
- Identification of specific sites: Historic knowledge of flow; height (upstream to downstream); possibility of diverting flow to power house. A lot of factors come into play. This is not a standardized approach. Very customized which is a hinderance. Costs are increasing, definitely a possibility of having an organization that would work with equipment supplier and engineering firms to take a look at this and streamline it. There are some conditions that will indicate certain solutions, could accelerate the discussions to create new small hydro.
- DOE and ORNL have been researching and developing a standardized and modular approach to small hydropower project design and equipment. DOE announced two research awards to applicant teams last week.
- Recent CEC work is understood to be a scaling up of limited data availability. Compared to actual water flow data that ORNL is proposing to collect.

R&D Projects to Address Challenge 6

What R&D Projects could the Energy Commission pursue to address PRODUCTION?

Make sure to specify if there is a specific aspect of the Key Challenge the project would address. (Additionally, we'll follow-up by asking who are the required stakeholders, what are the measures of success, and what could inhibit success for the suggested R&D project.)

- Multiple small companies have pre-commercial designs and prototypes of equipment (turbines and gates) that are benefiting from advanced materials and additive manufacturing.
- Lots of possibilities already explored by equipment suppliers to manufacture one-piece turbine runners, pre-assembled distributors, entire generators due to the smaller size and potential for transportation. Can be further developed by exploring modular approach and industry-wide standardization.
- A future vision could potentially involve commoditizing

Thank You and Next Steps

Closing Statement: What is the one thing the Energy Commission should keep in mind as we draft the roadmap?

- The most economically attractive new small hydro is not utility scale, but rather small and distributed and behind the meter: need to make sure small hydro is included in whatever work is being done by CEC focused on distributed energy resources
- Small hydro can address some of the current shortcomings in the energy imbalance market and additional awareness on its role and benefits should be provided.
- Modularity and standardization at the smallest scales, combined with co-development (recreation, water quality improvement, restoration), may lead to feasibility
- There is a need for aggregation of small-scale hydro generation--ranging from behind the meter, islanded microgrid installations to the larger, utility-scale contributions. This will be increasingly important in services markets. And understanding how players will be remunerated is also needed.

Public Comment Workshop Feedback

Tables D-16 and D-17 are a summary of the comments received during the public comment workshop held on June 28, 2019. E-comment numbers refer to the document numbers as tracked through CEC’s submission portal.

Table D-16: Public Comment Workshop Feedback

Submission Type	Name	Organization	Tech Area	Description of Comment
Ecomment: 228931	Curtis Oldenburg	n/a	Energy Storage	Limitations in pumped storage hydro
Ecomment: 228967	System	Hyperlight Energy	Concentrated Solar Power	Discussion on the best way to commercialize CSP and bring it to the market while still investing in R&D. LCFS connection is important.
Ecomment: 228977	Garry George	Audubon	Other	Roadmap should include conflicts with wildlife and habitats and how to plan and resolve them
Written Comment	Fred Morse	n/a	Concentrated Solar Power	Disagrees with CSP challenges and barriers relating to "both thermal energy storage and ramp rates need to improve". Called not describing PV and CSP as complimentary a missed opportunity
Webinar	n/a	n/a	Solar Photovoltaics	Optimal way to pair solar with storage, even small amount of storage is pivotal in meeting peak load and justifying more installation. Excel Energy example.
Webinar	n/a	n/a	Concentrated Solar Power	Market deployment is important should focus on a hybrid of PV and CSP (not good to compare PV to CSP, ignores application differences)
Webinar	n/a	n/a	Geothermal	High drilling cost and high flow rates are barriers. Synergy with 40MM DOE project should be looked at.
Webinar	n/a	n/a	Geothermal	Importance of field testing initiatives, step out to areas adjacent or in geothermal fields, to promote research for geothermal. Access to transmission important, more rapidly deployed.

Submission Type	Name	Organization	Tech Area	Description of Comment
Webinar	n/a	n/a	Small Hydropower	The most potential projects are conduits for hydro, man-made infrastructure, with an area of focus being how to connect to the grid and distribution system. Heavily governed by Rule 21 and there is no credit for the grid benefits offered .
Webinar	n/a	n/a	Small Hydropower	Small hydro provides grid benefits, but how can this be balanced with grid investments? Policy changes can allow small hydro to flourish and maintain necessary cash flow.
Webinar	n/a	n/a	Small Hydropower	Barriers to entry ripe for research – incentive programs or policy that would allow for co-op, IOU etc. which may defer grid upgrades. Configured based on capacity factors that seem low.
Written Comment	n/a	n/a	Concentrated Solar Power	TES will benefit CA as they provide 100% clean energy. It is also flexible dispatchable generation.
Ecomment: 228892	Ronald Stein	n/a	Other	General concern over shifting away from nuclear and nat gas generation
Ecomment: 228970	system	California Wind Energy Association	Land-based Wind	Tours for public information and education
Webinar	n/a	n/a	Offshore Wind	Lower cost of energy through taking account of farm land synergies Demonstration project to increase enthusiasm
Webinar	n/a	n/a	Bioenergy	Syngas cleanup is important, but similar to EPIC III initiative and shoudn't be limited to just gasification, but utilized for other methods of bioenergy.

Submission Type	Name	Organization	Tech Area	Description of Comment
Webinar	n/a	n/a	Bioenergy	Recommended initiatives do not address torrefaction pyrolysis at lower temps. Can it be expanded to include both (to include solid fuels from pyrolysis)?
Ecomment: 228961	System	Southern California Gas Company	Bioenergy	Bioenergy initiatives cover important research areas in the space of biomass conversion and adjustments to the language to not be too restrictive. The energy storage should include Hydrogen energy storage.
Written Comment	n/a	n/a	Bioenergy	THP is not just a pretreatment for AD and can be used for other processes including Hydrothermal Processing
Written Comment	n/a	n/a	Concentrated Solar Power	Mirror cleaning is applicable to both power generation and LCFS applications and has an increased chance of market deployment as opposed to a technology applicable only to power generation.
Webinar	n/a	n/a	Concentrated Solar Power	Cleaning mirrors - could be interest in combining PV and CSP cleaning Mirror washing is good initiative, but there is a wealth of int'l experience on this. Build on int'l experience.
Written Comment	n/a	n/a	Offshore Wind	Floating substructures that have funding should be prioritized to move to a prototype installation as quickly as possible. Focusing on developing new designs is time consuming and expensive.

Submission Type	Name	Organization	Tech Area	Description of Comment
Written Comment	n/a	n/a	Offshore Wind	The term tower should be replaced by more familiar terms for offshore wind infrastructure such as foundation and substructure as defind in IEC offshore wind standards and design guidelines
Ecomment: 229131	Markus Wernli	n/a	Land-based Wind	Recommend to be more inclusive at the entire logistic challenge of wind turbine fabrication, transportation and installation, creating prototypes, and a study for the potential impact of offshore wind generation.
Ecomment: 228972	Danielle Osborn Mills	American Wind Energy	Offshore Wind	Recommend building upon existing research on port infrastructure in California. Schatz Energy Research Center looking at Northern part of the State. Consider environmental clean-up at ports as well.
Written Comment	n/a	n/a	Offshore Wind	Focus on where HVDC should be deployed to bring power to high load areas.
Written Comment	n/a	n/a	Solar Photovoltaics	Size (cost) of field testing should be scaled to reflect the durability demonstrated by accelerated stress testing. Field testing will be especially valuable for thin-film and tandem products for evaluating performance in addition to failfure and durability
Ecomment: 228919	Sarah Kurtz	n/a	Solar Photovoltaics	Improved wording on 2.1 - thin film and tandem material PV cells
Webinar	n/a	n/a	Solar Photovoltaics	Tandem could be used to reduce operating cost. (current solicitation challenging in response, mixture of forward thinking yet commercial stage)

Submission Type	Name	Organization	Tech Area	Description of Comment
Ecomment: 228973	system	Center for Energy Efficiency and Renewable Technology (CEERT)	Concentrated Solar Power	Highlight commercial developments for CSP/other technologies. Other comments captured by other comments in this spreadsheet.
Ecomment: 228919	Sarah Kurtz	n/a	Solar Photovoltaics	Questions on the justifcation for and timing for 2.2 - PV cell recycling
Webinar	n/a	n/a	Concentrated Solar Power	CSP does not have unique land use issues
Webinar	n/a	n/a	Land-based Wind	Broadly longstanding permitting hurdles to wind(repower as well as greenfield development are substantial barriers).
Ecomment: 228932	Curtis Oldenburg	n/a	Energy Storage	Compressed Air Energy Storage (CAES) detail provided
Ecomment: 228985	n/a	CalWave Power Technologies	Other	Inclusion of Wave technologies
Ecomment: 228910	Roland Horne	Stanford University	Geothermal	Disagrees with downhole heat exchanger initiative. More attractive ideas on the list.
Ecomment: 228944	Gerald Robinson	n/a	Solar Photovoltaics	Hardware resiliency for solar PV arrays in preparation for fire storms and seismic events
Ecomment: 228947	System	Form Energy	Energy Storage	Form Energy recommends to include the following into the roadmap: increasing/improving the capacity of energy storage and integrating renewables
Ecomment: 228947	System	Form Energy	Grid Integration	Demonstrate Non-Wires Alternatives to Extend Existing Transmission Capacity and Integrate Renewables
Ecomment: 228947	System	Form Energy	Grid Integration	Demonstrate Zero-Carbon Solution to Provide Multi-day Grid Resilience in the Event of Transmission Contingencies

Submission Type	Name	Organization	Tech Area	Description of Comment
Ecomment: 228947	System	Form Energy	Energy Storage	Improve Capacity Expansion Modeling Tools to Optimize Multi-Day Energy Storage Needs
Ecomment: 228948	System	Business Network for Offshore Wind	Offshore Wind	3 Offshore wind initiatives excluding cabling should be combined. Cabling should include European intiatives. New ideas for initiatives 5.1-5.3.
Ecomment: 228948	System	Business Network for Offshore Wind	Offshore Wind	Floating Offshore Wind Energy value add project optimizing power output incorporating Big Data, AI research and Hydrogen production
Ecomment: 228954	System	Berkshire Hataway Energy Co.	Geothermal	Proposal to add lithium recovery from Salton Sea geothermal brine to the roadmap
Ecomment: 228957	Jason Cotrell	RCAM	Offshore Wind	RCAM recommends that the commission examine the potential for short-term and long-term fixed-bottom deployments in California
Ecomment: 228958	System	Magellan Wind	Offshore Wind	Opportunities to invest in the untapped offshore wind market; most specifically in the East Coast. This investment would stimulate CA economy while innovation in floating tech is occurring.
Ecomment: 228960	Kevin J. Watson	Lawrence Berkeley Laboratory (LBL)	Solar Photovoltaics	Solar PV arrays should withstand severe weather events
Ecomment: 228963	System	UCR CE-CERT	Geothermal	Addition to the roadmap to expand geothermal energy as a key research topic and to investigate mineral extraction and co-production of geothermal power and renewable hydrogen

Submission Type	Name	Organization	Tech Area	Description of Comment
Ecomment: 228964	System	Bright Energy Storage Technologies	Energy Storage	Advocating an initiative for the incorporation of Thermal Energy Storage Systems into CA grid. Offers commercial and industrial applications which store surplus energy so it's not wasted.
Ecomment: 228966	System	Fervo Energy Company	Geothermal	Increase funding into the the R&D of Geothermal Technologies. Current infrastructure is outdated and geothermal is largely untapped.
Ecomment: 228968	Jin Noh	CESA	Energy Storage	Recommend to focus on application and performance attributes that are needed for a decarbonized electric grid, multi-day and season system modeling capabilities, hydrogen storage, and grid integration for resiliency and non-wire solutions
Ecomment: 228969	William Pettitt	Geothermal Resources Council (GRC)	Geothermal	Recommend to expand the geothermal roadmap to include three more initiatives; mineral recover from geothermal brines, performing research that encourages investment in geothermal power projects, more funding
Ecomment: 228971	system	Bright Energy Storage Technologies	Energy Storage	Optimize the design and operation of carbon capture and storage (CCS) systems
Ecomment: 228978	Krishnan Thosecan	n/a	Other	Green hydrogen should be added to the list of energy resources
Ecomment: 229131	Markus Wernli	n/a	Land-based Wind	Climbing cranes that can ascend partially built towers and also install the turbine on the tower. Self-erecting tower/turbines (telescopic towers)
Written Comment	Fred Morse	n/a	Concentrated Solar Power	Inititative 3.1 is a real, but minor issue. CA siting inititatives would have a bigger impact

Submission Type	Name	Organization	Tech Area	Description of Comment
Webinar	n/a	n/a	Concentrated Solar Power	Materials work is challenging and might be beyond what can be done (DOE doing this work) Focus more on things that support evaluation of CSP to gain experience curve
Webinar	n/a	n/a	Concentrated Solar Power	Consider attacking problem from different angle, instead of designing material, less corrosion issues by look at different working fluids. Material research is time consuming
Webinar	n/a	n/a	Land-based Wind	There are DOE/EPIC Initiatives. Why not radar for wildlife mitigation
Webinar	n/a	n/a	Offshore Wind	Remote monitoring via drone inspection.
Webinar	n/a	n/a	Offshore Wind	Utilization of artificial intelligence to determine siting.
Webinar	n/a	n/a	Offshore Wind	Combination of wind and wave is higher than any individually, can address large part of storage issue to meet 100% target. Can allow improvement to infrastrucutre as well.
Webinar	n/a	n/a	Bioenergy	Utilize microbial fuels cells to treat wastewater and treat directly from microbial activity.
Webinar	n/a	n/a	Bioenergy	Conduct an assessment for feedstock logistics from forestry and agriculture.
Webinar	n/a	n/a	Grid Integration	Adding an inititative focused on long duration storage.
Webinar	n/a	n/a	Grid Integration	Suggest focus on transactive energy systems. Potential for intgrating renewables and improving load factor on the grid.

Submission Type	Name	Organization	Tech Area	Description of Comment
Webinar	n/a	n/a	Energy Storage	Long duration energy storage. Investigate hydrogen and renewable natural gas storage options.
Webinar	n/a	n/a	Energy Storage	Consider managed electrified fleet vehicle charging as an asset, a different form of DER.
Webinar	n/a	n/a	Energy Storage	Focus on improving round trip efficiency and reducting cost of flow batteries
Webinar	Media contacting Silvia	n/a	Grid Integration	Low sag high temperature conductor
Written Comment	n/a	n/a	Solar Photovoltaics	Light-induced degradation needs to be characterized both to predict electricity production and to enable business transactions.
Written Comment	n/a	n/a	Solar Photovoltaics	Reduced operating temperature not only increases operational efficiency, but also can slow many degradation mechanisms and can reduce local heating.
Written Comment	n/a	n/a	Concentrated Solar Power	CTES can provide this reheating of the compressed air required for efficient operation by reusing the heat of compression, avoiding the need to burn natural gas to generate heat.
Written Comment	n/a	n/a	Concentrated Solar Power	CEC should work with World Bank, CSP industry, and grid policy experts to convene and symposium and decide on potential vlaue and importance of CSP in CA and southwest

Submission Type	Name	Organization	Tech Area	Description of Comment
Written Comment	n/a	n/a	Land-based Wind	Increase Manufacturing Capabilities in CA. CA can increase both manufacturing output and attract new manufacturing facilities by demosntrated utility scale wind growth.
Written Comment	n/a	n/a	Land-based Wind	Additive manufacturing or shotcreting of tower in combination of climbing technologies
Written Comment	n/a	n/a	Offshore Wind	There is a potential to develop non-floating offshore wind in the state (43 GW)
Written Comment	n/a	n/a	Offshore Wind	Analysis of deep water storage system with idea of improving integration of offshore wind energy
Written Comment	n/a	n/a	Offshore Wind	Fabrication and installation studies in conjunction with develop of existing floating structures
Written Comment	n/a	n/a	Offshore Wind	Monitoring of Birds and other marine life in offshore Wind projects
Written Comment	n/a	n/a	Geothermal	Expand geothermal energy in the Imperial Valley since it is a strategically important element of a balanced renewable portfolio. Capital costs are higher in this area. Would help reach goal of 500 MW of energy in Imperial by 2030.
Written Comment	n/a	n/a	Geothermal	Lowering well field costs.
Written Comment	n/a	n/a	Geothermal	Modeling for flexible generation.
Written Comment	n/a	n/a	Geothermal	Developing flexible generation systems. Most power contract currently incentivize systems to run baseload.

Submission Type	Name	Organization	Tech Area	Description of Comment
Written Comment	n/a	n/a	Geothermal	Enhanced geothermal systems. Focus on funding that support wellbore flow rates, drilling reduction costs, and improved reliability in exploratory drilling
Written Comment	n/a	n/a	Geothermal	Concrete TES in combination with geothermal operations. CTES would allow geothermal systems to operate to match needed output.
Written Comment	n/a	n/a	Geothermal	Reduce drilling costs.Improve drill bit technology to deal with higher temperature higher strength rock. HTHP components. Characterize hydrothermal systems. Low-cost high temperature sensing electronics. Impove drilling efficiency. Look at laser drilling, electronic pulse drilling, other tech.
Written Comment	n/a	n/a	Geothermal	Play Fairway analysis. Improve certaintiy of goethermal locations. Use advanced reservoir models and field monitoring methods.
Webinar	n/a	n/a	Small Hydropower	Initiative 8.1 (standardization) will not move state of hydropower forward in California. There is a benefit to improving interconnection which can be done focusing on standardization of interconnecting components.
Webinar	n/a	n/a	Small Hydropower	Initiative 8.2 (PMGs) will not move state of hydropower forward in California
Ecomment: 228955	System	Offshore Wind Industry Participants	Offshore Wind	Relook at the cost estimates and projections on the draft roadmap for offshore wind and other renewable energy. They are based on outdated data.

Submission Type	Name	Organization	Tech Area	Description of Comment
Ecomment: 228965	System	Cierco Corporation	Offshore Wind	Cost analysis and budget for offshore wind is outdated
Webinar	n/a	n/a	Bioenergy	Report utilizes dated information
Ecomment: 228942	Kate Kelly	Defenders of Wildlife	Other	Resource Availability captured incorrectly, revisit. TAC could include others.
Webinar	n/a	n/a	Solar Photovoltaics	Confirmed interest in cell recycling: Recycling may be a good choice for public investment because businesses are unlikely to invest until government policy and business climate require it. Reword the initiative from cell recyling to modular recycling How to handle the transportation costs
Webinar	n/a	n/a	Solar Photovoltaics	R&D Facilities or Material design for recylability, material science or developing facilities or technologies for improved recycling processes. Need to be clear in initiative
Ecomment: 228972	Danielle Osborn Mills	American Wind Energy	Land-based Wind	PPA Prices are off for on-land wind. Also look into updating offshore wind due to continued development.
Ecomment: 228972	Danielle Osborn Mills	American Wind Energy	Offshore Wind	A number of points on issues to consider. Highlighting the Resource Availability (>10 GW) over next 10 years. Large response to BOEM call for information. 2020 BOEM auction.

Submission Type	Name	Organization	Tech Area	Description of Comment
Ecomment: 228972	Danielle Osborn Mills	American Wind Energy	Offshore Wind	Analysis of interconnection and transmission for wind energy – both land-based and offshore – is underway in other venues. While interconnection and transmission planning are critical to the renewable industry in general, expending limited EPIC funds is this area will likely be duplicative and unnecessary.
Ecomment: 228972	Danielle Osborn Mills	American Wind Energy	Offshore Wind	Do not focus research funding on floating platform technologies and anchoring. This work is already underway in the private sector by individual companies.
Ecomment: 228974	Patrick Dobson	n/a	Geothermal	Gives 8 technology areas for geothermal that are covered by US DOE's GeoVision study and that could be mentioned in Roadmap. Many of these were brought up in other comments and will be discussed. Appendix will include other EPIC/DOE/State initiatives

Submission Type	Name	Organization	Tech Area	Description of Comment
Ecomment: 228974	Patrick Dobson	n/a	Geothermal	Updated resource assessment for California (for both high temperature systems as well as lower temperature resources that could be utilized for direct use applications); Improved models and techniques are needed to identify zones of subsurface permeability. This would improve well success for both exploration and development drilling; Improved reservoir models and field monitoring methods (such as microseismic monitoring systems and the use of geochemical tracers) will enable operators to better manage the utilization of geothermal resources.
Ecomment: 228976	Katherine Young	National Renewable Energy Laboratory (NREL)	Geothermal	R&D should focus on drilling improvements and technologies
Ecomment: 228976	Katherine Young	National Renewable Energy Laboratory (NREL)	Geothermal	Recovery minerals from geothermal brines
Webinar	n/a	n/a	Small Hydropower	Small modular incentives already underway.
Webinar	n/a	n/a	Small Hydropower	Configure small hydro to be more connected and promote standardization.
Webinar	n/a	n/a	Small Hydropower	Every site is new for hydro. No incentive to take panel, lack of clarity on IOUs, no incentive for non-std panel thru nat'l certification process. Standardization of systems can help to fast track interconnection.

Submission Type	Name	Organization	Tech Area	Description of Comment
Ecomment: 228985	n/a	CalWave Power Technologies Inc.	Other	Advocation for TRL advancement
Webinar	n/a	n/a	Solar Photovoltaics	How to reduce heat degradation, thermal management of panels

Source: Energetics (2020)

Quantitative Comment Decision Process (Yes/No Process)

The yes/no process was a quantitative decision process used to score new ideas that were suggested for addition of recommended initiatives in the roadmap and disagreements with recommended initiatives in the roadmap (Table D-17). A detailed explanation of the process can be seen in Chapter 2.

Table D-17: Yes/No Process Results

			Questions in Yes/No Process (Bolded Questions worth 2 points)								
Brief Description of Idea	**Comment Type**	**Score**	**Are there few similar initiatives offered nationally or by other states?**	**Is there limited overlap with Past EPIC Initiatives?**	**Does this initiative have a medium or high potential impact on renewable penetration in California?**	**Does this initiative fulfill the Energy Commission's objectives for this roadmap?**	Does the idea improve key performance metrics for the technology area?	Does it require applied R&D and technology demon-stration?	Does the idea take advantage of opportunities in California?	Is the time horizon of the initiative less than 10 years?	Is the idea detailed and specific?
Additive manufacturing or shotcreting of tower in combination of climbing technologies	New idea	0 (Pass)	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Enhanced geothermal systems. Focus on funding that support wellbore flow rates, drilling reduction costs, and improved reliability in exploratory drilling	New idea	0 (Pass)	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Initiative 3.1 is a real, but minor issue. CA siting initiatives would have a bigger impact	Disagreement	0	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
3 Offshore wind initiatives excluding cabling should be combined. Cabling should include European initiatives. New ideas for initiatives 5.1-5.3.	New idea	1 (Pass)	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No
Consider attacking problem from different angle, instead of designing material, less corrosion issues by look at different working fluids. Material research is time consuming	New idea	2 (Pass)	No	*Yes*	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Climbing cranes that can ascend partially built towers and also install the turbine on the tower. Self-erecting tower/turbines (telescopic towers)	New idea	2 (Pass)	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Combination of wind and wave is higher than any individually, can address large part of storage issue to meet 100%	New idea	2 (Pass)	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No	Yes

Brief Description of Idea	Comment Type	Score	Questions in Yes/No Process (Bolded Questions worth 2 points)								
			Are there few similar initiatives offered nationally or by other states?	**Is there limited overlap with Past EPIC Initiatives?**	**Does this initiative have a medium or high potential impact on renewable penetration in California?**	**Does this initiative fulfill the Energy Commission's objectives for this roadmap?**	Does the idea improve key performance metrics for the technology area?	Does it require applied R&D and technology demon-stration?	Does the idea take advantage of opportunities in California?	Is the time horizon of the initiative less than 10 years?	Is the idea detailed and specific?
target. Can allow improvement to infrastructure as well.											
Materials work is challenging and might be beyond what can be done (DOE doing this work) Focus more on things that support evaluation of CSP to gain experience curve	Disagreement	2	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Initiative 8.1 (standardization) will not move state of hydropower forward in California. There is a benefit to improving interconnection which can be done focusing on standardization of interconnecting components.	Disagreement	3 (Pass)	Yes	No	Yes	Yes	No	Yes	Yes	Yes	Yes
Initiative 8.2 (PMGs) will not move state of hydropower forward in California	Disagreement	3 (Pass)	Yes	Yes	No	Yes	Yes	No	Yes	Yes	Yes
Do not focus research funding on floating platform technologies and anchoring. This work is already underway in the private sector by individual companies.	Disagreement	3 (Pass)	Yes	Yes	Yes	Yes	No	No	Yes	No	Yes
Fabrication and installation studies in conjunction with develop of existing floating structures	New idea	3	Yes	Yes	Yes	No	Yes	Yes	Yes	Yes	No
Green hydrogen should be added to the list of energy resources	New idea	3	Yes	Yes	Yes	No	Yes	Yes	Yes	Yes	No
Long duration energy storage. Investigate hydrogen and renewable natural gas storage options.	New idea	3	Yes	Yes	Yes	No	Yes	Yes	Yes	Yes	No
Recommend to focus on application and performance attributes that are needed for a decarbonized electric grid, multi-day and season system modeling capabilities, hydrogen	New idea	3	Yes	Yes	Yes	No	Yes	Yes	Yes	Yes	No

Brief Description of Idea	Comment Type	Score	Questions in Yes/No Process (Bolded Questions worth 2 points)								
			Are there few similar initiatives offered nationally or by other states?	**Is there limited overlap with Past EPIC Initiatives?**	**Does this initiative have a medium or high potential impact on renewable penetration in California?**	**Does this initiative fulfill the Energy Commission's objectives for this roadmap?**	Does the idea improve key performance metrics for the technology area?	Does it require applied R&D and technology demon-stration?	Does the idea take advantage of opportunities in California?	Is the time horizon of the initiative less than 10 years?	Is the idea detailed and specific?
storage, and grid integration for resiliency and non-wire solutions											
Concrete TES in combination with geothermal operations. CTES would allow geothermal systems to operate to match needed output.	New idea	3	Yes	Yes	No	Yes	No	Yes	Yes	Yes	Yes
Consider managed electrified fleet vehicle charging as an asset, a different form of DER.	New idea	3	Yes	Yes	Yes	No	No	Yes	Yes	Yes	Yes
CTES (Concrete TES) can provide this reheating of the compressed air required for efficient operation by reusing the heat of compression, avoiding the need to burn natural gas to generate heat.	New idea	3	Yes	Yes	No	Yes	No	Yes	Yes	Yes	Yes
RCAM recommends that the commission examine the potential for short-term and long-term fixed-bottom deployments in California	New idea	3	No	Yes	Yes	Yes	Yes	No	Yes	Yes	Yes
Suggest focus on transactive energy systems. Potential for intgrating renewables and improving load factor on the grid.	New idea	3	Yes	Yes	Yes	No	No	Yes	Yes	Yes	Yes
Focus on improving round trip efficiency and reducting cost of flow batteries	New idea	3	Yes	No	Yes	Yes	Yes	Yes	Yes	Yes	No
Utilization of artificial intelligence to determine siting.	New idea	3	Yes	Yes	Yes	No	No	Yes	Yes	Yes	Yes
Assess feedstock logistics from forestry and agriculture	New idea	3	Yes	Yes	Yes	No	Yes	Yes	Yes	Yes	No
Demonstrate Non-Wires Alternatives to Extend Existing Transmission Capacity and Integrate Renewables	New idea	3	Yes	Yes	Yes	No	No	Yes	Yes	Yes	Yes
Improve Capacity Expansion Modeling Tools to Optimize Multi-Day Energy Storage Needs	New idea	3	Yes	Yes	No	Yes	No	Yes	Yes	Yes	Yes

Brief Description of Idea	Comment Type	Score	Questions in Yes/No Process (Bolded Questions worth 2 points)								
			Are there few similar initiatives offered nationally or by other states?	**Is there limited overlap with Past EPIC Initiatives?**	**Does this initiative have a medium or high potential impact on renewable penetration in California?**	**Does this initiative fulfill the Energy Commission's objectives for this roadmap?**	Does the idea improve key performance metrics for the technology area?	Does it require applied R&D and technology demon-stration?	Does the idea take advantage of opportunities in California?	Is the time horizon of the initiative less than 10 years?	Is the idea detailed and specific?
Play Fairway analysis. Improve certaintiy of goethermal locations. Use advanced reservoir models and field monitoring methods.	New idea	3	Yes	Yes	Yes	No	No	Yes	Yes	Yes	Yes
Inclusion of Wave technologies	New idea	3	Yes	Yes	Yes	Yes	No	Yes	Yes	No	No
Increase Manufacturing Capabilities in CA. CA can increase both manufacturing output and attract new manufacturing facilities by demosntrated utility scale wind growth.	New idea	3	No		Yes	Yes	Yes	Yes	Yes	Yes	No
Modeling for flexible generation.	New idea	3	Yes	No	Yes	Yes	Yes	Yes	Yes	Yes	No
Reduced operating temperature not only increases operational efficiency, but also can slow many degradation mechanisms and can reduce local heating. Could be combined or incorporated	New idea	3	Yes	Yes	No	Yes	No	Yes	Yes	Yes	Yes
There is a potential to develop non-floating offshore wind in the state (43 GW)	New idea	3	No	Yes	Yes	Yes	No	Yes	Yes	Yes	Yes
Low sag high temperature conductor	Disagreement	4 (Pass)	Yes	Yes	No	No	Yes	Yes	Yes	Yes	Yes
Analysis of interconnection and transmission for wind energy – both land-based and offshore – is underway in other venues. While interconnection and transmission planning are critical to the renewable industry in general, expending limited EPIC funds is this area will likely be duplicative and unnecessary.	Disagreement	4 (Pass)	No	Yes	No	Yes	Yes	Yes	Yes	Yes	Yes
Developing flexible generation systems. Most power contract currently incentivize systems to run baseload.	New idea	4	Yes	No	Yes	No	Yes	Yes	Yes	Yes	Yes

Brief Description of Idea	Comment Type	Score	Questions in Yes/No Process (Bolded Questions worth 2 points)								
			Are there few similar initiatives offered nationally or by other states?	**Is there limited overlap with Past EPIC Initiatives?**	**Does this initiative have a medium or high potential impact on renewable penetration in California?**	**Does this initiative fulfill the Energy Commission's objectives for this roadmap?**	Does the idea improve key performance metrics for the technology area?	Does it require applied R&D and technology demon-stration?	Does the idea take advantage of opportunities in California?	Is the time horizon of the initiative less than 10 years?	Is the idea detailed and specific?
Hardware resiliency for solar PV arrays in preparation for fire storms and seismic events	New idea	4	Yes	Yes	No	No	Yes	Yes	Yes	Yes	Yes
Analysis of deep water storage system with idea of improving integration of offshore wind energy	New idea	4	Yes	Yes	No	Yes	No	Yes	Yes	No	Yes
Light-induced degradation needs to be characterized both to predict electricity production and to enable business transactions.	New idea	4	Yes	Yes	No	No	Yes	Yes	Yes	Yes	Yes
Addition to the roadmap to expand geothermal energy as a key research topic and to investigate mineral extraction and co-production of geothermal power and renewable hydrogen	New idea	4	No	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Monitoring of Birds and other marine life in offshore Wind projects	New idea	4	No	Yes	Yes	No	Yes	Yes	Yes	Yes	Yes
Utilize microbial fuels cells to treat wastewater and treat directly from microbial activity.	New idea	4	Yes	Yes	No	No	Yes	Yes	Yes	Yes	Yes
Demonstrate Zero-Carbon Solution to Provide Multi-day Grid Resilience in the Event of Transmission Contingencies	New idea	5	Yes	No	Yes	No	Yes	Yes	Yes	Yes	No
Advocating an initiative for the incorporation of Thermal Energy Storage Systems into CA grid. Offers commercial and industrial applications which store surplus energy so it's not wasted.	New idea	5	No	Yes	No	Yes	No	Yes	Yes	Yes	Yes
Solar PV arrays should withstand severe weather events	New idea	5	Yes	Yes	No	No	Yes	Yes	Yes	Yes	No
Expand geothermal energy in the Imperial Valley since it is a strategically important element of a balanced renewable portfolio. Capital costs are higher in this area. Would help	New idea	5	Yes	Yes	No	No	No	Yes	Yes	Yes	Yes

Brief Description of Idea	Comment Type	Score	Questions in Yes/No Process (Bolded Questions worth 2 points)								
			Are there few similar initiatives offered nationally or by other states?	**Is there limited overlap with Past EPIC Initiatives?**	**Does this initiative have a medium or high potential impact on renewable penetration in California?**	**Does this initiative fulfill the Energy Commission's objectives for this roadmap?**	Does the idea improve key performance metrics for the technology area?	Does it require applied R&D and technology demon-stration?	Does the idea take advantage of opportunities in California?	Is the time horizon of the initiative less than 10 years?	Is the idea detailed and specific?
reach goal of 500 MW of energy in Imperial by 2030.											
Increase funding into the the R&D of Geothermal Technologies. Current infrastructure is outdated and geothermal is largely untapped.	New idea	5	No	No	Yes	Yes	Yes	Yes	Yes	Yes	No
Form Energy recommends to include the following into the roadmap: increasing/improving the capacity of energy storage and integrating renewables	New idea	5	No	No	Yes	Yes	Yes	Yes	Yes	Yes	No
Lowering well field costs.	New idea	5	No	Yes	Yes	No	Yes	Yes	Yes	Yes	No
Proposal to add lithium recovery from Salton Sea geothermal brine to the roadmap	New idea	5	No	No	Yes	Yes	Yes	Yes	Yes	Yes	No
Recommend to expand the geothermal roadmap to include three more initiatives; mineral recover from geothermal brines, performing research that encourages investment in geothermal power projects, more funding	New idea	5	No	No	Yes	Yes	Yes	Yes	Yes	Yes	No
Reduce drilling costs. Improve drill bit technology to deal with higher temperature higher strength rock. HTHP components. Characterize hydrothermal systems. Low-cost high temperature sensing electronics. Impove drilling efficiency. Look at laser drilling, electronic pulse drilling, other tech.	New idea	5	No	Yes	Yes	No	Yes	Yes	Yes	Yes	No
Updated resource assessment for California (for both high temperature systems as well as lower temperature resources that could be utilized for direct use applications); Improved models and techniques are needed to identify zones of subsurface permeability. This	New idea	5	No	Yes	Yes	No	No	Yes	Yes	Yes	Yes

Brief Description of Idea	Comment Type	Score	Questions in Yes/No Process (Bolded Questions worth 2 points)								
			Are there few similar initiatives offered nationally or by other states?	**Is there limited overlap with Past EPIC Initiatives?**	**Does this initiative have a medium or high potential impact on renewable penetration in California?**	**Does this initiative fulfill the Energy Commission's objectives for this roadmap?**	Does the idea improve key performance metrics for the technology area?	Does it require applied R&D and technology demon-stration?	Does the idea take advantage of opportunities in California?	Is the time horizon of the initiative less than 10 years?	Is the idea detailed and specific?
would improve well success for both exploration and development drilling; Improved reservoir models and field monitoring methods (such as microseismic monitoring systems and the use of geochemical tracers) will enable operators to better manage the utilization of geothermal resources.											
Disagrees with downhole heat exchanger initiative. More attractive ideas on the list.	Disagreement	6 (Pass)	Yes	Yes	No	No	Yes	Yes	Yes	No	Yes
CEC should work with World Bank, CSP industry, and grid policy experts to convene and symposium and decide on potential vlaue and importance of CSP in CA and southwest	New idea	6	Yes	Yes	No	No	No	No	Yes	Yes	Yes
Floating Offshore Wind Energy value add project optimizing power output incorporating Big Data, AI research and Hydrogen production	New idea	6	Yes	Yes	No	No	Yes	Yes	Yes	No	No
Remote monitoring via drone inspection.	New idea	6	Yes	Yes	No	No	No	No	Yes	Yes	Yes
Adding an inititative focused on long duration storage.	New idea	6	No	No	Yes	Yes	No	Yes	Yes	Yes	No
Opportunities to invest in the untapped offshore wind market; most specifically in the East Coast. This investment would stimulate CA economy while innovation in floating tech is occurring.	New idea	7	No	Yes	No	No	Yes	Yes	No	Yes	Yes
Optimize the design and operation of carbon capture and storage (CCS) systems	New idea	7	No		No	No	Yes	Yes	Yes	Yes	No
There are DOE/EPIC Initiatives. Why not radar for wildlife mitigation	New idea	9	No	No	No	No	No	Yes	Yes	Yes	Yes

Source: Energetics (2020)

Final Public Review Feedback

Table D-18 are the results of the public webinar held on February 5, 2020 covering the final draft roadmap.

Table D-18: Final Public Review Feedback

Name	Tech Area	Question/Comment
Joe Desmund	BIO	Statement regarding the source and security of feedstock delivery. Wants to underscore on how important it is that there should be a BIO.3. Looking at the reference in 2013 that was done the commission has long funded the California Biomass collaborative at UC. There has been a long time since it has been updated for reference in 2010 there was 850,000 acres of almonds planted in 2019 there is close to 1.4 million acres. There should be an update on the assumptions since that is what investors will look into for security of invesment.
Audubon TN #: 232040	BIO	The bioenergy discussion does not explain loss of carbon sequestration and GHG emissions or the potentially significant loss of habitat when forest resources are used for bioenergy
Greg P. Smestad TN #: 231953	CSP.1	It is imperative to reach beyond the borders of California and the U.S. to provide information needed to slect, assess and manage projects and initiatives connected to CSP.1. Do not reinvent the wheel. Contact: Fabian Wolfertstetter fabian.wolfertstetter@dlr.de
Joe Desmond	CSP.1	There is a lot of work done looking toward automated cleaning to improve reflectivity. The challenge in creating a cleaning module is that there are multiple different shapes and sizes that causes issues with creating a single solution. Also the assumed 0.5% degradation per day never really happens in reality. The reflectivity is measured in real time and more heliostats can compensate for dust by finding an economical timing on when to clean the panels. There is potential in researching other substrates such as silicon carbide that can reduce abrasion and dust for less degradation in reflectivity
Greg Smith	CSP.2	Look across the pond in the European Union on research and technology
Katharina Gerber	ESS	There is a California EV battery recycling advisory board that's looking into recycling issue. Convene every 3 months in Sacramento and it's open to the public
Jesse Abel	ESS	Is thermal energy storage focused on electrical demand reduction eligible for the energy storage grant opportunities or is only electrical storage being considered.

Name	Tech Area	Question/Comment
Russel Teal	ESS.2	Liquid aluminum is also used in addition to molten salt for thermal energy storage
Joe Desmond	ESS.2	The optimized recycling recommendation here was not necessarily a strong fit as something else because of the timeframe and jurisdiction. Can fall under calrecycle. The big challenges are the storage opportunities for SB-100. Mentions near-term capacity issues, increased ramping needs and low renewable energy production from multi-day weather events to consider instead.
Audubon TN #: 232040	GEO	CEQA discussion is inaccurate and misleading. There is nothing in CEQA that treats projects over 50 MW differently from other projects-however, the Warren-Alquist Act provides the Energy Commission with the "exclusive power to certify all sites and related facilities in the state" for any thermal power plants over 50 MW. Since there is no information provided to support the implication that CEQA has delayed or inhibited any new geothermal projects, we suggest the draft roadmap revise this section and remove the recommendation regarding streamlining. (elaborates further within doc)
Kate Kelly	GEO	On page 84 this is under geothermal bottom paragraph. On the regulatory side, sequa has a number of environmental restrictions to prevent project permitting. Sequa is not in and of itself regulatory. The purpose of sequa is to provide informed decision-making and is not itself restrictive. Curious to see what specific components of Sequa you are looking at to come to that Conclusion
Evan Hughes	GEO	Page 68 of the report should tell the moisture content of food waste and ash content if that’s a factor because 3200 standard cubic foot of methane per ton of food waste is too low by far if dry tons is intended. More like 13,0000 standard cubic foot if dried tons.
Audubon TN #: 232040	GEO	Water use is a significant limiation on new Geothermal in California. We are concerned that the draft roadmap does not acknowledge the significance of high water use in geothermal projects as a limitation as it only briefly states that water is a limiting factor. (elaborates further within doc)
Lisa Belankeith	GEO	Water limitations mentioned in the report. Only the salinity is mentioned but what about the water supply? Main limiting factor on geothermal is water supply.

Name	Tech Area	Question/Comment
Chuck Gentry	GEO	Consider the importance of lowering capital costs why were there no initiatives recommendations for cost reduction on the main cost drivers like drilling, subsurface exploration and resource characterization
Katharina Gerber	GEO.2	What about the mineral recovery from geothermal brine to offset some of the cost and development of materials allowing to filter available minerals from brine
Patrick Dobson	GEO.2	What about direct use applications such as district heating and cooling that would displace the electricity use
Evan Hughes	GEO.2	Cooling is the use of water that is an issue. Geo power is using low temperatures compared to combustion power plants and therefore are low efficiency and hence more waste heat to be rejected and more cooling water needed. Cooling is often used because of this and limited water supply
Audubon TN #: 232040	GEO.2	We are concerned with the draft Roadmap's focus on the use of enhanced geothermal systems (EGS) to increase geothermal production in California. The EGS technologies may not be appropriate or feasible in many areas particularly because they require additional water in areas that now have few ground water resources and because fracking for EGS recovery may have significant impacts on other resources, increase seismicity, and affect natural systems including surface water resources (springs and seeps)
Claire Warshaw	SHP	Are in pipe turbines installed in coordination with water delivery and sewage utilities part of small hydro work or grid infrastructure or another part of R&D roadmap funding
California Wind Energy Association TN #: 232053	LBW	There is an overemphasis on older turbines.
California Wind Energy Association TN #: 232053	LBW	Typographical error re: value of wind energy.
California Wind Energy Association TN #: 232053	LBW	There needs to be context when referencing health and environmental impacts

Name	Tech Area	Question/Comment
California Wind Energy Association TN #: 232053	LBW	Data citation problems. "While the development of DRECP was a collaborative effort, when DRECP was announced, all wind projects being pursued in the region were cancelled, and there has been little to no development in wind power since in southeastern California." Please correct the citation to reference CalWEA. Please add citation for this statement:10 p. 47 and p. 51: "Based on 2018 generation data, the Capacity Factor for land-based wind turbines in California was 27 percent."
California Wind Energy Association TN #: 232053	LBW	Potential development made possible by the recommended RD&D should account for land-use and transmission constraints
Sujen International TN #: 232049	LBW.1	Our wind turbine solution is positioned to meet this objective with installation costs of $45,000 a 100 kWh Advanced WindWall, with a Capacity factor >40% and a lower LCOE, with a much small footprint needed than the best in class wind turbine solution. Our solution to meet the objectives of this initiative will not require new crane technology development or onsite 3D printing. Accordingly, we ask for modification of the working of this initiative to reflect the option to demonstrate meeting the objectives of this initiative without the need for new crane technology development or onsite 3D printing.
Kevin Wolffe	LBW.1	The 1985 California Wind Atlas shows its near ground wind resources on 7 m/s. Was this looked into?
Sujen International TN #: 232049	LBW.2	Our innovative blade and generator designs will obviate the need for use of larger wind turbine blades to attain the desired conversion efficiencies of 35 – 50%. Our 100 kWh Advanced WindWall has a 30-year life and needs a footprint of 225 sq. feet and a height of no more than 40 feet and is made from a space aged material called AT2LAS. AT2LAS is non-conductive, non-corrosive, lightning resistant, and will not biofoul. The American Wind generator has a capacity factor of >50%. Again, we ask for modification of the wording of this initiative to reflect the option to demonstrate meeting the objectives of this initiative without the need for new crane technology development or onsite 3D printing.

Name	Tech Area	Question/Comment
Michael	OSW	To take forward the first pre-commercial floating wind project in California is there a nuance support towards sensitive stakeholder engagement
Michael	OSW	Wind turbine fixed on retired oil platform to lower offshore wind cost
Claire Warshaw	OSW	Would offshore wind consider in place hydrogen fuel generation instead of underwater cable installation
Ahmed Hashem	OSW	Interested in developing the technology for Offshore Wind Energy with CEC.
Guidehouse	OSW	"RE Roadmap, pg. 58: This initiative recommends that California develops local manufacturing capabilities to enable large-scale deployment of a fully demonstrated floating offshore wind structure." Navigant assumes the report means platforms, but the phrasing is very general (i.e. the "initiative" is to pilot a local supply chain for all or many wind system components). Navigant avoided implying this was a good idea as most of the sources we spoke to suggest it isn't a good idea due to labor/land cost in California.
Guidehouse	OSW	"RE Roadmap, pg. 59: Recent reports declare it feasible for California to install 18 GW of Offshore Wind power by 2045." Navigant hasn't seen this # before other than as hypothetical value. What is the source of this number?
Guidehouse	OSW	"RE Roadmap, pg. 59: California is also positioned to become a leader across the Pacific Ocean as no floating structure manufacturing or deployment exists from the U.S. to Asia." There are multiple test projects and multiple commercial scale siting efforts underway in Asia.
Guidehouse	OSW	"RE Roadmap, pg. 59: Non-local manufacturing can add several more days of vessel transportation time resulting in hundreds of thousands of dollars of extra expenditure per floating turbine." In contrast, most stakeholders we spoke to believe local manufacturing will add millions to project costs due to high land and labor costs in California.

Name	Tech Area	Question/Comment
Guidehouse	OSW	"RE Roadmap, pg. 60: There are currently six ports in the state suitable for conversion and improvements: Humboldt Bay, San Francisco Bay, Hueneme, Long Beach, and San Diego." We only cite Humboldt as a suitable port for conversion and improvements; all other ports were mentioned to have serious restrictions (height, draft, military use, etc.). For example, the Golden Gate Bridge dimensions and the depth of the Bay limit the type of OSW assembly could be done in the San Francisco Bay.
Michael Jacobson	OSW	Does the commission recognize the need to pre-commercial projects ahead of the commercial deployments and if yes how can we support these projects to reach execution as they come
Kevin Wolffe	OSW.1	Confirm that in 2032 will be 7 to 8 cents per KWH.
Michael Jacobson from Share Co	OSW.1	Cost of energy and how to come down to the numbers of 7 to 8 cents per KWH. Undertaking a study from the UK government and sort of a bottoms-up calculation with all the details and with all the things being equal with fixed bottom wind and obviously this comes back to these fabrication manufacturings and serial production. In good wind speeds (9-10m/s) we're definitely on the pathway to reach the LCOE.
Michael	OSW.2	Is the goal new blades or would retrofittable technology be responsive
Michael	OSW.2	Seems to be an opportunity for repowering more than upgrading blade designs. What is the view on this?
Dan Petkovic	OSW.3	Resource assessments for wave energy look significantly lower than what was shown from NREL and US DOE
Michael	OSW.3	20% capacity is quite a low estimate and likely related to early stage systems
CalWave Power Technologies TN #: 232050	OSW.3	Suggest to solely focus on co-locating wind and wave farms instead of combining technolgies using the same permits, export cables, installation and maintenance vessels but leaving distinct clearance between farms (elaborates further within doc)
CalWave Power Technologies TN #: 232050	OSW.3	Assumptions in calculation of wave resources lack citation. Technical feasible percentage of wave resource is recommended to increase to 50-75%, see DOE: Quadrennial Technology Review 4N 2015, Chapter 4 (elaborates further within doc)

Name	Tech Area	Question/Comment
CalWave Power Technologies TN #: 232050	OSW.3	The cost of storage to achieve SB 100 is projected to become prohibitively large and could result to a significant delay in achieving the goal in time. A diversification of renewable generation assets, especially with resources that are more stable and predictable, can contribute to achieve a 100% mix. Thus, in the cost metrics, next to sole LCOE comparison, a system level cost comparison including cost of avoided storage is recommended that considers output profiles of resources (on daily and annual level), additional transmission line costs, curtailment rates of additional assets amount others. (elaborates further within doc)
Kate Kelly	Other	On page 15 last paragraph it discussed the DRECP and there isnt a section that is addressing barriers and constraints to energy development. It's curious to see the DRECP as a barrier or constraint since it has been a priority project for the state of California and the CEC itself has spent millions of dollars in developing and participating in the DRECP. Recommend that the team goes back and visit with Commisioner Caron Douglass's office, she was the lead commissioner on the DRECP to gain understanding of the purpose of the role of the DRECP renewable energy development in california.
Audubon TN #: 232040	Other	Audubon has planning efforts to identify "least-conflict" areas for utility scale renewable energy development and transmission including the DRECP. We emphasize again from our July 2019 comments that the Draft Roadmap's conclusions regarding DRECP are inaccurate and misleading and undervalue renewable energy planning. As stakeholders in the eight year DRECP process, we disagree with the Draft Plan's characterization of the DRECP as a "constraint" to renewable energy development in the desert. This characterization shows a lack of research, understanding, or interviews with the California and federal agencies who partnered in the eight-year process. The DRECP provided for 388,000 acres of public lands suitable for efficient and rapid solar PV and wind permitting near to transmission, and an additional 400,000 acres of public lands that may be available to renewable development. The Plan does not "constrain" renewable energy development. It facilitates it. (elaborates further within doc)

Name	Tech Area	Question/Comment
Audubon TN #: 232040	Other	The Draft Roadmap takes a minimal approach to wildlife/renewable energy issues despite California's wildlife agency, NGO conservation groups and the public's keen interest in supporting well-sited renewable energy projects. Further, the authors are seemingly unaware of CEC's EPIC Program's own research grant funding, as well as the Department of Energy's Wind and Solar Technology Offices funding, that benefit the more rapid and economic, and publicly supported, deployment of renewable energy through risk assessment data collection that avoids, minimizes and mitigates effectively for impacts on wildlife, including grants to study impacts to birds and the places bird need now and in the future. Many of these grants include new technologies. This is a key gap in the Draft Roadmap and must be incorporated in the final version. (elaborates further within doc)
Samuel Kanner TN #: 231935	SPV	Samuel Kanner is the lead of R&D at Principle Power, designer of the WindFloat platform. The technology of OSW platforms seek to minimize the effects of waves on platforms while wave energy seeks to maximize the effect. He recommends to modify OSW.3 to be "Integrate Energy Storage Systems with Floating Offshore Platforms" and link the initiatives that described in ESS.1 specifically around longer storage duration concepts. Floating offshore platforms are ideal places to locate energy storage technologies because there is substantial deck space and void spaces which can house technologies directly next to the sources of generation.

Name	Tech Area	Question/Comment
Audubon TN #: 232040	SPV	Page 20 of the RE roadmap statement is rife with incorrect generalities and includes assertions that appear to discount the decade of concerted landscape planning policy effort by the CEC, local government, and the federal government to identify appropriate lands for renewable energy development and transmission to meet California's energy needs. Indeed, this statement insinuates that the DRECP provides too little land for solar development when, in fact, this land use plan was developed with CEC leadership and provides nearly 400,000 acres of public land for development. Furthermore, no County in California has "banned solar energy development outright"7 and in fact, the California Solar Act provides clear limitations of the ability of local government to restrict rooftop and distributed generation solar. We request the draft roadmap be revised to reflect the substantive planning efforts that have undertaken for utility scale renewable energy. (elaborates further within doc)
Sarah Kurtz	SPV.2	There are two things to look at for the material recovery and recycling process and that is policy and resuse. Need to find the best ways to relabel and resell older modules at reduced price for continued use instead of tearing them apart
Greg Smith	SPV.2	There are several PV testing and certification labs in California that can test older panels, certify their performance and allow them to be used with confidence in a second stage of their life

Source: Energetics (2020)

CEC Feedback from Closeout Meeting

Table D-19 is a summary of comments received during a concluding call with CEC stakeholders on April 16, 2020.

Table D-19: Feedback from CEC Closeout Meeting

Tech Area	Question/Comment
CSP.1	Which technologies are covered by the initiative?
CSP.1	Soil reflectivity degradation seems high
ESS.1	Did we consider the cost point? Would be good to target.
GEO	There is EPIC geothermal work ongoing that we may want to consider

Tech Area	Question/Comment
GEO	Some fairly new/improved up-and-coming areas to consider also include directional drilling and closed-loop geothermal systems.
GEO	I note that this roadmap is considering the utility scale - however, I would encourage recognition of direct-use geothermal for its ability to offset conventional electrical consumption. California has significant geothermal potential for direct-use projects.
GEO.2	Is this mainly EGS, subsurface? We have a high number of conventional resources.
GEO.2	The International Geothermal Association's most recent work (attached presentation) identifies the highest risk of geothermal development as really coming from pre-survey, exploration, and test drilling. As the lead for the CEC's Geothermal Grant and Loan program and on my work on several geothermal grant projects, and from what I have heard at recent geothermal events - mapping, reservoir modeling, and drilling techniques are a high priority area of research as these efforts have the potential to reduce risk and costs that often prevent geothermal projects in the first place.
GEO.2	I also question the 1-3 year success timeline for EGS. While we can argue about the need for improvement in EGS, I would also like to point out that the DOE has this significant EGS funded project. The DOE wrote a roadmap that shows EGS as being on a 5-20 year timeline. It is a nascent technology in the geothermal community still and I struggle to see it having a 1-3 year success timeline.
GIT.1	Cybersecurity topic. This is hard because for EPIC everything is public. Did we take that in to account?
LBW.2	Does the report cover DOE overlap on this technology?
OSW	was there discussion here about hydrogen production in OSW? Are barriers mentioned?
OSW	Did we consider environmental impact of OSW?
OSW.2	Did you consider other offshore wind priority areas and not exclusively the port recommendation?
OSW.2	Question on the 8.4 GW value. Where is this from. Is it accurate?
OSW.2	What is the research element of this initiative, please explain?
SPV.1	What is different from current technology on this initiative?

Source: Energetics (2020)