DOCKETED	
Docket Number:	19-ERDD-01
Project Title:	Research Idea Exchange
TN #:	231956
Document Title:	Presentation EPIC Research Roadmap on Utility-Scale Renewable Energy
Description:	Public webinar presentation
Filer:	Silvia Palma-Rojas
Organization:	California Energy Commission
Submitter Role:	Energy Commission
Submission Date:	2/6/2020 9:09:44 AM
Docketed Date:	2/6/2020

California
Energy Commission
Research & Development

Draft Utility-Scale Renewable Energy Generation Technology Roadmap

Energy Research and Development Division

Silvia Palma-Rojas, PhD
February 5, 2020

Webinar Objective

- California Energy Commission staff is facilitating this webinar to request public comments on the research and development (R&D) opportunities prioritized for the Electric Program Investment Charge (EPIC) research roadmap on renewable energy generation technologies for utility-scale applications.

Research Roadmap

- Develop an actionable research roadmap that describes prioritized investment opportunities to increase the cost competitiveness, flexibility, and reliability of renewable energy generation in California.
- The research roadmap will serve as support to the development of research initiatives that provide optimal benefits to investor-owned utility (IOU) electric ratepayers, and maximize the use of public R&D investments.

CEC Administered EPIC Funding

Applied Research and Development

Applied Research and Development includes activities to support pre-commercial technologies and approaches at applied lab-level or pilot-level stages.

Technology Demonstration and Deployment

Technology Demonstration and Deployment involves installation and operation of pre-commercial technologies or strategies at a scale that will reflect actual operating, performance, and financial characteristics and risks.

Market Facilitation

Market Facilitation focuses on a range of activities, such as commercialization assistance, local government regulatory assistance and streamlining, market analysis, and program evaluation to support deployment and expand access to clean energy technology and strategies.

EPIC Symposium

https://web.cvent.com/event/24dc6f78-b953-49f1-80b7-c883138bbce6/summary?rp=00000000-0000-0000-0000-000000000000

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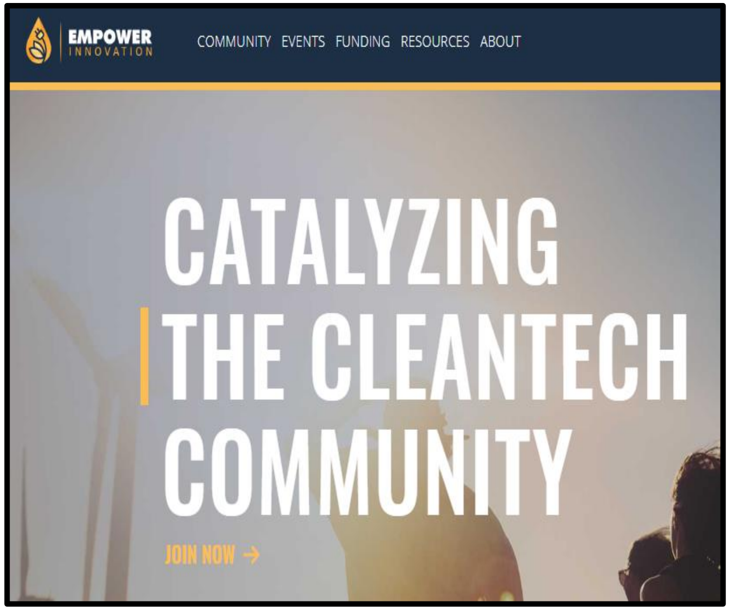

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Announce your interest in a funding opportunity and message other potential project partners.

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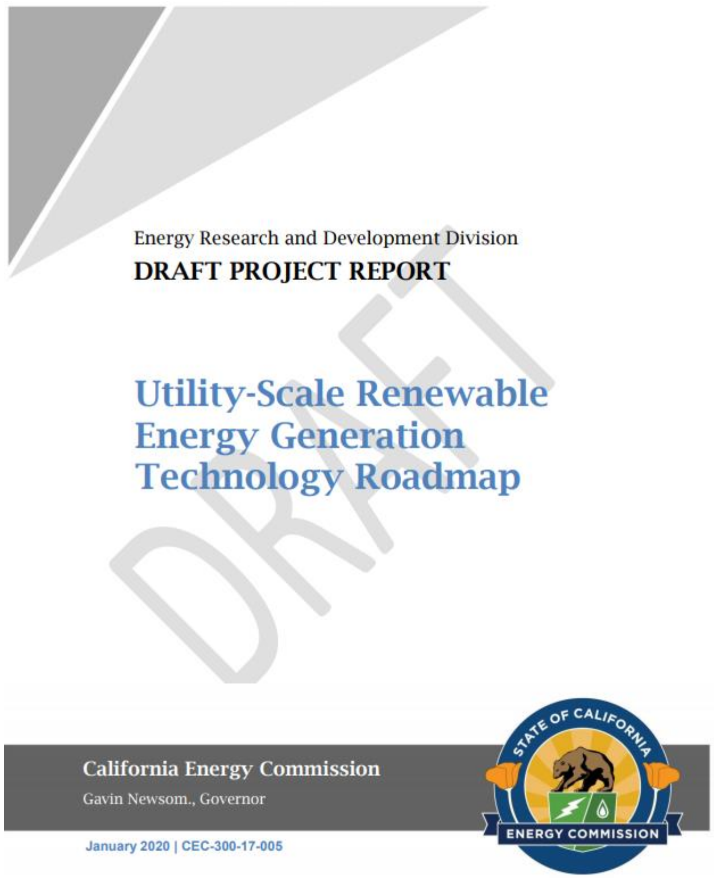
Draft Roadmap Report

Please go to https://efiling.energy.ca.gov/Lists/DocketLog.aspx?docketnumber=19-ERDD-01 to download the Draft Research Roadmap


Energy Research and Development Division

DRAFT PROJECT REPORT

Utility-Scale Renewable Energy Generation Technology Roadmap

California Energy Commission

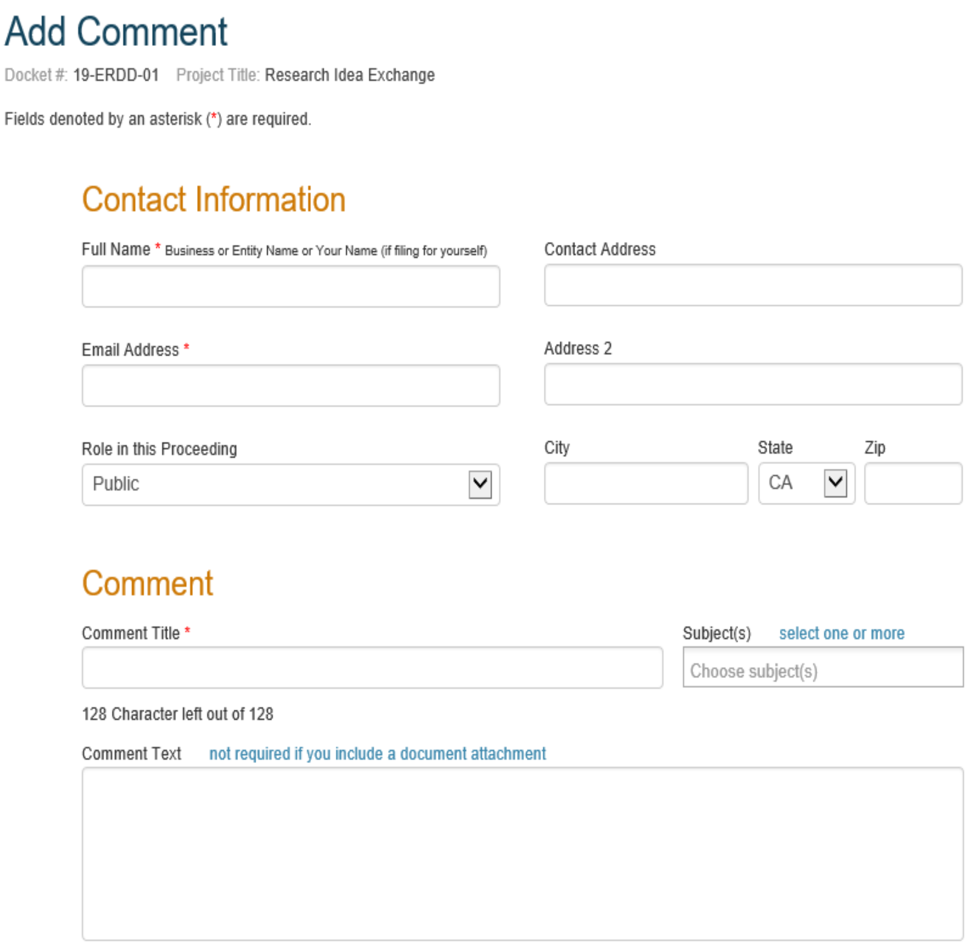
Gavin Newsom., Governor

January 2020 | CEC-300-17-005

DOCKETED	
Docket Number:	19-ERDD-01
Project Title:	Research Idea Exchange
TN #:	231930
Document Title:	Draft Utility-Scale Renewable Energy Generation Technology Roadmap
Description:	*** THIS DOCUMENT SUPERSEDES TN 231926 *** - This Draft Utility-Scale Renewable Generation Technology Roadmap provides the Energy Commission with 17 recommended initiatives to guide research development, demonstration, 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.

Written comments will be received by the Energy Commission through February 14, 2020.

Submitting Comments



Add Comment

Docket #: 19-ERDD-01   Project Title: Research Idea Exchange

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Written comments will be received by the Energy Commission through February 14, 2020.

Webinar agenda

✓ 10:00 am Introduction

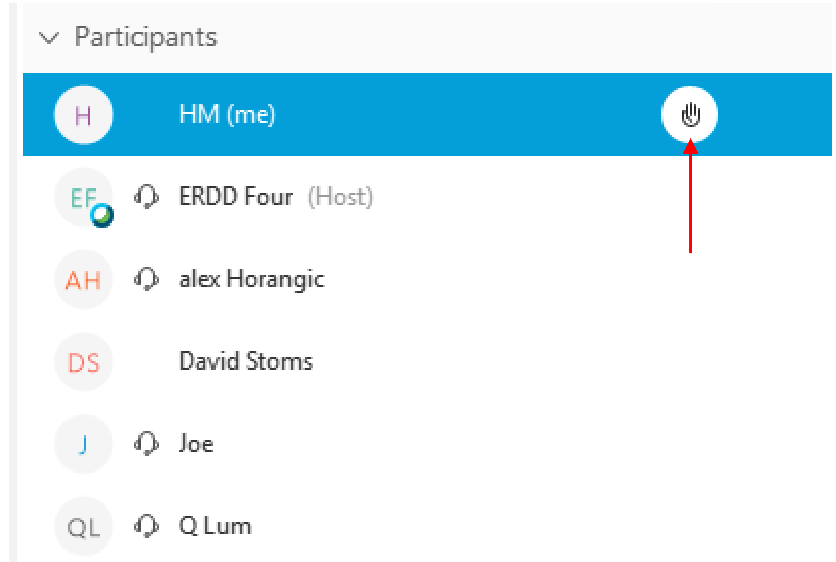
10:10 am Roadmap Methodology

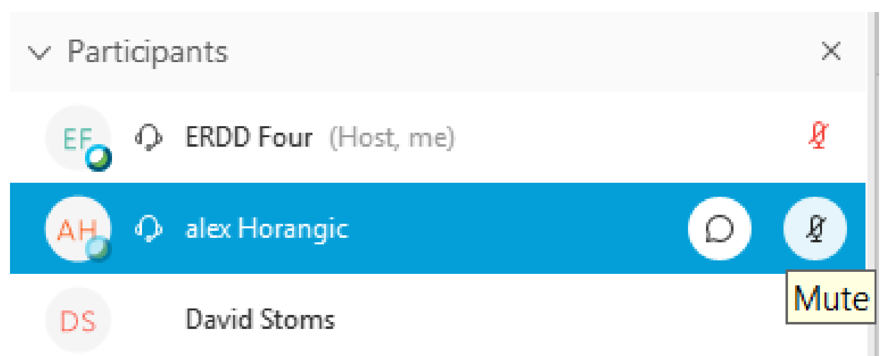
10:20 am Roadmap Discussion

- 10:20 Photovoltaic Solar Discussion and Q&A
- 10:30 Concentrated Solar Discussion and Q&A
- 10:40 Land-Based Wind Discussion and Q&A
- 10:50 Offshore Wind Discussion and Q&A
- 11:00 Bioenergy Discussion and Q&A
- 11:10 Geothermal Discussion and Q&A
- 11:20 Small Hydropower Discussion and Q&A
- 11:30 Grid Integration Discussion and Q&A
- 11:40 Energy Storage Discussion and Q&A

11:50 Q&A

12:00 Closing





FINAL DRAFT
UTILITY-SCALE RENEWABLE ENERGY GENERATION TECHNOLOGY ROADMAP

Public Comment Webinar,
February 5, 2020

Sabine Brueske, sbrueske@energetics.com

WEBINAR HOSTS

- Silvia Palma-Rojas
  Energy Commission, Commission Agreement Manager
- Sabine Brueske
  Energetics, Project Manager
- Harrison Schwartz
  Energetics, Lead Project Analyst
- Joan Pellegrino
  Energetics, Senior Technology Specialist
- Terry Peterson
  Solar Power Technology, Subcontract
- Justin Minas
  Davenergy Solutions, Subcontract

ROADMAP PROJECT OBJECTIVE

This roadmap is intended to identify, describe, and prioritize research, development, demonstration, and deployment (RDD&D) **technology opportunities that have potential to achieve higher penetrations of renewable energy** into California's electricity grid.

Working with stakeholders and subject matter experts to identify:

- Significant barriers to achieving greater use of renewable energy and storage in California
- Current research efforts at both the state and federal level that are addressing these knowledge gaps
- Research gaps that may be addressed by the Electric Program Investment Charge (EPIC) program
- Prioritizing future research needs in the near (1 to 3 years), mid-term (3 to 5 years), and long-term (>5 years)
- Indicators of success for renewable energy resource technologies and strategies
- Performance and cost targets, and other metrics

PROJECT TEAM

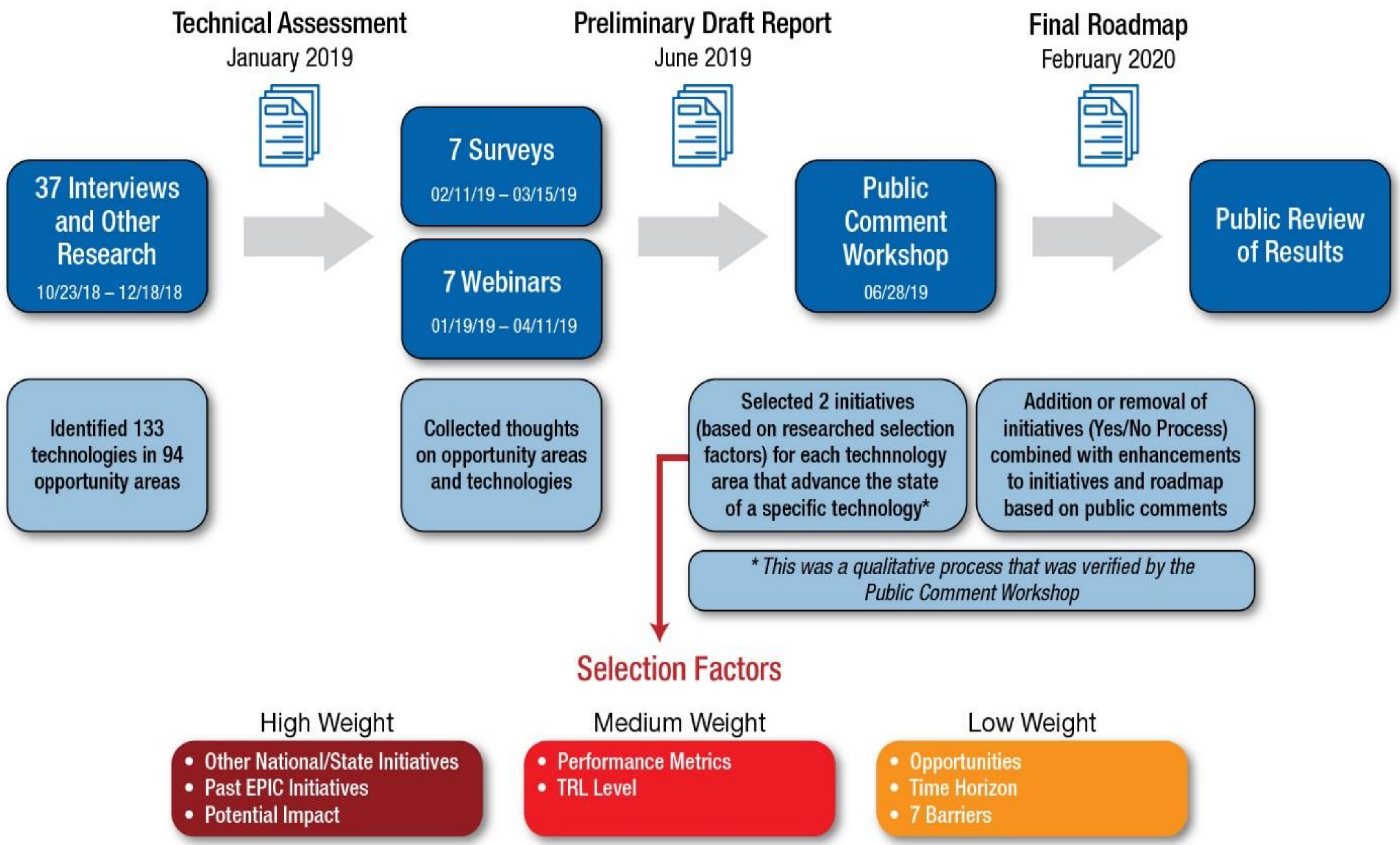
This Roadmap is led by **Energetics**, with valuable contributions from several subcontractors: **Center for Sustainable Energy**, **DAV Energy**, **Renewable Energy Consulting Services Inc.**, **Solar Power Consulting**, and **TSS Consultants**

Silvia Palma-Rojas managed this project for the California Energy Commission and provided valuable feedback and guidance throughout the effort.

Many thanks to the Technical Advisory Committee for their review and feedback on this project:

- Cara Libby, Senior Technical Leader, Electric Power Research Institute
- Dara Salour, Program Manager, Alternative Energy Systems Consulting
- Greg Kester, Director of Renewable Resource Program, California Association of Sanitation Agencies
- Jan Kleissl, Associate Director, University of California, San Diego, Center for Energy Research
- Julio Garcia, Geothermal Production Analysis Manager, Calpine
- Kevin Smith, Asset Management & Operating Services, DNV GL
- Kurt Johnson, Chief Executive Officer, Telluride Energy
- Lenny Tinker, Acting Photovoltaics Program Manager, U.S. Department of Energy, Solar Energy Technologies Office
- Robert Baldwin, PhD, Principal Scientist, National Renewable Energy Laboratory
- Terra Weeks, Advisor to the Commissioner, California Energy Commission

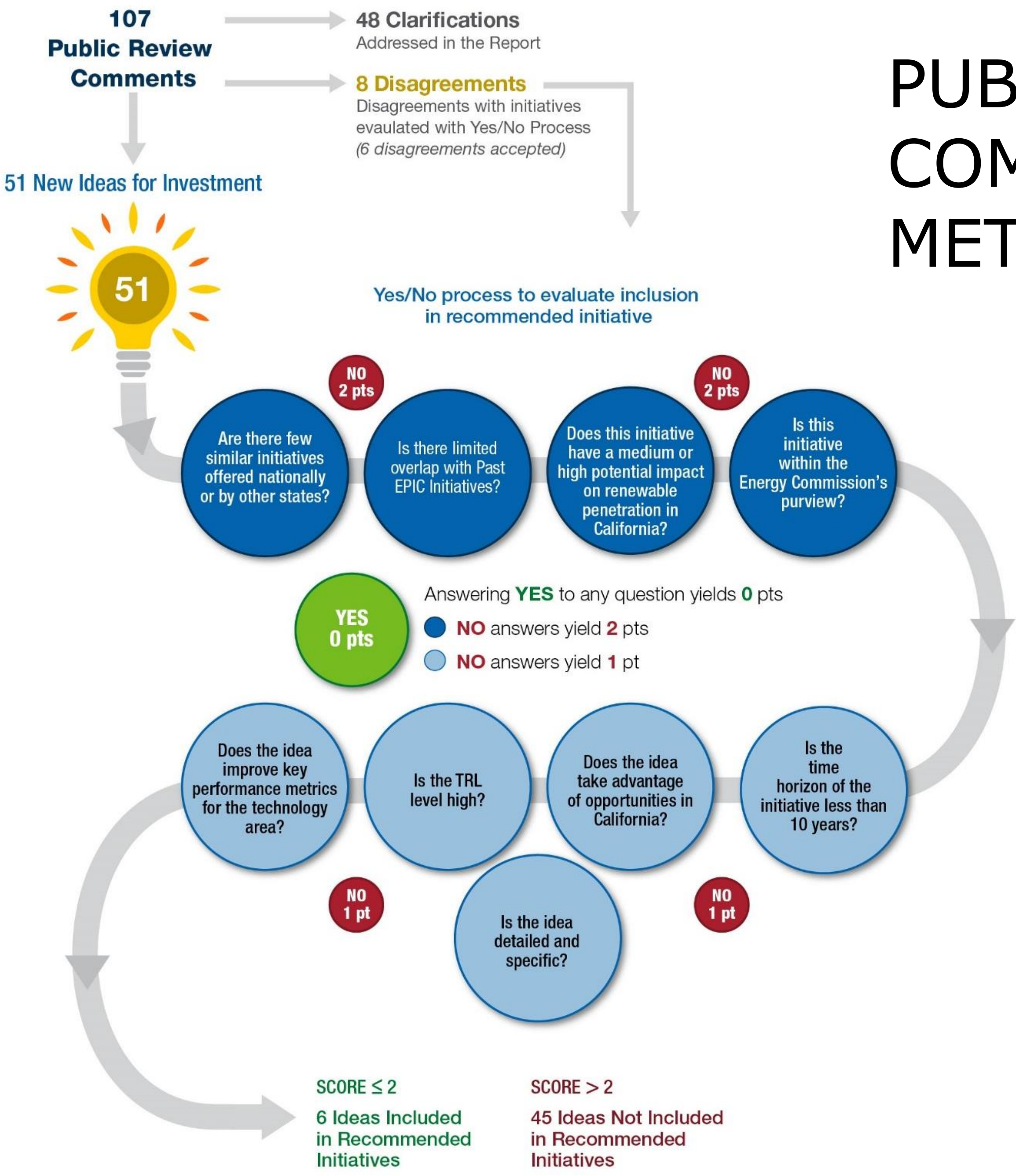
METHODOLOGY OF ROADMAP PROJECT



PROJECT TIMELINE (SIMPLIFIED)

- Sept 2018 - Kickoff
- Research and grouping of findings
- Jan 2019 - Specific R&D ideas were identified within groups – Tech Assessment
- Considered the identified selection factors holistically to select two recommended initiatives per tech area
- June 2019 - Public workshop to seek public input on Preliminary Draft and selected recommendations, with a methodology for decision making
- Feb 2020 – Final Draft of roadmap with results of process

PUBLIC COMMENT METHODOLOGY



PARTICIPATION IN ROADMAP METHODOLOGY

	Solar	Wind	Bioenergy	Geothermal	Small Hydro	Grid Integration	Energy Storage	Total
Interviews	6	10	6	5	4	5	3	39
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	114 unique invited participants
Public Comment Workshop Participants								81 external public participants

STRUCTURE OF FINAL REPORT

Acknowledgements
Preface
Abstract
Executive Summary
Chapter 1 – Introduction
Chapter 2 – Project Approach
Chapter 3 – Project Results
(9 technology areas)
Chapter 4 – Technology Transfer
Chapter 5 – Conclusions
App A – Calculations Related to SB-100
App B – Considerations outside of Scope
App C – Related Initiatives from CEC and Other Agencies

Concentrated Solar Power Considerations

Provided here (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,

Technology Area	Initiative	Success Timeframe
Solar Photovoltaics (SPV)	Initiative SPV.1: Field Test Tandem Material PV Cells	Mid- term/Long- term
	Initiative SPV.2: Increase PV Material Recovery from Recycling Processes	Near- term/Mid- term
Concentrated Solar Power (CSP)	Initiative CSP.1: Improve Cleaning Systems for CSP Mirrors	Near- term
	Initiative CSP.2: Advance Materials and Working Fluids for High Temperature TES	Mid- term
Land-Based Wind (LBW)	Initiative LBW.1: Advance Construction Technologies for Land- based Wind Turbines	Near- term/Long- term
	Initiative LBW.2: Demonstrate New Blades that Improve Conversion Efficiency	Mid- term/Long- term
Offshore Wind (OSW)	Initiative OSW.1: Pilot Demonstration of Floating Offshore Platform Manufacturing	Long- term
	Initiative OSW.2: Design Port Infrastructure to Deploy Floating Offshore Wind Technologies	Long- term
	Initiative OSW.3: Integrate 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: Deploy 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: Advance Techniques to Assess Potential EGS Development Sites	Near- term
Grid Integration Technologies (GIT)	Initiative GIT.1: Deploy Smart Inverters to Improve Communication and Cybersecurity	Near- term
	Initiative GIT.2: Advance 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

17 RECOMMENDED INITIATIVES

RESEARCH ROADMAP: TECHNOLOGY AREAS

- Solar (PV and CSP)
- Land-Based Wind
- Offshore Wind
- Bioenergy
- Geothermal
- Small Hydropower
- Grid Integration
- Energy Storage

CURRENT CALIFORNIA ENERGY MIX AND SB-100 GOALS

2018 CA 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%
Renewables	63,028	32.4%	23,671	30.4%	26,474	89,502	31.4%
Other Zero-Carbon Sources	40,364	20.7%	14,647	31.5%	15,976	56,340	19.7%
Unspecified Sources of Power	N/A	N/A	0	N/A	30,095	30,095	10.5%
Total	194,842	100.0%	80,304	27.7%	90,647	285,488	100.0%

SB-100 Goals and Estimates

2030

Estimated Electrical Consumption: 340,000 GWh

Renewable Energy Target: 60%

Estimated Renewable Generation: 204,000 GWh

New Generation Required (SB-100 Goal): 141,000 GWh

2045

Estimated Electrical Consumption: 411,000 GWh

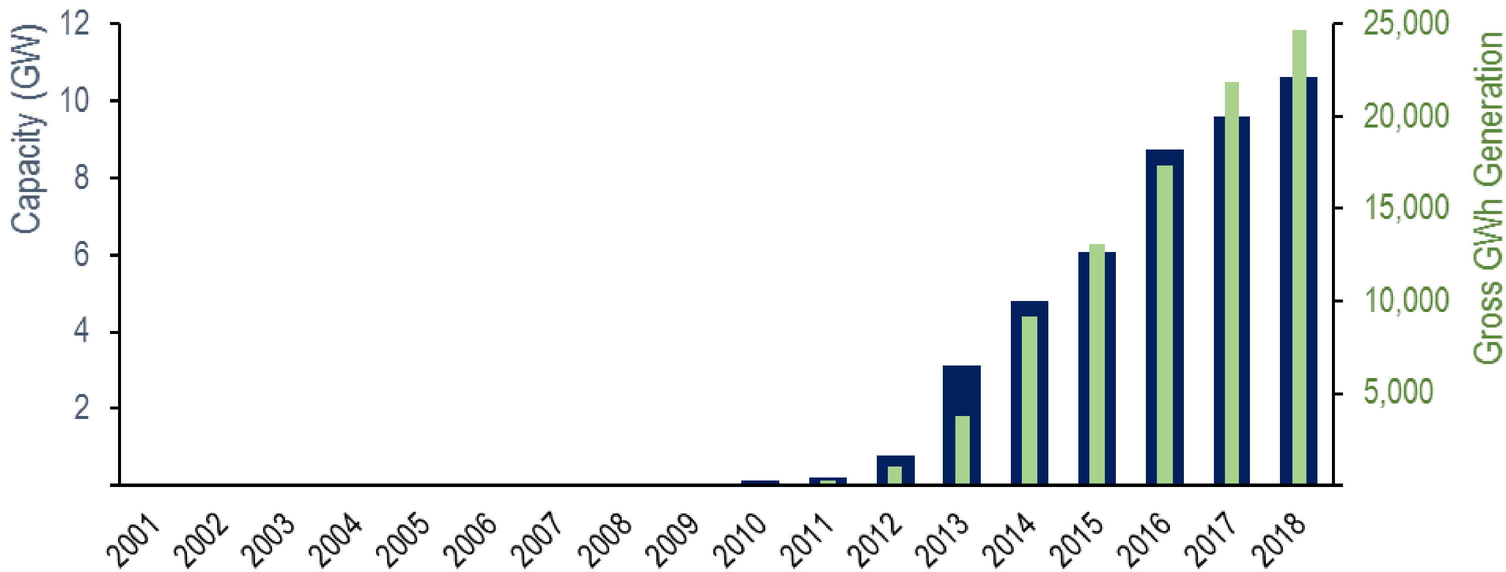
Zero-Carbon Energy Target: 100%

Estimated Renewable Generation: 389,000 GWh

New Generation Required (SB-100 Goal): 326,000 GWh

SOLAR PV OVERVIEW

Solar PV Energy Generation in California from 2001 to 2018



Resource Assessment: 4,100 GW Technical Potential

California 2018 Capacity Factor: 26.5%

Potential to Reach 2045 SB-100 Goals: 93,700,000 GWh technically feasible; 29x 2045 SB-100 Goal

SOLAR PV COST METRICS

Solar PV Cost Estimates and Projections

Source: Lazard (2018)				
	2018			
Photovoltaic (PV)	3.6 cents/kWh – 4.4 cents/kWh; $950/kW – $1,250/kW			
Source: 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
Source: California Energy Commission 2018 Update				
	2017	2018	2019	2030
Photovoltaic (PV)	N/A	4.7 cents/kWh	4.5 cents/kWh	3.5 cents/kWh
Source: IRENA Renewable Power Generation Costs				
	2017	2018	2019	2020
Photovoltaic (PV)	9.7 cents/kWh	8.5 cents/kWh	5.1 cents/kWh	4.7 cents/kWh

SOLAR PV RECOMMENDED INITIATIVE #1

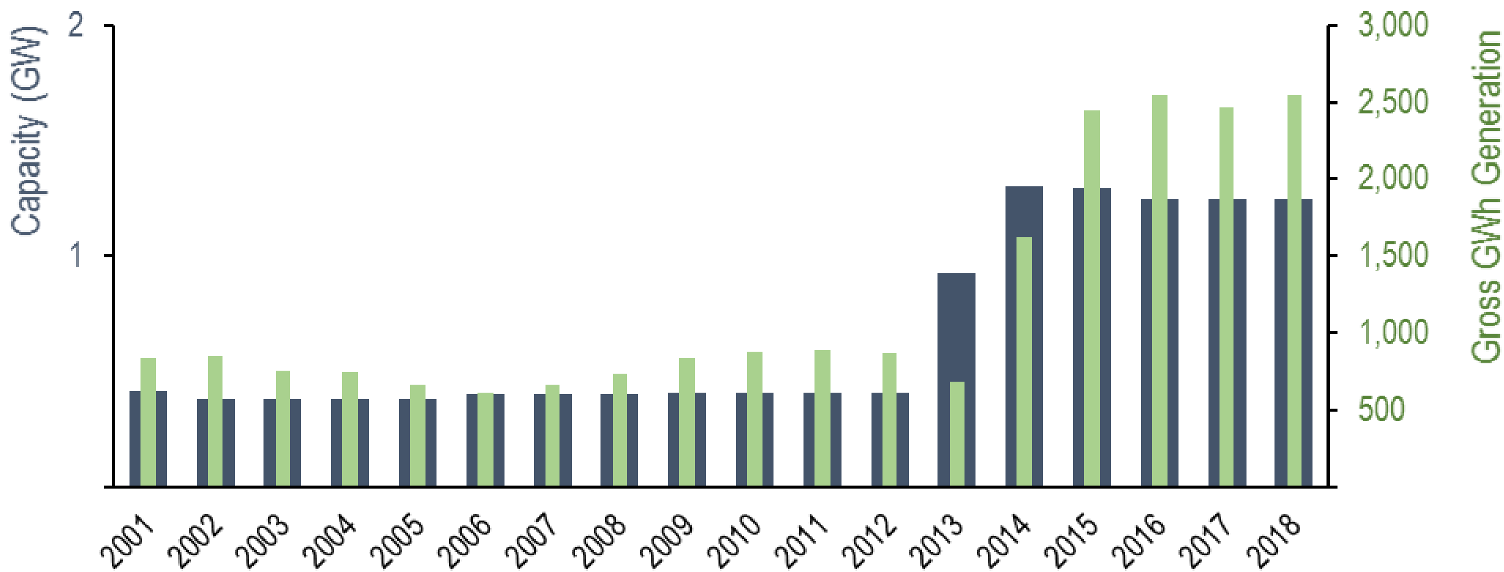
Initiative SPV.1: Field Test Tandem Material PV Cells
Goal: Provide a pathway to test tandem material PV cells in the field to help move the technology from lab-scale to commercialization. Tandem PV cells have the potential to surpass the conversion efficiency limits of single cell silicon PV.
Estimated Impact on SB-100: Reaching conversion efficiency targets would increase production from new installations. Estimated to provide an additional 7,200 GWh or 2.2% of 2045 SB-100 goals.
Technology Baseline: 23% Efficiency of current silicon PV modules; 22% demonstrated conversion efficiency of tandem PV cells.
Performance Indicators: Achieve conversion efficiency above 31 percent limit of single-junction PV cells.
Success Timeframe: Mid-term for testing of prototypes (3-5 years); Long-term for commercial deployment (>5 years)

SOLAR PV RECOMMENDED INITIATIVE #2

Initiative SPV.2: Increase PV Material Recovery from Recycling Processes
Goal: Improve recycling and recovery rates of retired PV modules to reduce environmental impacts and lower end-of-life costs for PV panels. Will be particularly impactful as current PV installations are retired in 20+ years.
Estimated Impact on SB-100: The retirement of 4.8 GW of solar PV modules is expected between 2030 and 2045. A high-end estimate for savings enabled by this initiative is $240 million.
Technology Baseline: Recycling costs of $10-$30 per module (15% of module price). 90% recovery of glass. 95% recovery rate of semiconductor.
Performance Indicators: Net recycling costs lower than 10% of initial capital cost; Module mass recovery rates of 98-99% to lower landfill impacts; Recovery rates of high value materials over 95%.
Success Timeframe: Near-term for Recycling Processes (1-3 years)

CONCENTRATED SOLAR POWER (CSP) OVERVIEW

CSP Energy Generation in California from 2001 to 2018



Resource Assessment: 2,700 GW Technical Potential

California 2018 Capacity Factor: 23.5%

Potential to Reach 2045 SB-100 Goals: 5,500,000 GWh technically feasible; 17x 2045 SB-100 Goal

CSP COST METRICS

CSP Cost Estimates and Projections

Source: Lazard (2018)				
	2018			
Concentrating Solar Power	9.8 cents/kWh – 18.1 cents/kWh; $3,850/kW – $10,000/kW			
Source: 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
Source: California Energy Commission 2018 Update				
	2017	**2018**	**2019**	**2030**
Concentrating Solar Power	N/A	15 cents/kWh	14 cents/kWh	13 cents/kWh
Source: 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

CSP RECOMMENDED INITIATIVE #1

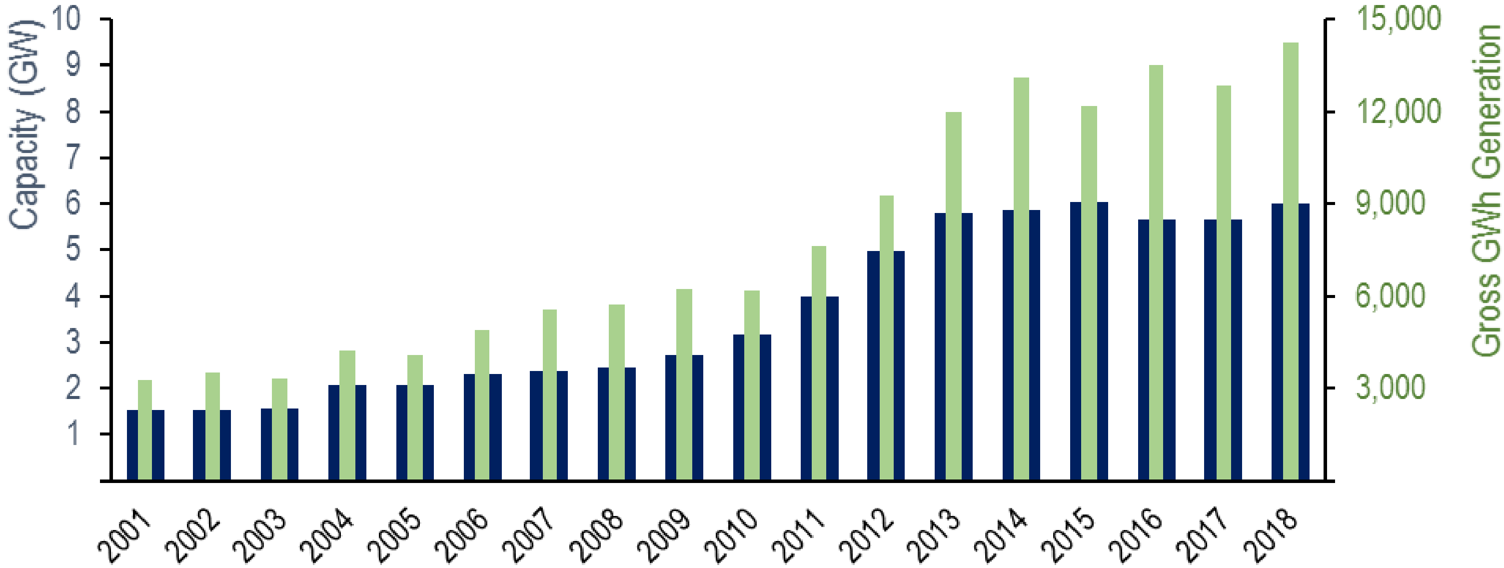
Initiative CSP.1: Improve Cleaning Systems for CSP Mirrors
Goal: Without increasing water use, introduce systems that can maintain high mirror reflectivity of CSP systems. Initiative should build upon knowledge gained globally to push systems to deployment.
Estimated Impact on SB-100: An increase in plant production by 15% annually would provide an additional 381 GWh or 0.5% of 2030 SB-100 goals.
Technology Baseline: Soil degrades reflectivity below 80% in a few months and severe dust events can lower reflectivity to 50%.
Performance Indicators: Average reflectivity maintained above 90%.
Success Timeframe: Near-term (1-3 years)

CSP RECOMMENDED INITIATIVE #2

Initiative CSP.2: Advance Materials and Working Fluids for High Temperature TES
Goal: Assist DOE efforts to achieve high temperature CSP systems with increased efficiency and effective paired energy storage. Focus on materials and working fluid research.
Estimated Impact on SB-100: Lower costs result in the construction of an additional 400 MW plant (similar capacity to Ivanpah). Would provide roughly 816 GWh per year or 0.3% of 2045 SB-100 goals.
Technology Baseline: CSP systems operate at 565˚C
Performance Indicators: Materials that support operation at 700˚C
Success Timeframe: Mid-term (3-5 years)

LAND-BASED WIND OVERVIEW

Land-based Wind Energy Generation in California from 2001 to 2018



Resource Assessment: 128 GW Technical Potential

California 2018 Capacity Factor: 26.8%

Potential to Reach 2045 SB-100 Goals: 301,000 GWh technically feasible; 92% of 2045 SB-100 Goal

LAND-BASED WIND COST METRICS

Land-Based Wind Cost Estimates and Projections

Source: Lazard (2018)				
	2018			
Land-based Wind	2.9 cents/kWh – 5.6 cents/kWh; $1,150/kW – $1,550/kW			
Source: 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
Source: California Energy Commission 2018 Update				
	2017	**2018**	**2019**	**2030**
Land-Based Wind	N/A	5.3 cents/kWh	6.3 cents/kWh	6.7 cents/kWh
Source: 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 WIND RECOMMENDED INITIATIVE #1

Initiative LBW.1: Advance Construction Technologies for Land-based Wind Turbines
Goal: Reduce installation costs of wind turbines in remote and rough-terrain areas. This initiative can improve financials for larger and taller turbines in California leading to new deployment in remaining wind resource areas in state.
Estimated Impact on SB-100: If wind energy maintains its current share of California's energy mix, 6,000 turbines will be installed by 2045. Savings up to $960 million are possible.
Technology Baseline: $80,000 per day for crane rental. 1-5 days to install a turbine.
Performance Indicators: Save 1-2 days for onsite assembly ($80,000-$160,000)
Success Timeframe: Near-term for crane technologies (1-3 years); Long-term for other advanced technologies (>5 years).

LAND-BASED WIND RECOMMENDED INITIATIVE #2

Initiative LBW.2: Demonstrate New Blades that Improve Conversion Efficiency

Goal: Improve the efficiency of large wind turbines to increase their total capacity and capacity factors. Demonstration of blade materials and designs will eventually lead to reductions in the LCOE for these systems.

Estimated Impact on SB-100: An increase in conversion efficiency of 35% would reduce capacity requirements for wind by 4,600 MW and increase production from turbines installed between 2030 and 2045 by 10,700 GWh or 3.3% of 2045 SB-100 Goals.

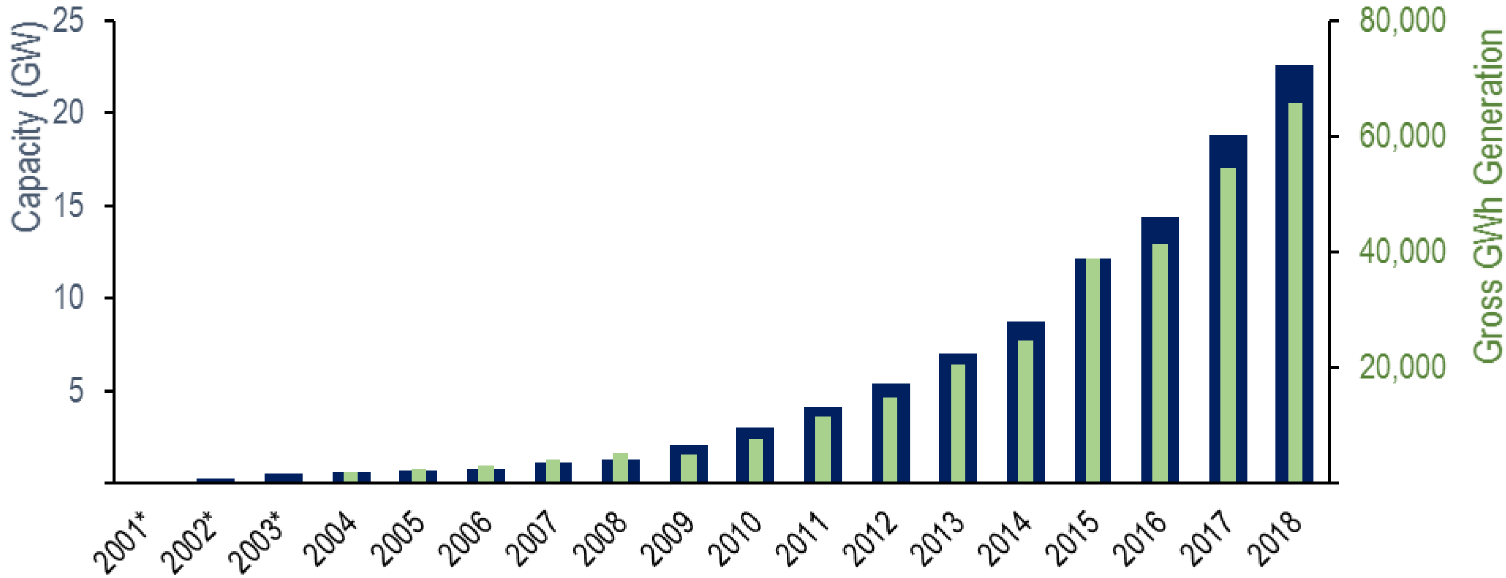
Technology Baseline: Average capacity factor in California was around 27%. Converted energy between 35-45%.

Performance Indicators: Help raise state capacity factors above 35%. Help achieve converted energy near 50%.

Success Timeframe: Mid-term for improved blade materials (3-5 years); Long-term for flexible blades (>5 years)

OFFSHORE WIND OVERVIEW

Global Offshore Wind Energy Generation from 2001 to 2018



Resource Assessment: 160 GW Technical Potential

Anticipated Capacity Factor: 40%

Potential to Reach 2045 SB-100 Goals: 561,000 GWh technically feasible; 1.8x 2045 SB-100 Goal

OFFSHORE WIND COST METRICS

Offshore Wind Cost Estimates and Projections

Source: Lazard (2018)	
	2018
Offshore Wind	6.2 cents/kWh – 12.1 cents/kWh; $2,250/kW – $3,800/kW

Source: 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 9.3 cents/kWh by 2030

Source: 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

SUPPLEMENT: WAVE ENERGY

Resource Assessment: 7.4 GW Technical Potential

Anticipated Capacity Factor: 20%

Potential to Reach 2045 SB-100 Goals: 13,000 GWh technically feasible; 4.0% of 2045 SB-100 Goal

Cost Metrics: 2014 Estimates – 36.6 cents/kWh – 69.9 cents/kWh

Projected Cost Metrics: For 2030 – 12.5 cents/kWh – 25.1 cents/kWh

OFFSHORE WIND RECOMMENDED INITIATIVE #1

Initiative OSW.1: Pilot Demonstration of Floating Offshore Platform Manufacturing
Goal: Demonstrate a manufacturing supply chain for a demonstrated floating wind turbine design. Selection of turbine design has to take into account transportation and deployment port characteristics. A necessary step in established an instate industry.
Estimated Impact on SB-100: Feasible to install 18 GW of Offshore Wind by 2045. Critical enabling step to unlock this capacity which could produce 63,000 GWh or 19% of SB-100 2045 goals.
Technology Baseline: Non-local manufacturing requires overseas transport of offshore turbines from out of state.
Performance Indicators: Vessel transportation times of less than 1 day for floating offshore installations in California.
Success Timeframe: Long-term (>5 years)

OFFSHORE WIND RECOMMENDED INITIATIVE #2

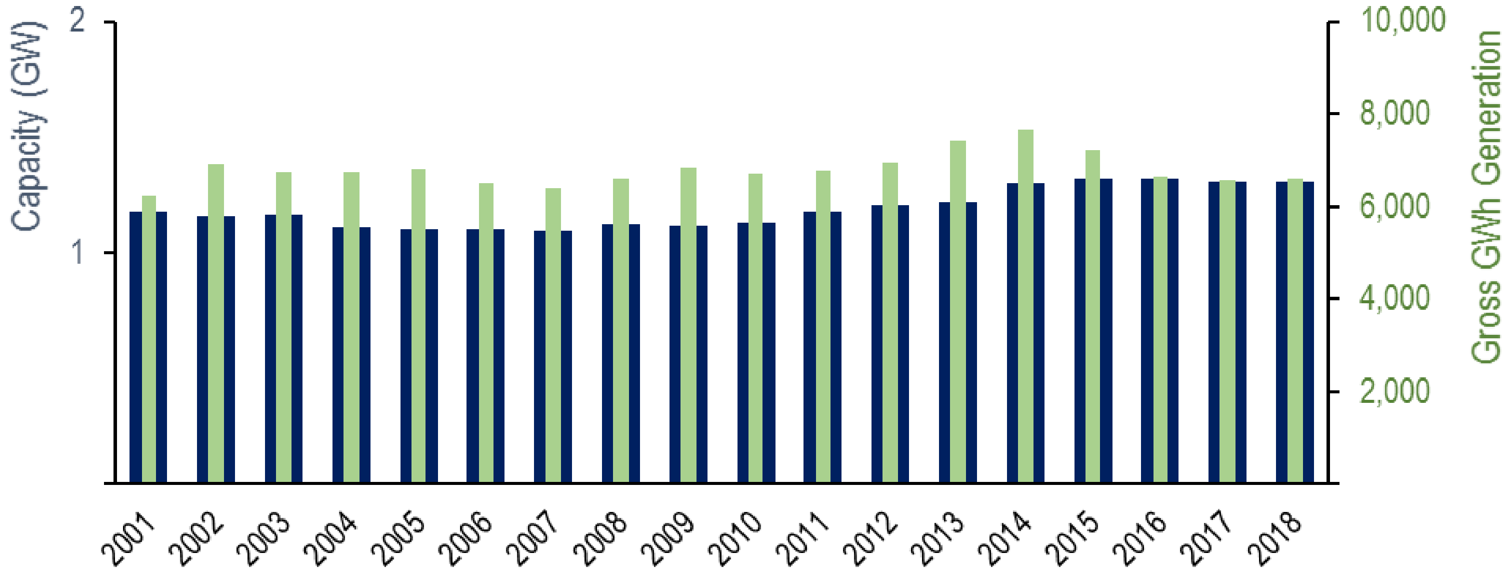
Initiative OSW.2: Design Port Infrastructure to Deploy Floating Offshore Wind Technologies
Goal:. Research port infrastructure design to allow ports to pair with manufacturing, installation, and deployment infrastructure. Without a port capable of deploying offshore wind turbines, California will be dependent on other states and countries to ship turbines
Estimated Impact on SB-100: Feasible to install 18 GW of Offshore Wind by 2045. Critical enabling step to unlock this capacity which could produce 63,000 GWh or 19% of SB-100 2045 goals.
Technology Baseline: Non-local manufacturing requires overseas transport of offshore turbines from out of state.
Performance Indicators: Vessel transportation times of less than 1 day for floating offshore installations in California.
Success Timeframe: Long-term (>5 years)

OFFSHORE WIND RECOMMENDED INITIATIVE #3

Initiative OSW.3: Integrate Wave Energy Systems with Floating Offshore Platforms
Goal: Take advantage of synergies between floating offshore wind and wave systems including offshore interconnection infrastructure and deployment and maintenance vessels to lower LCOE of both systems. Focus on this initiative is development of hybrid systems.
Estimated Impact on SB-100: Based on feasible deployment of 18 GW of offshore wind energy, an estimated 2,250 turbines would be expected. Coupled with 1 MW wave systems, these devices could provide 3,900 GWh or 1.2% of 2045 SB-100 goals.
Technology Baseline: LCOE of 30-40 cents per kWh for wave energy systems; LCOE of 17.5-30 cents/kWh for floating offshore wind turbines. Installation costs represent 41 percent of lifetime costs.
Performance Indicators: LCOE less than 20 cents/kWh for wave energy systems. Floating offshore wind LCOE around 7.5 cents/kWh.
Success Timeframe: Long-term (>5 years)

BIOENERGY OVERVIEW

Bioenergy Generation in California from 2001 to 2018



Resource Assessment: 4.65 GW Technical Potential

California 2018 Capacity Factor: 52.9%

Potential to Reach 2045 SB-100 Goals: 21,500 GWh technically feasible; 6.6% of 2045 SB-100 Goal

BIOENERGY COST METRICS

Bioenergy Cost Estimates and Projections

Source: 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
Source: California Energy Commission 2018 Update				
	2017	2018	2019	2030
Bioenergy (combustion)	N/A	15.9 cents/kwh	15.9 cents/kWh	16.6 cents/ kWh

BIOENERGY RECOMMENDED INITIATIVE #1

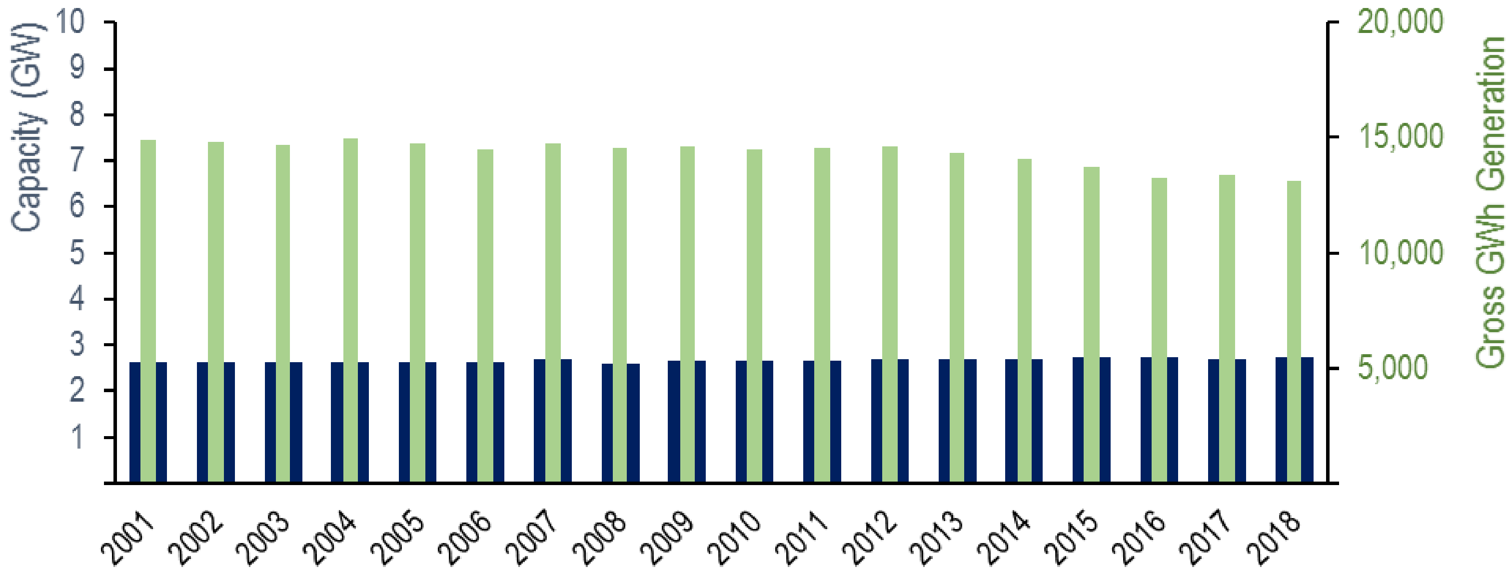
Initiative BIO.1: Improve Cleaning Methods to Produce High Quality Biomass-Derived Syngas
Goal: Improving clean-up of syngas can to enable greater use for electricity production. Reducing costs and complexity of this process can open up gasification and other conversion methods to enable electricity production for a variety of new feedstocks.
Estimated Impact on SB-100: Assuming 50% of all forestry waste can be captured, bioenergy facilities utilizing derived syngas would enable 8,800 GWh or 1.4% of 2045 SB-100 goals.
Technology Baseline: 23 cents/kWh for biomass gasification electricity production.
Performance Indicators: 6-20 cents/kWh from gasification systems utilizing syngas. 20% increase in syngas yields.
Success Timeframe: Mid-term (3-5 years)

BIOENERGY RECOMMENDED INITIATIVE #2

Initiative BIO.2: Deploy Thermal Hydrolysis Pretreatment (THP) to Increase Biogas Production
Goal: Development of THP systems that can effectively handle multiple waste streams. Pretreatment of waste streams before anaerobic digestion can increase biogas available for bioenergy production.
Estimated Impact on SB-100: Increase in biogas production at existing plants would increase production by 1,030 GWh or 0.7% of 2030 SB-100 goals.
Technology Baseline: Sludge disposal costs between $20-$50 per ton. Yields from anaerobic digestion as high as 3,200 scf of methane per ton raw food waste.
Performance Indicators: 75-80% increase in biogas production; Enhanced degradation of organic matter from 25% to 33%; Reduce sludge disposal costs by 25%
Success Timeframe: Mid-term (3-5 years)

GEOTHERMAL OVERVIEW

Geothermal Energy Generation in California from 2001 to 2018



Resource Assessment: 5.4 GW for Conventional Systems; 48.1 GW for EGS

California 2018 Capacity Factor: 48.2%

Potential to Reach 2045 SB-100 Goals: 226,000 GWh technically feasible; 69% of 2045 SB-100 Goal

GEOTHERMAL COST METRICS

Geothermal Cost Estimates and Projections

Source: IRENA (2017)				
	2017			
Traditional Geothermal Systems	4 cents/kWh – 14 cents/kWh			
Source: IEA (2011)				
	2011			
Enhanced Geothermal Systems (EGS)	10 cents/kWh – 30 cents/kWh			
Source: 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
Source: California Energy Commission 2018 Update				
	2017	**2018**	**2019**	**2030**
Geothermal System (Flash)	N/A	13 cents/kWh	13 cents/kWh	14 cents/kWh
Source: 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

GEOTHERMAL RECOMMENDED INITIATIVE #1

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

Goal: Find alternatives to titanium-alloys that are able to avoid degradation from corrosive geothermal brines. Need to further develop materials with high performance that will enable lower cost installations in high salinity areas.

Estimated Impact on SB-100: Lowering costs to enable deployments in the Salton Sea are (1.8 GW potential). Will enable an additional 7,600 GWh to reach the grid or 2.3% of 2045 SB-100 Goals.

Technology Baseline: Geothermal plants operation maintained above 90%. Maintenance costs between 1-3 cents per kWh.

Performance Indicators: Achieve operation uptime in high-salinity zones above 90%; Maintenance costs at lower cent of normal range (~1 cent per kWh).

Success Timeframe: Mid-term (3-5 years)

GEOTHERMAL RECOMMENDED INITIATIVE #2

Initiative GEO.2: Advance Techniques to Assess Potential EGS Development Sites

Goal: Identify specific subsurface formations that are ideal for EGS and discover additional areas with EGS potential. Assessment methods can be improved to determine sites with the lowest environmental impacts and lowest potential costs.

Estimated Impact on SB-100: Could lead to additional discovery of 12 GW of additional EGS capacity. If developed, this resource could provide 16% of 2045 SB-100 goals.

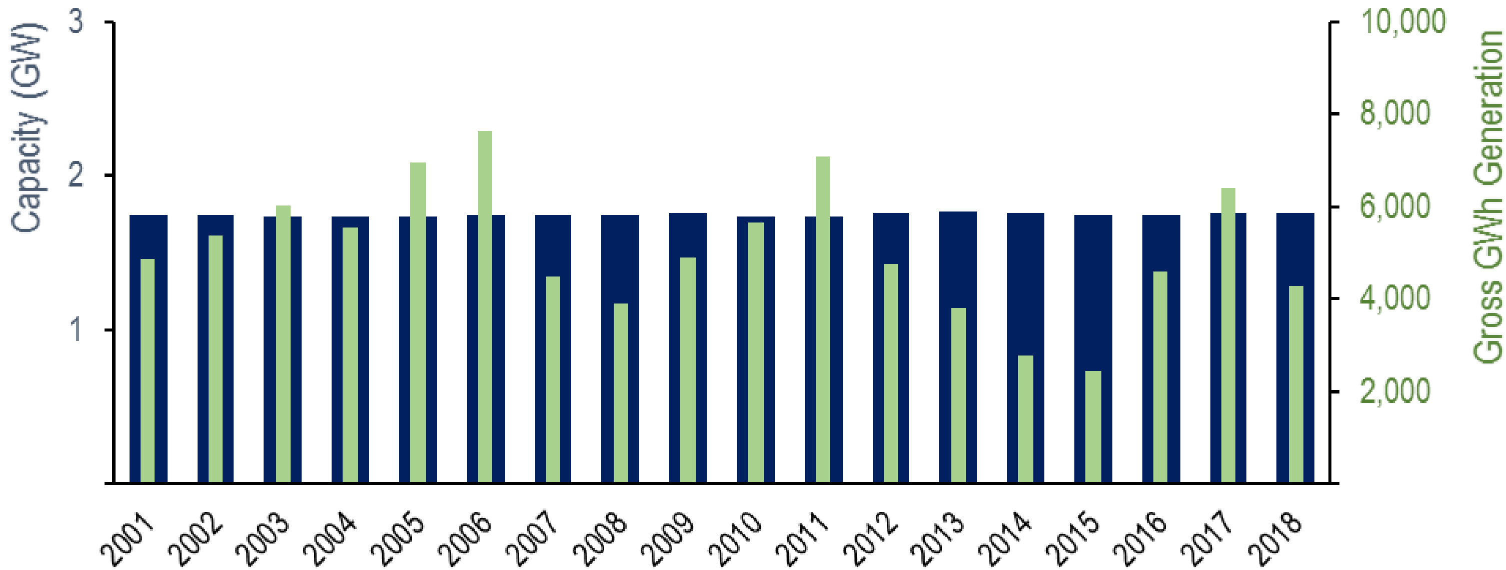
Technology Baseline: Estimated that 50% of total geothermal resource in California is discovered.

Performance Indicators: Increase estimated discovered resource to 75%.

Success Timeframe: Near-term (1-3 years)

SMALL HYDROPOWER OVERVIEW

Small Hydropower Generation in California from 2001 to 2018



Resource Assessment: 2.5 GW Technical Potential

California 2018 Capacity Factor: 27.6%

Potential to Reach 2045 SB-100 Goals: 6,000 GWh technically feasible; 1.8% of 2045 SB-100 Goal

SMALL HYDROPOWER COST METRICS

Small Hydropower Cost Estimates and Projections

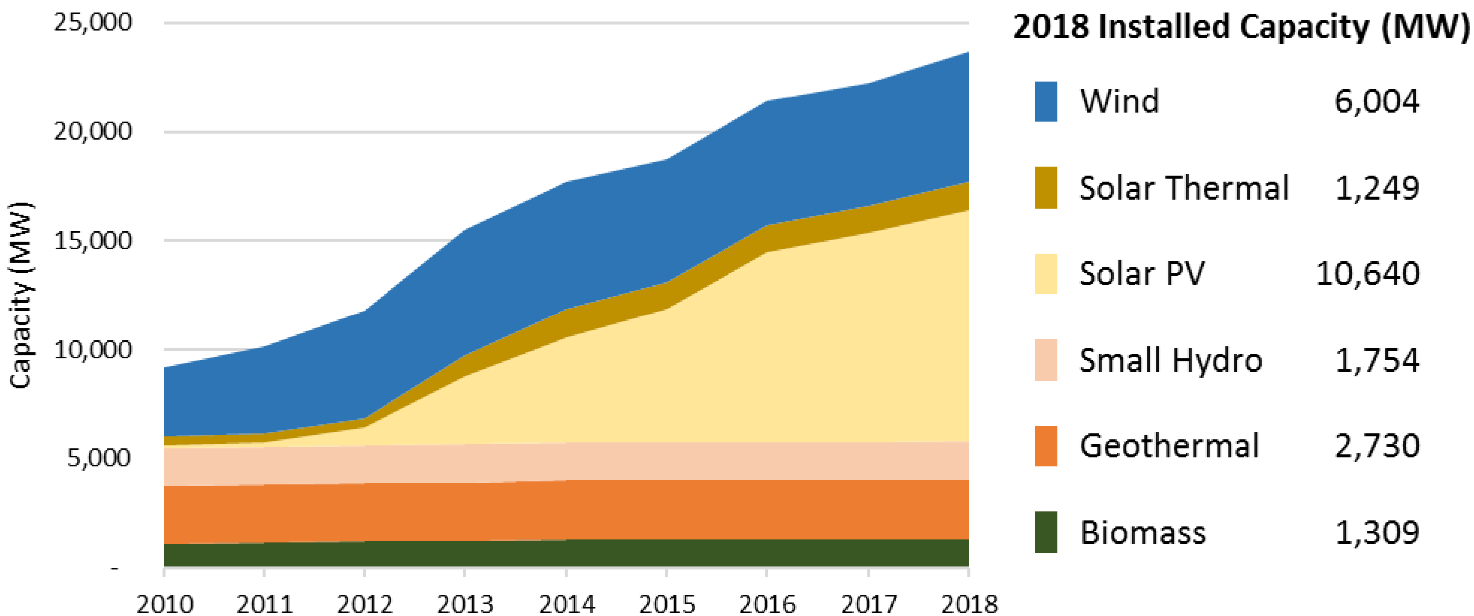
Source: IRENA (2018)				
	2018			
Small Hydropower	5 cents/kWh – 18 cents/kWh			
Source: O'Conner (2015)				
	2015			
Small Hydropower	$2,500/kW - $5,000/kW			
Source: U.S. Department of Energy 2018 Budget Request				
	FY 2017	**FY 2018**	**FY 2019**	**Endpoint Target**
Small Hydro (streams)[1]	11.5 cents/kWh (target met)	11.4 cents/kWh	11.15 cents/kWh	10.9 cents/kWh by 2020 8.9 cents/kWh by 2030
Source: 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

SMALL HYDROPOWER RECOMMENDATIONS

Roadmap Revealed 4 Possible R&D Focus Areas
Advanced assessment of velocity and head of small hydropower resources: Limited technical resource potential reduces the impact of any small hydropower improvements. A better understanding of the true hydropower resources in the state can encourage future development of small hydropower designs such as hydrokinetic systems.
Modular systems for hydropower: While demonstrated in some capacity already, modular systems can reduce installation and maintenance costs even for customized installations.
Improve interconnection: The remote location and complicated interconnection process increases costs especially for smaller systems. A standardized process with adaptable technologies can lower complexity and costs associated with small hydropower development.
Additive manufacturing for small hydropower systems: Additive manufacturing would enable developers to meet site specific needs and lower costs of unique installations. As a early-stage technology, much has to be learned about the scale-up of additive manufacturing.

GRID INTEGRATION TECHNOLOGIES OVERVIEW

Cumulative Installed Utility-Scale Renewable Energy Capacity in California from 2001 to 2018



Estimated Renewable Capacity to reach SB-100 Goals: 79 GW in 2030; 153 GW in 2045

GRID INFRASTRUCTURE COST METRICS

Grid Infrastructure Cost Estimates and Projections

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

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

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

GRID INTEGRATION TECHNOLOGIES RECOMMENDED INITIATIVE #1

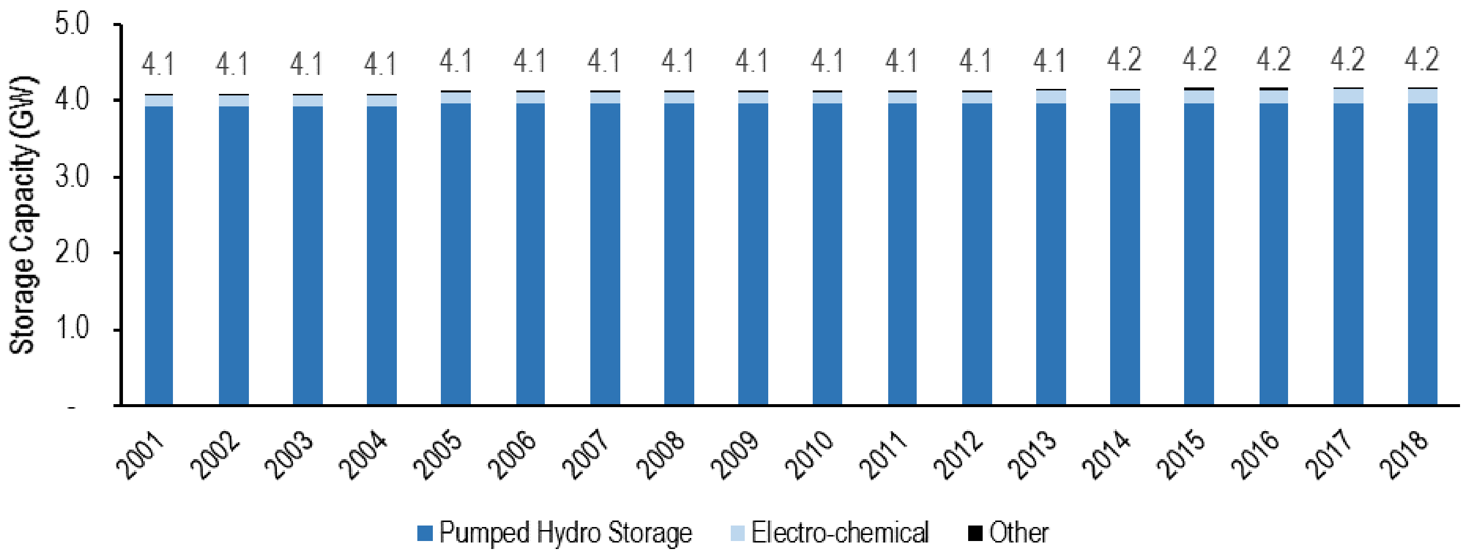
Initiative GIT.1: Deploy Smart Inverters to Improve Communication and Cybersecurity
Goal: Secure the grid from cyberattacks during deployment of additional remote renewable capacity, energy storage systems, and distributed energy resources. All of these systems will put stress on the grid and require real-time monitoring and control.
Estimated Impact on SB-100: Protection of 55,000 MW of new renewable capacity by 2030 and 129,000 MW by 2045.
Technology Baseline: 250 cyber incidents in the U.S. electricity sector between 2013 and 2015.
Performance Indicators: No successful cyber attacks in California.
Success Timeframe: Near term (1-3 years)

GRID INTEGRATION TECHNOLOGIES RECOMMENDED INITIATIVE #2

Initiative GIT.2: Advance Underwater High-Voltage Infrastructure for Offshore Energy Interconnection
Goal: Improvements to interconnection infrastructure including adapting high-voltage DC (HVDC) to California to limit line losses and lower deployment costs. The high cost of offshore interconnection adds an additional challenge for offshore wind development.
Estimated Impact on SB-100: Feasible to install 18 GW of offshore wind by 2045. If fully developed, reduction in line losses can save 4,750 GWh of electricity or 1.5% of 2045 SB-100 goals.
Technology Baseline: HVDC cable costs range from $2.5 million to $5 million per mile.
Performance Indicators: Achieve deployment costs lower than currently possible. Estimated reduction in line losses over High Voltage AC systems of 30-50%.
Success Timeframe: Long-term (>5 years)

ENERGY STORAGE OVERVIEW

Cumulative Installed Energy Storage Capacity in California from 2001 to 2018



Estimated Capacity Required to Reach SB-100 Goals: 85 GW by 2045

ENERGY STORAGE COST METRICS

Energy Storage Cost Estimates and Projections

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

ENERGY STORAGE RECOMMENDED INITIATIVE #1

Initiative ESS.1: Lengthen Storage Duration of Energy Storage Systems (8-hour or greater)
Goal: Improve energy storage systems so that their capacity can ensure reliable energy distribution from the grid during times of low variable renewable production. Increasing the duration of storage reduces the risk of blackouts when more renewable generation is online.
Estimated Impact on SB-100: Increase in storage duration from 8 to 10 hours would reduce high-end 2045 capacity requirements by 17 GW (from 85 GW).
Technology Baseline: Highly variable due to variety of energy storage technologies. Currently 8-hours is achievable with lithium-ion, flow batteries, lead-acid batteries, hydrogen, molten salt, pumped hydro, and compressed air.
Performance Indicators: Demonstrated ability provide 10-12 hours of storage at utility-scale.
Success Timeframe: Mid-term (3-5 years)

GEOTHERMAL RECOMMENDED INITIATIVE #2

Initiative ESS.2: Optimize Recycling Processes for Lithium-Ion Batteries
Goal: Improve the environmental impact of lithium-ion deployments and reduce lifetime costs for the system. Recycling of lithium batteries can also help establish new supply chains for future battery production in California.
Estimated Impact on SB-100: Improvement of environmental outcomes of 100 MW of current lithium-ion deployments and 600 MW of planned deployments. Reduce risk of financing projects.
Technology Baseline: Less than 5% of lithium-ion batteries in the United States are recycled.
Performance Indicators: Target of 90% recycling rate for lithium-ion batteries.
Success Timeframe: Mid-term (3-5 years)

AVAILABLE REFERENCES

(accessible on the Energy Commission Research Idea Exchange docket)

Now:

- Technical Assessment
- Preliminary Report
- 6/28/19 Public Webinar Slides and Recording
- Draft Report (posted 3/3/20)

Later this Week:

- 2/5/20 Public Webinar Slides and Recording

TBD:

- Final Roadmap Report

QUESTIONS?

Thank you

Please go to https://efiling.energy.ca.gov/Lists/DocketLog.aspx?docketnumber=19-ERDD-01 to download the Draft Research Roadmap

Please go to CEC electronic commenting system
https://efiling.energy.ca.gov/Ecomment/Ecomment.aspx?docketnumber=19-ERDD-01

Written comments will be received by the Energy Commission through February 14, 2020.