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ENERGETICS

STATE OF CALIFORNIA ENERGY COMMISSION

Preliminary Draft Utility-Scale Renewable Energy Generation Research Roadmap

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Preliminary Draft Utility-Scale Renewable Energy Generation Research Roadmap

Prepared for the California Energy Commission

June 2019

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Project Title: Research Roadmap for Cost and Technology Breakthroughs for Renewable Energy Generation

Commission Agreement Manager: Silvia Palma-Rojas, silvia.palma-rojas@energy.ca.gov

Prepared by:

ENERGETICS
A Subsidiary of VSE Corporation

Energetics
7075 Samuel Morse Drive
Suite 100
Columbia, MD 21046

For more information, contact
Sabine Brueske
SBrueske@energetics.com
(360) 752-2494

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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

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1 | Introduction

California's recent passage of Senate Bill 100 (SB 100) has reaffirmed the state's commitment to achieving a clean-energy-driven and carbon-free electric grid in the near future.[1] To reach the targets of 60% of electricity production from renewable sources by 2030 and 100% zero-carbon electricity by 2045, California must drastically increase its capacity of renewable energy generation and deal with a number of grid integration challenges such as variability of the state's power production portfolio.

This roadmap is broken into 9 different technology groupings that serve as the foundation for the recommended EPIC funding initiatives presented in this Preliminary Draft. Research and advancement across these sectors (shown in ***Figure 1*** below) will support California in reaching its energy and emissions goals.

Figure 1. Technology Areas Covered in the Research Roadmap

1.1 | Roadmap 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. The development of this roadmap relies on input from stakeholders and subject matter experts (SME) to:

- Identify significant barriers to achieving greater use of renewable energy and storage in California and the information needed to address these barriers.
- Assess current research efforts at both the state and federal level that are addressing these knowledge gaps.
- Identify suitable research gaps at the applied, demonstration, and deployment stages that may be addressed by the Electric Program Investment Charge (EPIC) program.
- Develop a methodology for prioritizing future research needs in the near (1 to 3 years), mid-term (3 to 5 years), and long-term (>5 years).
- Apply this methodology to the research gaps to prioritize near, mid-, and long-term research needs.
- Identify critical indicators of success for renewable energy resource technologies and strategies, as well as a methodology utilizing these indicators to estimate benefits, including benefits to IOU electric ratepayers.

[1] "SB-100 California Renewables Portfolio Standard Program: emissions of greenhouse gases," California Legislative Information, September 10, 2018, accessed December 7, 2018, leginfo.legislature.ca.gov/faces/billNavClient.xhtml?bill_id=201720180SB100.

- Develop performance and cost targets, and other metrics to be critical indicators of research success and the probability of marketing success.
- Provide comprehensive references, workshop summaries, comments and attendees to document road mapping process.

The focus of this research roadmap is focused on technologies and solutions that increase cost competiveness, flexibility, and reliability of renewable energy generation and operation.

1.2 | Goal of June 28th, 2019 Public Comment Webinar

This Public Comment Webinar will build on prior stakeholder and SME activities (interviews, surveys, and webinars) by gathering input and feedback from the public on identified research initiatives that advance renewable energy technologies and solutions. This Public Webinar will be a part of the methodology used to finalize recommended research initiatives. Feedback received during this Webinar will be evaluated for incorporation in to the Roadmap Report. Attendees will be asked to provide input during a facilitated discussion for each of the nine technology areas, with questions on selected initiatives, cost and performance targets, and gaps.

The webinar agenda is provided here for context:

10:00 am: Introduction to the Renewable Generation Roadmap Project

Silvia Palma-Rojas, Energy Commission:

Roadmap project objective and scope, and comment submission process

Sabine Brueske, Energetics Inc.:

Structure of webinar and methodology for Roadmap project, materials for reference

Universal barriers and recommendations

10:15 am: Discussion

- Current baseline and best in class
- Cost and performance targets
- Recommended initiatives
- Discussion
  - Are these research areas/initiatives the right ones for cost and technology breakthroughs for utility-scale renewable energy generation?
  - What are the cost/performance targets for each technology that should be considered for California?
  - Are there any gaps in these initiatives?

10:15–10:30 am Photovoltaic Solar

10:30–10:45 am Concentrated Solar

10:45–11:00 am Land-Based Wind

11:00–11:15 am Offshore Wind

11:15–11:30 am Bioenergy

11:30–11:45 am Geothermal

11:45–12:00 pm Small Hydropower

12:00–12:15 pm Grid Integration

12:15–12:30 pm Energy Storage

12:30 pm: Closing

Recap materials for reference and methodology for submitting written comments.

Project references can be found on the following Energy Commission website: energy.ca.gov/event/webinar/2019-06/webinar-public-comments-preliminary-draft-research-roadmap

The public is invited to review and provide comments on this Preliminary Draft document until July 12, 2019. Comments can be submitted as instructed on the electronic commenting page electronic commenting page.

1.3 | Methodology of the Roadmap Project

This Roadmap project consists of two major reports covering nine technology areas: the Technical Assessment Report (TA) and the Final Research Roadmap. The TA was completed January 19, 2019 and can be accessed at the Research Idea Exchange docket. The Research Roadmap is currently in development; comments from this Preliminary Draft will help guide the contents of the final Roadmap.

Interviews - The TA was developed based on a series of expert interviews and related research. There were 37 total interviews conducted for the TA between October 23rd, 2018 and December 18th, 2018. 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.

Surveys - The findings presented in the TA formed the basis for a series of surveys that were sent out to experts in each technology area. In the surveys, experts were asked how they would prioritize both RDD&D opportunity areas and emerging and breakthrough technologies. Additionally, experts provided opinions for prioritizing investment in RDD&D opportunity areas or specific technologies in the near-, mid-, and long-term. Surveys were distributed the week of February 11th, 2019 and collected until March 15th, 2019 during which time 62 responses were collected. The results from each survey were used to focus discussion during the next roadmapping activity, the webinars.

Webinars - 7 webinars were was hosted between the dates of March 19th, 2019 and April 11th, 2019 with 75 total webinar participants. Targeted topic area experts were invited to participate in the webinars. To guide discussion toward RDD&D advances that could most impact California's grid, experts were asked to rank 7 different barriers by their level of inhibition on achieving greater renewable energy penetration from respective technology areas. The highest ranked barriers were determined and experts then suggested and discussed R&D projects that the Energy Commission could pursue to address those barriers.

Findings from the webinar were referenced in generating a draft list of opportunity areas. The most important opportunity areas were then selected based on their ability to address highly ranked barriers and challenges. Emerging and breakthrough technologies identified through expert interviews and research, presented in the TA, and brought up in the webinars were grouped in to these opportunity areas. In total, 94 candidate opportunity areas and 133 technologies were identified during the methodology steps described here. Table 1 shows the number of participants in each stage of the methodology.

The 20 recommended initiatives outlined in this Preliminary Draft Roadmap are the result of a down-selection process. The criteria considered in selecting recommended initiatives included: level of investment in the technology by other organizations, past interest by the Energy Commission, current technology readiness, and potential impact on cost and performance metrics. There are two recommended initiatives for each of the nine Roadmap technology areas, with the exception of Offshore Wind which has 4 recommended initiatives (identified as an area with immense potential in California).

Table 1. Summary of Participation in Roadmap Project Methodology

	Solar	Wind	Bioenergy	Geothermal	Small Hydro	Grid Integration	Energy Storage	Wave Power*	Total
Interviews	6	8	6	5	4	5	3	2	39
Survey Respondents	10	8	12	10	5	11	6	0	62
Webinar Participants	13	13	8	9	8	10	14	0	75
Unique Participants Across Activities	19	21	21	17	13	22	18	2	114**

* Wave Power is not included in the Roadmap as an independent technology area. The technology was explored understanding that the TRL is very low for most wave technologies.

** Total Unique Participants sum is not equal to the sum of all topic areas since some participants were involved in multiple topic areas.

1.4 | Key Barriers and Challenges Summary

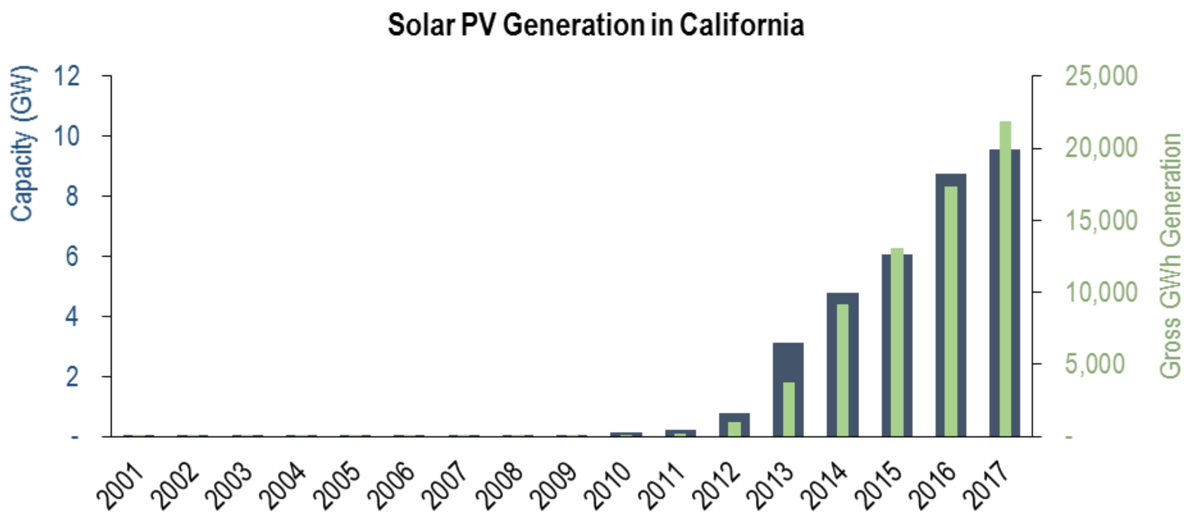
Within each technology area, the roadmap discusses key barriers and challenges to utility-scale renewable energy deployment. Seven universal challenges, identified below, were selected to broadly encompass the array of barriers and challenges facing each technology area. Inputs from the technical assessment, literature reviews, expert interviews, and consultations with the Energy Commission and the roadmap technical advisory committee were examined within the context of the following questions. The seven barriers and challenges 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?

2 | Solar PV

Solar energy is the largest source of renewable energy in the state. Beneficial policies have supported the growth of photovoltaic (PV) power systems across the state. PV has gone from being a small percentage of California's total renewable generation to being the largest source of renewable energy generation in the state. Solar generation from PV is seen in Figure 2.

Figure 2. Solar PV Energy Generation in California from 2001 to 2017



Data from energy.ca.gov/almanac/renewables_data/solar/

California contains some of highest solar irradiance levels of any state, making the state ideal for large scale solar energy development. While the southern deserts have been an area of focus, northern regions of the state are still suitable for solar development as well. The technical potential capacity of solar PV in the state is over 4,000 GW.[2]

The LCOE for large-scale PV solar systems ranges from \$0.036/kWh to \$0.046/kWh unsubsidized, assuming a 30-year plant life. Installed costs for photovoltaic systems range from \$950/kW to \$1,250/kW.[3] PV power is still poised to lead the field in new renewable development based on these estimates, as it remains one of the cheapest forms of renewable energy.

Table 2. Solar Power Cost Performance Targets (DOE)

	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
Solar + Storage	\$1.96/Wdc	n/a	\$1.65/Wdc	\$1.45/Wdc

Photovoltaics: The PV solar energy cost target is an unsubsidized cost of energy at utility scale.
Solar + Storage: The solar + energy storage cost target is an unsubsidized cost of energy at utility-scale array with 4 hours of battery storage, actual installed costs in Watts direct current (Wdc). Model assumptions based on NREL analysis: 2017 NREL PV Benchmark Report, the Annual Technology Baseline, and PV-plus-storage analysis.

Source: "Department of Energy FY 2019 Congressional Budget Request." Volume 3–Part 2: 22. DOE. March 2018. energy.gov/sites/prod/files/2018/03/f49/FY-2019-Volume-3-Part-2.pdf.

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[2] Lopez, Roberts, Heimiller, Blair, and Porro, "U.S. Renewable Energy Technical Potentials: A GIS-Based Analysis," National Renewable Energy Laboratory, July 2012, nrel.gov/docs/fy12osti/51946.pdf.

[3] "Levelized Cost of Energy and Levelized Cost of Storage 2018," Lazard, November 8, 2018, lazard.com/perspective/levelized-cost-of-energy-and-levelized-cost-of-storage-2018/

Figure 3. Comparison of Theoretical Solar Energy Conversion Efficiencies

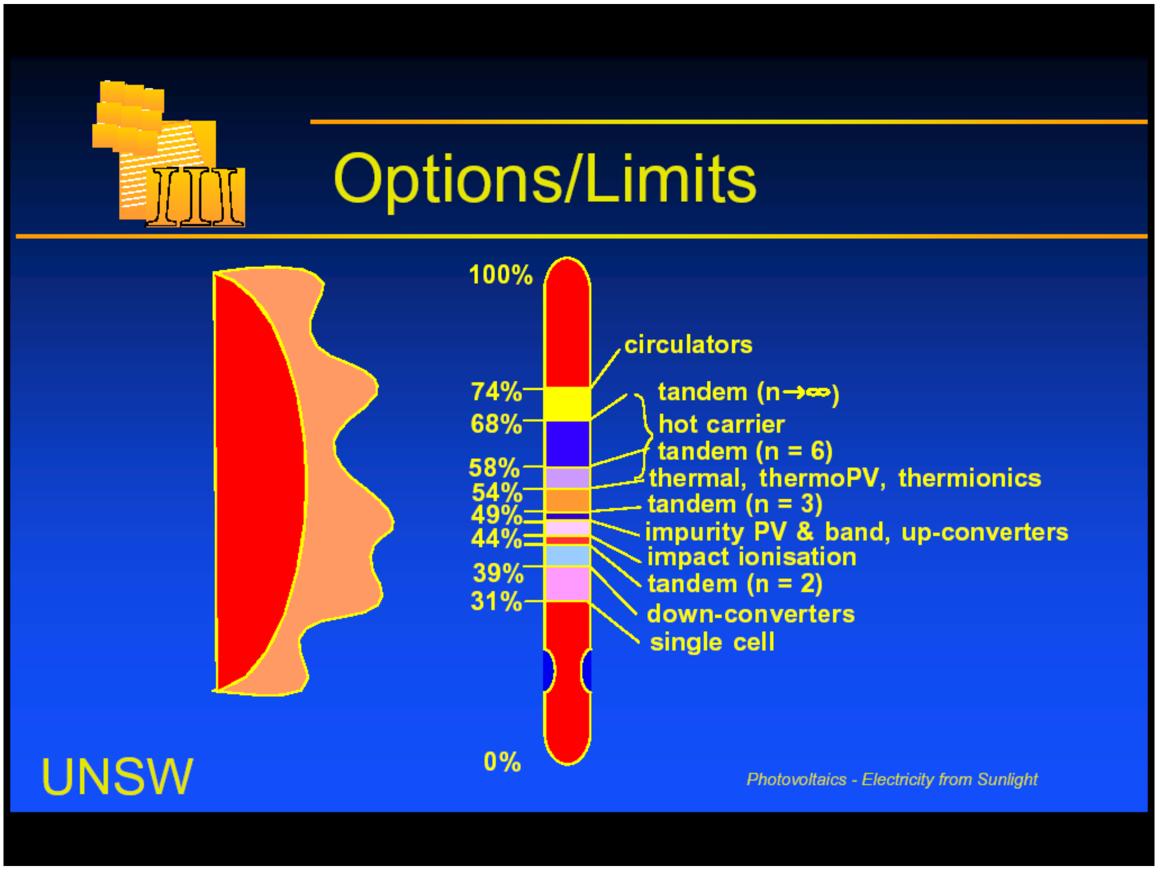


Figure 3.1 by M. Green from [*Feasibility of High-Efficiency Photovoltaics Breakthrough Research*, EPRI Palo Alto, CA, and California Energy Commission, Sacramento, CA: 2005. 1012872.]

As Figure 3 shows, there is significant room for increased conversion efficiency beyond silicon single-junction cell technology, which sits just below the maximum of 31% for the optimum material. In particular, multijunction ("tandem") technologies range upward of 50% in theory and they have achieved nearly 50% in the laboratory to date. This is part of the promise of thin-film tandem cells.

2.1 | Key Barriers and Challenges

Solar PV's rapid growth has produced some challenges to further integration of solar PV technologies. The chief characteristics of solar PV technologies that introduce these challenges are its intermittent energy production, predominantly overseas manufacturing, overproduction of energy during peak solar hours, and land requirements. The four key challenges for solar PV are given in more detail below.

Dispatchability – While it is possible to forecast how much energy solar power systems can generate throughout the day, its peak generation typically does not match system peak load. 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". The drop off of solar energy in the evening requires either additional sources to provide ramping power or significant over building of PV with substantially more midday curtailments.

Developing the capacity to generate, store, and dispatch PV solar when it is needed can make it more reliable and consistent. A lack of storage will limit the grid-value of increased solar PV installations.

Deployment of storage systems can also allow produced energy to be stored instead of curtailed when overgeneration occurs.

Grid Integration – The vast solar resource and increase in installations of grid-tied PV has led to over-generation and increased curtailment of solar power in California. Consideration should be paid to where new solar installations are built so over-generation problems are not exacerbated.

Production – The vast majority of PV modules in use and sold today are built in China where manufacturing costs are much lower. Many solar cell technologies also require rare metals, which primarily are mined overseas as well. Overseas manufacturing limits the control that U.S. power suppliers have on the type of panels produced and the manufacturing techniques used. Additionally, solar panels produced overseas are subject to tariffs that add uncertainty, complexity, and cost to solar panel importation.

Solar panels are also difficult to salvage at end-of-life and their disposal can be hazardous. The cost of decommissioning panels is part of the supply chain for solar PV and must be considered when looking at the lifecycle impact of solar PV. As the industry matures, decommissioning will become a more prevalent issue for solar PV.

Resource Availability – Many locations in California are ideal for PV solar energy development (and concentrated solar power (CSP) development) but are being limited due to local and national ordinances (The Desert Renewable Energy Conservation Plan [DRECP] for example). Counties have outright banned solar energy developments in their state, while national land use plans have limited the amount of land that can be used for renewable energy development in the southwest. Steps must be taken to work with both local and national entities to identify and develop land ideal for solar generation and ensure that these lands can be developed.

2.2 | Recommended Initiatives

Initiative 2.1: Deploy Thin Film and Tandem Material PV Cells

Description and Characteristics	Thin-film and Tandem-Junction PV technologies offer significant potential advantages over current crystalline silicon single-junction PV in terms of lower manufacturing costs, less material usage, and higher conversion efficiency. Achieving these, however, will require substantial field experience as well as manufacturing scale-up in addition to further laboratory development. This initiative would establish field testing programs to accelerate acquisition of real-world experience with novel technologies having such promise. This experience is vital for transferring laboratory advances toward commercial products.
Technology Baseline, Best in Class	Present-day commercial crystalline silicon PV modules have narrowed the gap between practical and theoretical performance such that future gains in LCOE will come only from further economies of larger-scale manufacturing and deployment. Meanwhile, thin-film technologies have shown increasing laboratory performance, but have not achieved the manufacturing scale needed to demonstrate their potential cost advantages.
Impacts	Thin-film PV devices have potentially lower costs due to better manufacturing scalability and lesser use of expensive materials than crystalline silicon devices. Tandem-junction PV technologies, which also may be thin-film, have substantially higher theoretical efficiency limits than crystalline silicon's, which translates into significantly lower energy cost potential.
Metrics and/or Performance Indicators	Metrics of success for these test deployments would include demonstration of specific failure mechanisms to aid in improved manufacturing as well as greater durability of subsequent deployments.
Associated Technology Advancements	The deployment program would encourage manufacturers to explore a greater number of material and manufacturing options and increase the likelihood of early commercial success.
Success Timeframe	Ultimate success is likely in ten years or more, but nearer term useful results would also be likely.
Primary Users and/or Beneficiaries	Primary users would be manufacturers attracted to California by this program. Beneficiaries would include all purchasers of PV technology.
Challenges Addressed	This initiative addresses mainly the challenge of successfully transferring a promising research laboratory result into a viable commercial product.
Key Published References (considered in addition to Tech Assessment Interviews, Surveys, Webinars)	*Feasibility of High-Efficiency Photovoltaics Breakthrough Research*, EPRI Palo Alto, CA, and California Energy Commission, Sacramento, CA: 2005. 1012872.

Initiative 2.2: Reduce Capital Costs of PV by Improving Cell Recycling

Description and Characteristics	Commercial PV modules have expected service lives that are much longer than essentially all of the product deployed to date. As such, end-of-life issues have not been given major emphasis. However, these aspects of the technology will inevitably arise as the larger-scale systems now in use reach retirement. This initiative is designed to get in front of potential environmental damage caused by improper salvage and recycling.
Technology Baseline, Best in Class	Commercial crystalline silicon PV modules typically contain some amounts 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.
Impacts	Successful application of the results of this initiative will substantially reduce PV decommissioning costs while safeguarding the environment from hazardous material disposal.
Metrics and/or Performance Indicators	Useful metrics for this initiative include quantitative assessments of cost reductions versus current practices in recycling PV modules and estimates of reduced impacts on landfills due to improved recovery of spent materials.
Associated Technology Advancements	Likely additional benefits include possible uses of newly developed recycling techniques for non-PV waste streams.
Success Timeframe	True success of this initiative awaits the retirement of the many gigawatts of PV recently deployed, which will take well over a decade. However, smaller-scale benefits may be achieved sooner by applying new techniques to other recycling processes.
Primary Users and/or Beneficiaries	The primary beneficiaries of this initiative will be the owners of retiring PV systems who will be faced with less disposal costs, or may even benefit from residual value of their PV modules constituent materials.
Challenges Addressed	The addressed challenge is the cost looming in the future as large quantities of today's PV modules arrive at end of life.
Key Published References (considered in addition to Tech Assessment Interviews, Surveys, Webinars)	Refer to Roadmap Report for complete list of references.

2.3 | Related EPIC and DOE Initiatives

2.3.1 | 2018-2020 EPIC Triennial Investment Plan

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.

2.3.2 | U.S. Department of Energy Research Initiatives

Advanced Systems Integration for Solar Technologies – Strengthen the integration of solar on the electricity grid, especially critical infrastructure sites, and improve grid resilience.

Solar Energy Technologies Office (SETO) Funding for 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.

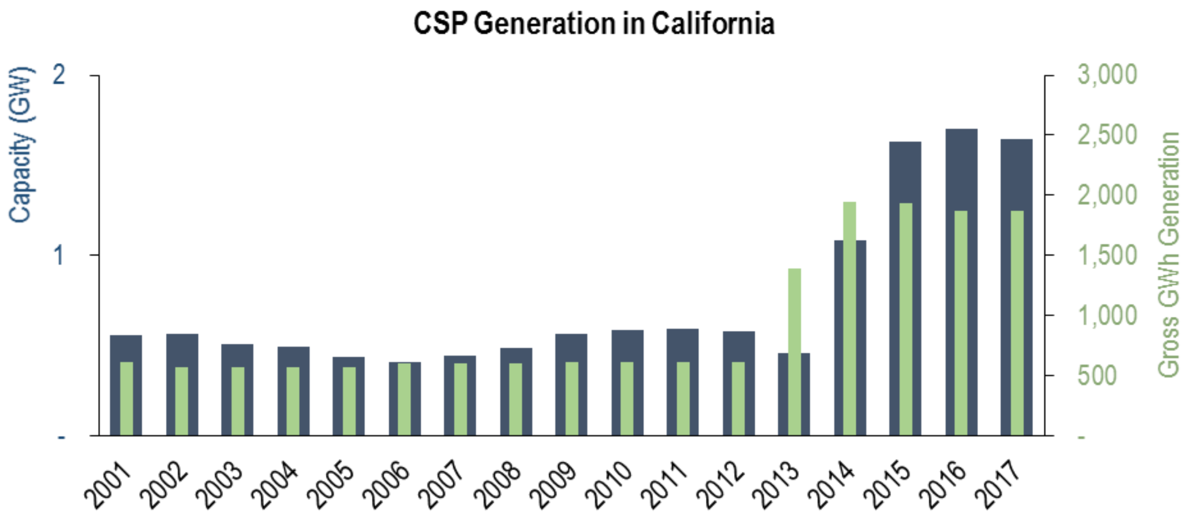
SETO funding Workforce Training – Support projects that seek to prepare the solar industry and workforce for a digitized grid. Increase the number of veterans in the solar industry.

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.

3 | Solar CSP

After capacity from CSP systems remained relatively constant for over a decade, CSP capacity has seen a recent expansion with the introduction of 3 new California facilities since 2012 (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 recent growth of CSP can be seen in Figure 4.

Figure 4. Solar – CSP Energy Generation in California from 2001 to 2017



Data from energy.ca.gov/almanac/renewables_data/solar/

The high solar irradiance levels in California that make PV so desirable also make the state ideal for large scale CSP development. California, Arizona, Nevada, and Florida are the only 4 states that currently have operational CSP deployments and look most attractive for future development. The southeastern part of California remains the 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.[4]

The LCOE for CSP systems with thermal storage, assuming a 35 year plant life, ranges from $.098/kWh to $.181/kWh while installed costs range from $3,850/kW to $10,000/kW.[5] These costs are actually below those of CSP installations that lack thermal storage because the value of production added by storage can more than offset the additional plant capital equipment.

Table 3. Solar Power Cost Performance Targets (DOE)

	FY 2017	FY 2018	FY 2019	Endpoint Target
Concentrating Solar Power	10 cents/kWh	n/a	8 cents/kWh	5 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.

Source: "Department of Energy FY 2019 Congressional Budget Request." Volume 3–Part 2: 22. DOE. March 2018. energy.gov/sites/prod/files/2018/03/f49/FY-2019-Volume-3-Part-2.pdf.

[4] Lopez, Roberts, Heimiller, Blair, and Porro, "U.S. Renewable Energy Technical Potentials: A GIS-Based Analysis," National Renewable Energy Laboratory, July 2012, nrel.gov/docs/fy12osti/51946.pdf.

[5] "Levelized Cost of Energy and Levelized Cost of Storage 2018," Lazard, November 8, 2018, lazard.com/perspective/levelized-cost-of-energy-and-levelized-cost-of-storage-2018/

3.1 | Key Barriers and Challenges

CSP technologies have been in California commercial operation for several decades but are still limited in deployment. The characteristics impeding further CSP system installations are their inherently large scale, site-specific manufacturing requirements, relatively high system cost, and lack of market valuation for their flexible and dispatchable energy. The five key challenges for CSP are given in more detail below.

Performance – CSP systems are often coupled with an energy storage medium which allows the technology to be competitive with other renewable sources. For CSP to act as a flexible, dispatchable resource, both thermal energy storage and its ramp rate of energy production need to improve in order to compete with traditional peaker plants.

Cost – CSP is one of the most expensive renewable options due to its high upfront costs and site specific design. These high costs of CSP systems are often prohibitive when selecting a solar technology to install at a specific site, as PV systems can produce similar amounts of energy with lower costs. Improved thermal storage that allows CSP systems to more flexible and dispatchable has the downside of raising costs as well.

Production – As a newer technology with few large scale deployments, CSP still faces a learning curve that limits the efficiency of its supply chain. It will take time to build the skilled labor force that is present in the manufacture and supply of other types of renewable technology. Additionally, most CSP designs are unique to the specific site which increases the time and complexity of installation.

Resource Availability – While solar irradiance is high in California, CSP installations require a large amount of space and are best suited for remote, desert locations. These areas have other concerns such as encroachment on military lands, violation of the Desert Renewable Energy Conversation Plan (DRECP), and soiling of mirrors from high concentrations of dust. The concentrated solar energy used for these plants also threatens birds and other wildlife. Environmental effects need to be understood before installation.

Resource Valuation – Solar energy from CSP systems is not valued for its ability to store and dispatch electricity quickly. CSP systems are therefore often overlooked and solar PV installations are made instead. While in some locations CSP systems are cheaper than equivalent solar PV plus storage systems, solar PV systems are still preferred because of their relative maturity and familiarity..

3.2 | Recommended Initiatives

Initiative 3.1: Improve Dust Cleaning Systems for CSP Mirrors

Description and Characteristics	CSP systems have large areas of mirrors used to concentrate sunlight onto their receivers. These mirrors need high reflectivity for good performance, but they become soiled with wind-blown sand and dust. Mirror soiling can reduce plant energy production substantially (>50% loss) so frequent cleaning is necessary. Current cleaning methods are time consuming, expensive, prone to causing mirror breakage, and they can be water intensive.
Technology Baseline, Best in Class	Today's CSP systems use combinations of mechanized and manual cleaning techniques and even the best systems have difficulty maintaining peak mirror performance.
Impacts	Better mirror reflectivity maintenance would raise plant production by at least 10% to 15% over current practice and improved mechanized cleaning would also lower costs.
Metrics and/or Performance Indicators	Average mirror reflectivity and cost per unit area cleaned would provide comprehensive metrics.
Associated Technology Advancements	Improved electronic control systems used for better mechanization could have broad applications; e.g., for reduced-cost building window cleaning.
Success Timeframe	Near term. This Initiative could produce highly useful results in a few years.
Primary Users and/or Beneficiaries	CSP plant owners would be the primary users, but system-wide benefits would also accrue to the electric grid from greater CSP production reliability.
Challenges Addressed	The challenge is to cost-effectively maximize CSP power production.
Key Published References (considered in addition to Tech Assessment Interviews, Surveys, Webinars)	Refer to Roadmap Report for complete list of references.

Initiative 3.2: Research Corrosion Resistant Materials Able to Handle High Temperature Salts used for TES

Description and Characteristics	Achieving the DOE CSP endpoint cost target of 5 cents/kWh will require an increase in system efficiency. This is envisioned to involve power-block cycle conversion efficiencies of over 50% and getting those will require the high-temperature side of the cycle to exceed 700°C (1300°F). Such temperatures are higher than current system plumbing components and heat-transfer and heat-storage materials can handle.
Technology Baseline, Best in Class	Today's CSP system power cycles have high-temperature reservoirs at up to about 565°C (1050°F). This temperature is limited by both fluid stability and plumbing durability.
Impacts	Raising the upper temperature in the power cycle from 565°C to 700°C would increase its efficiency from about 30% to 50% with LCOE reduction in nearly inverse proportion.
Metrics and/or Performance Indicators	Useful metrics will be material strength and corrosion rate versus temperature as these will determine the amounts needed for salt containment and, therefore, the cost of the containers.
Associated Technology Advancements	Other thermal power systems would benefit from development of high-temperature lower-cost materials to increase their efficiency and lower costs.
Success Timeframe	Medium term.
Primary Users and/or Beneficiaries	CSP system developers would be the primary users and electricity ratepayers would benefit from lower costs.
Challenges Addressed	The key challenge addressed is in finding low-cost materials that have sufficient high-temperature strength and corrosion resistance to contain molten salt at 700°C and permit CSP power cycles with over 50% efficiency.
Key Published References (considered in addition to Tech Assessment Interviews, Surveys, Webinars)	Refer to Roadmap Report for complete list of references.

3.3 | Related EPIC and DOE Initiatives

3.3.1 | 2018-2020 EPIC Triennial Investment Plan

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.

3.3.2 | U.S. Department of Energy Research Initiatives

Advanced Systems Integration for Solar Technologies – Strengthen the integration of solar on the electricity grid, especially critical infrastructure sites, and improve grid resilience.

Solar Energy Technologies Office (SETO) Funding for Concentrating Solar-Thermal Power – Advance components found in CSP sub-systems including collectors, power cycles, and thermal transport systems.

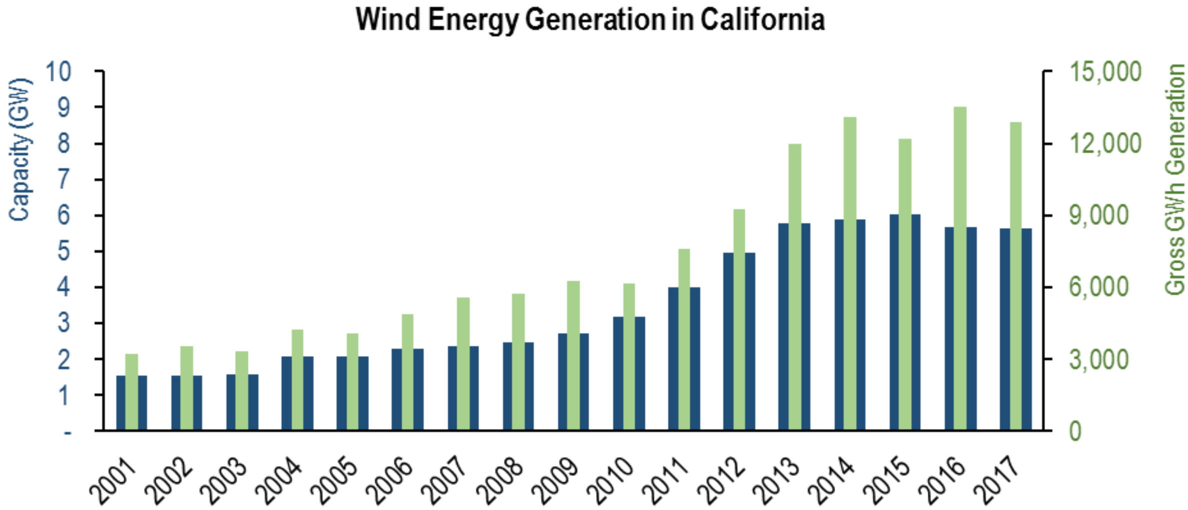
SETO Funding for Workforce Training – Support projects that seek to prepare the solar industry and workforce for a digitized grid. Increase the number of veterans in the solar industry.

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.

4 | Land-Based Wind

Wind energy is one of the most established renewable energy sources in the state, as turbines have been utilized in California for over three decades. Like solar, wind has benefited from policies that have supported its continued development in the state. Since California's RPS law was adopted in 2002, California's wind energy generation has more than tripled. This energy growth is shown in Figure 5.

Figure 5. Wind Energy Generation in California from 2001 to 2017



Data from energy.ca.gov/almanac/renewables_data/wind/

California's existing wind fleet is currently focused in six designated wind resource areas (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.[6] Another opportunity exists at higher hub heights that can be accessed with the taller towers and larger blades of advanced wind technologies. NREL estimates that at a 140 m hub height, California's wind energy potential can be increased by almost 25,000 square miles to unlock an additional capacity of 128 GW.[7]

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 levelized cost of electricity (LCOE) for land based wind from $0.029/kWh to $0.056/kWh unsubsidized, assuming a 20-year system life. Installed costs for onshore wind systems range from $1,150/kW to $1,550/kW.

Table 4. Wind Power Cost Performance Targets

	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

[6] N. Rader, "Repowering 1980s-Vintage Turbines: Benefits & Barriers," presentation at California Energy Commission, Sacramento, January 28, 2016.
[7] Wind Exchange, accessed December 2018, windexchange.energy.gov/maps-data/14.

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 (WACC) of 5.6%; national capacity weighted average installed CapEx and OpEx values; 7.25 m/s wind speed @50 m hub height; and 25-year plant life.

Source: Department of Energy FY 2019 Congressional Budget Request. Volume 3–Part 2: 23. DOE. March 2018. energy.gov/sites/prod/files/2018/03/f49/FY-2019-Volume-3-Part-2.pdf.

4.1 | Key Barriers and Challenges

Production – The lack of local production of wind turbine components in California limits the state's ability to ramp production and lower manufacturing costs. This lack of instate manufacturing capabilities increases transportation and capital costs of wind turbines systems.

Resource Availability –Permitting and land use restrictions are limiting further development as well. Multiple municipalities have banned the development of wind turbine projects out of concern for both for the environment and community and scenic aesthetic. Environmental and social issues focus on bird and bat fatalities and sound and sight concerns. National plans such as the desert renewable energy conservation plan (DRECP) have limited potential locations for wind resource development as well.

Dispatchability – Since California's wind generation is not from state-of-the-art turbines, it is produced at lower capacity factors which means less reliable power. Older turbines also do not have the same ability to provide ancillary services such as fast frequency response. The lack of dispatchability means lower production from wind energy has to be anticipated and offset with non-variable capacity on the grid.

Grid Integration – Ideal wind resources in California can still be limited by the cost of grid integration, especially if the development site is far from existing transmission lines. New potential sites for wind development currently lack grid infrastructure which raises the cost and complexity of installation.

4.2 | Recommended Initiatives

Initiative 4.1: Onsite Assembly Improvement by Advancing Crane Technologies

Description and Characteristics	As California's WRAs are filled with wind turbines, new installations will have to occupy more treacherous terrain at remote locations. In addition, new wind turbines are typically much larger with wider, longer, and heavier components that in some cases are not possible to deploy due to the logistics of transportation to wind sites. Onsite assembly and manufacturing allows wind components to be broken up and transported in more manageable pieces. However, the ultimate assembly of wind components requires on-site cranes that also must journey to the job location and be capable of lifting and installing the large components. To reach the heights required for component installation on large turbines, cranes with a larger weight capacity that can attach to the turbine towers may be required. Other crane designs that are able to reach turbine locations and fit in small installation areas would also would serve the need for onsite manufacturing.
Associated Technology Advancements	Rough-Terrain Cranes; Turbine Tower Attached Cranes
Technology Baseline, Best in Class	$80,000 a day for Crane rental. Days to install depends heavily on location, number of pieces to lift, and size of turbine.
Impacts	Proper crane selection and use can lower the time it takes to assemble wind turbines which will lower the cost of installation. Additionally, advanced cranes can enable assembly in areas where traditional wind installation is not possible by removing barriers to transportation and onsite manufacturing. This can unlock wind resources that are not currently accessible in California.
Metrics and/or Performance Indicators	Installation Time: Saves 1.5 to 2 Days ($120,000 to $160,000 on installation); Square Feet of Land Accessible for Wind Development; Weight Supported by Cranes; Blade and Tower Size that can be Installed
Success Timeframe	Near-Term
Primary Users and/or Beneficiaries	Wind Manufacturers, Wind Installers
Challenges Addressed	Land-based Component and Machinery Transportation, Onsite Assembly
Key Published References (considered in addition to Tech Assessment Interviews, Surveys, and Webinars)	https://www.mammoet.com/news/optimized-wind-farm-installation-delivers-two-week-time-saving/ https://www.forconstructionpros.com/rental/lifting-equipment/crane/article/21021834/terex-rough-terrain-crane-excels-at-behindthescenes-wind-turbine-construction

	https://www.mammoet.com/news/mammoet-heralds-new-era-for-windturbine-assembly-and-maintenance/

Initiative 4.2: Deployment of Flexible Blades to Improve System Efficiency and Enable Access to Low-Wind Speed Areas

Description and Characteristics	On-land wind development in California is unlike any other state because of the age of the industry in the state. As a result of decades of operation, most high wind, attractive wind development areas are already taken by less efficient machines that have lower capacity factors and operate more variably than modern wind turbines. For land-based wind development in California to continue to grow, low wind speed areas will have to be used and ideally will generate electricity with less variability than current wind installations in the state. Flexible blades are one early stage technology that can decrease the variability of output from low-wind regions while increasing overall power output. When combined with longer blades and larger rotors, these flexible blade systems have the ability to increase economical production from wind in California. Flexible blades are also able to handle variations in high wind speeds due to their ability to bend and twist passively to adapt to wind forces. The first testing of passively adapting blades in underway in Colorado by a Germany company. There is room for R&D from U.S. counterparts as well as these designs are developed further.
Associated Technology Advancements	Bend-twist Coupling
Technology Baseline, Best in Class	35% increase in converted energy compared to rigid counterparts. Increase in Capacity Factor due to decreased downtime. Capacity factor baseline and best in class: TBD
Impacts	Flexible and adaptable blades are able to operate in a wider range of wind conditions and dampen peak loads during times with high variable wind speeds. The use of these blades will also increase the lifespan on blades and reduce maintenance costs. Since flexible blades increase power production, they may also enable smaller capacity turbines to be more economical.
Metrics and/or Performance Indicators	Converted Energy: 35% increase; Capacity Factor; $/MWh; Lowest Wind Speed to Operate
Success Timeframe	Near-term
Primary Users and/or Beneficiaries	Wind Turbine Components Manufacturers, Utilities, Grid Operators
Challenges Addressed	Low-Wind Speed Resources; Variable High-Speed Winds;
Key Published References (considered in addition to Tech Assessment Interviews, Surveys, Webinars)	https://royalsocietypublishing.org/doi/10.1098/rspa.2016.0726 https://techxplore.com/news/2017-02-turbines-flexible-blades-efficient.html https://www.iwes.fraunhofer.de/en/press---media/smartblades2-rotor-blades.html https://www.windpowermonthly.com/article/1520855/bend-twist-coupling-tests-begin

4.3 | Related EPIC and DOE Initiatives

4.3.1 | 2018-2020 EPIC Triennial Investment Plan

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.

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.

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).

4.3.2 | U.S. Department of Energy Research Initiatives

Atmosphere to Electrons (A2e) Initiative – Investigate systems-level interactions influenced by atmospheric conditions, variable terrain, and machine-to-machine wake interactions.

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.

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.

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.

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.

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.

Wind Energy Technology Office (WETO) Funding for Wind Energy Research – Broad funding opportunity aimed at advancing R&D in land-based, offshore, and distributed wind sectors.

5 | Offshore Wind

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 of California has many ideal wind resources. It is projected the technical capacity of wind resources off of the coast of California is 160 GW.[8] This potential can be unlocked if the right stakeholders are involved from the outset. These include state and federal agencies, port managers, wind developers, grid operators, and the military.

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 lack of a port infrastructure capable of dealing 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, the lack of global manufacturing and deployment infrastructure for offshore turbines presents a unique opportunity for California to become a leader in this field.

For offshore wind, assuming a 20 year system life, current LCOE ranges from $.062/kWh to $.121/kWh while installed costs range from $2,250/kW to $3,800/kW.[9] This puts offshore wind among one of the most expensive forms of renewable energy, which is due partially due to the low number of deployments globally. However, offshore wind is a valuable resource due to higher wind speeds, leading to higher capacity factors.

Table 5. Wind Power Cost Performance Targets (DOE)

	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: Department of Energy FY 2019 Congressional Budget Request. Volume 3–Part 2: 23. DOE. March 2018. energy.gov/sites/prod/files/2018/03/f49/FY-2019-Volume-3-Part-2.pdf

[8] Walt Musial, "Offshore Wind Energy Briefing," National Renewable Energy Laboratory, presentation at California Energy Commission Integrated Energy Policy Workshop Offshore Renewable Energy, May 25, 2016.

[9] "Levelized Cost of Energy and Levelized Cost of Storage 2018," Lazard, November 8, 2018, lazard.com/perspective/levelized-cost-of-energy-and-levelized-cost-of-storage-2018/

5.1 | Key Barriers and Challenges

Cost – Offshore wind is one of the most expensive forms of renewable energy due to the high capital costs of transport and installation and the lack of offshore systems in development. Floating turbines, which will be necessary in California, are especially costly due to a lack of current development and understanding of platform design. The operational and maintenance costs of these systems are also high due to their location.

Production – California does not have the infrastructure to manufacture turbines in state. Due to the size of necessary components for offshore wind turbines, it is logistically difficult to transport offshore systems from distant manufacturing locations to be deployed in California.

Port infrastructure in California is also unable to handle offshore deployment. Ports need to be upgraded to handle the towers and turbine blades necessary for offshore wind deployment. A proper vessel to transport and install offshore systems will also be required on the west coast of the United States.

Resource Availability – As with land based turbines, the environmental impact of offshore turbines must be thoroughly studied. For offshore turbines, these studies must include avian impacts as well as impacts on fish and other forms of aquatic life that could be harmed by wind system deployment.

Various different groups and entities will challenge the development of offshore wind systems when they are ready for demonstration as well. Along with marine life impacts, aesthetic impacts could pose limits on development locations. Cooperation with the military on developments will also be necessary to ensure that wind turbines to not interfere with their operations and goals in the region. Radar specifically is impacted by offshore deployments.

Grid Integration – The development of underwater cables will be necessary to integrate offshore wind into California's grid. Interconnection and centralization of offshore wind cables requires deployment of new technologies and systems such as high-voltage DC interconnection cables. Also, location of and integration into onshore grid infrastructure is an important factor to consider when siting offshore wind resources.

Performance – While offshore wind systems promise to deliver a large amount of capacity per turbine (some over 10 MW) with large potential capacity factors (>50%), the long-term performance of offshore wind turbines is not well understood due to lack of current installations. Maintenance and down-time due to extreme weather events may decrease lifetime system performance.

5.2 | Recommended Initiatives

Initiative 5.1: Cost Reduction of Offshore Floating Systems with a Focus on Platform and Anchoring Systems

Description and Characteristics	Floating offshore wind turbines place a horizontal 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 50 meters due to the engineering complexity and cost associated with fixed bottom structures at those depths. California's coastline is best suited for these types of installations due to the water depth at high wind speed locations. Any development of offshore wind resource in California above a small scale will require the development of floating platforms. There is currently only a single offshore demonstration project in operation globally (Hywind in Scotland) with another funded (WindFloat in Portugal). The early-stage development of offshore wind technology means that the understanding of platform and anchoring design remains limited especially when considering factors such as water-depth and environmental concerns.
Associated Technology Advancements	Spar-Buoy Platform; Semi-Submersible Platform; Tension Leg Platform; Barge Platform; Multi-Turbine Platform; Hybrid Wind-Wave Platforms
Technology Baseline, Best in Class	TBD
Impacts	Early demonstrations of floating wind platforms will contribute much needed data on performance, cost, and timeframes to the global offshore wind industry. While local production is not necessary for this initiative, the installation of several offshore wind turbines will lead to California becoming one of the only states familiar with installation of offshore wind turbines giving the state rare institutional knowledge.
Metrics and/or Performance Indicators	$/MW Installation; LCOE; Capital Expenditures (CAPEX)
Success Timeframe	Long-Term (>5 Years)
Primary Users and/or Beneficiaries	Offshore Wind Turbine Manufacturers; Ports and Vessel Operators; Global Wind Industry
Challenges Addressed	Instate Offshore Wind Access
Key Published References (considered in addition to Tech Assessment Interviews, Surveys, Webinars)	https://www.greentechmedia.com/articles/read/floating-offshore-wind-commercialize-europe#gs.lll7ih https://www.irena.org/-/media/Files/IRENA/Agency/Publication/2016/bIRENA_Offshore_Wind_Floating_Foundations_2016.pdf https://www.carbontrust.com/media/670664/floating-offshore-wind-market-technology-review.pdf

Initiative 5.2: Establishment of Local Manufacturing Capabilities for Offshore Tower Components

Description and Characteristics	Offshore wind turbines are able to utilize much larger turbines and tower structures as they are not limited by any on-land transportation or construction constraints. The larger blades and towers also allow offshore wind turbines to reach higher wind resources to produce more energy. However, California, currently lacks significant manufacturing capabilities throughout the wind turbine supply chain. With limited manufacturing facilities in the state and on the west coast as a whole, California will suffer from higher transportation costs and complex logistics associated with new land-based and offshore wind turbine installations. With the offshore wind industry still in a fledgling state, and floating offshore wind turbines at an even earlier stage of development, California has an opportunity to become one of the first global manufacturing centers for offshore wind infrastructure. Focusing on the manufacturing of offshore specific technologies like floating platforms, tower structures, and radar and wildlife detection systems will allow California to become a global leader in offshore development.
Associated Technology Advancements	TBD
Technology Baseline, Best in Class	TBD
Impacts	Developing an offshore wind manufacturing industry in California will decrease the costs of transportation of wind turbine components and create jobs within the state. California is also positioned to become a leader across the Pacific Ocean as no floating structures and limited offshore deployment exists from the U.S. to Asia.
Metrics and/or Performance Indicators	$/MW Installed Cost of Offshore Turbines; Average Transportation Distance from Facility to Port
Success Timeframe	Long-term (>5 Years)
Primary Users and/or Beneficiaries	Offshore Wind Energy Developers (Utilities, Private Companies), Turbine Manufacturers, Blade Manufacturers,
Challenges Addressed	Cost, Production
Key Published References (considered in addition to Tech Assessment Interviews, Surveys, Webinars)	DOE-NREL 2016 Offshore Wind Technologies Market Report Refer to Roadmap Report for full list of References

Initiative 5.3: Ensuring that Port Infrastructure can Handle Large Wind Turbine Components

Description and Characteristics	Due to the large size of offshore wind turbines, large cranes and ample space are required at ports to pre-assemble and load turbine components onto installation vessels. Currently, no port in California has the ability to load offshore turbine components and few ports are able to accommodate the necessary equipment. 6 ports possible for improvements: Humboldt Bay, San Francisco Bay, Hueneme, Long Beach, and San Diego. Locating and retrofitting a port so it is able to load an offshore wind turbine will be necessary to install any offshore wind turbines in California. Improvements to these ports could include road/rail connections, higher capacity cranes, quayside space increases, and vessel availability. Other improvements will be necessary based on the specific transportation and assembly requirements of the port.
Associated Technology Advancements	Fabrication & Construction Ports; Quick Reaction Ports; Assembly Ports
Technology Baseline, Best in Class	TBD
Impacts	This would enable entry of large components into the California market.
Metrics and/or Performance Indicators	Average Distance from Launching Port to California Installation Sites, Days saved with in-state Port Infrastructure, $/MW Installed Cost
Success Timeframe	Long-Term (>5 Years)
Primary Users and/or Beneficiaries	Port Operators, Offshore Wind Energy Developers (Utilities, Private Companies)
Key Published References (considered in addition to Tech Assessment Interviews, Surveys, Webinars)	https://www.boem.gov/CORE-Phillips/

Initiative 5.4: Improve Offshore Energy Interconnection through Development of Offshore High-Voltage Cables

Description and Characteristics	To connect offshore resources to the onshore grid, an extensive cabling and interconnection systems is required. Underwater cabling represents a very high cost for offshore systems, so optimal design and management of cables, interconnections, and substations is important to limit costs. Also, the type, structure, and location of cables should minimize electrical losses for the system. Currently, high-voltage alternating current (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, High-voltage direct current (HVDC) transmission lines have been implemented.
Technology Baseline, Best in Class	High-voltage AC Cables
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.
Metrics and/or Performance Indicators	Lines Losses (%); Cost/Mile; Substation Cost
Associated Technology Advancements	HVDC Cables;
Success Timeframe	Long-term (5+ Years)
Primary Users and/or Beneficiaries	Grid Operators; Offshore Wind Developers/Owners; Utilities; California ISO operators
Key Published References (considered in addition to Tech Assessment Interviews, Surveys, Webinars)	https://www.boem.gov/NREL-Offshore-Wind-Plant-Electrical-Systems/

5.3 | Related EPIC and DOE Initiatives

Initiatives are repeated from the Land-Based Wind Chapter because they are relevant to both topics.

5.3.1 | 2018-2020 EPIC Triennial Investment Plan

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.

5.3.2 | U.S. Department of Energy Research Initiatives

National Offshore Wind R&D 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.

National Offshore Wind Strategy – Combined approach from the DOE and U.S. Department of the Interior (DOI) seeking to facilitate the development of the offshore wind industry in the United States. Explores a number of actions for the DOE and DOI in regulation, R&D, and other fields.

Atmosphere to Electrons (A2e) Initiative – Investigate systems-level interactions influenced by atmospheric conditions, variable terrain, and machine-to-machine wake interactions.

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.

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.

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.

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.

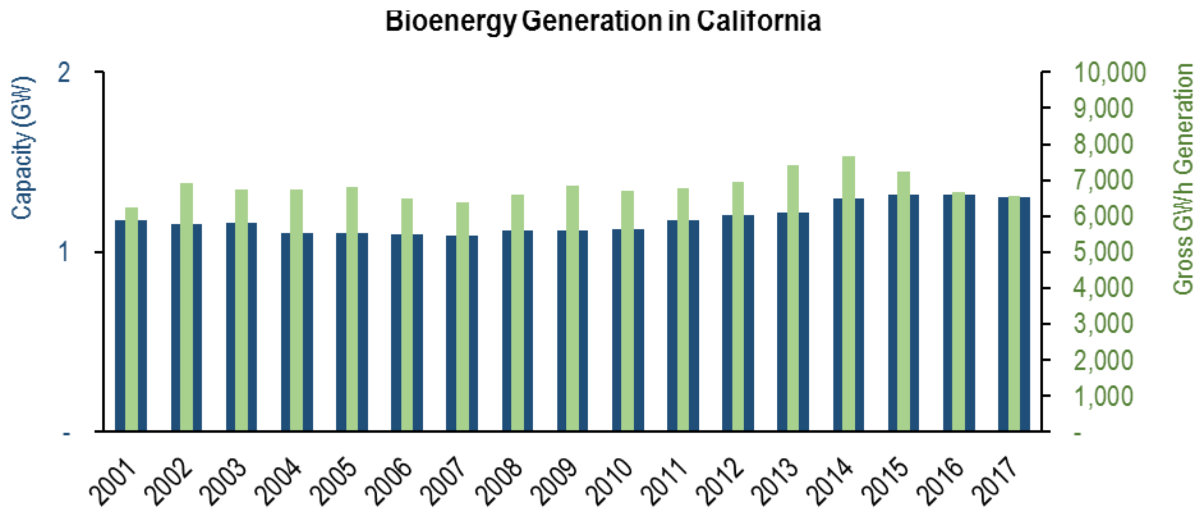
Beyond Batteries Initiative – Conduct laboratory-based R&D on adaptable, wind-based, energy storage alternatives. Focus on advances in controllable loads, hybrid systems incorporating generation from all sources, and new approaches to energy storage.

Wind Energy Technology Office (WETO) Funding for Wind Energy Research – Broad funding opportunity aimed at advancing R&D in land-based, offshore, and distributed wind sectors.

6 | Bioenergy

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 both 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 woody biomass plants 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. Electricity production from bioenergy in California can be seen in Figure 6.

Figure 6. Bioenergy Generation in California from 2001 to 2017



Data from energy.ca.gov/almanac/renewables_data/biomass/

There are a variety of bioenergy technologies that fall into two major pathways for production: direct combustion of biomass and combustion of biogas. Biogas is generated from digesters and landfills among other sources. Gas can also be produced through pathways such as anaerobic digestion, gasification, and pyrolysis. Biogas and other gaseous products 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 given below.

Table 6. Cost Range and Estimated Range for Common Bioenergy Conversion Systems

	2014 (Low Range)	2014 (High Range)	2025 (Low Estimate)	2025 (High Estimate)
Stoker	6 cents/kWh	21 cents/kWh	5 cents/kWh	19 cents/kWh
Gasification	7 cents/kWh	23 cents/kWh	6 cents/kWh	20 cents/kWh
Anaerobic Digestion	6 cents/kWh	14 cents/kWh	5 cents/kWh	12 cents/kWh
Co-Firing	4 cents/kWh	12 cents/kWh	4 cents/kWh	11 cents/kWh

Source: "Renewable Power Generation Costs in 2014." IRENA. January 2015. irena.org/DocumentDownloads/Publications/IRENA_RE_Power_Costs_2014_report.pdf.

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 TWh or enough to support 4,650 MW of capacity.[10]

[10] An Assessment of Biomass Resources in California, California Biomass Collaborative, March 2015, CEC (CEC-500-11-020).

6.1 | Key Barriers and Challenges

Resource Availability – When looking at waste-to-energy (WTE) pathways, waste must be available in large enough quantities and from consistent enough sources to be able to be counted on for grid-scale electricity production. Additionally, a breakdown in recycling programs is limiting the availability of resources.

The source and security of all biomass feedstock delivery is important to ensure consistent production from bioenergy sources. Ensuring this stability is especially critical for new sources of bioenergy. Load serving entities are reluctant to embrace new source of bioenergy due to inconsistent feedstock supply.

Resource Valuation – The societal and environmental benefits of using excess wood for bioenergy are not captured in the market today. Chief among these benefits in California is the potential to mitigate forest fires by removing excess wood from forest floors and other high risk areas. Additionally, the GHG reduction pathways for bioenergy are not currently well understood which makes carbon accounting difficult.

Cost – While forest fire prevention is a major benefit of woody biomass conversion, the cost of collecting and delivering distributed wood resources remains prohibitively expensive. In addition, 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 lack of consistent power purchase agreements with utilities is another major barrier for bioenergy systems. The costs of feedstocks are also highly variable and dependent on the amount of waste created and used throughout the entire bioenergy systems. While bioenergy producers may currently receive a tipping fee for even taking a waste stream that can be converted to energy, as more producers enter the market and convert waste, the value of that waste increases which decreases revenue from tipping fees.

Grid Integration – Interconnection costs tied to plant siting must be considered for bioenergy facilities as well. This has to be balanced with a location that limits the costs associated with feedstock delivery and co-product dispatch. Typically, these types of costs make small-scale bioenergy systems unideal in the market place.

Dispatchability – Bioenergy plants typically run in a baseload configuration. Adjusting bioenergy plants to run as flexible and dispatchable power requires storage for feedstocks and performance improvements to the combustion technologies currently used in most bioenergy plants.

Production – Within WTE facilities, it is difficult to separate small scale food and organic waste feedstocks for bioenergy production. While incorporating multiple waste streams and attractive way to divert waste from landfills, scale-up is extremely difficult without better separation techniques.

The introduction of RNG into energy markets will have a disruptive affect by displacing incumbents such as natural gas. Longer term supply agreements are required to ensure that shorter term economic shifts tied to changing markets does not affect the revenue of a bioenergy plant detrimentally.

6.2 | Recommended Initiatives

Initiative 6.1: Improved Cleanup of Syngas Resulting from Gasification

Description and Characteristics	Syngas from biomass gasification can be combusted to produce electricity or converted to chemical intermediates (e.g., Fischer–Tropsch liquids, methanol, mixed alcohols, hydrogen). Produced syngas must meet exacting purity requirements for unique end-uses in internal combustion engines, gas turbines, fuel cells or as feedstocks for catalytic upgrading to chemicals and fuels or fermentation to fuels and high-value chemicals. Raw biomass product gas may contain contaminants (e.g., particulates, tar, alkali and alkaline-earth metals, chlorine, nitrogen, sulfur compounds) depending on the biomass feedstock and operating conditions such as temperature, pressure, and the presence of reactive gases (e.g. oxygen or steam). Syngas cleaning is a very challenging aspect of the overall process and one which is often overlooked. While advances have been made, syngas contaminant cleanup remains expensive and can require multiple techniques and unit operations which add CAPEX and OPEX. Depending on the exact application, removal of tar, metals, and nitrogen compounds areare generally most problematic. Catalytic reforming – including the development of active tar reforming catalysts - has been developed to solve the tar problems, but this technology suffers from high cost and catalyst fouling/deactivation. Catalyst application requires solving scale-up issues including reactor design (fixed-bed vs. recirculating fluid beds), reaction severity (temperature and pressure) andand catalyst attrition. Biomass gasification research has been ongoing for decades but it still considered expensive and unreliable compared to conventional combustion. Research areas include more active catalysts, hot-gas filtration to remove catalyst contaminants prior to tar reforming, feed pre-processing to reduce tar formation during gasification, and scale-up.
Technology Baseline, Best in Class	Tar removal during gasification (e.g., small particle feedstock) or post-gasification methods such as hot gas cleaning, thermal cracking, catalytic cracking (e.g., 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% (high cost).
Impacts	Potential for higher yields and heating value of syngas; higher purity, lower-cost syngas with greater market acceptance for fuel and chemical production.
Metrics and/or Performance Indicators	Lower-cost gasification: (2025) 6 cents/kWh – 20 cents/kWh; 20% or more syngas yield increase via tar reforming; 30% hydrogen enrichment in syngas via tar reforming.
Associated Technology Advancements	Catalytic cracking (nickel-based); biomass ash or natural catalysts for tar and contaminant removal; physical or in situ upstream tar removal including hot gas filters and catalytic hot gas filters; solids handling technologies for feeding biomass to the gasifier.
Success Timeframe	Med-term; gasification is mature technology; biomass gasification is at pilot stage but has scale-up issues at larger sizers. Gas cleanup requires cheaper, better catalysts and integrated processes for multiple contaminants.
Primary Users and/or Beneficiaries	Current natural gas markets; large- and small-scale power generators; non-petroleum based biochemical markets (chemical producers)
Challenges Addressed	Make small scale gasification competitive for electricity; fouling/deactivation of catalysts; trade offs for syngas purity and yield (balancing operating conditions for high gas purity).
Key Published References (in addition	Biomass Gasification: Overview of Technological Barriers. 2018. https://cdn.intechopen.com/pdfs/59423.pdf Gas Cleaning Strategies for biomass gasification product gas. 2012. International Journal of Low-Carbon Technologies, Volume 7, Issue 2.

to Tech Assessment resources).

Initiative 6.2: Fund Thermal Hydrolysis Precursor to Anaerobic Digestion System Capable of Accepting Multiple Waste Streams

Description and Characteristics	Thermal hydrolysis pretreatment (THP) can be used as a precursor to Anaerobic Digestion (AD) to increase biogas production and increase breakdown of organic material.
Technology Baseline, Best in Class	Wet AD systems (high-moisture-content feedstock types) such as covered lagoon and complete mix digester; dry AD systems for relatively low-moisture-content feedstock (e.g., yard waste), including plug flow digesters. THP used successfully for wastewater treatment to reduce sludge.
Impacts	THP can potentially improve cake dewaterability, increase methane production, increase digester loading rates and produce bio-solids ready for land disposal. Potential cost reductions.
Metrics and/or Performance Indicators	Implementation of full scale thermo pressure hydrolysis (TDH) shown to provide higher anaerobic degradation efficiency; increased biogas production (+75-80%) achieved from waste activated sludge. Enhanced degradation of organic matter and improved cake's solids content from 25.2 to 32.7% TSS reduce sludge disposal costs about 25%. Increased biogas production (75-80%).
Associated Technology Advancements	Thermo-pressure hydrolysis, high pressure thermal hydrolysis. Studied primarily for wastewater pretreatment to reduce sludge. Studied for algae digestion.
Success Timeframe	Medium term; available for wastewater pretreatment, requires study and adaptation to biomass/dairy AD operations (common in CA).
Primary Users and/or Beneficiaries	AD operations at CA farms; wastewater treatment facilities.
Challenges Addressed	Increased ammonia release and generation of soluble inert materials.
Key Published References (considered in addition to Tech Assessment Interviews, Surveys, Webinars)	Impact of Operating Conditions on Thermal Hydrolysis Pre-Treated Digestion Return Liquor Nandita Ahuja 2015. https://pdfs.semanticscholar.org/f916/64cf71db9557fa3ca5a28997aa37d8975baf.pdf A Review of the Processes, Parameters, and Optimization of Anaerobic Digestion. 2018. file:///C:/Users/jpellegrino/Downloads/ijerph-15-02224.pdf Benefits and drawbacks of thermal pre-hydrolysis for operational performance of wastewater treatment plants. https://www.ncbi.nlm.nih.gov/pubmed/19001706 A Review of Sludge-to-Energy Recovery Methods. 2019. file:///C:/Users/jpellegrino/Downloads/energies-12-00060.pdf High pressure thermal hydrolysis as pre-treatment to increase the methane yield during anaerobic digestion of microalgae. 2012. https://www.sciencedirect.com/science/article/pii/S0960852412019839

6.3 | Related EPIC and DOE Initiatives

6.3.1 | 2018-2020 EPIC Triennial Investment Plan

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.

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.

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.

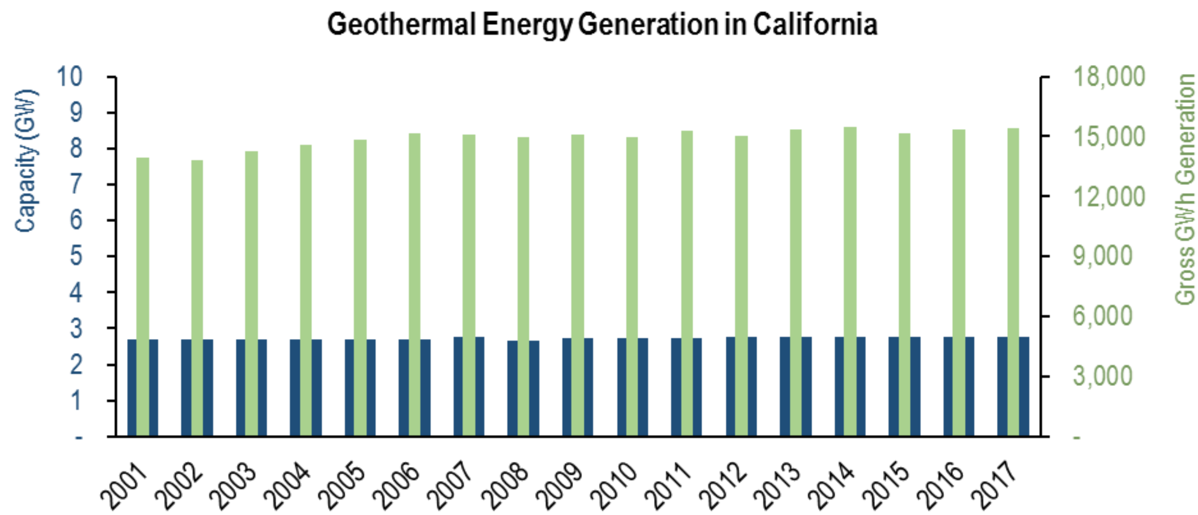
6.3.2 | U.S. Department of Energy Research Initiatives

Bioenergy Technology Office (BETO) Funding Opportunity for Bioenergy Research and Development – Wide ranging funding opportunity looking to advanced R&D for biofuels, bioproducts, and biopower.

7 | Geothermal

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 7.

Figure 7. Geothermal Energy Generation in California from 2001 to 2017



Data from energy.ca.gov/almanac/renewables_data/geothermal/

Estimates of additional capacity in California range from 4,000 MW–20,000 MW for conventional geothermal generation and estimates as high as 50,000 MW with the inclusion of enhanced geothermal systems (EGS).[11,12] California has 25 known geothermal resource areas (KGRAs), of which 14 have temperatures above 300°F.[13] 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.

The LCOE for geothermal designs ranges from \$0.04/kWh to \$0.14/kWh, assuming a 25-year plant life.[14] The estimated costs for EGSs range from \$0.10/kWh to \$0.30/kWh.[15]

Table 7. Geothermal Power Cost Performance Targets (DOE)

	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

The geothermal energy cost target is an unsubsidized cost of energy at utility scale. 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.

Source: "Department of Energy FY 2019 Congressional Budget Request." Volume 3–Part 2: 25. DOE. March 2018. energy.gov/sites/prod/files/2018/03/f49/FY-2019-Volume-3-Part-2.pdf.

[11] Colin F. Williams et. al., "Assessment of Moderate- and High-Temperature Geothermal Resources of the United States," USGS 2008, pubs.gov/fs/2008/3082/pdf/fs2008-3082.pdf.
[12] "Western U.S. Geothermal Assessment Summary," USGS, accessed November 28, 2018, certmapper.cr.usgs.gov/data/energyvision/?config=config_Geothermal.json.
[13] "Geothermal Energy in California," California Energy Commission, accessed November 28, 2018, https://www.energy.ca.gov/geothermal/background.html.
[14] "Geothermal Power: Technology Brief," International Renewable Energy Agency, September 2017, irena.org/-/media/Files/IRENA/Agency/Publication/2017/Aug/IRENA_Geothermal_Power_2017.pdf.
[15] "Technology Roadmap: Combined Heat and Power," International Energy Agency, 2011, iea.org/publications/freepublications/publication/Geothermal_Roadmap.pdf.

7.1 | Key Barriers and Challenges

Cost – The most substantial cost tied to geothermal production is for initial exploration and production. The high cost of exploration, which can account for over 50% of total project cost, remains one of the largest barriers to reducing the ultimate consumer-facing price of geothermal energy. 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.

Once a well is developed and productive in a KGRA, maintenance and material costs can continue to hamper geothermal profitability. Geothermal brines found in many KGRAs, such as the Salton Sea, contain large concentrations of corrosive impurities that degrade equipment and require constant maintenance.

Dispatchability – Geothermal power is typically run in a baseload configuration that reduces the dispatchability of geothermal power. One discussed method of increasing the dispatchability of geothermal power is flexible generation. However, the processes used for flexible generation, including controlling steam release and shutting in wells and equipment, put wear on equipment and introduce risks to normal system operation. In addition to system risks, there are cascading effects tied to flexible generation such as byproduct development. Also, flexible generation may not improve project economics at all and may only

Grid Integration – 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. Existing systems have also had integration problems. For example, the Geysers have had curtailment issues due to transmission congestion.

Performance – Geothermal systems suffer from a number of performance issues due to system degradation over time. One of these problems is a drop-off in performance due to fluid depletion. The loss of water to cooling towers is a problem affecting both new and existing systems that can be solved by fluid reinjection. However, reinjection of water comes with its own issues, and creative schemes such as the treated wastewater reinjection used at the Geysers are not one-size-fits-all solutions.

Material issues also hamper performance for new and existing systems. The Salton Sea area in particular contains brines so corrosive they wear down titanium liners after only five years of service. Advanced material design and integration with new and existing systems can help alleviate corrosion issues.

Resource Valuation – The 24-7 availability of geothermal power is not currently valued in energy markets despite being one of the few baseload renewable energy sources. While, geothermal resources also have the potential to provide black start capabilities and ramping flexibility services for the grid, these ancillary services will require a higher value in energy markets as well to incentivize geothermal producers to launch new developments. The California Public Utilities Commission’s current structure provides incentives for solar production while leaving little incentive for new geothermal installations.

7.2 | Recommended Initiatives

Initiative 7.1: Improving Materials to Combat Corrosion from Geothermal Brines

Description and Characteristics	The high salinity of geothermal brines, especially in the Salton Sea region of California, degrades metal used throughout the power production process. As a result, expensive titanium-alloys are often used to prevent corrosion and reduce maintenance costs. 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 reveal lower cost and more corrosion-resistant materials.
Associated Technology Advancements	Titanium-Alloys
Technology Baseline, Best in Class	TBD
Impacts	TBD
Metrics and/or Performance Indicators	TBD
Associated Technology Advancements	TBD
Success Timeframe	TBD
Primary Users and/or Beneficiaries	TBD
Challenges Addressed	TBD
Key Published References (considered in addition to Tech Assessment Interviews, Surveys, Webinars)	http://www.materialsperformance.com/articles/material-selection-design/2019/02/testing-corrosion-resistant-alloys-for-use-in-geothermal-power-plants

Initiative 7.2: Explore Electricity Potential from Idle Oil and Gas Wells through the Use of Downhole Heat Exchangers

Description and Characteristics	Oil and gas wells are plentiful in the state of California with around 30,000 of those wells being abandoned. These wells present an opportunity to extract geothermal energy by using heat exchangers that are placed in the drilled wells. Extracting geothermal energy in this way avoids the extremely high drilling costs necessary for the majority of new projects. Typical downhole heat exchangers
Technology Baseline, Best in Class	TBD
Impacts	TBD
Metrics and/or Performance Indicators	TBD
Associated Technology Advancements	Borehole Heat Exchangers
Success Timeframe	TBD
Primary Users and/or Beneficiaries	TBD
Challenges Addressed	TBD
Key Published References (considered in addition to Tech Assessment Interviews, Surveys, Webinars)	https://www.pasadenastarnews.com/2019/03/05/what-toxins-are-being-emitted-from-la-countys-abandoned-oil-wells-a-lawmaker-wants-to-find-out/ https://geothermal-energy-journal.springeropen.com/articles/10.1186/s40517-017-0071-2

7.3 | Related EPIC and DOE Initiatives

7.3.1 | 2018-2020 EPIC Triennial Investment Plan

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.

7.3.2 | U.S. Department of Energy Research Initiatives

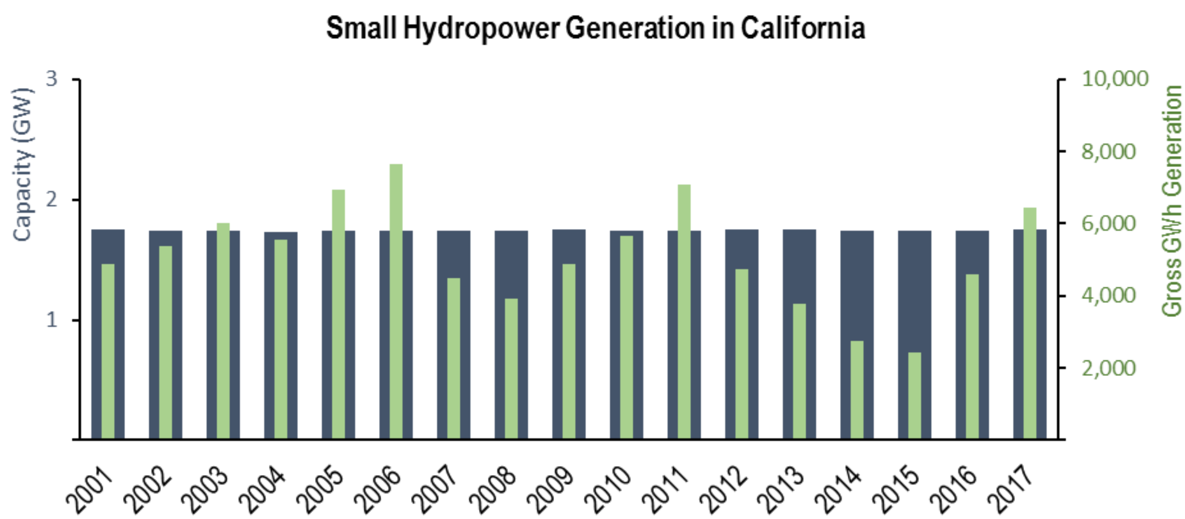
Frontier Observatory for Research in Geothermal Energy (FORGE) – Dedicated site where scientists and engineers can test, develop, and accelerate breakthroughs in EGS technologies.

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. Several geothermal projects were chosen to receive funding under this program.

8 | Small-Scale Hydroelectric (<30 MW)

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 8. Of the total small hydro energy capacity in California, 320 MW is in-conduit hydropower.[16]

Figure 8. Small Hydropower Energy Generation in California from 2001 to 2017



Data from energy.ca.gov/almanac/renewables_data/hydro/

As shown in the graph, 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 shown in Figure 8 all occurred during droughts).

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.[17] Installed costs can vary highly among systems, ranging from $2500/kW to $5000/kW.[18] 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 8.

Table 8. Small Hydro Cost Performance Targets (DOE)

	FY 2017	FY 2018	FY 2019	Endpoint Target
Small Hydro (streams)	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

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

Source: "Department of Energy FY 2019 Congressional Budget Request." Volume 3–Part 2: 24. DOE. March 2018. energy.gov/sites/prod/files/2018/03/f49/FY-2019-Volume-3-Part-2.pdf.

[16] N.M. Samu et al., "National Hydropower Plant Dataset, Version 1, Update FY18Q2 (2018), Existing Hydropower Assets [series] FY18Q2," Oak Ridge National Laboratory, National Hydropower Asset Assessment Program, nhaap.ornl.gov/submission-id/eha-3224.

[17] "Renewable Power Generation Costs in 2017," International Renewable Energy Agency (IRENA), 2018, irena.org/-/media/Files/IRENA/Agency/Publication/2018/Jan/IRENA_2017_Power_Costs_2018.pdf.

[18] Patrick W. O'Conner et al., "Hydropower Baseline Cost Modeling," Oak Ridge National Laboratory, January 2015, hydropower.ornl.gov/docs/publications/ORNL_Hydropower%20Baseline%20Cost%20Development%202015-01-28_OConnor.pdf.

8.1 | Key Barriers and Challenges

Cost – System development costs are high enough that they prohibit small hydropower development. These costs stem from a variety of factors. Each site is custom engineered, as a site's particular hydrology and current structure must factor into a unique (and therefore expensive) design. To incorporate small hydropower, many sites require civil work construction.

Smaller system designs face high soft costs for permitting and grid integration as well. Regulatory changes at both the national and state levels have sought to mitigate permitting costs, but challenges still remain at local levels. Grid integration may be an additional soft cost, as some systems are far from existing transmission lines.

Production – The cumulative costs of site-specific, custom engineering can make projects cost-prohibitive. Additionally, the small size of units lowers the efficiency of the manufacturing cycle and limits the ability of small hydropower system to be built at the utility-scale. The market for small-hydro units which raises the per-unit cost substantially. Typically, awards and funding given to small-hydro projects are focused on the unit design and not the manufacturability of the units as well.

Dispatchability – While hydropower systems do have the ability to provide ramping and dispatch control to the grid, small hydro systems in California have limited control over water flows that affect downstream water distribution since the state places tight controls on water use to meet farming and municipal needs. Additionally, water flow in California is tied heavily to unpredictable weather patterns which makes long term forecasting of small-hydro's capabilities problematic.

Grid Integration – The remote location of some small hydropower units increases the challenge and cost associated with interconnection. The market also currently exists with an incentive to size systems below CAISO's dispatching threshold which limits the size of units.

Resource Valuation – Ancillary services that could be provided by small hydro units are not currently valued in California energy markets. The benefits of hydropower such as quick start-up time are therefore mitigated.

8.2 | Recommended Initiatives

Initiative 8.1: Developing Parts and Systems to Standardize Hydropower Development

Description and Characteristics	Developing small hydro systems requires site-specific engineering, which raises costs. Developing standardized components and methods can both decrease these costs and enhance system feasibility. Standardized components that can be reused in a variety of flows and sites can allow an economy of scale to develop, further decreasing costs.
Technology Baseline, Best in Class	TBD
Impacts	Standardized turbine components can make the manufacturing, deployment, and maintenance of in-conduit systems cheaper and faster by developing an economy of scale for the industry.
Metrics and/or Performance Indicators	This initiative should decrease system costs, which in turn should enable more system deployment.
Associated Technology Advancements	Standardized turbine components can incorporate new technologies to further drive down turbine costs. Composite materials and inflatable weirs offer potential methods of standardization for turbines. Reusable versions of these materials can also reduce costs.
Success Timeframe	Near Term
Primary Users and/or Beneficiaries	Turbine Manufacturers, Site Developers
Key Published References (considered in addition to Tech Assessment Interviews, Surveys, Webinars)	https://www.hydroworld.com/articles/hr/print/volume-36/issue-7/articles/making-small-hydro-development-affordable-and-acceptable.html

Initiative 8.2: Fund Deployment of Small Hydro Systems that Use Permanent Magnet Generators

Description and Characteristics	TBD
Technology Baseline, Best in Class	TBD
Impacts	TBD
Metrics and/or Performance Indicators	TBD
Associated Technology Advancements	TBD
Success Timeframe	TBD
Primary Users and/or Beneficiaries	TBD
Challenges Addressed	TBD
Key Published References (considered in addition to Tech Assessment Interviews, Surveys, Webinars)	TBD

8.3 | Related EPIC and DOE Initiatives

8.3.1 | 2018-2020 EPIC Triennial Investment Plan

The EPIC 2018–2020 Triennial Investment Plan does not mention R&D priorities to increase small hydropower deployment in California.

8.3.2 | U.S. Department of Energy Research Initiatives

HydroWIRES Initiative – Focused on understanding and enabling utilization of the full potential of hydropower and pumped hydropower storage to contribute to electric system reliability and resilience, now and into the future.

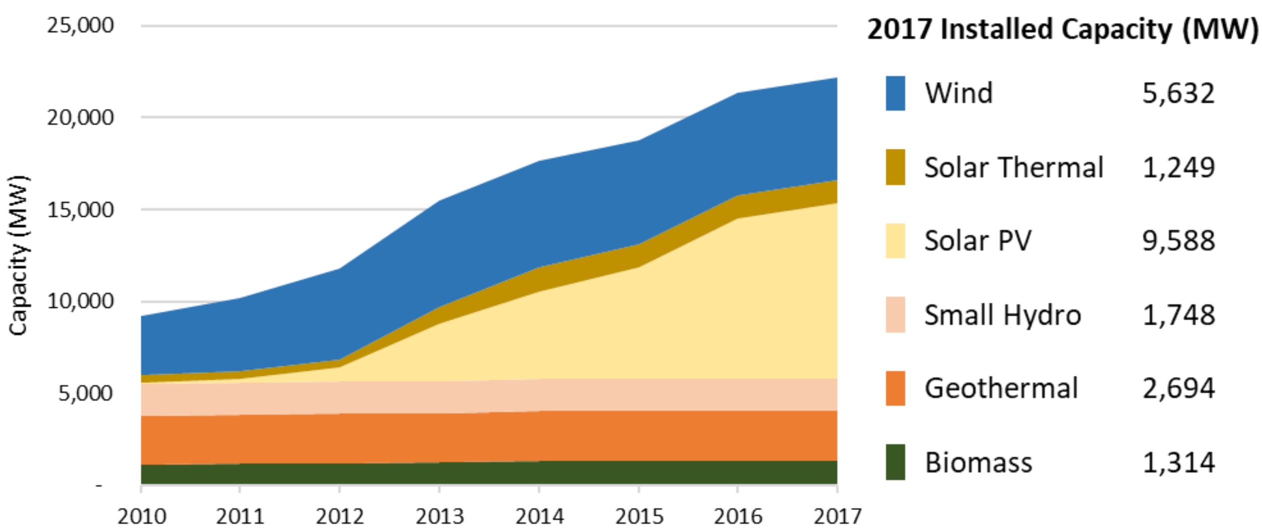
Water Power Technologies Office (WPTO) Funding Opportunity for Innovation Design Concepts for Standard Modular Hydropower and Pumped Storage Hydropower – Supports R&D efforts to modernize the U.S. hydropower fleet through practical engineering applications like standardization and modularity.

WPTO Funding Opportunity to Advanced Marine and Hydrokinetics Industry – Aims to lower the costs of hydropower and marine energy while strengthening the U.S.'s manufacturing capabilities in these technology areas.

9 | Grid Integration Technologies

In 2017, California's electricity system generated over 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 below in Figure 9. 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 9. Cumulative Installed Large-Scale Renewable Energy Capacity, 2010–2017



Data from energy.ca.gov/almanac/electricity_data/total_system_power.html

To handle all electric load in the state, California has over 4,400 miles of high-voltage (>230 kV) transmission lines and over 10,300 miles of low-voltage (<230 kV) transmission lines.[19] 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 (CAISO) was forced to curtail over 187,000 MWh of solar and wind generation. In 2016, that total rose to over 300,000 MWh.[20]

Effective planning can help California achieve 100% zero carbon energy by 2045 by both 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.

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[19] "State of California – Energy Sector Risk Profile," U.S. Department of Energy, 2015, energy.gov/sites/prod/files/2015/05/f22/CA-Energy%20Sector%20Risk%20Profile.pdf.
[20] "Fast Facts: Impacts of renewable energy on grid operations," California ISO, 2017, caiso.com/documents/curtailmentfastfacts.pdf.

9.1 | Key Barriers and Challenges

Dispatchability – The transition from a conventional grid to a flexible grid with more dispatchable resources requires the development of sensors and communications systems to interpret measurements from across the grid. With constantly changing loads due to variable generation, distributed energy resources, and energy storage systems, all systems must be connected and monitored to ensure that grid operators can maintain a balanced system.

Performance – Existing grid integration technologies like transmission towers have lower efficiencies than new technologies. Traditional transmission towers feature steel cross-arms and vertical insulators on pylons. Replacing these steel cross-arms with insulating cross-arms can allow for increases in transmission capacity of up to 150% compared to existing infrastructure. Similar upgrades of grid infrastructure like transmission lines, semiconductors, and Supervisory Control and Data Acquisition (SCADA) equipment can increase the grid's overall efficiency and performance.

Cost – Grid infrastructure does not produce revenue. Ratepayers are therefore left to pick up the costs of integrating new power lines and grid devices into the energy system. The high cost of major infrastructure expansion (new power lines and transformers for example) creates an incentive for utilities to focus on improving existing infrastructure. Uncertainty and cost of new state-of-the-art infrastructure leads to technology lock-in on existing components which stifles new innovation as well.

9.2 | Recommended Initiatives

Initiative 9.1: Support Continued Advancement of High-Temperature Low-Sag Conductors

Description and Characteristics	Transmission lines in California are operating either near, at, or above their design rating, limiting the amount of electricity which can flow along them. Utilities still primarily use traditional aluminum-conductor steel-reinforced (ACSR) cable technology for their transmission lines. New developments in conductors have led to commercialization of several types of high-temperature low-sag (HTLS) conductors. HTLS conductors use different materials than ACSR conductors. Typically some type of aluminum is used as the conductor and the interior features a material with high tensile strength. To eliminate issues with heat and sag that result from the use of a steel core in ACSR conductors, the core is typically replaced with a different metals or composite materials. These new conductors can carry 2.5 times the amount of current of ACSR conductors of the same size and are able to handle continuous temperatures of 150-210°C compared to 100°C for ACSR. The lower coefficient of thermal expansion for HTLS conductors reduces sag even as more current is transported over the lines. HTLS conductors have been on the market over the past decade, but still are not deployed widely due to their higher cost than ACSR conductors and the long lifetime of conductor cables.
Technology Baseline, Best in Class	
Impacts	Replacing existing conductors in California with HTLS conductors can increase line capacity on existing infrastructure without the need for new power towers and other expensive infrastructure. The reduced sag on power lines will reduce the risk of wildfires due to powerlines. Further decreases in HTLS conductor costs over time will decrease the payback period of these conductors and make them an even more attractive alternative to ACSR wires. HTLS conductors also reduce line losses which increases the overall efficiency of the grid.
Metrics and/or Performance Indicators	MW/Power Line; Percent of Line Losses; Sag Distance of Power Lines; Number of Wildfire caused by Power Lines
Associated Technology Advancements	Gap-type Thermal Aluminum Conductor Steel Reinforced (GTACSR); Super Thermal Aluminum Conductor Invar Reinforce (ZTACIR); Aluminum Conductor Steel Supported (ACSS); Aluminum Conductor Composite Reinforced (ACCR)
Success Timeframe	Mid Term
Primary Users and/or Beneficiaries	Utilities, T&D Developers
Challenges Addressed	Performance, Cost
Key Published References (considered in addition to Tech Assessment Interviews, Surveys, Webinars)	https://www.navigantresearch.com/news-and-views/advanced-conductors-are-changing-the-economics-of-new-transmission-line-buildsand-existing-line-upgr https://www.ee.co.za/article/high-temperature-low-sag-power-line-conductors.html https://www.hindawi.com/journals/jece/2018/2073187/ https://www.sciencedirect.com/science/article/pii/S1876610216313935 https://repository.asu.edu/attachments/134758/content/Banerjee_asu_0010N_13601.pdf Online PDF: "Characterization of Composite Cores for High Temperature-Low Sag (HTLS) Conductors" https://cleanenergygrid.org/wp-content/uploads/2014/08/High-Temperature-Low-Sag.pdf

https://phys.org/news/2016-12-tabs-aging-power-cables-outages.html

Initiative 9.2: Advancement of Smart Inverters to Improve Communication and Cybersecurity

Description and Characteristics	The electricity grid is transitioning to a system with multiple points of generation and consumption which integrates variable energy systems, large scale energy storage, and net metering 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 responsive and security available on the market or possible with further development. 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.
Technology Baseline, Best in Class	
Impacts	Inverters will be able to transfer data and be remotely controlled with limited risk of cyberattack. Contingencies will be required in case a cyberattack does occur. 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
Metrics and/or Performance Indicators	MWh of Curtailed Renewable Energy, MWh of Energy Losses due to Interconnection, Cyberattacks Reported per Year
Associated Technology Advancements	Synchrophasor technology can collect 30 to 60 samples per second to provide grid performance data; Encryption of transferred data; Virtual Oscillator Control (VOC).
Success Timeframe	Near-Term (1-3 Years)
Primary Users and/or Beneficiaries	Utilities, T&D Developers, California ISO Operators
Challenges Addressed	Grid Integration
Key Published References (considered in addition to Tech	https://blog.aurorasolar.com/californias-new-smart-inverter-requirements-what-rule-21-means-for-solar-design https://microgridknowledge.com/derms-smart-inverters-grid/ https://www.cpuc.ca.gov/rule21/ https://www.greentechmedia.com/articles/read/is-the-solar-industry-secure-enough-for-smarter-technology#gs.jwd2bi

Assessment Interviews, Surveys, Webinars)	

9.3 | Related EPIC and DOE Initiatives

9.3.1 | 2018-2020 EPIC Triennial Investment Plan

Assess Performance of Load Control Systems – Build sufficient data on performance to reduce uncertainty and provide confidence in demand response reliability such that telemetry on each load is unnecessary.

Optimize and Coordinate Smart Inverters Using Advanced Communication and Control Capabilities – Develop distributed energy resource management system (DERMS) algorithms to optimize the settings and coordination of advanced smart inverters to maximize the output of solar generation on the grid and improve the ability of solar PV to respond to signals from a utility or other grid operator.

Provide Visibility into Load and DER Responses to Weather and Other Variables and into the Effects of DER on Gross Load – Establish a database of DER production and gross load data and enhance tools for grid operators to visualize the effects of weather patterns and other events on rooftop solar production, electric vehicle charging, and other DER usage. Improve forecasting tools leveraging the database to better predict the net load that will need to be met through geothermal, natural gas, and other utility-scale generation.

Improved Understanding of Climate- and Weather-Related Risks and Resilience Options – Improve projections and probabilistic forecasts of hydrological and meteorological parameters needed for operations and seasonal and decadal planning. Develop strategies supported by analysis of projected and historical data for parameters of importance to the energy system: snowpack conditions, stream flows, ambient temperature, precipitation levels, relative humidity, and solar radiation.

Integrate Climate Readiness into Electricity System Operations, Tools, and Models – Expand access to vulnerability and resilience tools with region-specific detail that leverage probabilistic forecasts at seasonal and decadal scales to inform utilities' management, planning, and operations, including cost–benefit analyses of resilience investments. Facilitate use of these tools to improve understanding of the electricity system's interconnectedness with other areas (e.g., emergency response, public health, and interconnected infrastructure between sectors) and integrate this information into models.

9.3.2 | U.S. Department of Energy Research Initiatives

Systems Integration Subprogram (Solar Energy Technologies Office) – Funds early-stage grid integration R&D with focus on power variability, voltage regulation, frequency control, unintentional islanding, protection coordination, and two-way power flow.

Mitigate Market Barriers Subprogram (Wind Energy Technologies Office) – Funds R&D in wind energy grid integration, such as how to effectively operate the power grid under high penetrations of wind energy.

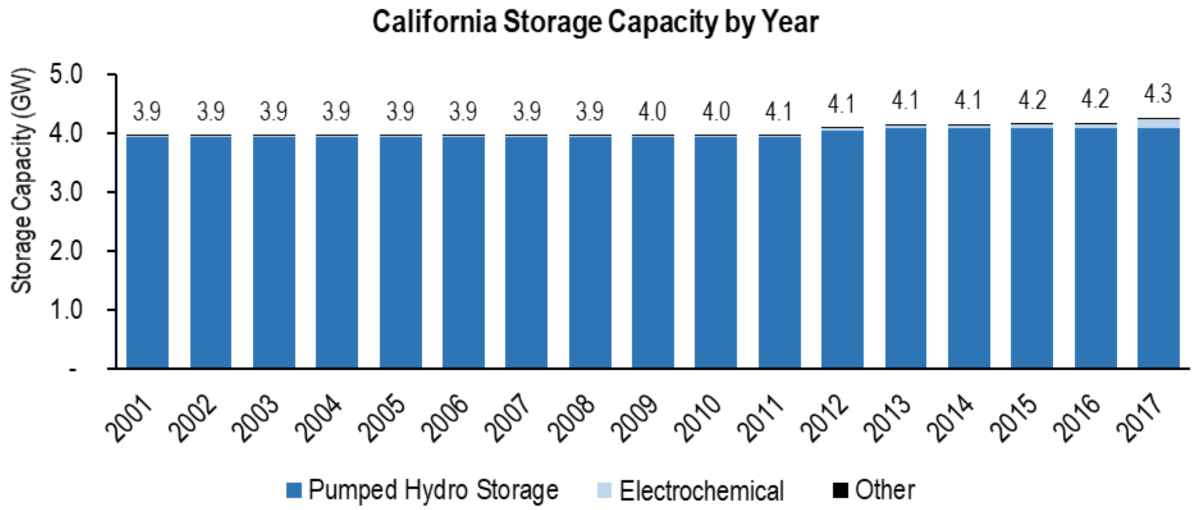
Federal Energy Management Program – Assists federal agencies in energy savings and reliability projects by providing a two-way grid interface.

Grid Modernization Multi-Year Program Plan – Recommends 6 technical areas to focus on for RDD&D activities: Devices and Integrated Systems Testing; Sensing and Measurement; Systems Operations, Power Flow, and Control; Design and Planning Tools; Security and Resilience; and Institutional Support.

10 | Energy Storage Systems

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 10 below.

Figure 10. Energy Storage Capacity in California from 2001 to 2017



Data from DOE Energy Storage Database (energystorageexchange.org)

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 **Error! Reference source not found.** Aqueous soluble organic electrolyte batteries (redox flow battery systems) currently represent DOE's choice for the chemistry of a utility-scale battery.

Table 9. Energy Storage Cost Performance Targets (DOE)

	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: "Department of Energy FY 2019 Congressional Budget Request." Volume 3–Part 1: 32. DOE. March 2018. energy.gov/sites/prod/files/2018/03/f49/DOE-FY2019-Budget-Volume-3-Part-1_0.pdf.

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.[21] Other types of storage systems have a bevy of capacity available since they can be

[21] "Hydropower Vision Chapter 3: Assessment of National Hydropower Potential," U.S. Department of Energy, Water Power Technologies Office, energy.gov/eere/water/downloads/hydropower-vision-chapter-3-assessment-national-hydropower-potential

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.

10.1 | Key Barriers and Challenges

Cost – 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.

The cost of capacity remains high for underdeveloped systems. These systems include compressed air energy storage (CAES), flywheels, pumped hydro, 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. Additionally, as the lifetime of these energy storage systems increases, maintenance and disposal costs will play into the ultimate cost of electricity as the original cost of capacity depreciates. Also, the full life cycle costs of energy storage systems are not well understood since these systems are being deployed at an increasingly rapid pace with a similar rapid rise in the efficiencies of the energy storage systems.

Performance – The most important performance characteristics are site- and use-dependent for energy storage systems. System performance can be determined by a variety of factors including power output, energy density, and efficiency. Energy storage requires a standardized way to judge system performance. 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.

Grid Integration – The variety of energy storage systems increases the complexity of interconnection and introduces technology specific considerations for each installation. Pumped hydropower and compressed air energy storage (CAES) systems have many more environmental and permitting challenges than smaller lithium-ion or other battery systems that can be sited flexibly. These challenges must be considered when accounting for the time and cost of a larger energy storage project. Energy storage systems also face integration barriers due to cybersecurity risks. Communications devices and smart inverters can reduce issues with integrating storage systems into the grid.

Resource Availability – The availability of storage is mostly determined by location and grid structure. There are some barriers to installation for certain storage technologies in areas with constrained space. Additionally, there are both charging and dispatching constraints related to the location of storage systems within the larger grid infrastructure.

One additional consideration for energy storage is its ability to increase the supply of renewable energy available to the grid at any time. 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, possibly non-renewable systems. Long-duration storage is currently only provided by the large capacity and expensive systems like pumped-hydro.

10.2 | Recommended Initiatives

Initiative 10.1: Support Research into Long Duration Energy Storage Systems (8-hour or greater)

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. Long duration storage time frames need to increase to lengths of many hours to days in order to support additional renewable resources.. 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.
Technology Baseline, Best in Class	Lithium-ion batteries – minutes to a few hours; flow batteries – up to about 8 hours; fly wheels – minutes, usually less than an hour; pumped hydro – hours; thermal storage technologies – up to 8 hours
Impacts	Long duration energy storage will support continued renewable energy deployment in California, reduce renewable curtailment, and reduce evening natural gas plan ramping.
Metrics and/or Performance Indicators	Duration – typically measured in minutes to a few hours. Duration should increase beyond 8 hours into multiple days.
Associated Technology Advancements	Flywheels, Battery Improvements, Small-Scale Pumped Hydro Storage, Thermal Energy Storage
Success Timeframe	Long Term: 5 years +
Primary Users and/or Beneficiaries	California ISO, Utilities, Utility Customers, Storage Developers
Challenges Addressed	Increasing energy density of storage technologies, reducing both hard and soft costs, finding available sites for certain technologies
Key Published References (considered in addition to Tech Assessment Interviews, Surveys, Webinars)	https://www.navigantresearch.com/reports/long-duration-energy-storage https://www.popularmechanics.com/technology/gadgets/a23890619/sila-silicon-anode-batteries-consumer-electronics/

Initiative 10.2: Fund Recycling Programs for Energy Storage Systems (Particularly Lithium-Ion Batteries)

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 are currently no lithium-ion battery recycling programs in California. Without recycling programs, these batteries will either be thrown away or sent out of state or out of country for repurposing or recycling, and potentially pose a serious environmental hazard if recycling is not done properly. Sending used batteries out of California is a massive lost opportunity for the state as keeping the battery materials in-state could create new markets for recycled battery materials and components and spur California's battery manufacturing industry.
Technology Baseline, Best in Class	Less than half of lithium-ion batteries are currently recycled. Those that are recycled are typically sent to Europe or China where batteries are incinerated to extract materials.
Impacts	Reduce environmental impacts of discarded or improperly dismantled batteries; economic benefit through job and market creation and potentially reduced costs of batteries; creation of battery manufacturing industry.
Metrics and/or Performance Indicators	MW/MWh capacity of recycled/reused batteries; number and percentage of recycled batteries, number of jobs created.
Associated Technology Advancements	Streamlined recycling processes; metal and material extraction processes; battery manufacturing from recycled materials.
Success Timeframe	Mid-term/long-term
Primary Users and/or Beneficiaries	Battery manufacturers, utility customers, waste management facilities
Challenges Addressed	Battery disposal; battery manufacturing; material recycling/repurposing.
Key Published References (considered in addition to Tech Assessment Interviews, Surveys, Webinars)	https://www.mckinsey.com/Industries/Automotive-and-Assembly/Our-Insights/Second-life-EV-batteries-The-newest-value-pool-in-energy-storage https://batteryuniversity.com/learn/article/recycling_batteries https://www.duesenfeld.com/

10.3 | Related EPIC and DOE Initiatives

10.3.1 | 2018-2020 EPIC Triennial Investment Plan

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.

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.

Grid-Friendly PEV Mobility – Demonstrate advanced vehicle-to-grid (VGI) functions to better characterize the business cases for emerging applications.

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.

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.

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.

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.

10.3.2 | U.S. Department of Energy Research Initiatives

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.

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.

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.

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.

Advanced Energy Storage Initiative – Proposed for Fiscal Year 2020, this initiative would develop a coordinated strategy for aligning DOE R&D and establish aggressive, yet achievable goals for cost competitive energy storage services.