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Energy Research and Development Division

FINAL PROJECT REPORT

Distributed Energy Resources Integration Research Roadmap

Efficient Integration to Achieve California's Energy Goals

Gavin Newsom, Governor

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PREFACE

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

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

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

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

Distributed Energy Resources Integration Roadmap is the final report for Contract Number 300-17-003 conducted by Navigant, a Guidehouse company. The information from this project contributes to the Energy Research and Development Division's EPIC Program.

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

ABSTRACT

The California Energy Commission (CEC) administers a portfolio of energy research and development programs that drive innovation to make California's energy system more safe, reliable, sustainable, and affordable for its residents. Distributed energy resources (DER) — defined as distribution-connected generation resources, energy efficiency, energy storage, electric vehicles, and load flexibility technologies—represent an opportunity to further these goals and present a challenge for integrating efficiently with the existing, more centralized energy system. The CEC produced this research roadmap to identify opportunities that can help integrate DER into the existing system to maximize benefits for electric ratepayers. A wide range of DER types are considered, though not energy efficiency — which is the focus of numerous other studies. This roadmap uses three major organizing groups: (1) load-modifying technologies, (2) DER communications and controls, and (3) DER planning and strategy.

This project included a technical assessment of DER and barriers to efficient adoption, development of a prioritization method to assess research opportunities that relieve those barriers, and execution of that method to identify high-value research. The technical assessment included expert interviews and a broad literature review across the three major groups and seven technology and strategy subgroups. Professionals from the industry provided guidance to the project team, and public input was solicited through a series of open workshops. These sources helped identify market barriers to DER deployment, potential research opportunities to address the barriers, and metrics to assess progress. The prioritization factors included benefit to ratepayers, technical impact, market scalability and alignment with policy goals. The project resulted in 41 prioritized recommendations across the seven technology and strategy subgroups to guide the CEC in developing research solicitations in the short, medium, and long term. Major research themes across the roadmap include using DER to improve grid resiliency, enabling proactive DER participation as a primary option in planning and operations, and development of robust public data on DER capabilities and performance.

Keywords: Distributed energy resources, DER, solar, storage, flexible loads, electric vehicles, PEV, grid integration, communications, distribution planning, demand response, load shifting

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EXECUTIVE SUMMARY

Introduction

California has embraced distributed energy resources (DER) as a strategic priority in the pursuit of a more sustainable electrical grid. DER are defined by California code as distribution-connected distributed generation resources, energy efficiency, energy storage, electric vehicles, and load flexibility technologies. A robust suite of legislative and regulatory directives, including Public Utilities Code Section 769 (2019) and the California Public Utilities Commission's DER Action Plan (2016), has spurred uptake of these resources among customers and energy providers. Meanwhile, progress by grid operators and load-serving entities toward including distributed energy resources in resource planning and operations means DER meet a larger share of California's energy needs than ever before.

While acknowledging this progress, there is still much to do. Fulfilling California's energy and climate goals, including safety, sustainability, affordability, reliability, and equity, will require further improvements in distributed technologies as well as the tools used by grid operators and load-serving entities to coordinate with them. The Electric Program Investment Charge program, California's primary means of funding electric system research and development, technology demonstration and deployment, and market facilitation, will help accelerate achievement of these improvements. This roadmap provides a suggested set of research projects to guide the California Energy Commission's (CEC) DER integration studies in the short, medium, and long term.

Project Purpose

California's energy system is transforming from one powered primarily by centralized, fossil-fueled generation stations to one incorporating higher amounts of carbon-free and distributed generation. Total installed capacity of technologies like distributed solar grew almost twenty-fold over the last decade according to data from the California Solar Initiative. These changes have been driven by legislation such as the California Renewables Portfolio Standard Program (Senate Bill 100, de Leon, Chapter 312, Statues of 2018) which mandates that zero-carbon resources supply 100 percent of retail electric sales by 2045 and encourages decreased costs associated with distributed generation and communications. These changes have brought many more participants to the energy system and initiated dozens of regulatory proceedings to guide the electric system transition.

The CEC produced this research roadmap to identify the barriers to efficiently integrating these new distributed resources with the grid and to solicit and evaluate potential research opportunities that can resolve those barriers. It is primarily intended to support CEC's prioritization of research. However, it can also provide other stakeholders with valuable information on research opportunities. While there are research needs that require immediate attention and funding, particularly for grid hardening for resiliency purposes, this roadmap provides longer-term guidance for the CEC's research agenda. The timeframes for opportunities in this roadmap are in the short (one to three years), medium (three to five years), and long (five-plus years) time horizons.

Project Approach

Navigant, a Guidehouse company, led the project team, partnering with Gridworks, Gregg D. Ander, LLC, Redhorse Corporation, and GC Green, Incorporated. The project team developed a list of California's relevant energy policies and energy system goals, aligning with efforts by the U.S. Department of Energy. Next, the project team identified the barriers preventing distributed resources from supporting these goals. After identifying the barriers, the team collected proposed research solutions to resolve those barriers.

Acknowledging that there are many valid ways to group these technologies and strategies, the project team worked with CEC staff and the technical advisory committee to develop a categorization scheme. Three major groups and seven technology and strategy subgroups were identified:

- Load-modifying technologies
  - Energy storage
  - Energy flexible load assets
  - Electric vehicle integration
- Distributed energy resource communications and controls
  - Distribution grid communications
  - Distribution grid management
- Distributed energy resource planning and strategy
  - Grid planning
  - Distributed energy resources for reliability and resiliency

Energy efficiency was not included as a focal area given that it is the focus of numerous other studies. For each subgroup, the project team performed a technical assessment to determine the current status of each technology, identify barriers preventing efficient integration into California's grid, and define metrics that can be used to chart progress. This assessment included performing a broad literature review, conducting a series of expert interviews, and consulting with the project's technical advisory committee.

The project team created a six-step method to identify, filter, and prioritize research opportunities that could be pursued by the CEC to relieve the barriers discovered in the technical assessment. The team solicited research needs from CEC staff, the technical advisory committee, and the public stakeholders to implement the method to find the highest benefit uses of ratepayer funds.

The research roadmap contains the projects that can help to relieve the barriers identified in the technical assessment, screened and prioritized using the project team's prioritization methodology.

Project Results

Integrating distributed resources with the physical grid as well as the regulatory policies and procedures governing grid planning and operation are complex issues connecting to many proceedings, working groups, and research initiatives. This roadmap seeks to present a broad view of potential research to provide high-level guidance for designing future CEC initiatives. The roadmap combines these opportunities into a path that can guide future CEC research to most effectively reach California's energy policy goals while creating the greatest benefit for Electric Program Investment Charge ratepayers.

The project team performed a technical assessment across seven categories of technologies and strategies, identified technical barriers preventing these resources from efficiently supporting California's energy policy goals, and identified 87 research opportunities that can help alleviate these barriers and support the efficient integration of distributed energy resources with the electrical grid. Of these, 41 passed an initial go/no-go screening where they were identified to meet the goals of the EPIC program and appropriate for this roadmap. Based on the results of the prioritization screening and input from the technical advisory committee and CEC staff, the passing research opportunities were assigned high, medium, and low priorities. The research suggestions are split across technologies that directly modify electrical loads, technologies that relate to communications with and management of distributed resources, and improvements to planning strategy. Major research themes across the roadmap include using these resources to improve grid resiliency, enabling proactive participation as a primary option in planning and operations, and developing robust public data on capabilities and performance.

Technology/Knowledge Transfer/Market Adoption

The roadmap is intended as a document to guide future CEC research; as such, it was reviewed by several CEC offices. A technical advisory committee — consisting of industry experts included California Independent System Operator, Lawrence Berkeley National Laboratory, Pacific Gas and Electric and Sonoma Clean Power — provided input and guidance.

A wider stakeholder community was also involved through a series of four public workshops. The draft and final documents were docketed to the CEC website, and public comment was solicited and incorporated following each event. One of the project team entities, Gridworks, provided links to the content on its website and used its mailing lists to distribute the content from the project to increase engagement with stakeholders.

Benefits to California

The roadmap identifies research opportunities found to provide the greatest potential value to achieving California's energy policy goals. The umbrella of distributed energy resources and their integration is broad and ties into many legislative, regulatory, and market processes. This roadmap provides value because it is a high-level reference document that synchronizes needs from many different areas and links to more detailed initiatives that deal more specifically with individual research areas. The project also provided an opportunity for a variety of stakeholders to convey their experiences and suggestions for upcoming CEC research in a formal and uniform process.

CHAPTER 1: Introduction and Project Approach

Overview

California has embraced the adoption of distributed energy resources (DER) as a strategic priority in the pursuit of a less carbon intense and resilient electrical grid. DER are defined by California code as distributed generation, energy efficiency, energy storage, electric vehicles (EVs), and demand response (DR) connected at the distribution level.[1] For the purpose of this research roadmap, energy efficiency was not selected as a focal area given detailed treatment in a number of other studies, including a recent California Energy Commission (CEC) report.[2] The growing involvement of DER has created many questions about how to effectively integrate these resources with the planning and operational processes of the conventional electric grid. DER represent a range of capabilities, challenges, and opportunities for a more efficient energy system. The project team created this DER research roadmap to guide the California Energy Commission (CEC) research agenda in a way that will help resolve the associated challenges and more fully allow distributed resources to provide value to the energy system and be compensated in turn. The effort was structured around three questions:

- What goals do DER technologies need to achieve?
- What are the current limitations to DER supporting these goals?
- What research can resolve these limitations?

Project Team

Navigant, a Guidehouse company, led the project team, partnering with Gridworks, Gregg D. Ander, LLC, Redhorse Corporation, and GC Green, Incorporated. The team was supported by a committed technical advisory committee consisting of experts from the following organizations:

- CEC
- California Independent System Operator (California ISO)
- Lawrence Berkeley National Laboratory (Berkeley Lab)
- SLAC National Accelerator Laboratory (SLAC)
- Pacific Gas and Electric (PG&E)
- Sonoma Clean Power
- Southern California Edison (SCE)
- The Greenlining Institute
- Lancaster Choice Energy

[1] *Public Utilities Code Section 769*, California Legislature (2020)

[2] *Research Gap Analysis for Zero-Net Energy Buildings*, Energy Commission (2019)

The team solicited and received additional input from the California Solar & Storage Association, California Electric Transportation Coalition, and the Electric Power Research Institute.

Energy System Goals

The first project question -- What goals do DER need to achieve? – looks for end goals that the contributions of each DER technology can be evaluated against. Setting these goals allows different solutions to be pursued to the degree they meet the goals rather than as ends themselves. The project team selected the energy system goals that align with those developed by the U.S. Department of Energy's (USDOE) Grid Modernization Laboratory Consortium in the Foundational Metrics Analysis Project, shown in Figure 1. The goals are presented in no particular order.

Figure 1: Energy System Goals

These six goals represent the qualities California would like to promote for its electric grid. Research suggested by this roadmap should be assessed on its ability to provide improvements in one or more of these categories.

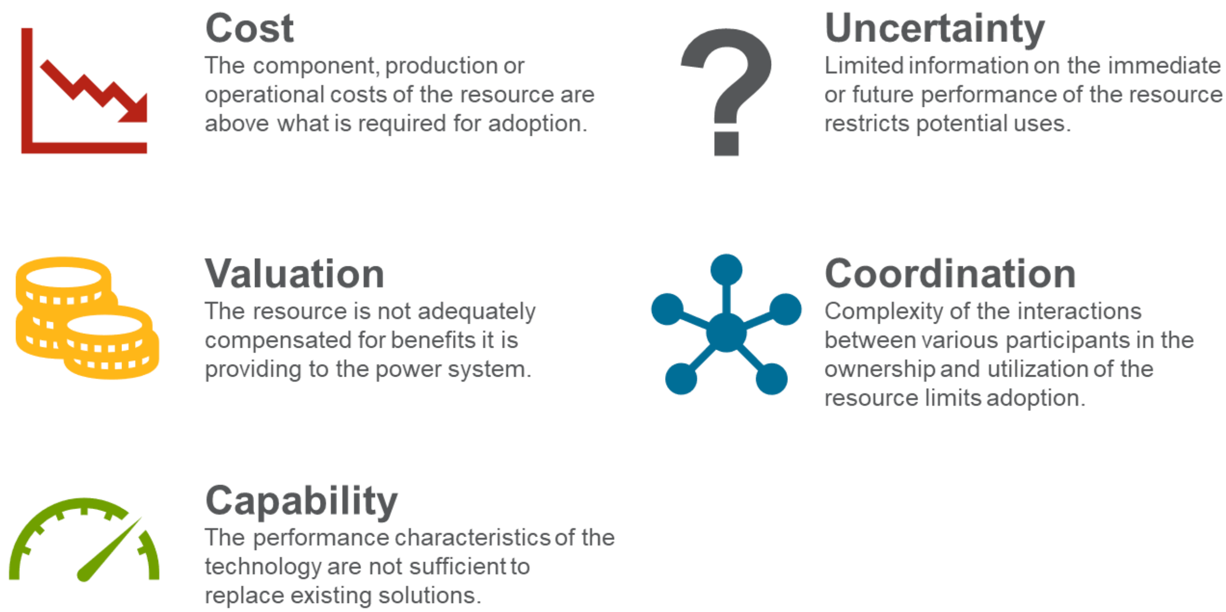
Source: Grid Modernization Laboratory Consortium

Each metric identified to assess DER capabilities was assigned to one or more of these goal categories to align DER improvement with benefits to the energy system.

Technical Assessment

The technical assessment focused on answering the second question: What are the current limitations to DER? This required a broad literature review to assess current DER contributions and research, interviews with experts, and engagement with public stakeholders to determine the technical barriers to further DER use. Because there are many different policies and regulations surrounding DER use, many of the barriers identified were of a nontechnical nature such as timing requirements for interconnection or the creation of new market products. The scope of this roadmap focuses on technical barriers, leaving the consideration of policy limitations to the Legislature and regulatory bodies. Figure 2 presents the major categories of barriers identified; the project team used these categories to organize the barriers.

Figure 2: Distributed Energy Resources Barrier Categories



This figure displays five categories of barrier that were identified in the technical assessment report. Research opportunities should support an improvement in at least one of these categories.

Source: Navigant

In the technical assessment, the project team divided DER into three major groups and then further divided them into seven subgroups:

1. Load-modifying technologies
    a. Energy storage
    b. Energy flexible load assets
    c. Vehicle-grid integration
2. DER communications and controls
    a. Distribution grid communications
    b. Distribution grid management
3. DER planning and strategy
    a. DER in grid planning
    b. DER for reliability and resiliency

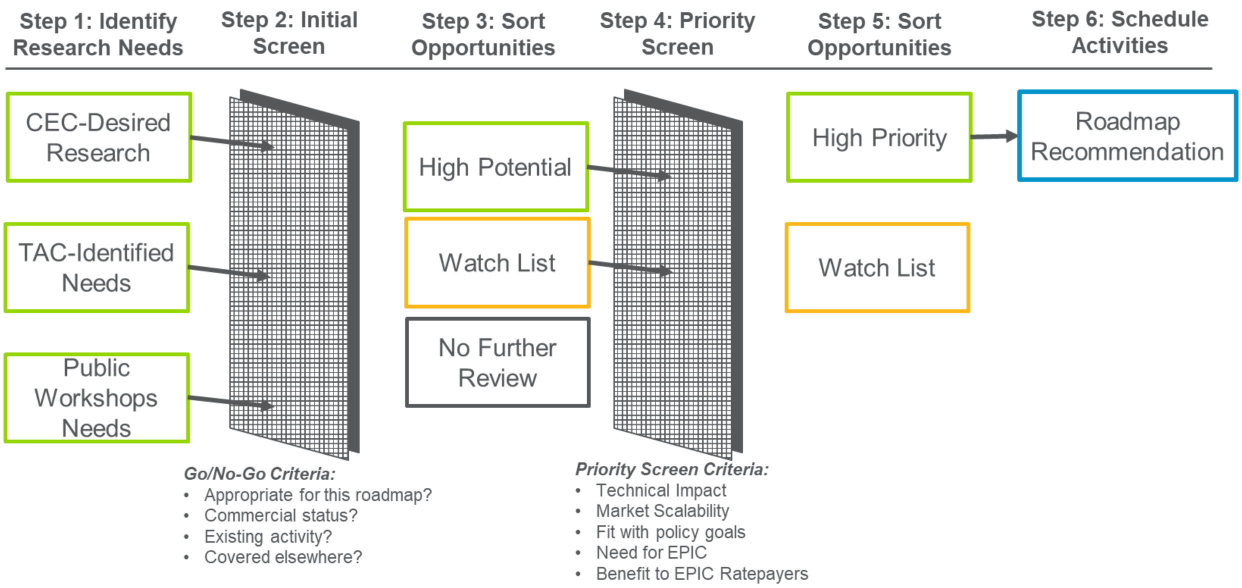
The technical assessment document is accessible at the CEC's website.[3] The energy system goals and barriers were presented in a public workshop in March 2019 and adapted based on stakeholder feedback.

[3] *DER Technical Assessment*, California Energy Commission (2019).

Prioritization Methodology

The third question — what research can resolve these limitations? — is the focus of the research roadmap. To answer this question, the project team developed a prioritization methodology, solicited the broadest spectrum of research ideas, and used that framework to filter and prioritize the ideas to find those most suitable for the roadmap. Figure 3 shows the method steps.

Figure 3: Prioritization Methodology Steps



This flowchart shows the six steps in the framework used to prioritize research needs.

Source: Navigant

Step 1: Identify Research Needs

To evaluate different research needs fairly, the project team developed a standardized template that includes the following fields:

- Description of proposed project
- EPIC investment area
- Policy goals addressed
- Barriers resolved
- Metrics impacted
- Benefit to ratepayers

The project team presented the DER status and barriers from the technical assessment and the proposed prioritization methodology at a public workshop in July 2019. After incorporating feedback from this workshop into the methodology and research needs template, the project team worked with CEC staff, the technical advisory committee, and public stakeholders to develop a set of 87 potential research ideas. The collection of original research need submissions is available at the CEC docket page for the roadmap.[4] Each research need is categorized as primarily developing a new technology (technology advancement), integrating

[4] *Initial Research Need Submissions*, California Energy Commission (2019).

mostly existing technologies with each other and the conventional grid (technology integration) and providing additional information to guide policy and procurement decisions (additional data). While the technology advancement and technology integration research needs have been assigned quantitative performance targets, some of the research needs associated with the additional data category require further information to enable setting quantitative targets. Where quantitative performance targets could not be based on an explicit public source, an estimate was developed based on the project team's discussions with DER stakeholders and expertise in the field.

Step 2: Go/No-Go Screen

The project team evaluated the set of initial research opportunities across the following four criteria to determine whether each had high, medium, or low potential:

1. Appropriate for this roadmap? This roadmap focuses on technical issues on the distribution grid. Research around the bulk power system or the resolution of policy barriers is better suited to another initiative.
2. Commercial status? Research topics in areas that have achieve full commercial status were filtered out. Novel precommercial services were not filtered, even if built on top of commercial technologies (for example, new smart home applications).
3. Existing activity? Research topics already sufficiently under investigation were filtered out.
4. Covered elsewhere? Research topics that would better be covered by another research entity were filtered out.

Step 3: Sort Opportunities

After applying the "go/no-go" screen, 41 research ideas remained. The topics that did not pass the screening are included along with the reason for their removal are presented in APPENDIX D: List of All Proposed Research Needs. Because topics were submitted simultaneously from a range of public stakeholders, the project team and the advisory committee, several submissions had significant overlap. These suggestions were consolidated into a single topic, representing most of the reduction from the initial set of research opportunities.

Step 4: Prioritization Screen

The second screening evaluated the research needs under a second set of criteria:

- Benefit to EPIC ratepayers: How much do EPIC ratepayers benefit relative to the estimated cost of the project?
- Technical impact: How much is this research expected to improve DER performance metrics?
- Market scalability: How much can the performance improvements benefit the energy system?
- Fit with policy goals: How effectively does the research achieve California's energy system goals?
- Need for EPIC: How necessary is EPIC research funding to performing this research?

Step 5: Sort Opportunities

The project team presented the remaining research needs to technical advisory committee members in survey format to solicit feedback on the perceived relative importance. Each category in the prioritization screen was scored on a scale of 1 to 5. An aggregate rating for each research need was calculated using the weights shown in Table 1.

Table 1: Prioritization Screen Weighting

Metric	Weight
Technical Impact	20%
Market Scalability	15%
Fit with Policy Goals	30%
Need for EPIC	15%
Benefit to EPIC Ratepayers	20%

The total score of a research idea was calculated by weighting each individual category score using the values in this figure.

Source: Navigant

The survey results were presented at a public workshop in September 2019. Comments were received and integrated into the relative scorings of the different opportunities. Because the sample size of the technical advisory committee was small, these ratings were considered informational in the evaluation process; the project team binned research ideas by priority level rather than ranking them individually by score.

Step 6: Schedule Activities

The project team evaluated the potential research activities based on their priority level, complexity, and estimated duration; the team then identified prerequisite research and assigned each activity to short (one to three years), medium (three to five years), and long (five-plus years) time horizons. Priority level is influenced by the estimated level of impacts as well as the level of urgency driven by state policy and electrical system conditions. Chapter 6 presents the output of this process, the research roadmap.

CHAPTER 2: Relevant Energy Policies

CEC research supports the efficient pursuit of California's energy policy goals by removing technical barriers. To align research pursuits in each category with these policy goals, Table 2 covers the range of energy policy drivers relevant to each category. Appendix A summarizes the content of these policies and legislation and Appendix B identifies policies supported by each research need.

Table 2: Summary of Policies and Legislation Affecting Technological Development within DER Subgroups

Policy/ Legislation	Energy Storage	Flexible Load Assets	VGI	Dist. Grid Comms	Dist. Grid Management	Grid Planning	Reliability/Resiliency
AB 1144	x		x			x	x
AB 2514	x		x			x	
AB 2868	x		x		x	x	
AB 32	x	x			x	x	
AB 3232	x	x		x	x	x	
AB 327						x	
AB 38					x		x
AB 523						x	x
AB 693		x				x	x
AB 758						x	
SB 100 (RPS)	x	x	x	x	x	x	x
SB 1339						x	x
SB 1371						x	
SB 1382						x	
SB 1477		x					
SB 150						x	
SB 32	x	x			x	x	
SB 338	x	x		x	x	x	x
SB 350	x	x			x	x	
SB 49	x	x		x	x	x	
SB 535						x	x
SB 676			x		x	x	
SB 70							x

Policy/ Legislation	Energy Storage	Flexible Load Assets	VGI	Dist. Grid Comms	Dist. Grid Management	Grid Planning	Reliability/Resiliency
SB 700	x		x				
SB 901			x		x		x
SB 167			x		x		
California Executive Order B-48-18			x		x		
California Executive Order B-55-18	x	x			x	x	
California Executive Order: Petroleum Use Reduction			x				
CEC Mandate: Solar on New Construction		x			x		x
CEC: Clean Energy in Low-Income Multifamily Buildings Action Plan		x			x	x	x
CEC: Energy Innovations Small Grant Program		x					x
California Code: Title 24		x					
CPUC: Alternative Fuels Vehicles (R. 13-11-007)		x	x		x		
CPUC: California Long-term Energy Efficiency Strategic Plan		x					
CPUC DER Action Plan		x	x	x	x	x	
CPUC: Decision 18-02-004		x			x		
CPUC: Demand Response (R. 13-09-011)				x	x	x	
CPUC: DER Interconnection (R. 17-07-007)		x	x		x	x	
CPUC: Distributed Generation (R.12-11-005)			x		x	x	
CPUC: Net Energy Metering (R. 14-07-002)						x	
CPUC: Rates and Infra-structure for Vehicle Electrification (R. 18-12-006)			x				
CPUC: Rule 21					x	x	
CPUC: Self-Generation Incentive Program	x						
Federal: Build America Investment Initiative					x		
Federal: USDOE's Grid Modernization Initiative					x		

Policy/ Legislation	Energy Storage	Flexible Load Assets	VGI	Dist. Grid Comms	Dist. Grid Management	Grid Planning	Reliability/Resiliency
Federal: Energy Independence and Security Act of 2007		x		x			
Federal: FERC Order 719	x	x		x	x		
Federal: FERC Order 745	x	x		x	x		
Federal: FERC Order 755/784	x			x	x		
Federal: FERC Order 792	x			x	x		
Federal: FERC Order 841	x			x	x		
Federal: Partnership for Energy Sector Climate Resilience	x			x	x		
Other: Net Zero Carbon Buildings Commitment	x	x			x	x	
Other: Pacific Coast Collaborative Greenhouse Gas Reduction Target	x	x			x	x	

Items in the table were identified policy drivers addressed by each proposed research need.

Source: Navigant

CHAPTER 3: Load-Modifying Technologies

Load-modifying technologies are a subset of the wider DER integration challenge and consist of the devices that directly affect usage on the electric grid. While there are many ways to categorize these types of assets, this research roadmap looks at three subgroups:

- Energy storage: Stationary devices capable of both consuming and delivering energy.
- Energy flexible load assets: Customer-sited loads that can be modulated or shifted in response to a price signal, a financial incentive, an environmental condition, or a reliability signal, but that would not provide generation themselves.
- Vehicle-grid integration: Interactions around electric vehicles (EVs) and the power grid.

Vehicle-grid integration is a separate category because the mobile nature of the loads provides an additional layer of complexity with coordination relative to geographically stationary devices. Figure 4 lists technologies and strategies in each of the subgroups.

Figure 4: Load-Modifying Technologies by Subgroups

There are many different types of device or service in each load-modifying technology area.

Source: Navigant

Energy Storage

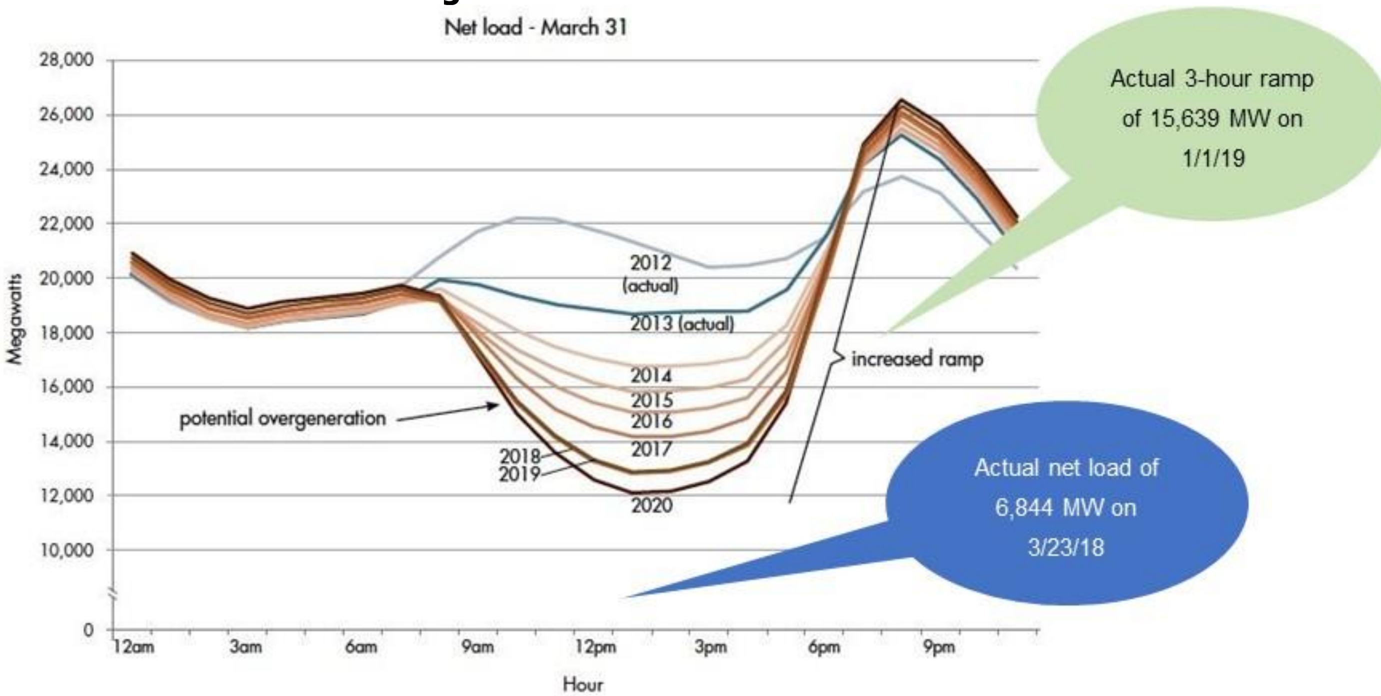
Higher penetrations of intermittent resources like wind and solar lead to a need for flexibility in the electric system. Energy storage is one of several solutions able to provide rapid response at both the bulk and distributed levels to smoothly balance supply and demand. At the bulk level, energy storage can use existing transmission infrastructure while distributed energy storage connected to the distribution network, either behind or in front of the customer meter, is able to provide flexibility more locally.

The grid experiences high periods of imbalance between load and generation at two points during the day:

- The early evening when solar power drops off and load rises
- Close to midday when solar generation is high and load is relatively low, particularly during the spring and autumn

This imbalance has led to a phenomenon known as the duck curve, named for the resemblance of the graph in Figure 5 to the animal. These ramping constraints have led to instances of negative wholesale energy prices when power plants submit bids below zero but above the total cost of turning off when transmission or generator flexibility constraints arise.

Figure 5: California Duck Curve



The need to quickly ramp generation up and down is increasing with the installation of more solar resources.

Source: California ISO

A work group presentation by the California ISO[5] shows a maximum 3-hour ramp of 15,639 MW in 2019. This swing in net demand requires significant generation to be brought online rapidly to simultaneously match the demand as renewable generation from wind and solar decreases and customer load increases. Ramping requirements will increase as the amount of solar generation grows.

Energy storage can help flatten the duck curve by storing renewable-generated energy during periods where generation exceeds demand and then providing that stored energy during periods of peak demand and low generation. This will reduce the grid's reliance on the fast-reacting fossil-fuel peaker plants that are currently used to meet peak demand and keep supply and demand of electricity balanced. Energy storage solutions can also be used as spinning, non-spinning, or regulation reserve capacity to lower the requirements of traditional reserve capacity, and increase the efficiency of running generators, resulting in reduced fossil fuel use and their associated emissions if dispatched to that objective. Energy storage is applicable to today's flexibility concerns and will be increasingly important to provide dispatchability as California transitions to a fully decarbonized power system. In March 2019,

5 *Resource Adequacy Enhancements*, California ISO (2019.)

the California ISO curtailed 122,225 MWh of wind and solar generation compared to 94,778 MWh in March 2018, and 81,776 MWh in March 2017.[6]

Ramping requirements have increased to support the fluctuations in generation from renewables and the large shift required to meet peak evening demand as solar generation decreases. This ramp, especially in California, is commonly supported by combined-cycle natural gas turbines because of their ability to quickly start and ramp up, but the need can increasingly be met with alternative resources like energy storage.

Energy Storage - Technical Assessment

The technical assessment identified several energy storage use cases and technologies. The primary use cases are listed below in order of decreasing cycle frequency:

- Power quality: Frequency regulation, frequency response, voltage support, power factor management, and volt/volt-ampere reactive (Volt/VAR) optimization support
- Bulk energy: Wholesale energy arbitrage, operating reserves, load following, and generation portfolio optimization
- Peak shaving: Generation, transmission, and distribution capacity support and renewable curtailment avoidance
- Contingency: Regional black start, reliability, and backup power.

The design and construction of energy storage systems depends strongly on the technical needs. Power-oriented systems are designed to provide instantaneous power output for a short time. Energy-oriented systems are designed to provide energy for longer durations, with a longer output capacity relative to their power capacity. These systems can be classified as follows:

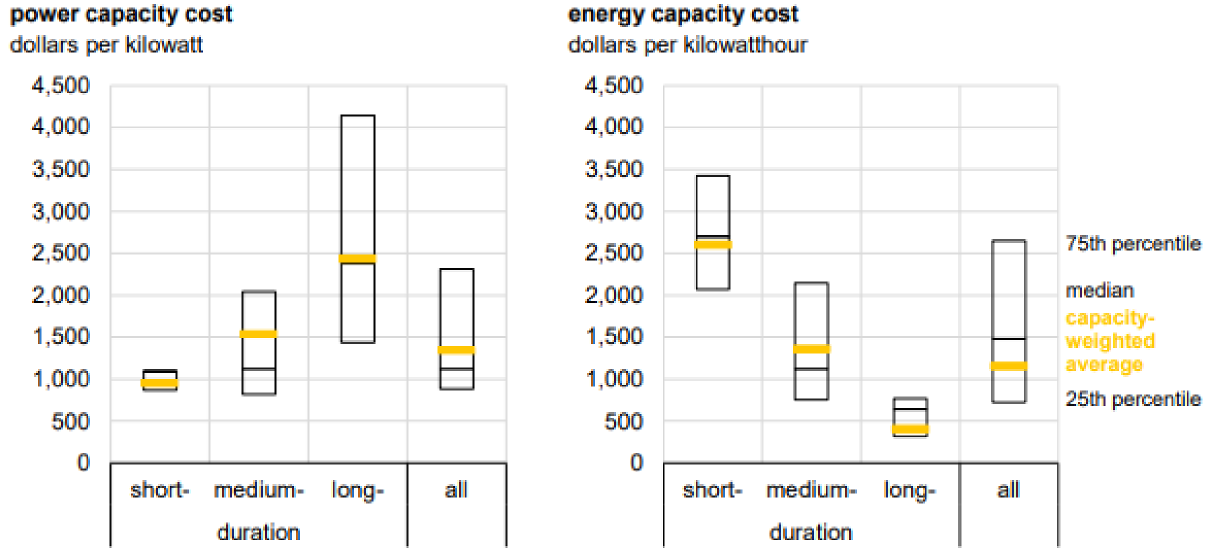
- Short duration: Power-oriented, durations less than 30 minutes
- Medium duration: Durations ranging between 30 minutes and 10 hours
- Long duration: Energy-oriented, more than 10 hours with the potential to provide 100+ hours of energy.

While much of the distributed energy storage installed to date has focused on short and medium duration applications, long-duration, energy-oriented storage systems are expected to be increasingly important for shifting the bulk of the solar generation peak into the evening hours when solar is unavailable. As displayed in Figure 6, longer duration, energy-oriented battery systems have higher average costs per kilowatt and lower costs per kilowatt-hour, and vice versa for shorter duration, power-oriented battery systems. Early-stage research completed by the CEC indicates that long duration energy storage (10 hours or longer) has the potential to be produced at a price per kilowatt hour is substantially lower than the price per kilowatt hour for short or medium duration energy storage technologies. Upcoming CEC

[6] *Managing Oversupply*, California ISO (2019).

research efforts like GFO-19-306[7] and GFO-19-308[8] are underway to further study these issues.

Figure 6: Total Installed Cost of Large-Scale Battery Storage Systems by Duration (2018)



The power and energy capacity costs of battery storage vary significantly based on the duration; both should be considered when evaluating storage cost.

Source: EIA, Form EIA-860

There are several types of storage technologies to choose from, each with their own inherent strengths and weaknesses. Typically, the optimal storage technology is selected based on the economics of the technology's designed operational use case. The technical assessment document provides further details on the capabilities and development status of different energy storage technologies.

Energy Storage - Barriers

Cost

Capital costs higher than conventional generation: While the costs of battery storage have dropped significantly over the last decade, the cost to provide a set amount of power from distribution-connected storage is often greater than existing centralized generation when emissions and environmental impacts are not considered. However, growing numbers of larger grid-scale energy storage systems are being installed in California under AB-2514 and AB-2868 and in other locations outside of California. Where most of these systems are not

[7] *Demonstrating Long Duration and Title 24-Compatible Energy Storage Technologies*, California Energy Commission (2020).

[8] *Assessing Long-duration Energy Storage Scenarios to Meet California's Energy Goals*, California Energy Commission (2020).

considered DER, their growth will result in a substantial reduction in the cost of smaller scale energy storage technologies.

Competition for limited energy storage components: While increases in the scale of production of consumer electronics and EV batteries have driven down the production cost of grid battery technology, growing demand for batteries in these other applications and the instability of the rare mineral supply chain may cause the costs of the raw materials to rise. Alternative storage technologies not suitable for transportation applications may have less competition. The CEC is studying alternate, non-lithium ion storage technologies including thermal storage using heated carbon blocks, flow batteries and a variety of zinc ion chemistries.[9]

Valuation

Not all potential benefits compensated: Though there are several active proceedings to assess and compensate for the value provided to the electric system by the flexibility of energy storage, not all devices may have direct opportunities to participate in markets. The CPUC's Multiple-Use Applications proceeding provided clarity on how storage resources in different domains can participate in multiple use cases, but the wholesale market opportunities are still in development, especially for smaller, behind the meter resources.

Socialized customer grid costs: Customer cost of utility electric service to outlying and potentially fire-prone areas of California is intentionally limited in the existing market design so that all customers can have equal access to electricity. If customers were exposed to the full costs, distributed energy storage would become more cost-competitive with traditional distribution system service. Energy storage may also see higher rates of adoption if public safety power shutoffs increase due to potential fire risk.

Capability

Safety concerns: Recent incidents of lithium-ion battery fires[10] and fuel cell explosions[11] have prompted concerns from customers and investors about the safety of energy storage systems. Lithium-ion technologies face a fundamental tradeoff between energy density and stability, but alternative storage technologies are not free of safety risks. For examples, flywheels have the risk of rotor failures. In addition to acute safety incidents, damaged battery cells may also require hazardous material treatment. Public perception may also overestimate the risk associated with new technologies relative to conventional technologies; additional research can support an accurate understanding of risk. As new alternative battery chemistries and new technology designs mature, some of these concerns are expected to be substantially reduced or mitigated.

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[9] *Developing non-Lithium Ion Energy Storage Technologies*, California Energy Commission (2020).

[10] *McMicken Battery Facility Update*, Arizona Public Service (2019).

[11] *Hydrogen Safety Concerns*, Ars Technica (2019).

Hardware requires too much physical space: The dense urban areas where potentially replaceable distribution grid infrastructure improvements have the highest cost are also usually the most space-constrained. This limits lower energy density energy storage technologies from participating in potentially lucrative opportunities.

Complexity of scheduling multiple applications with imperfect foresight: While regulations permit time-differentiated (using the resource for different jobs at different times) and capacity-differentiated (reserving part of the resource capacity for different jobs at the same time) participation in multiple applications, and some vendors market solutions that optimize controls across these opportunities, the facilities studied in the literature review showed limited capacity-differentiated optimization; rather, the facilities focused on a primary use case, potentially with additional secondary use cases.

Multiday storage duration: Multiday durations are important for resiliency and emergency services in the case of extended grid outages. Most storage technologies currently installed are focused on short-term applications but are not designed to support multiday durations for energy-shifting. While the difference in energy prices at different times is often not high enough to justify storage-based energy arbitrage, achieving California's ambitious decarbonization mandates may increase the spread between the low and high wholesale market energy prices and provide additional economically viable applications. In 2020, the EPIC program began researching long duration energy storage technologies that can provide 10 hour or longer capability in a variety of use cases, studying both the role of these technologies in the state achieving its carbon reduction goals[12] as well as developing the technologies themselves[13].

Flexibility of installation size: Many grid service applications, such as infrastructure deferral, are scoped based on upcoming load forecasts. While these forecasts are as accurate as possible, changes in projected load, and required storage size, are not uncommon. Technologies that are more able to scale up and down in capacity without a system redesign will have an advantage in procurement.

Coordination

Requires specialized installation and maintenance: Relatively new technologies require specialized skillsets in installers and maintainers. Anecdotal evidence showed that limited familiarity with new code requirements has created difficulties with storage adoption. The project team was not able to identify California-specific installation and permitting cost figures during the literature review however, in 2020, the EPIC program began developing a publicly available energy storage guidebook to help address these challenges DER systems encounter and to shorten the time frame and reduce the cost of installing energy storage DER systems.

[12] *Assessing Long-duration Energy Storage Scenarios to Meet California's Energy Goals*, California Energy Commission (2020).

[13] *Demonstrating Long Duration and Title 24-Compatible Energy Storage Technologies*, California Energy Commission (2020).

Still-nascent permitting processes and safety requirements: Requirements for developing technologies may not be fully apparent in all locations, particularly when considering the full range of national, state, and municipal requirements. The additional coordination required with local fire and building codes may delay storage installations. An CEC study noted that permitting barriers were not a major problem but that there remained significant room for improvement.[14]

Difficulty in customer acquisition: During PG&E's Behind-the-Meter Storage EPIC project,[15] PG&E encountered challenges acquiring participants. The key reasons included lack of access to customer information for vendors, customer solar sales fatigue, improper incentives, and lack of clear strategy. Furthermore, many existing solar system inverters could not participate because the residential vendor's solar lease contracts prohibited solar generation curtailment. Challenges in customer acquisition mean that behind-the-meter storage assets may not be able to be sited in the specific locations required by non-wires alternatives applications.

Dynamic and resilient control: Pilots like PG&E's Behind-the-Meter Storage EPIC project[15] have tested fixed control signals and identified several follow-on opportunities to study what more dynamic and variable controls of customer-sited storage would look like, particularly emphasizing communications performance and asset performance. Barriers to at-scale implementations related to communications performance include inadequate communication uptime, gaps in asset data accuracy and visibility, and lack of scalability of communications between utilities and aggregators. A challenge related to asset performance involves discrepancies in listed and actual unit charging efficiency, which could lead to less energy being available for peak reduction— an expected 4-hour operation could end 15 minutes early, exposing the customer to a demand charge spike and the distribution grid to unexpected overload conditions.

? Uncertainty

Third-party controls visibility: Distribution system operators (DSOs) do not have control over or visibility into behind-the-meter storage resources. Potential negative effects to distribution system operation are mitigated by non-export requirements on solar plus storage installations. With more awareness of, and communication with, third-party devices, restrictions could be relaxed, and the system can be operated more efficiently.

Resiliency valuation: As of the writing of this roadmap, no framework has been finalized to quantify the potential resiliency benefits of energy storage. The issue is however under discussion in CPUC proceeding R.19-09-009.[16] Demonstration and evaluation of storage used for some of these additional use cases would support certainty in deployment decisions.

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[14] *Final Report on Policy Recommendations for Permitting Energy Storage*, California Energy Commission (2017).

15 *EPIC 2.19C – Customer Sited and Behind-the-Meter Storage*, PG&E (2018).

[16] *Order Instituting Rulemaking Regarding Microgrids Pursuant to Senate Bill 1339*, CPUC (2019).

Technology market maturity: While some technologies like lithium-ion batteries are seeing widespread adoption, alternate battery chemistries or means of energy storage are less familiar and face more uncertainty when obtaining financing.

Energy Storage - Research Needs

Distributed Thermal Energy Storage Aggregation

Research Description

This project will expand on the research conducted in an EPIC project[17] to assess the ability to control behind-the-meter thermal loads in response to wholesale grid prices and for the loads to be considered to support resource adequacy requirements. The project report notes that the thermal resources participated in simulated frequency response along with day-ahead and real-time energy market participation. However, the control strategies used were highly complex and dependent on a range of factors including wholesale market pricing, the actual loads available to modulate (depending on customer occupancy), building characteristics, and environmental conditions. There is significant potential to use these types of existing loads as storage, but the full interaction with real market uncertainties, aggregation issues, telemetry and communications requirements needs to be studied. This project would develop a more standardized model for estimating potential contributions of thermal energy storage for different types of building loads to allow a quicker and more accurate assessment of the abilities to participate in wholesale markets.

Barriers Resolved

- Third-party controls visibility: Providing communication between grid needs and behind-the-meter flexible loads can allow grid planners and grid operators additional flexibility; this communication can also provide an opportunity to reduce energy costs for customers.
- Difficulty in customer acquisition: Additional research on issues that arise with localized customer acquisition, both on contracting and coordinating the physical installation of required hardware, will facilitate more efficient integration of behind-the-meter thermal storage.

Metrics Impacted

- Reliability
    - Installed energy capacity of thermal storage portfolio available to market participation
    - Installed power capacity of thermal storage portfolio available to market participation
- Flexibility
    - Ramp rate of thermal storage portfolio
    - Number and percentage of customers on time-variant or dynamic pricing tariffs

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[17] *Meeting Customer and Supply-side Market Needs with Electrical and Thermal Storage, Solar, Energy Efficiency and Integrated Load Management Systems, EPC-15-074*, Center for Sustainable Energy (2016).

Benefits to Ratepayers

- Total electricity deliveries from grid-connected distributed generation facilities
- Customer bill savings

Metrics and Targets (Technology Integration)

- Performance
  - Total capacity of behind-the-meter thermal loads responding to wholesale market signals in kilowatts
  - Resource must deliver ancillary service capacity within 10 minutes of request with at least 90 percent of the amount of energy requested in the dispatch[18]
  - Resource must succeed in at least 5 of the qualifying tests in the above bullet in one month to pass performance audit
  - Capacity of the resource bid into the market must exceed 80 percent of the initial estimated resource capacity
- Price
  - Market revenues and bill savings enough to fully offset lifetime installation, maintenance and operations costs
  - Provide bulk energy shifting at less than $0.05 per kWh shifted
  - Wholesale participation fees less than $10/kw-year of participating load[19]

Priority

- High

Time Horizon

- Short-Term

Funding Category

- Technology Demonstration and Development

Battery Performance Testing Protocols for Grid Applications

Research Description

Previous demonstration projects[20,21] have identified a series of potential issues with real-world operation of energy storage across communication, battery management system, inverter, and cell components. This project would establish testing protocols to ensure systems are resilient to gaps in communications, incorrect state of charge measurements or efficiency expectations, and conflicting customer and grid instructions. These protocols would allow vendors and installers to confirm their project meets the requirements tested during the utility

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[18] *Resource Performance Verification*, California ISO (2020).

[19] To match the participation fees of an individual 1 MW resource. *Grid Management Charge Rates for 2014-2019*, CAISO (2019).

[20] *EPIC 2.19C – Customer Sited and Behind-the-Meter Storage*, PG&E (2018).

[21] *EPC-14-053 Direct Current Building Scale Microgrid*, California Energy Commission (2018).

interconnection application, avoiding costly re-dos that have been identified as a barrier to cost-effectively installing storage systems. Coordination with the CPUC, investor-owned utilities and California ISO is necessary to ensure the tests cover the appropriate range of situations. The results of this testing could be added to existing work begun through the CEC's Solar Equipment Lists[22].

Barriers Resolved

- Third-party controls visibility: This project would reduce uncertainty of the extent to which distributed storage can be relied on for critical grid applications.

Metrics Impacted

- Reliability
    - Energy storage capacity

Benefits to Ratepayers

- Increased number of and total nameplate capacity of distributed generation
- Maintain or reduce operations and maintenance costs

Metrics and Targets (Additional Data)

- Performance
    - Increase the number of reviewed systems and technologies on the CEC's published equipment lists from 31 to greater than 50
    - Performance testing protocols should include:
        - Battery management system controls function as intended
        - Battery management system communications function as intended
        - Communications failures are raised
        - Communications latency is sufficient for participation in intended grid services (~4 seconds for frequency regulation)
        - Data collection and recording system is functional
        - Battery management system reports status accurately
        - Charge and discharge rates match expectations across all operating temperatures and states of charge
        - Any required non-export hardware or software functions as intended
        - Battery round trip efficiency meets product specifications
        - Battery depth of discharge meets product specifications

Priority

- Low

Time Horizon

- Short-Term

Funding Category

- Applied Research and Development

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[22] *Solar Equipment Lists (includes storage)*, California Energy Commission (2020).

Storage Safety Standards

Research Description

With the wide adoption of DER including storage, a common set of safety standards needs to be developed and validated. New safety protocols such as UL 3001 need to be reviewed and potentially required. Technology developers typically do not have access to sophisticated onsite tools to assess health and performance of individual components. Additional studies in this area can help to resolve uncertainty barriers being experienced by potential DER adopters. Incidents like the McMicken lithium-ion battery fire in Arizona in April 2019[23] demonstrate the potential dangers of high energy density solutions, and the need to provide safety protocols to decrease fire risks. The testing protocols need to study the battery cells themselves and the appropriate enclosures, ventilation, and fire control strategies, including for emerging applications like second-life EV batteries being used as stationary storage. This project would include coordination with the National Fire Protection Association to extend the content in their Emergency Field Guide on battery and fuel cell EVs to include stationary technologies, as well as with local fire department requirements for siting and permitting stationary storage. Deploying effective training for firefighters and other first responders will increase confidence and reduce concerns that could otherwise inhibit the adoption of battery storage, fuel cells, and other energy storage technologies in the market. This project would expand existing work begun through the CEC's Solar Equipment Lists[24] and following the Energy Storage Safety Best Practices published by the Public Utility Commission[25].

Barriers Resolved

- Still-nascent permitting processes and safety requirements: This research can inform fire code and other safety requirements, especially for emerging storage technologies.

Metrics Impacted

- Flexibility
  - Nameplate capacity (megawatts) of grid-connected energy storage.

Benefits to Ratepayers

- Maintain or reduce operations and maintenance costs.
- Improved system operation efficiency from increased flexibility.
- Energy security.
- Improved public safety.
- Improved utility worker safety.
- Support for energy system resiliency in the face of power shutoffs.

Metrics and Targets (Additional Data)

- Performance

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[23] *McMicken Battery Facility Update*, Arizona Public Service (2019).

[24] *Solar Equipment Lists (includes storage)*, California Energy Commission (2020).

[25] *Safety Best Practices – Energy Storage*, California Public Utility Commission (2020).

    - Measure average duration of safety inspection process in first year; reduce this time by 10 percent year over year.
    - Increase the number of reviewed systems and technologies on the CEC's published equipment lists from 31 to greater than 50. Energy storage installations must include a function to prevent contributing to the formation of an unintended island (energizing an electrically isolated portion of the distribution system) and cease to energize the distribution system within two seconds of island formation per California Rule 21 Section H.1a.iii.
    - Electrolyte-based energy storage should follow IEEE 1578 recommended practice for Electrolyte Spill Containment and Management.
    - Battery energy storage systems should follow the UL 9540 standard for potential energy, electrical, mechanical and chemical hazards.[26]
    - Battery energy storage systems should be evaluated for runaway fire propagation following the UL 9540A test method.[27]
    - Energy storage should meet National Fire Protection Association (NFPA) Standard 855.[28]
- Price
    - Reduce costs of validating technologies against safety protocols.

Priority

- Medium

Time Horizon

- Short-Term

Funding Category

- Technology Demonstration and Development

Evaluate Alternate Storage Technologies

Research Description

Recently, lithium-ion batteries have represented most new storage installations and studies[29] predict that lithium-ion batteries will continue to lead the energy storage market across several use cases. However, to enable greater renewable energy integration, the energy system needs to move large blocks of energy from peak renewable generation hours to peak demand hours. At present, many storage resources are focused on use cases involving shorter duration flexibility and are most active in the regulation and ancillary services markets. Some research suggests that this is because the cycling costs and potential degradation to the cells for fully discharging their full capacity are too high. More information is needed on the total cost of

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[26] *Standard 9540 for Energy Storage Systems and Equipment*, Underwriters Laboratory (2020).

[27] *Test Method 9540A for Evaluating Thermal Runaway Fire Propagation*, Underwriters Laboratory (2020).

[28] *Standard for Installation of Stationary Energy Storage Systems*, NFPA (2020).

[29] "Projecting the Future Levelized Cost of Electricity Storage Technologies," *Joule* Volume 3, Issue 1 (2019).

storage for the different technologies and which are best suited to each use case, particularly considering the potential of non-lithium ion storage. The CEC is specifically studying the potential for alternate distributed storage technologies such as thermophotovoltaic-based storage, flow batteries, green electrolytic hydrogen, and a variety of zinc-ion chemistries.[30] The goal of this research should be to find the least total cost solution, including capacity costs and variable costs, to move energy, accounting for the bulk of the energy to be moved. The parameters of the bulk energy needed to be shifted can be informed by upcoming CEC research under GFO-19-308[31]. Many studies focus on the total capacity cost of batteries but do not account for limitations on cycle life, depth of discharge, and other operating requirements that would affect the total economics of shifting energy. This research would assess different storage chemistries and configurations on the total cost to perform the bulk shifting of energy that will be required as the state moves toward a 100 percent zero-carbon energy standard. The project would also evaluate the capability of different technologies of supporting significant multi-day energy storage needs in support of distributed resilience. New technologies evaluated can be included in California generation resource modeling for SB 100 alongside existing technologies to assess additional flexibility they are able to provide to the power system.

Barriers Resolved

- Capital costs higher than conventional generation: Better information on the levelized costs of storage can lead to storage technologies procurements that best match the use case.

Metrics Impacted

- Flexibility
    - Load arbitrage opportunities
- Sustainability
    - Maintain performance over time

Benefits to Ratepayers

- Avoided procurement and generation costs
- Increased nameplate capacity (megawatts) of grid-connected energy storage

Metrics Targets (Technology Advancement)

- Performance
    - Provide bulk energy shifting capabilities for a minimum of 10 hours.
    - Provide 10 years of full productivity at the use profile required for bulk energy shifting.
    - Minimal geographic siting constraints.
    - Round-trip efficiency greater than 50 percent.

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[30] *Developing non-Lithium Ion Energy Storage Technologies*, Energy Commission (2020).

[31] *Assessing Long-duration Energy Storage Scenarios to Meet California's Energy Goals*, Energy Commission (2020).

- Price
    - Provide bulk energy shifting at less than 5 cents per kWh per cycle.[32]

Priority

- High

Time Horizon

- Short-Term

Funding Category

- Applied Research and Development

Next Generation Lithium-ion Storage

Research Description

As mentioned previously, lithium-ion batteries have been the technology of choice for many recent installations, particularly around shorter duration use cases. Alongside the research into improving the performance and reducing the costs of alternate storage technologies, study into improvements in lithium-ion battery design, operation and recycling is also merited. This research project would also study the optimal control strategies to use lithium-ion batteries for longer-term energy shifting while minimizing adverse impacts to battery life. Another potential improvement in lithium-ion technology is to reduce the cost and environmental impact of production. The CEC is studying the potential for a "Lithium Valley", producing California-sourced lithium using clean geothermal energy to lower the lifecycle impact of the production of critical battery components.[33]

Barriers Resolved

- Capital costs higher than conventional generation: Better information on the levelized costs of storage can lead to storage technologies procurements that best match the use case.

Metrics Impacted

- Flexibility
    - Load arbitrage opportunities
- Sustainability
    - Maintain performance over time.

Benefits to Ratepayers

- Avoided procurement and generation costs
- Increased nameplate capacity (megawatts) of grid-connected energy storage

Metrics and Targets (Technology Advancement)

- Performance[34]

[32] Price target aligning with Duration Addition to Electricity Storage (DAYS) goal, DOE (2019.)

[33] *California's Lithium Recovery Initiative*, California Energy Commission (2020).

[34] *A Forum on Batteries: From Lithium-ion to the Next Generation*, National Science Review (2020).

- Energy density of at least 400 Wh/kg at the pack level.
    - Cycle life beyond 10,000 cycles.
    - Cycling stability at high temperatures.
    - Operating temperature range between –40°C to 80°C.
    - Reduce carbon emissions below 50 kg CO_2e/kWh of battery pack.[35]
- Price
    - Provide grid services at less than $100/kWh of battery capital cost.[36]
    - Provide grid services at less than $400/kW of battery capital cost.

Priority

- High

Time Horizon

- Short-Term

Funding Category

- Technology Demonstration and Development

Energy Storage Recycling

Research Description

Not enough research exists on the end-of-life waste stream of different DER technologies, particularly storage. Recycling is challenging, with a major barrier being the range of different battery technologies with different alloys and solutions making a standardized approach difficult. Studies should be conducted to identify what technology is needed to profitably recycle different battery chemistries, and what information would be needed to inform potential regulation around battery recycling efficiency. The project will also report on safety considerations in recycling any toxic storage components. The CEC is studying the re-use of electric vehicle batteries for the integration of solar power[37] but additional study can be performed on recycling of these components.

Barriers Resolved

- Competition for limited energy storage components: Providing insights to facilitate more frequent and efficient recycling for battery technologies will alleviate concerns on raw material supply.
- Capital costs higher than conventional generation: Recovering costly input materials can help lower the production costs of new batteries.

Metrics Impacted

- Affordability
    - Full life cycle cost of battery energy storage

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[35] *Analysis of the Climate Impact of Lithium-Ion Batteries*, Transportation & Environment (2019).

[36] Based on break-even price given estimated market revenues for a 1 MW / 4 MWh unit.

[37] *Validating Capability of Second-life Batteries to Integrate Solar Power*, California Energy Commission (2020).

Benefits to Ratepayers

- Non-energy economic benefits from providing more cost-effective measures to recycle or process energy storage devices at their end of life
- Improved public safety from more standardized energy storage processing at end of life

Metrics and Targets (Technology Advancement)

- Performance
    - Improve percentage of Li-ion batteries that are recycled to 5 percent, 10 percent and 15 percent in successive years
    - Improve recycling efficiency rate (RER), or percentage of Li-ion batteries that can be recovered through recycling processes, to over 50 percent (current rate)
    - Reduce waste generation from recycling processes
    - Increase year-over-year recycling capacities of spent batteries in metric tons (MT)
- Price
    - Number of additional charging cycles enabled, allowing more usage from each battery and thus lowering the cost per use
    - 40 percent reduction in cost for recycled relative to virgin cathode materials[38]

Priority

- Medium

Time Horizon

- Long-Term

Funding Category

- Applied Research and Development

Green Electrolytic Hydrogen for Long-Duration Storage

Research Description

While lithium-ion battery chemistries have proven to be effective at providing short- and medium-term energy storage, longer-duration applications may be more effectively served with fuel cells. Electrolysis-based hydrogen production (at times of solar or wind over-generation) and storage could improve the flexibility of the electric grid. This "green electrolytic hydrogen" is defined in the Green Electrolytic Hydrogen senate bill[39] as hydrogen produced through electrolysis and not a fossil fuel feedstock and is included as an eligible form of energy storage. This research project would explore distributed fuel cell installations and hydrogen production in support of reducing wind and solar generation curtailment. The project would also establish cost and performance targets for effective hydrogen-based long-duration

[38] Economics and Challenges of Li-Ion Battery Recycling, NREL (2019).

[39] *Senate Bill 1369*, California Legislature (2018).

energy storage, particularly compared to other energy storage technologies. The CEC is in the process of studying this topic under Group 2 of the Non-Lithium Ion Energy Storage initiative.[40]

Barriers Resolved

- Technology market maturity: Market support for distributed fuel cell applications would allow a wider range of energy storage technologies to be developed.
- Capital costs higher than conventional generation: Additional research for alternative energy storage technologies can help to drive down costs and increase confidence in deployments of these technologies.

Metrics Impacted

- Sustainability
  - Reduction in curtailed renewable energy.

Benefits to Ratepayers

- Non-energy economic benefits.
- Improved public safety.
- Support for energy system resiliency in the face of de-energizations.

Metrics and Targets (Technology Advancement)

- Performance
  - Provide bulk energy shifting capabilities for a minimum of 10 hours.
  - Provide 10 years of full productivity at the use profile required for bulk energy shifting.
  - Minimal geographic siting constraints such that electrolytic hydrogen can pursue all storage opportunities.
  - Round-trip efficiency greater than 50 percent.
- Price
  - Provide bulk energy shifting at less than 5 cents per kWh per cycle.[41]

Priority

- High

Time Horizon

- Medium-Term

Funding Category

- Applied Research and Development

Energy Flexible Load Assets

The increasing penetration of non-dispatchable and intermittent generation assets has required a greater focus on flexibility in the energy system because system operators have less control of their supply. Even as the supply side becomes less dispatchable, the demand side

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[40] *Developing non-Lithium Ion Energy Storage Technologies*, California Energy Commission (2020).

[41] Price target aligning with Duration Addition to Electricity Storage (DAYS) goal, DOE (2019).

shows potential to increase flexibility behind the customer meter. Flexible load assets can alter their load profile in response to a price signal, a financial incentive, an environmental condition, or a reliability signal, and are an important tool to manage supply and demand in the energy system.

The Lawrence Berkeley National Laboratory (Berkeley Lab) *2025 Demand Response Potential Study (Phase 2)*[42] divides this load management into four categories depending on the timescale of the modulation:

- Shape captures frequent or continual changes in customer load profiles through price response or behavioral campaigns.
- Shift represents moving energy consumption from times of high demand, cost, or impact to times when demand, cost or impact are reduced.
- Shed describes conventional curtailment to provide peak demand reduction and support the system in emergency or contingency events. The support can be at the statewide level, in local areas, or on the distribution system with a range of dispatched advance notice times.
- Shimmy involves using loads to dynamically adjust demand to alleviate short term ramps and disturbances; these adjustments can range from less than a second up to an hour.

Identifying how customer-side loads can be managed to match the generation resources available in a location will be key to effectively integrate distributed resources—whether to reduce peak consumption or achieve other modulation based on emissions rates and renewable curtailment reduction.

Energy Flexible Load Assets - Technical Assessment

The technical assessment identified four major categories defining the interaction of energy flexible load assets with the wider energy system:

- Flexible loads are the loads associated with devices whose usage can be modulated to help balance supply and demand. Most residential major appliances, space conditioning and water heating in most buildings, and heavy water pumping loads are examples of end uses that can shift or shape operations in response to a price or other signal.
- Control devices and strategies instruct the flexible load assets when and how to operate or provide a signal to inform the decision to participate. Effective controls automate customer defined load flexibility, optimize between the primary purpose of the load and the needs of the grid, and support grid operations while minimizing disruption to the customer experience.
- Communications architecture includes both the hardware and software that transmits signals from a grid operator or third-party aggregator to the customer, using any of several protocols like OpenADR or IEEE 2030.5.
- Grid integration concerns how the larger energy system manages load assets, by either directly controlling the assets or providing price information to allow asset owners (and their devices) to make their own decisions.

[42] *2025 Demand Response Potential Study (Phase 2)*, Berkeley Lab (2017).

Energy Flexible Load Assets - Barriers

Cost

Lack of low-cost control networks and optimization capabilities: These capabilities need to be focused on engaging assets while not disrupting the comfort of building occupants. Savings are often only realized by retrofit solutions or expensive controls. The cost to implement communicating controls is a major barrier, particularly for smaller commercial buildings.

Lack of available financing: While the cost-benefit ratio of many grid-side efficiency or demand-side management investments may be appealing, large-scale financing has traditionally focused around smaller numbers of large investments like conventional power plants. Demand-side investments will have partially limited access to financing until they can be aggregated and standardized.

Valuation

Value stacking is limited: Customer participation in multiple DR programs is limited by policy, market, and technical conditions. While policy changes are required to fully address this challenge, research into developing affordable sub-metering options to enable measurement and verification of additional loads could enable customers to demonstrate participation in DR.

Capability

Inadequate data synthesis capabilities: Per the expert interviews conducted for this project, many existing building energy management system (EMS) solutions do not have the capacity to interface with a large or varied set of data sources such as external environmental conditions and wholesale market pricing.

Unreliable communications: DR aggregators have noted that reliability issues with Wi-Fi-based communication protocols have led to unmet commitments. Other communications pathways are technically feasible (such as FM broadcast or mesh networks) but are not widely used for load management. The Smart Electric Power Alliance (SEPA) produced a report detailing some of these issues.[43]

Difficulties integrating DR with existing grid management systems: Some distribution operators lack the infrastructural capability to provide detailed and timely insights into location-specific operational and distribution challenges, which negatively affects the utility's ability to optimize the DR resources and programs in place.[44] In addition, customer managed load automation is necessary before such investment can yield value for the system operator.

Big data and analytical capabilities are lacking: The high temporal and geographic granularity of data relevant for DR can be challenging for utilities to store and analyze.

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[43] *Smart Grid System Stability with Broadcast Communications, SEPA (2015).*

[44] *Assessment of Barriers to Demand Response in the Northwest's Public Power Sector*, Cadmus (2018).

Coordination

Limited interoperability with proprietary systems: Uncoordinated installation and use of appliances and systems has led to individual operation of demand resources, limiting the development multi-objective optimization capabilities. The extensive competition among EMS providers leads to proprietary systems that only work with devices from the same manufacturer, limiting the development of innovative applications.[45] Existing and emerging solutions are inconsistent in the formats of their data and architecture, making it difficult to integrate and share across buildings, communities, and nationally. As connected buildings and building systems become more prevalent, standardizing building data elements is necessary to reduce data processing loads and enable consistency in repositories.

Uncoordinated implementation: Distinct program budgets and funding cycles for energy efficiency, DR, and distributed generation make it challenging to integrate multiple technology solutions.[46]

Customer acquisition challenges: Because DER can provide services only when present in sufficient quantities, at the optimal locations, at the time and duration required by the grid, and when they are more cost-effective than other approaches, difficulties with customer adoption can limit the ability of DER to effectively provide grid services. Customer recruitment challenges like the ones PG&E encountered during the DERMS Demonstration[47] mean that DERs may not be present in sufficient quantities and at optimal locations to effectively provide grid services.

Lack of transmission and distribution (T&D) coordination: Coordinating multiple DR opportunities for needs on the distribution and transmissions systems will require tighter coordination between planning and operations.[48]

Uncertainty

Value to customer is uncertain: There are existing frameworks to evaluate the cost-effectiveness of traditional DR programs, such as the National Assessment and Action Plan on Demand Response[49] developed jointly by the Federal Energy Regulatory Commission (FERC)

[45] *Technology for Building Systems Integration and Optimization – Landscape Report*, DOE (2018).

[46] *Barriers and Opportunities for Integrated DSM*, Berkeley Lab (2018).

[47] *Coordinating Distributed Energy Resources for Grid Services: A Case Study of Pacific Gas and Electric*, National Renewable Energy Laboratory (2018).

[48] *Future Opportunities and Challenges with Using Demand Response as a Resource in Distribution System Operation and Planning Activities*, Berkeley Lab (2016).

[49] *A Framework for Evaluating the Cost-Effectiveness of Demand Response*, National Forum on the National Action Plan on Demand Response: Cost-Effectiveness Working Group (2013).

and the DOE and the DR Cost-Effectiveness Protocols[50] used by the CPUC. However, the costs and benefits to the customer for providing DR services in the context of dynamic prices are not well understood.[51] Additional work is necessary to quantify the costs associated with different types of DR resources providing different types of bulk power system services.[52]

Value to operator is uncertain: A standard method to value DR does not exist, which limits the adoption of DR products and services at utilities.

Interaction between DR and energy efficiency programs is not well understood and often not incorporated in cost-benefit analyses. There may be marketing and participation benefits from offering both types of programs to customers.[49]

Energy Flexible Load Assets - Research Needs

Assess Costs of Demand Response Automation in New Buildings

Research Description

An especially attractive opportunity in DR is integrating automated DR technologies into new building projects. Some of the most pressing unknown future quantities in grid management are the participation of automated DR and the associated costs for new buildings. Seeking to characterize general costs for different levels of automation in new buildings will be a great advantage to driving automated DR deployment.

Developing a generalized cost characterization tool will facilitate understanding of the cost-benefit analysis that goes into deploying new DR technology. This understanding will lead to opportunities to identify and deploy financing tools specifically for new construction, providing a deeper pool of DR resources to the grid. This tool should incorporate changes in cost, technologies, and rates under development and build on similar past efforts by Berkeley Lab on small to medium building energy efficiency calculators through the Public Interest Energy Research (PIER) program. Study of demand response automation in small, existing buildings can be pursued in a separate effort. While an appropriate accounting framework was developed and initial study values identified in a study by Lawrence Berkeley National Laboratory[53], research to update the costs of each category is required to make informed decisions given technology advancements in the last several years.

Barriers Resolved

- Lack of available financing: Developing a cost model is a vital step to identifying existing financing options that could be appropriated to support automated DR.
- Value to customer is uncertain: Characterizing the cost of automation in new buildings helps to begin framing the cost-benefit analysis for customers.

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[50] *Demand Response Cost-Effectiveness*, CPUC (2019).

[51] "Review of barriers to the introduction of residential demand response: a case study in the Netherlands," *International Journal of Energy Research* (2016).

[52] *Demand Response and Energy Storage Integration Study*, DOE (2016).

[53] *Comparison of Actual Costs to Integrate Commercial Buildings with the Grid*, Lawrence Berkeley National Lab (2016).

Metrics Impacted

- Flexibility
  - Number of connected devices: Outlining cost factors may increase the appeal of DR automation in new buildings.
- Affordability
  - DR enablement costs: Develops an additional lens of the cost for consideration by policymakers.

Benefits to Ratepayers

- Peak load reduction (megawatts) from summer and winter programs.
- Customer bill savings.

Metrics and Targets (Additional Data)

- Performance
  - Using the existing framework, determine updated cost performance targets for each of the following categories:
    - Communications – Communications Service
    - Communications – Hardware (Gateway)
    - Communications – Software (Client)
    - Communications – Configuration Labor
    - Controls – Equipment
    - Controls – Installation Labor
    - Controls – Controls Programming
    - Telemetry – Meters, meter communications
    - Telemetry – Installation Labor
    - Telemetry – Configuration Labor

Priority

- High

Time Horizon

- Medium-Term

Funding Category

- Market Facilitation

Enable Load Flexibility Alongside Fuel Shifting

Research Description

The building decarbonization effort in California will drive a significant number of new heat pumps replacing natural gas heating systems. This replacement will remove emissions, but further emissions reductions and renewable integration may be realized by enabling sophisticated, grid-informed smart controls. This project would provide market facilitation for smart controls in space and water heating heat pumps that optimize heating and cooling services in response to a price signal, a financial incentive, an environmental condition, or a reliability signal. It would begin with an assessment of the rate at which new heat pumps include the capability to, and are effectively participating in, demand response programs, and could coordinate with the CEC's grant funding opportunity "Advancing Next-Generation Heating, Cooling and Water Heating Systems"[54].

Barriers Resolved

- Lack of low-cost control networks and optimization capabilities: Demonstrating a scalable controls solution is a first step in reducing costs.
- Uncoordinated implementation: This effort will leverage investments in the building decarbonization effort to support DR goals.
- Customer acquisition challenges: This effort will reduce marketing and recruitment needs because it targets customers that are already adopting new equipment.

Metrics Impacted

- Sustainability
  - Reduced greenhouse gas (GHG) emissions
  - Reduced criteria air pollution emissions
- Affordability
  - Lower systems costs

Benefits to Ratepayers

- Percentage of DR with automated DR capability (for example, Auto DR).
- Improved system operation efficiency from increased flexibility.
- Reduced greenhouse gas (GHG) emissions.
- Reduced criteria air pollution emissions.

Metrics and Targets (Technology Integration)

- Performance
  - Percentage of fuel shifted load with load flexibility controls.
  - Percentage of all customers capable of receiving information from grid operators.
  - Percentage of total DERs in California that can be controlled in response to grid needs.
  - Number of customers adopting heat pump with smart controls.
  - Resilience to cybersecurity incidents.
- Price
  - Price under $350 per control.[55]

Priority

- High

Time Horizon

- Medium-Term

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[54] *CEC GFO-19-301*, California Energy Commission (2019).

[55] *Summer Study on Energy Efficiency in Buildings*, American Council for an Energy-Efficient Economy (2016).

Funding Category

- Technology Demonstration and Development

Coordinate Water Heater Design and Controls

Research Description

The current plumbing system design with recirculation pumps can cause heat pump water heaters to operate inefficiently. The recirculation loop in a larger building results in enough heat loss that the heat pump water heater will frequently cycle on to heat the reservoir a relatively small amount, which results in an efficiency well below the nameplate expectation. Proper design requires at least two hot water reservoirs and some other changes to the system. This project will consider heat pump water heater system design through the lens of DR capabilities to create load flexibility while not reducing the actual coefficient of performance.

Barriers Resolved

- Uncoordinated implementation: Identifies synergies between system design and controls implementation to improve efficiencies.

Metrics Impacted

- Sustainability
    - Improved efficiency in water heating

Benefits to Ratepayers

- Peak load reduction (megawatts)
- Percentage of DR enabled by automated DR technology (for example, Auto DR)
- Customer bill savings (dollars saved)
- Improved system operation efficiency from increased flexibility

Metrics and Targets (Technology Advancement)

- Performance
    - Retains 2-2.5 energy factor under normal operations and while providing load flexibility[56]
- Price
    - Reduce system costs through coordinated design

Priority

- High

Time Horizon

- Medium-Term

Funding Category

- Applied Research and Development

[56] Metric based on maintaining current efficiency while adding flexibility. Heat Pump Water Heater, Energy Guide (2020)

Evaluate the Effect of Demand Response on Market Decisions

Research Description

This project would evaluate the effect of utility rate-based DR programs on wholesale market dispatch decisions, and how that translates into supply-side DR impacts. It would also compare the effectiveness of market-integrated versus non-integrated programs, and automated DR programs, at the retail utility level against system operator-driven events like Flex Alerts. To complete the research, the project would review historical data and compare DR events outside of market dispatch against California ISO proxy DR calls, for their effect on the rest of the dispatch order. While the different DR programs are evolving rapidly, an assessment of the effects of different flexible load strategies can guide the development of optimal dynamic pricing structures.

Barriers Resolved

- Lack of T&D coordination: Evaluates the current state of coordination between utility programs and system operator events and identifies opportunities for improvement.
- Value to customer is uncertain: Compares the value of wholesale and utility DR activities to customers.
- Value stacking is limited: Informs future decisions that affect value stacking.

Metrics Impacted

- Affordability
    - Effectiveness in reducing costs to net load
- Sustainability
    - Avoided renewable curtailment
- Flexibility
    - Customer enrollment (number of customers, amount of load)

Benefits to Ratepayers

- Avoided procurement and generation costs
- Customer bill savings (dollars saved)

Metrics and Targets (Additional Data)

- Performance
    - Percent of total capacity participating when called through load-side programs
    - Percent of total capacity participating when called through supply-programs
- Price
    - Average $/kW for demand response provided through load-side programs
    - Average $/kW for demand response provided through supply-side programs

Priority

- High

Time Horizon

- Medium-Term

Funding Category

- Applied Research and Development

Develop National Electrical Code-Approved Home Energy Management System to Reduce Panel Upgrade Costs

Research Description

With increasing electrification, particularly of heating and transportation energy consumption, the amount of load on customer electric panels has been growing. This research opportunity would develop and test Home Energy Management Systems (HEMSs) to provide customer panel-level demand management that avoids the need for electrical upgrades while complying with National Electrical Code (NEC). The effort would demonstrate the effectiveness of micro-peak load reductions to enable potential improvements to electric codes. This work would enable greater building electrification through reduced costs and complexity.

Barriers Resolved

- Uncoordinated implementation: This effort will leverage investments in the building decarbonization effort to increase the amount of load available for demand-side management cost effectively.
- Lack of low-cost control networks and optimization capabilities: This effort would reduce electrification costs by allowing additional loads while avoiding electrical upgrades behind the customer meter.

Metrics Impacted

- Affordability
  - Lowered by removing need for panel upgrades or additional grid service
- Flexibility
  - Uptake of electrification: Increased by removing barrier (cost) for panel-constrained customers

Benefits to Ratepayers

- Maintain/reduce capital costs
- Reduced emissions from increased electrification

Metrics and Targets (Technology Advancement)

- Performance
  - Management system provides smart controls for loads including but not limited to HVAC, water heating, and electric vehicle
  - Meet UL 67 standard for panelboards
  - Meet UL 916 standard for energy management equipment
  - Meet UL 869a standard for service equipment
- Price
  - Hardware cost of management system less than cost of panel upgrade (roughly $1,000)[57]

Priority

- High

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[57] *EV Charging in Single Family Residences*, PG&E (2018).

Time Horizon

- Medium-Term

Funding Category

- Applied Research and Development

Improve Building-to-Grid Coordination

Research Description

Simplifying and improving coordination protocols between the grid and buildings is an important step to enabling flexible loads. This project would demonstrate building-to-grid functionality by implementing a pilot using the DOE's open source VOLTTRON software platform.[58] The project would coordinate building loads, electric vehicle supply equipment (EVSE), distributed generation, and behind-the-meter storage with a focus on controllable building loads. It would assess the effect of being able to characterize behind-the-meter loads to better construct DR portfolios and allow better load forecasting at the system level. Publicly releasing the developed source code and project data would allow for greater community access and knowledge transfer. The improved understanding of load flexibility response of building loads would be useful to distribution and transmission operators considering potential flexibility solutions.

Barriers Resolved

- Lack of low-cost control networks and optimization capabilities: Addresses costs and other problems with complex communication and business arrangements.
- Lack of uniformity in building IT infrastructure: Studies DER coordination protocols within buildings to mitigate the incompatibility issues identified in prior demonstration projects.
- Limited interoperability with proprietary systems: Assesses the current state of interoperability within buildings and provides recommendations for improvement.

Metrics Impacted

- Flexibility and Sustainability
    - Increased DER penetration

Benefits to Ratepayers

- Avoided procurement and generation costs
- Number and percentage of customers on time-variant or dynamic pricing tariffs
- Peak load reduction (megawatts) from summer and winter programs
- Avoided customer energy use (kilowatt-hours saved)
- Percentage of DR enabled by automated DR technology (for example, Auto DR)
- Customer bill savings
- Improved system operation efficiency from increased flexibility
- Reduced GHG emissions

[58] *VOLTTRON Platform*, Department of Energy (2018).

Metrics and Targets (Technology Integration)

- Performance
    - Percent decrease in project facility peak demand from pre- to post-intervention
    - Ten percent year over year increase in behind-the-meter loads responding to coordinated signals across California
    - Project will optimize multiple electric vehicles across multiple chargers with consideration of on-site generation and load
- Price
    - Average cost of controls per square foot below $2.50[59]

Priority

- Medium

Time Horizon

- Long-Term

Funding Category

- Applied Research and Development

Enhance Commercial Building Monitoring and Controls

Research Description

Loads in commercial buildings are significantly more controllable and tunable than in years past because of the proliferation of enabling technologies such as dimming systems for lighting, variable speed drives for HVAC, and wireless communication networks. At the same time, only modest advances have been made in determining how and when to control and tune these systems. This project would explore the opportunities and challenges associated with building systems that gather a greater granularity of data on the built environment than typical building systems (for example, 10 temperature sensors in a room rather than one at the thermostat) and provide a better understanding of the needs and desires of the people who occupy these buildings. The analysis would study the impacts of finer grained control, both to occupant experience as well as the ability to respond to load flexibility requests from the grid. The opportunities include direct energy reduction from more closely matching climate controls with preferences, and improved grid flexibility from rescheduling temperature control actions according to grid signals while maintaining personal preferences.

Barriers Resolved

- Limited interoperability with proprietary systems: Provides in-situ verification of interoperability with other DER assets.
- Data availability limitations: Enables data collection at a greater spatial and temporal granularity.

Metrics Impacted

- Sustainability
    - Lower energy use from more efficiently meeting user requirements

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[59] *Building Automation System Cost per Square Foot*, Ready One (2017).

- Flexibility
    - More load responds to grid signals

Benefits to Ratepayers

- Avoided procurement and generation costs
- Increased number and percentage of customers on time-variant or dynamic pricing tariffs
- Peak load reduction (megawatts)
- Avoided customer energy use (kilowatt-hours saved)
- Improved system operation efficiency from increased flexibility
- Customer bill savings
- Reduced GHG emissions

Metrics and Targets (Technology Advancement)[60]

- Performance
    - Data recording a five-minute sample rate
    - No more than one network connectivity outage per year
    - Provides 15-35 percent energy savings
    - Operational power lifetime of sensors over 96 hours
- Price
    - Average cost of networked sensors below $57 per node[61]
    - Occupancy-centric controls below $49/occupant

Priority

- High

Time Horizon

- Long-Term

Funding Category

- Technology Demonstration and Development

Coordinate Residential Loads with Commercially Available Home Automation Hubs

Research Description

Residential loads have traditionally been too small or too widely distributed to make them attractive to grid-responsive programs such as DR load shedding. The rapidly expanding use of residential home automation systems such as the Amazon Alexa, Google Home, and others, present new opportunities to connect, aggregate, and control residential loads at scales that are consequential for the grid. An EPIC project studied a low-cost Retail Automated

[60] *Innovations in Sensors and Controls for Building Energy Management*, Department of Energy (2020).

[61] *Innovations in Sensors and Controls for Building Energy Management*, Department of Energy (2020).

Transactive Energy System (RATES)[62] that developed an experimental subscription transactive tariff and optimization platform that allowed customer devices to respond to more granular prices. The project allowed customers to input temperature settings, pool pump schedules, and other personal preferences, and it enabled home automation voice commands to input these settings. This project would explore opportunities to use intelligence in home automation hubs to more automatically determine these preferences with the intent to lower the required level of customer engagement to participate. Additionally, further research into customer engagement with transactive energy hardware installation and operation can support increased adoption beyond highly-engaged technically savvy customers.

Barriers Resolved

- Limited interoperability with proprietary systems: This research aims to improve inter-building communication across various devices to optimize load shifting.
- Lack of low-cost control networks and optimization capabilities: Demonstrating how existing home automation networks can be used for aggregated demand-side management can eliminate the extra costs associated with implementing a new energy control network.

Metrics Impacted

- Sustainability
  - Reduced customer energy use during high emissions periods
- Flexibility
  - Load arbitrage (shifted/balanced/consumed) to improve system efficacy

Benefits to Ratepayers

- Number and percentage of customers on time-variant or dynamic pricing tariffs
- Peak load reduction (megawatts) from summer and winter programs
- Avoided customer energy use (kilowatt-hours saved)
- Customer bill savings
- Reduced GHG emissions

Metrics and Targets (Technology Advancement)

- Performance
  - Home automation hub forecasts customer preferences with a predictive accuracy of over 70%[63]
  - Home automation hub able to control customer loads
  - Home automation hub able to receive grid signals
  - Home automation hub able to learn from customer feedback about load control and adapt customer preference profile
  - Home automation hub operates at high reliability

[62] *Complete and Low Cost Retail Automated Transactive Energy System (RATES),* California Energy Commission (2016).

[63] Based on conversations with industry stakeholders and the expertise of the project team.

    - Home automation hub achieves 20% savings in HVAC and 30% in lighting usage[64]
- Price
    - Home automation cost fully offset by participation in load flexibility or time of use management

Priority

- High

Time Horizon

- Long-Term

Funding Category

- Technology Demonstration and Development

Study Load-Modifying Participation Models

Research Description

California has both load flexibility programs that are exposed to wholesale market signals and programs that work through local distribution operators. This effort will evaluate options for non-wholesale market-integrated DER participation models and develop recommended programs that permit stacking of multiple services. These could be controlled directly by the distribution operator or indirectly through an aggregator. It will evaluate the effectiveness of these non-market-integrated participation models to understand the benefits and challenges compared to the wholesale market-sensitive programs like California ISO's proxy demand response and distributed energy resource provider participation paths. Load-modifying capacity services may be based on distribution system needs, transmission system needs, community choice aggregation planning optimization, resource adequacy, or other grid needs. The development and comparison of non-market- and market-integrated programs for DER will be completed with an evaluation of the effect on the California ISO, DSOs, community choice aggregators, and customers. The outcomes of the research would help to design more effective participation models. The research could also include a project demonstrating the implementation of aggregated demand response participating in multiple uses in the wholesale market. This should also investigate the impacts of the requested enhancements from the third phase of the CAISO Energy Storage and Distributed Energy Resource stakeholder initiative, namely the capability to provide hourly and fifteen-minute scheduling options for demand flexibility resources in the real-time market and the ability to aggregate demand flexibility resources across load-serving entities.[65]

Barriers Resolved

- Lack of transmission and distribution (T&D) coordination: California's resource adequacy rules require specific program participation to qualify. The only option available for customer participation is within the demand response auction mechanism via the California ISO's proxy demand resource program. Proxy demand resource is a program

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[64] *Innovations in Sensors and Controls for Building Energy Management*, Department of Energy (2020).

[65] *Tariff Amendment to Implement Demand Response Enhancements*, California ISO (2019).

for customer load curtailment—not the full capacity benefits advanced DER can provide to the distribution system, regional networks, and the bulk electric system.

- Value stacking is limited: Understanding the relative effectiveness of market-integrated and non-market-integrated participation models will inform market design and value stacking rules, which will allow for more value to be realized.

Metrics Impacted

- Affordability
  - Avoided regional and system peaking generation and infrastructure
  - Development of recommendations and comparison for nonmarket and market-integrated participation models/programs for DER
  - Evaluation of market and resource effectiveness of market-integrated and nonmarket-integrated participation models

Benefits to Ratepayers

- Avoided procurement and generation costs
- Total electricity deliveries from grid-connected distributed generation facilities
- Nameplate capacity (megawatts) of grid-connected energy storage

Metrics and Targets (Additional Data)

- Performance
  - Aggregated demand flexibility demonstration resource should aggregate over multiple load-serving entities
  - Aggregated demand flexibility demonstration resource should respond to wholesale market signals within 15 minutes
  - Count of customers participating in multiple use applications across California
  - Count of different types of DER participating in multiple use applications. For example storage, solar, and electric vehicles would be three different types of DERs.

Priority

- Medium

Time Horizon

- Medium-Term

Funding Category

- Market Facilitation

Evaluate Distributed Resources Performance in New Construction

Research Description

While building codes like Title 24 have requirements for energy efficiency and load control technologies, it is important to review the effectiveness of those technologies after they have been deployed to ensure the expected efficiencies are gained. This project would create two-year case studies to measure and verify the performance of customer-side load modification technologies in new construction starting in 2020.

Barriers Resolved

- Data availability limitations: Provides more robust, grounded data on which to base policy decisions.
- Uncoordinated implementation: Measures the joint energy efficiency and DR effects of load-modifying technologies to ensure their interactions are considered appropriately.

Metrics Impacted

- Sustainability
    - Number of baseline metrics for new building DER performance

Benefits to Ratepayers

- Maintain/reduce operations and maintenance costs by ensuring that installed devices are working as designed

Metrics and Targets (Additional Data)

- Performance
    - Percent of DER in new construction found to be meeting nominal performance metrics
    - Distribution of performance metrics for DER in new construction not meeting nominal targets
    - Year-over-year change in percentage of DER in new construction meeting nominal performance metrics

Priority

- Medium

Funding Category

- Technology Demonstration and Development

Assess Device-Level Lifespan Effects of Load Flexibility

Research Description

Smart home devices are key to load shifting in the future. However, the extent of the constraints on these devices' ability to shift load is not well understood. One question is the impact of load modification on end device wear and tear as well as how efficiently they run? For example, do refrigeration cycles need to be synchronized with DR events and other grid signals? Does load shifting decrease the useful life of a refrigerator? This research would quantify the effect of load shifting on devices, especially as it relates to energy consumption and lifespan in a lab setting. Researching such constraints to DER optimization for flexible loads has the potential to remove uncertainty around the potential gains from shifting loads.

Barriers Resolved

- Lack of low-cost control networks and optimization capabilities: Demonstrating how existing home automation networks can be used for aggregated demand-side management can eliminate the extra costs associated with implementing a new energy control network.

Metrics Impacted

- Reliability

    - Proactively identify potential sources of asset damage that would require replacement
- Flexibility
    - Load arbitrage (shifted/balanced/consumed) to improve system efficacy

Benefits to Ratepayers

- Number and percentage of customers on time-variant or dynamic pricing tariffs
- Maintain/reduce operations and maintenance costs
- Maintain/reduce capital costs

Metrics and Targets (Additional Data)

- Performance
    - Estimated impact of load flexibility participation on cycle efficiency of agricultural pumping
    - Estimated impact of load flexibility participation on cycle efficiency of refrigeration
    - Estimated impact of load flexibility participation on cycle efficiency of pool pumps
    - Estimated impact of load flexibility participation on cycle efficiency of HVAC
    - Estimated impact of load flexibility participation on device lifespan for agricultural pumping
    - Estimated impact of load flexibility participation on device lifespan for refrigeration
    - Estimated impact of load flexibility participation on device lifespan for pool pumps
    - Estimated impact of load flexibility participation on device lifespan for HVAC

Priority

- High

Time Horizon

- Medium-Term

Funding Category

- Technology Demonstration and Development

Derive Capacity Value of Variable Distributed Energy Resources

Research Description

This project aims to explore new methods to understand and derive the capacity value of DR, particularly DR that has a variable nature—that is, DR that demonstrates variability by day, hour, or season due to temperature, weather, production cycles, or occupancy. For example, a program based on curtailing air conditioner load would be sensitive to the temperature influencing how many of air conditioners are on and available to curtail. The goal is to apply a new resource adequacy capacity valuation method to DR that measures its ability to meet system load requirements and reduce GHG emissions to meet California's renewable integration goals. Providing more confidence into the reliability of load flexibility resources allows California ISO to operate with less conservative reserves. Because most DR is variable, there is a need to study how effective variable DR is at helping the system meet load requirements in all hours of the year and how effective (and cost-effective) it is at reducing GHG emissions, considering its use and availability limitations. It is important to evaluate how DR relieves current grid constraints, as well as those predicted in future years as California progresses toward its renewable portfolio and climate goals. Research into applying effective load carrying capability or similar probabilistic-based capacity valuation methods to DR should be explored to inform policymakers and ratepayers about what resource types are the most effective and least cost to achieve California's energy policy goals.

Barriers Resolved

- Value to operator is uncertain: The research will inform policymakers about the value of DR in the context of the evolving grid. It will determine how effective DR is at reducing load at both current peak times as well as when peak is expected to occur in the future; these findings will inform grid and resource planning studies conducted by system operators and utilities so that accurate capacity valuation methods are applied in technical planning studies. This information will allow policymakers to make informed decisions about future resource investments that can help achieve California's GHG reduction goals at the least cost to ratepayers.

Metrics Impacted

- Reliability
    - Capacity value: Number of grid-balancing services provided by DER
- Sustainability
    - GHG impacts: Capacity of DER aggregations able to provide grid services
- Affordability
    - Comparability/benchmarking: How capacity value compares to other resource types to make informed investment decisions

Benefits to Ratepayers

- Avoided procurement and generation costs

Metrics and Targets (Additional Data)

- Performance
    - Estimated demand response program participation rate across California per technology. Different technologies would include water heaters, HVAC, and more.
    - Estimated demand response program participation rate per geographic area
    - Estimated demand response program participation rate per time period
    - Reduced percentage of flexible loads being unable to respond to grid signals
    - Improved accuracy in forecasting demand response program participation rate

Priority

- High

Time Horizon

- Medium-Term

Funding Category

- Technology Demonstration and Development

Vehicle-Grid Integration

The primary use of plug-in electric vehicles (PEV) is transportation, but they have the potential to contribute significantly as distributed energy resources as well. They can act similarly to stationary storage, but their inherent mobility and primary use case add an additional layer of complexity to integrating their contributions with the conventional grid processes. For example, the location of charging infrastructure needs to account for both customer utility and convenience and impact to the electric grid. While the vehicles can contribute to load flexibility and even push energy back to the grid, these activities need to be scheduled around their primary transportation application. Their size also generally requires aggregation reach the scale of other grid resources, and while programs exist to allow market participation of aggregated small resources, there is an extra coordination step required relative to larger stationary resources. PEV have unique potential due to their flexibility in location and scale but a matching challenge in coordination.

California is strongly invested in the electrification of the transportation sector. For example, in May 2018, the CPUC approved $738 million in transportation electrification projects for the state's investor owned utilities,[66] and the CEC has invested $830 million cumulatively through the Clean Transportation Program[67]. From the grid perspective, the growth of EV load creates both a challenge and an opportunity as unmanaged charging could overload infrastructure, but managed charging could help balance increasing variable generation. Several California initiatives support this vehicle-grid integration, defined as "any method of altering the time, charging level, or location at which grid-connected PEV charge or discharge"[68]. For example, the CEC is coordinating efforts to update California's Vehicle-Grid Integration Roadmap[69], and the CPUC has convened a series of vehicle-grid integration working groups[70] to assess the value of different vehicle-grid integration use cases and to determine how different communications protocols should be coordinated. The working group final report provides numerous policy recommendations for CPUC to consider as well as recommendations for technology demonstrations of specific VGI functionalities.[71]

This section of the roadmap is intended to provide a high-level summary while providing references to more focused efforts like the Vehicle-Grid Integration Roadmap update and working group reports.

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[66] *Transportation Electrification Activities Pursuant to Senate Bill 350*, CPUC (2018).

[67] *2019-2020 Investment Plan Update for the Clean Transportation Program*, California Energy Commission (2019).

[68] *Senate Bill 676*, California Legislature (2019).

[69] *California Vehicle-Grid Integration Roadmap Update*, California Energy Commission (2019).

[70] *VGI Working Group*, CPUC (2018).

[71] *VGI Working Group Final Report*, Gridworks (2020).

Vehicle-Grid Integration - Technical Assessment

Efficiently integrating EV loads into the electric grid involves a wide group of stakeholders, from car and EVSE manufacturers to utilities to service providers to end use customers; with these many stakeholders come multiple viewpoints on the best way to achieve EV integration with the grid at scale.

While grid support services are widely acknowledged as a potential opportunity for EVs to provide value, they are not the primary use case for many stakeholders; as such, they must have a definite value proposition to be implemented at scale. The 2019 VGI Initiative[72] discussed a broad framework including four major categories of potential application:

- Customer: Applications including bill management, upgrade deferral, backup resiliency and renewable integration.
- Grid: Applications including grid upgrade deferral, grid backup resiliency, and voltage quality support.
- Wholesale Market: Applications including energy arbitrage, frequency regulation, spinning and non-spinning reserves, flexible ramping capability and overgeneration reduction.
- Resource Adequacy: Applications including system capacity, system flexible capacity and local capacity.

The value of participating in these applications is balanced against the hardware and soft costs of installing the appropriate EVSE infrastructure. Table 3 breaks down the hardware cost components of EVSE infrastructure.

Soft costs may include customer acquisition, permitting, operations and maintenance, and financing, and can vary significantly from case to case. However, mirroring the development of solar generation, soft costs may represent a significant opportunity for cost reduction.[73]

The research needs discussed in this section focus on the technical barriers preventing further commercialization of the use cases as well as research that can support reduced costs. The needs do not cover valuation, leaving those areas to the detailed initiatives and working groups.

[72] *VGI Initiative Framing Document*, Gridworks (2019).

[73] *EV Charging Infrastructure Costs*, Rocky Mountain Institute (2019).

Table 3: Plug-In Electric Vehicle Infrastructure Component Costs

Cost Element	Lowest Cost	Highest Cost
Level 2 residential charger	$380 (2.9 kW)	$689 (7.7 kW)
Level 2 commercial charger	$2,500 (7.7 kW)	$4,900 (16.8 kW); outlier: $7,210 (14.4 kW)
DCFC (50 kW)	$20,000	$35,800
DCFC (150 kW)	$75,600	$100,000
DCFC (350 kW)	$128,000	$150,000
Transformer (150-300 WA)	$35,000	$53,000
Transformer (500-750 WA)	$44,000	$69,600
Transformer (1,000+ kVA)	$66,000	$173,000
Data contracts	$84/year/charger	$240/year/charger
Network contracts	$200/year/charger	$250/year/charger
Credit card reader	$325	$1,000
Cable cost	$1,500	$3,500

A 2019 Rocky Mountain Institute study provides a range of cost estimates for different PEV infrastructure cost components.

Source: Rocky Mountain Institute (2019)

Vehicle-Grid Integration - Barriers

Cost

Vehicle-to-grid vehicle costs: V2G is more expensive than V1G because most EVSEs are not bidirectional, and current plug-in EVs (PEVs) do not natively support bidirectional power flow through alternating current ports. Commercialization of DC V2G systems, as achieved by Enel and Nissan, is likely to drive reduced costs through economies of scale. Most hardware is proprietary, so cost and price information are not publicly available.

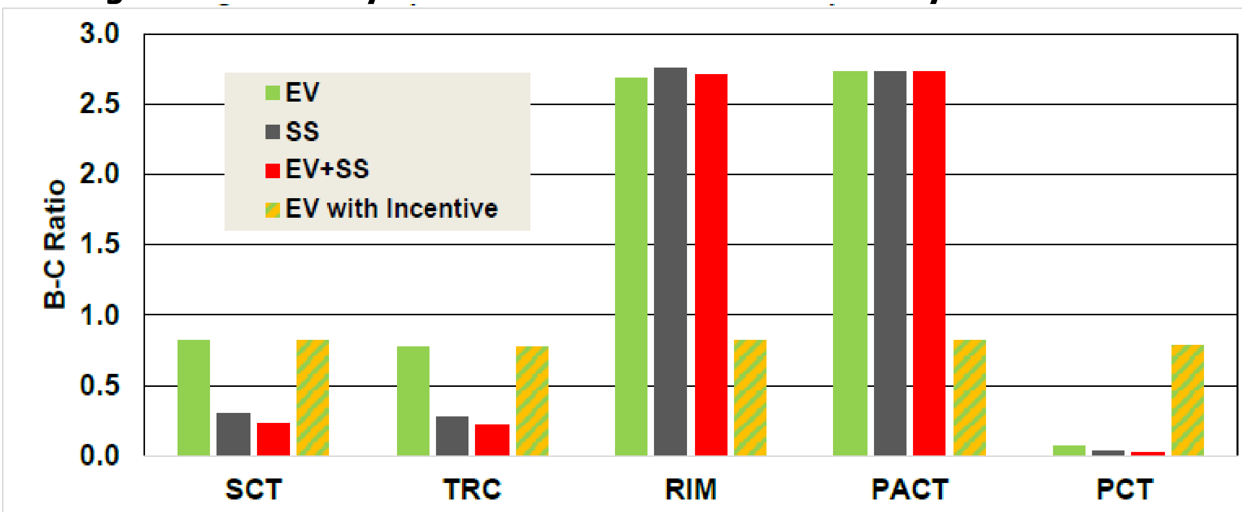
In an EPIC-funded vehicle-to-home pilot,[74] PG&E calculated the cost-effectiveness of participation in the California ISO's supply-side pilot program under four scenarios: with a PEV, with distributed solar and storage (SS), with all three (EV+SS), and with a PEV taking account of an incentive payment (EV+I). These scenarios were assessed using the five cost tests defined in the *California Standard Practice Manual*[75]. When the customer EVSE installation costs are included, as in the definition of the societal cost test (SCT), total resource cost test

[74] *Vehicle to Home EPIC 2.03b Report*, PG&E (2018).

[75] *Standard Cost Tests*, CPUC (2018).

(TRC) and participant cost test (PCT), the benefit-cost-ratio was less than 1, which implies the program is not cost-effective. The Program Administrator Cost Test (PACT) and Ratepayer Impact Measure (RIM) assess the costs to the program administrator and ratepayer, respectively, and do not include the EVSE installation costs that were borne by the individual customers. In these cases, the benefits ratio is significantly greater than one and show the system is positively impacted by V2G program participation if the EVSE infrastructure had already been installed separately by those customers.

Figure 7: Summary of Cost-Effectiveness Measured by Cost-Benefit Ratios



When the customer EVSE installation costs are included, the benefit-cost ratio of participation in the vehicle-to-home pilot was less than one for the societal, total resource and participant cost tests.

Source: PG&E Vehicle to Home EPIC Pilot, February 2018

Incentives required for multiple components of the supply chain: PEV owners must be compensated to ensure participation, which reduces the revenue potential for aggregators. Relative to other competing technologies where an identified grid need can be met with one or a few larger assets, the VGI solution requires coordination of many participants. VGI pilot programs are more likely to emerge in markets with low minimum capacity requirements as a smaller scale of aggregation is required for participation.

Valuation

The full value of VGI is difficult to capture: As is the case with many DER technologies, VGI could participate in some markets, such as wholesale frequency regulation, but the requirements of those markets are not designed with small distributed resources in mind. Vehicle batteries could be used for potential resiliency applications, but these are not formally supported at this point.

For V1G, companies in California have started incorporating vehicles in the DR market and day-ahead wholesale market. Furthermore, most California electricity providers have EV-specific rate classes. As such, a portion of the value associated with V1G assets in these markets is defined and creates confidence that the functionality to participate in those markets would be worth the investment. V2G will require similar increases in market participation to create market confidence in the value of the technology.

Capability

Charger efficiency can be improved: In the process of charging and discharging EVs, electrical losses occur. These loses vary by the battery state of charge, the rate of charging, and the voltage at which the devices are operating. Lowering these losses would allow more function per unit of energy consumed.

Different use cases require different levels of communication: Many V1G and V2G use cases can be served with communications latencies on the order of minutes or hours. However, while the batteries are technically capable of providing market products like frequency regulation, they would need to receive operating instructions every four seconds. The value of these high requirement use cases must be weighed against the additional cost of enabling the capabilities.

Coordination

Aggregation required for feasibility: To deliver enough value to grid services markets, aggregators need to connect and manage many vehicles. A single vehicle provides limited value to grid services, and major grid services markets have minimum capacity requirements, as shown in Table 4. From the perspective of a grid operator or planner, coordinating many vehicles represents additional complexity relative to conventional grid resources. From the perspective of an aggregator, the fixed costs of market participation fees are relatively large without significant scale.

Table 4: Minimum Capacity Requirements of Major Markets (2017)

Grid Network	Service	Capacity
California ISO	Ancillary services	500 kW
ISO New England	DR	100 kW
FERC Proposed Rules	Electric storage and DER	100 kW
Electric Reliability Council of Texas	Frequency response	100 kW
New York Independent System Operator	Emergency DR/day-ahead DR	100 kW/1 MW
National Grid (UK)	Frequency response by demand management	3 MW
Midcontinent Independent System Operator (MISO)	DR	1 MW

Each system operator has its own minimum size of aggregated resources required for participation.

Source: Navigant Research

Interoperability: Multiple pathways exist to connect vehicle-grid integration devices across a range of stakeholders. For example, approaches can be EV-centric or EVSE-centric and can interact with building management systems in multiple ways based on use case and most beneficial solution. The CEC has studied the requirements, design and integration processes for V2G, as well as modeling the potential benefits of grid-aware vehicle charging.[76] While

[76] *Distribution System Constrained V2G Services for Grid Stability*, California Energy Commission (2019).

protocols like IEEE 2030.5 exist for DER integration and control, VGI in particular needs additional nuance to coordinate with other protocols that are more focused on the primary transportation use case.

Uncertainty

Battery warranty uncertainty: Unclear battery warranty conditions may limit customer interest, particularly participation in V2G implementations. The effect of and associated cost of battery degradation in V2G application is not well understood and not typically covered under the manufacturer warranty. Efforts to quantify the extent of battery degradation have been inconclusive. Different control strategies accounting for both grid needs and battery health should be studied further.

A Hawai'i Natural Energy Institute study found that grid participation of V2G-enabled vehicles can reduce the battery life to less than five years,[77] while a Honda study found no impact.[78] A third study used models to simulate ideal case grid participation of a V2G-enabled vehicle, and found that there are use cases that actually extend the battery life.[79] In practice, the EPIC-funded Los Angeles Air Force base V2G pilot project found that it was too difficult to isolate the source of battery degradation in the participating EVs, though they assumed that grid services contributed to degradation.[80] More research is needed to understand the cost-benefit balance of V2G as it pertains to EV battery life.

Vehicle battery availability: Vehicles are mobile assets; given their primary function of moving people or goods between locations, their availability to respond to grid signals and location at any time is uncertain. Unlike stationary storage or other generation assets, PEVs are not always on call to participate in services, and only a percentage of a regional set of vehicles will be available at any moment. This unpredictability creates more difficulty tracking EV patterns of availability and an aggregator must have a larger potential resource pool than a resource that offers guaranteed availability. Different types of vehicle batteries may also respond to a given control signal at different rates and with different efficiencies; care must be taken to ensure that a portfolio of assets participating in grid services is behaving as designed.

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[77] *Durability and reliability of electric vehicle batteries under electric utility grid operations: Bidirectional charging impact analysis*, Power Sources (2017).

[78] *Deployment of Vehicle-to-Grid Technology and Related Issues*, Honda R&D (2015).

[79] "On the possibility of extending the lifetime of lithium-ion batteries through optimal V2G facilitated by an integrated vehicle and smart-grid system", *Energy* (2017).

[80] *Los Angeles Air Force Base Vehicle-to-Grid Demonstration,* California Energy Commission (2018).

Vehicle-Grid Integration - Research Needs

Vehicle-to-Building for Resiliency

Research Description

This effort would use EV energy storage to power community resiliency centers during unplanned outages and public safety power shutoff events. The focus is a technical demonstration of equipment required to island a community resilience center from the electrical grid, and the practical considerations of using vehicle fleets that may be required for both transportation and non-transportation use cases. Lessons learned from this demonstration can help inform standards development and technical considerations around vehicle-to-building. This effort could also include a residential customer demonstration. This project would expand on the California E-Bus to Grid Integration project[81] with the focus on resiliency in addition to demand charge management and fleet scheduling.

Barriers Resolved

- The full value of V1G/V2G is still relatively uncompensated: Better understanding of the ability of EVs to support community resiliency can inform efforts to quantify the value of V2G.

Metrics Impacted

- Flexibility
  - Percentage of vehicles with bidirectional inverters

Benefits to Ratepayers

- Reduced GHG emissions
- Support for energy system resiliency in the face of outages

Metrics and Targets (Technology Integration)

- Performance
  - Ability to provide full state of charge for resiliency purposes within 24 hour notice
  - Ability to provide 50% state of charge for resiliency purposes within 6 hours of notice[82]
  - Ability to specifically serve critical loads
  - Ability to serve loads directly from the vehicle in support of mobile community resilience centers
  - Measure hours of critical load service per year
  - Measure rate of availability of vehicle-based support when requested
  - Measure amount of energy delivered relative to expected
- Price
  - Decrease the cost of additional hardware required to enable vehicle-to-building

[81] *California E-Bus to Grid Integration Project*, California Energy Commission (2019).

[82] Based on conversations with industry stakeholders and the expertise of the project team.

Priority

- High

Time Horizon

- Short-Term

Funding Category

- Applied Research and Development

Model EV Charging and Price Responsiveness

Research Description

This project will model EV charging behavior under different pricing and timing scenarios and assess the effects on distribution grid stability. It will build on previous projects like Smart Charging for Demand Management[83], Total Charge Management[84] and the SLAC non-residential VGI demonstration[85]. that studied the responsiveness of individual customers to price signals by studying what is necessary to contribute to load flexibility at the distribution circuit and wholesale level where a specific impact needs to be achieved. It will investigate the ability of direct managed charging and differential price signals to shape EV load and resolve potential distribution grid constraints. The study will review the impacts of different vehicle classes. The effort also aims to study the response of the general population, not just early adopters who may be abnormally aware and motivated to respond. For example, the Total Charge Management project provided an optimized charging option that would ensure that charging for grid benefit would not interfere with customer transportation requirements, but only saw ~60% adoption. Reducing barriers to entry and continued participation can significantly increase the resources available for vehicle grid integration. The outputs of the simulations should be tested against real cohorts of EV drivers for calibration purposes. This project does not directly develop new technology, but the information it will provide around barriers to further participation will enable greater utilization of PEV charging infrastructure flexibility.

Barriers Resolved

- Vehicle battery availability: Provides data on the how EVs respond to managed charging and grid signals under availability constraints.
- Aggregation required for feasibility: Investigates the effects of aggregated charging behavior on grid stability to reduce the uncertainty faced by grid operators on aggregated EV performance.
- The full value of V1G/V2G is still relatively uncompensated: Understanding EV effects on grid stability can inform efforts to quantify the value of V1G and V2G.

Metrics Impacted

- Flexibility and Sustainability

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83 *Smart Charging for Demand Management*, California Energy Commission (2019).

84 *Total Charge Management*, California Energy Commission (2019).

85 *Non-Residential VGI Demonstration*, California Energy Commission (2020).

- Increased DER penetration

Benefits to Ratepayers

- Maintain/reduce operations and maintenance costs
- Maintain/reduce capital costs
- Number of operations of distribution grid devices
- Improved system operation efficiency from increased flexibility

Metrics and Targets (Additional Data)

- Performance
  - Evaluate rate at which personal consumers of Level 1, 2, and 3 charging, as well as fleet users, will participate in price-based managed charging
  - Evaluate rate at which personal consumers of Level 1, 2, and 3 charging, as well as fleet users, will participate in direct managed charging
  - Evaluate ongoing rate of participation for program enrollees in each category
  - Provide interview summaries with consumers in each class regarding their decisions around managed charging
  - Percent of load responsive to price and grid signals relative to baseline
  - Percent of customers responsive to price and grid signals relative to baseline

Priority

- Medium

Time Horizon

- Short-Term

Funding Category

- Technology Demonstration and Development

Assess Plug-In Electric Vehicle Charging Technology Efficiencies

Research Description

One 2017 study[86] showed that the bulk of charging and discharging losses were because of the in-vehicle AC/DC converter; the losses were measured up to 16.5 percent and 21.8 percent, respectively, and were dependent on the battery state of charge and current. DC charging using a solar energy DC output (and increasingly, a stationary battery DC output) would largely avoid the losses due to the conversion. In addition, stationary transformers (AC/DC) may be much more efficient than in-vehicle systems. Further research on efficiency levels, and options to encourage deploying the most efficient charging solutions, could significantly reduce EV charging loads and provide more miles per kilowatt of electrical system capacity.

The 2017 study also showed a wide range of roundtrip efficiencies depending on state of charge, current, and portion of transformer capacity being used, with higher percentage losses at lower currents. Further study on optimizing V2G requests to minimize losses is warranted.

Barriers Resolved

[86] "Measurement of Power Loss during EV Charging and Discharging," *Energy*, Vol. 127 (2017).

- Charger performance: Better understanding of the factors of charging and discharging performance would allow EVs to more efficiently participate in a range of grid services. Charging directly from DC solar generation could also lower losses.

Metrics Impacted

- Sustainability
    - Reduced charging losses (megawatt-hours saved)

Benefits to Ratepayers

- Reduced GHG emissions
- Avoided customer energy use (kilowatt-hours saved)

Metrics and Targets (Additional Data)

- Performance
    - Provide assessment of total round trip efficiency across the following dimensions:
        - Ambient temperature
        - Service current
        - Battery state of charge
        - Battery size
    - Effective charging cycle efficiency greater than 90 percent
    - Report on cost effectiveness of providing grid services under each combination of the dimensions above

Priority

- Medium

Time Horizon

- Medium-Term

Funding Category

- Applied Research and Development

PEV Charging Device Performance Standards

Research Description

Load management systems are becoming popular to maximize electrical load capacity use, especially in existing buildings with limited electrical capacity available for EV charging or areas with high levels of EV adoption. Systems can be as simple as a dual head charger on a 40 amp, 208V/240V circuit that can share power between two vehicles or as complex as allocating capacity over dozens of vehicles while managing non-EV loads. Existing research has identified a dozen such systems, and the Canadian Standards Association developed the 2019 *Electric Vehicle Energy Management Systems* report[87] on how the technology is intended to work. However, the market lacks standardized and publicly available information on EVSE performance. This research project would produce and continue to update a database of available products.

[87] *EV Energy Management Systems*, Canadian Standards Association (2019).

Barriers Resolved

- Incomplete standards: Limited standards for EV energy management systems exist. This research can inform standards development and guide product design.

Metrics Impacted

- Sustainability
  - Reduced charging losses, megawatt-hours saved per year

Benefits to Ratepayers

- Reduced GHG emissions
- Avoided customer energy use (kilowatt-hours saved)

Metrics and Targets (Additional Data)

- Performance
  - Database of charging device performance metrics including:
    - Type of Duty Cycle
    - Claimed Capabilities
      - Scheduling control logic
      - Managed charging settings
      - Grid services communications
      - Sub-metering functions
    - Device Certifications (UL, SAE, IEC, etc.)
    - Current Deployment Status
    - Reliability
    - Existing Consumer Ratings
    - Product, Installation, and Maintenance Costs
  - Count of distinct users accessing database

Priority

- Low

Time Horizon

- Medium-Term

Funding Category

- Technology Demonstration and Development

Assess Second Life PEV Batteries

Research Description

The degradation of EV batteries through many cycles will eventually begin to affect battery capacity. A battery with a diminished capacity may no longer be suitable for an EV, but it has the potential to be a valuable resource for secondary applications such as aggregated battery storage. Many first-generation EVs are approaching the time when their original batteries are no longer suited to vehicular use, so the supply of these reduced-capacity batteries will begin to expand quickly.

Initial research at the UC Davis RMI Winery Microgrid Project[88] and by Honda Research & Development, Americas has been conducted, but the need for further investigation and outreach is merited to ease customer concerns and ensure that EV batteries are reused. The CEC opened a solicitation in this area in February 2020[89]. Important questions to resolve include:

- What is the degradation rate of the batteries?
- What are customer concerns?
- What are the effects of recycling on the battery supply chain?
- What is the target market price for second life batteries relative to the initial primary use case price?
- How can cells from multiple different battery packs at different levels of degradation be safely combined?
- Are there safety concerns unique to these batteries, and if so, how can they be mitigated?

Barriers Resolved

- V2G vehicle costs: Sourcing degraded batteries would constitute a nascent secondary market at a lower cost than new batteries.

Metrics Impacted

- Sustainability
    - Installed capacity of second-life batteries
    - Percent of vehicle batteries being re-used

Benefits to Ratepayers

- Increased storage provides greater grid flexibility
- Reduced cost of storage procurement

Metrics and Targets (Additional Data)

- Performance
    - Effective state of charge relative to nominal over the reused battery's useful life
    - Number of additional battery cycles in the reused battery's useful life
    - Rate of degradation of capacity over the reused battery's useful life
- Price
    - Cost of battery reuse relative to new battery

Priority

- High

Time Horizon

- Medium-Term

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88 *Robert Mondavi Institute Microgrid Project*, UC Davis (2019).

89 *Validating the Capability of Second-life Batteries to Cost-Effectively Integrate Solar Power*, California Energy Commission (2020).

Funding Category

- Applied Research and Development

VGI Data Program

Research Description

This project would create a vehicle-grid integration data platform that helps collect and catalogue information from an array of vehicle-grid integration-related sources. This information could be available online for a range of stakeholders.

The vehicle-grid integration data platform can collect different sets of data on the technical and market capabilities of vehicle-grid integration projects and programs, which will result in lower levels of uncertainty on the technical, market, and customer aspects of vehicle-grid integration solutions, services, and capabilities. The program could collect data from a literature review and expert interviews with projects and programs in many charging market sectors and make it easy to access and understand. While much data already exists, even larger amounts of new data are coming. This data includes timeseries profiles of usage profiles from charging infrastructure that would be beneficial to both grid planners and informed placement of additional charging infrastructure. The data integration platform will be able to reduce the uncertainty of vehicle-grid integration efforts by comparing findings to determine best practices and make more informed decisions. The platform will be updated as new data becomes available unlike a fixed report.

Barriers Resolved

- Uncoordinated research: The vehicle-grid integration data platform would break down barriers between and within agencies by gathering data from the CPUC, CEC, California Air Resources Board, and more in one spot and suggest best practices. Similarly, the private sector will use the vehicle-grid integration data platform to better design programs.
- The full value of V1G/V2G is still relatively uncompensated: The vehicle-grid integration data platform can collect data related to different aspects of valuation:
    - Benefits and costs
    - Customer participation and satisfaction
    - Service effectiveness and reliability
    - Market evolution and progress

  The platform could also collect data on the net value (benefits minus costs) of a wide range of vehicle-grid integration use cases. Understanding and comparing different results will allow the public and private sectors to determine best practices and better make decisions.

Metrics Impacted

- Affordability
    - Level of information available about existing and future studies and real-world projects on the costs and benefits of vehicle-grid integration.
- Reliability
    - Level of information available about existing and future studies and real-world projects on vehicle-grid functionality and ability to scale.

Benefits to Ratepayers

- Increased adoption of EVs driving reduced GHG emissions

Metrics and Targets (Additional Data)

- Performance
    - Count of projects listed in VGI database
    - Database should include:
        - Project Sponsor
        - Project Funding
        - Project Report Link
        - Time Series Charging Profiles
        - Vehicle and Charger Classes
        - Vehicle and Charger Measured Performance Metrics
        - Level of Grid Interactivity and Associated Revenues
            - Price signals
            - Direct load control
            - Ancillary services
    - Count of distinct users accessing database

Priority

- Medium

Time Horizon

- Long-Term

Funding Category

- Applied Research and Development

CHAPTER 4:
DER Communications and Controls

Increased DER adoption has driven the shift from an energy system of centralized generation and top-down control to a much more complex structure, including a signification portion of behind-the-meter generation. Grid operators are working to increase the number of points of communication and control in the distribution system, but they need to account for variable loads and generation sources with limited visibility. Effectively integrating DER requires coordination to use these new devices to help rather than hinder operations.

Distribution Grid Communications

As the distribution system incorporates more customer-sited resources, the requirements for visibility into these assets and communications to provide controls have increased. In addition to the communications network that enables interaction, different distributed resources require protocols to pass information between themselves, with aggregators, and with the distribution operator.

Distribution Grid Communications - Technical Assessment

The DER Technical Assessment document[90] describes and analyzes the advantages and disadvantages of the different communications network technologies that have been used to coordinate distributed resources. This roadmap document focuses on the identified barriers and suggested research solutions.

Distribution Grid Communications - Barriers

Cost

Attribution of enabling platform costs: Distribution communications assets are required for almost all grid modernization use cases, but it is difficult to justify the cost if only implementing a limited number of these use cases when installing the communications assets. This also makes staged implementations difficult.

Coordination

Limited assignment of cybersecurity responsibilities: While not directly a barrier to future adoption, devices may be coming onto the grid with insufficient consideration of cybersecurity impacts. Further review is needed to ensure the future distributed grid remains secure.

Integration between utility and third-party communications systems: A wealth of information is being generated by third-party devices, including EVs, end load automation portals, and smart inverters. Finding an effective way for this data to be shared with the distribution grid operator

[90] *DER Technical Assessment*, California Energy Commission (2019).

could greatly increase the value and reduce the concerns of the operator, allowing greater adoption.

Lack of clear architecture: A centralized approach could require all participants in the future energy system adopt and follow the same standards and protocols for all DER technologies. This would provide clarity but would significantly limit flexibility and interoperability between different types of DER devices. Standardized, widely available, and machine-readable real time energy price information is an especially significant missing piece. Translational protocols could enable different types of end devices to coordinate through a common language. This option would allow many different device types to develop separately, but it could also lead to overwhelming complexity.

Distribution Grid Communications - Research Needs

Low-Cost Telemetry for Aggregated Distributed Energy Resources

Research Description

Aggregated DER are subject to the same metering and telemetry requirements as utility-scale generators when participating in wholesale markets. The costs of these requirements can be prohibitive for smaller DER providers. To encourage more aggregated DER to participate in wholesale markets, lower-cost metering and telemetry options that meet the wholesale market requirements need to be developed. Developing telemetry alternatives (for example, using statistical methods instead of additional telemetry equipment) may also be an option. Three PG&E EPIC projects[91] [92] [93] noted that communications infrastructure was as critical as the distributed resources themselves if they were to be deployed for central control use cases. The costs and performance of telemetry vary significantly across the various potential technologies. This project would begin with an interview-based assessment of the different costs across a range of use cases and establish publicly available data on these costs.

Barriers Resolved

- Attribution of enabling platform costs: Addresses the high cost of telemetry equipment, which is preventing more widespread aggregation of DER.

Metrics Impacted

- Affordability
    - Customer bill savings from participation in aggregated DER
    - Wholesale market participation by DER
    - Cost of telemetry equipment

Benefits to Ratepayers

- Customer bill savings
- Improved system operation efficiency from increased flexibility

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[91] *DERMS Report*, PG&E (2018).

[92] *Test Smart Inverter Enhanced Capabilities – PV*, PG&E (2019).

[93] *Distributed Demand-Side Technologies*, PG&E (2018).

- Reduced GHG emissions
- Reduced criteria air pollution emissions
- Improved public safety

Metrics and Targets (Technology Advancement)

- Performance
    - Communications latency < 4 second for frequency regulation
- Price[94]
    - Reduce metering equipment and installation from $600 to $400
    - Reduce secure gateway equipment and installation from $1,000 to $800
    - Reduce monthly maintenance for telemetry from $20 to $15/month
    - Reduce all-in telemetry costs to $1/MWh/month

Priority

- High

Time Horizon

- Medium-Term

Funding Category

- Applied Research and Development

Secure Communications for DER

Research Description

The California Public Utility Commission has directed the use of the IEEE 2030.5 as the default DER communications protocol.[95] The Common Smart Inverter Profile (CSIP)[96] was developed to support interoperability between utility operators and inverters or the services managing those inverters. This project would assess the practical implementation and scalability of DER using the IEEE 2030.5 protocol. It would test the ability of the communications protocol to withstand cyber intrusions. If the intrusions are successful, the project would assess and demonstrate the level of intrusion (DER control, utility control, etc.). The project will look at the cybersecurity implications to utility distribution operations of connecting third-party DER—any potential barriers in communications latency and availability between the grid operator and end devices—and will research issues integrating these third-party assets with grid management systems. It will also investigate the potential issues arising from participation of devices installed prior to the IEEE 2030.5 requirements, and any potential resolutions if these are found to compromise cybersecurity.

This project would also investigate the level of trust and certification necessary for grid operators to know what end points they are communicating with; it would also investigate whether grid operators have any continuing concerns about the robustness of IEEE

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94 *DER & NYISO's Real-Time Telemetry Needs*, NYISO (2018).

95 *Recommendations for Trust and Encryption in DER Interoperability Standards*, Sandia National Lab (2019).

96 *Common Smart Inverter Profile*, SunSpec (2018).

cybersecurity standards. The project would build on findings from the SunSpec/Sandia DER Cybersecurity Working Group[97] and SCE's Distribution Resources Plan Demonstration Demo E. Initially, Demo E was intended to demonstrate secure communications and coordination of multiple DER, but it was determined that "the threat environment that Demo E was slated to operate in has evolved, necessitating additional cybersecurity controls to minimize the risks to the grid production systems,"[98] resulting in project termination. This proposed project would work with the utilities and DER providers to find a safe resolution to the cybersecurity deficiencies identified in SCE's Demo E. The results would allow DER providers to resolve these issues to prevent additional interconnections from being rejected for these cybersecurity reasons.

Barriers Resolved

- Integration between utility and third-party communications systems: Grid operators need to integrate third-party DER resources, especially those not directly controlled by the operator, with existing control schemes.
- Limited assignment of cybersecurity responsibilities: The effort investigates secure, authenticated communications between third-party DER and utilities to understand the level of cybersecurity that will be required for end use devices.

Metrics Impacted

- Affordability
  - Increases the value proposition of DER as a non-wires alternative to provide real-time grid services (capacity, reliability)
- Sustainability
  - Enables increased DER penetration
- Flexibility
  - Enables increased third-party DER that is visible and controllable by grid operator

Benefits to Ratepayers

- Energy security
- Increased system monitoring capabilities

Metrics and Targets (Technology Integration)

- Performance
  - Field verify the percent of installed DER with firmware properly set to the IEEE 2030.5 protocol
  - Study the benefits and consequences of a shift to expiring certificates or the addition of a certificate revocation method
  - Study the benefits and consequences of the addition of physical security requirements

[97] *Cybersecurity Working Group*, Sunspec / Sandia (2019).

[98] *SCE DRP Demo E Final Report*, SCE (2019).

- Verify security requirements for DER aggregator servers and propose extensions based on project learnings

Priority

- High

Time Horizon

- Short-Term

Funding Category

- Applied Research and Development

Standardization of Device Protocols and Data Transparency and Availability

Research Description

With the proliferation of DER and smart devices such as connected thermostats and plugs, it is important that all devices use a common protocol for communication. Many manufacturers have proprietary protocols, which preclude (or at least complicate) device interoperability and necessitates that energy service providers undertake duplicative systems integrations to support multiple protocols. Furthermore, the difficulty for energy service providers to access device data—including real-time device energy usage—is a significant barrier to quantifying the benefits of flexible loads within a building. As noted above, California Rule 21 identifies IEEE 2030.5 as the default protocol for DER communication but allows others under mutual utility and third-party agreement. Other adjacent protocols fulfill similar but distinct use cases – for example, OpenADR 2.0b communicates load flexibility requests primarily with a device gateway, building energy management system, or aggregator as opposed to the end device directly. When the operator requests an amount of load reduction, this allows the management system to be responsible for translating the load reduction to specific end device behaviors like temperature settings rather than requiring all end devices to be able to process a load reduction request.[99] This Open ADR protocol can facilitate additional DER participation by allowing end devices and loads to communicate over an existing protocol to an OpenADR endpoint rather than requiring them to implement IEEE 2030.5 and be directly controlled by the grid operator.

The OpenADR 2.0b Draft Addendum for DER Profile Specification makes recommendations as to how the requirements of the Common Smart Inverter Profile Implementation Guidelines can be met using OpenADR 2.0b.[100] This research will support demonstrations of these proposed standards for devices and data accessibility including secure communications back to a grid operator or integrator following efforts like the CEC's 2020 Load Management Rulemaking and the SunSpec / Sandia DER Cybersecurity Work Group.[101]

Barriers Resolved

- Uncertainty in customer and behind-the-meter resources behavior: Much remains unknown as to how reliably traditional devices like air conditioners, refrigerators, and

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[99] *How OpenADR Can Compare with IEEE 2030.5 for CA Rule 21*, OpenADR Alliance (2020).

[100] *OpenADR 2.0b Profile Specification DER*, OpenADR Alliance (2019).

[101] *DER Cybersecurity Work Group*, SunSpec / Sandia (2019).

pool pumps will respond when asked to shift load. This research will seek to understand and quantify the effect of those unknowns, particularly related to communications, to remove the barrier of uncertain reliability with flexible load.

- Difficulty separating value streams: Additional visibility into device data will help associate load impacts with the grid value provided, which will support efforts to quantify the benefits of flexible loads within a building.

Metrics Impacted

- Number of smart devices
- Controllable load from smart devices (Megawatts)

Benefits to Ratepayers

- This research will reduce the costs of flexible loads on hardware by creating a unified system and hub of smart devices.

  This research will improve ADR technology and consequently increase DR capacity as a result of standardization.

Metrics and Targets (Technology Integration)

- Performance
  - Project will demonstrate customer-owned OpenADR 2.0 controlled DER meeting at minimum the following requirements:
    - Autonomous functions default settings shall be able to be set by operator instruction
    - Pre-scheduled autonomous power values and modes shall be able to be set by operator instruction
    - Aggregator shall be able to store at least 24 scheduled DER control events for each resource in its portfolio
    - Given a loss of communications, DERs shall complete any scheduled events and then revert to default settings
    - When given possibly conflicting instructions, DER shall select the operation with highest priority
    - Unless otherwise specified in the utility's Interconnection Handbook, default polling for new controls and posting of monitoring information shall be at 10 minutes and 5 minutes, respectively[102]
    - Smart inverters shall provide the following grid support functions:
      - Low/High Voltage Ride Through
      - Low/High Frequency Ride Through
      - Ramp Rate Setting
      - Connect/Disconnect
      - Dynamic Volt-Var
      - Fixed Power Factor Control

[102] Based on conversations with industry stakeholders and the expertise of the project team.

- Real Power Output Limit Control
- Volt-Watt Control
- Frequency-Watt Control
- Set Active Power Mode

Priority

- Medium

Time Horizon

- Medium-Term

Funding Category

- Technology Demonstration and Development

Distribution Grid Management

Distribution grid management is an increasingly complex task as the electrical grid transitions from a one-directional system with relatively complete visibility into the major assets to a bidirectional distributed network controlled by a variety of different entities. This transition is accompanied by a greater portion of the generation resources existing beyond the current visibility of the grid operator. Advanced distribution grid management technologies seek to improve the visibility, communications, and management of these distributed resources in a way that efficiently integrates them into the existing grid. The bulk of distribution grid management will fall under utility control, with grid management research c within utility EPIC research programs. However, a discussion of distribution grid management is included to identify any potential collaborative research areas.

Distribution Grid Management - Technical Assessment

Operating the distribution grid requires coordination of many IT and operational technology (OT) systems. Though the configuration and nomenclature changes from one distribution operator to another, relevant systems could include:

- Geographic information system (GIS): Application dealing with the spatial orientation and properties of the electrical network assets.
- Outage management system: Applications dealing with optimized power outage resolution and notification processes.
- Supervisory control and data acquisition (SCADA): Systems responsible for sending and receiving data from the electrical grid.
- Distribution management system (DMS): Applications dealing with network analysis functions, estimation of the distribution system state, and visualization; this system often provides a high-level interface to SCADA systems.
- DER management system (DERMS): Applications coordinating control and optimization for DER.

Distribution operators are upgrading these systems, adding new functionality, decision support, and automation to more smoothly integrate new resources and improve operations. This section focuses on the barriers preventing DER from interfacing with these systems and the potential research opportunities to relieve them.

Distribution Grid Management - Barriers

Cost

Attribution of enabling platform costs: The user must be able to justify the cost of the DERMS based on the expected benefits it will garner. The cost varies whether the solution is on-site or a software service, the number and scale of programs integrated, the number of enrolled customers, and the extent of integration with internal systems and third-party equipment. DERMS are necessary to fully integrate distributed resources, but it is difficult to attribute the specific benefits, some of which will occur in the future, of enabling increased DER participation.

Valuation

Cost-of-service ratemaking: Cost-of-service ratemaking builds in the cost of infrastructure upgrades to the cost of service and conducts rate case proceedings to determine rates and recovery. This leaves little room for innovation and unplanned upgrade projects in years without a rate case proceeding because utilities are under constant pressure to keep costs down to maintain their predetermined profit margin and operating cash flow. Even utilities with strong relationships with regulators struggle to include innovative technology upgrades, as most are deemed too expensive. The CPUC has provided increased guidance on including DERMS and other grid modernization upgrades,[103] but consensus on exactly which upgrades provide enough customer benefit, has yet to be achieved.

Benefits of grid modernization investments limited to a subset of customers: Utilities are using measures of customer interruption as a metric to justify grid modernization investments. Some customers (such as large commercial and industrial customers manufacturing goods) have a much higher interruption cost than others. While the benefits of improved reliability are disproportionately realized by a relatively small number of customers, utility investments in fault location and service restoration (FLISR), automated switching, and other distribution automation investments, are paid for across all ratepayers. These investments are unlikely to be made in areas with low population density but that are likely high risk for outages. This type of situation could be aptly addressed by DER, within microgrids or as standalone resources. How the value of reliability is calculated will affect what kinds of investments are made.[104]

Capability

Lack of integrated solutions: Resource planning tools need to integrate data from across the utility, but few vendors provide integrated forecasting and planning solutions developed and equipped to support DER integration.

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[103] *D.18-03-023*, CPUC (2018).

[104] *LNBA Working Groups 1 and 2 Status Report*, DRPWG (2016).

Limitations of cloud communication: Data sent to the cloud has a latency issue that reduces its value when a fast, local decision is desired. Other limits to cloud services exist, such as paying for network bandwidth, data storage, and compute power. Security is another consideration when considering cloud solutions for sensitive grid operations.

Physical network model quality: Advanced distribution management functionalities require the physical network model to be as reflective of the real network as possible and track more granular details than have been necessary up to this point. The data models residing in utility GIS systems are often either incomplete, inaccurate, or both. The extensive model clean-up required before deployment is a barrier.[105,]

Flexibility and interoperability limitations: Another challenge noted by the utilities is the limited flexibility of the DERMS options available. Even though vendors claim that their DERMS solution is highly flexible, utilities note that several features cannot be customized.

Limited DER inclusion: In a 2017 assessment, PG&E found that commercially available DERMS solutions were often limited to a subset of DER, including only behind-the meter storage and smart inverters for photovoltaic generation and not demand response or PEV integration.[106]

Unreliability of communications: In Location 2 of PG&E's Smart Inverter EPIC project[109], the IEEE 2030.5 smart inverter (SI) aggregator solution routinely failed to recover from temporary satellite and cellular communications outages, requiring a manual reset to restore visibility and control of SI-enabled PV systems. Similarly, two other SI demos performed by PG&E and SDG&E showed that the reliability of SI communications was well below the average communication reliability for SCADA-enabled devices, such as line reclosers. For distribution services, this is a challenge because customer needs require a high degree of distribution system reliability. Communications reliability is measured as the probability of successful communication. One study found that the network needs to be at least 98 percent reliable to not impact the effectiveness of the inverter to provide voltage control.[107]

Coordination

Challenges integrating grid management systems: Integration between the legacy system components is a large challenge for the design and deployment of advanced distribution management systems. Specific challenges include the piece-meal integration of new systems into existing systems, as well as integration of solutions from multiple vendors.[108]

Challenges integrating sensing and control assets: Utilities face significant challenges integrating new capabilities into their existing asset management and condition monitoring software infrastructure. It is also difficult for utilities to justify the cost of advanced sensing

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105 *Big Data Techniques to Address ADMS Data Quality Issues*, GridBright (2018).

106 *Joint IOU EPIC 3 Planning Workshop*, California IOUs (2017).

107 *Evaluation of Communication Requirements for Voltage Regulation Control with Advanced Inverters*, SNL (2016).

108 *ADMS State of the Industry and Gap Analysis,* Pacific Northwest National Lab (2016).

hardware without spreading the costs across a series of use cases that each provide some measured benefit, especially if some of the use cases are planned. Based on expert interviews, the large-scale integration of new devices into legacy grid management systems often requires additional, unplanned work as latent issues are identified.

Operational silos: DER-integrated forecasting and planning analysis needs to be coordinated across different parts of the distribution operator organization to support optimized dispatch of DER and control of the grid.

Insufficient communications standards: Every utility deploys a variety of different communications protocols, many of which are proprietary and limited to specific systems. This puts pressure on the sensing and measurement device manufacturers to build multiple communications systems into their products. The result is a complicated and diverse market for equipment and limited universal adoption of devices across the industry. While IEEE has drafted a standard protocol for utility communication with DER, according to PG&E, the standard is not yet prescriptive or stable enough to enable consistent interpretation by aggregators for all desired functions[47].

Customer acquisition: Often, residential PV systems are owned by third parties, not the customers or DER vendors. Because third-party ownership rights typically prevent any possibility to intentionally curtail power, which was part of the real power control use case, many existing customer systems cannot be retrofitted to provide smart inverter functionality. In the PG&E's Smart Inverter EPIC Project[109], the vendor faced difficulties acquiring new customers to participate in the technology demonstration despite a $300 credit and a free residential energy storage device incentive.

Consistency and interoperability: An Electric Power Research Institute (EPRI) project[110] developed two communication systems that included head-end software and local modem/modules that could be plugged into the inverters. In both cases, the local connection to the inverter was the same, based on the SunSpec protocol, with the modem/modules providing translation to/from their native system protocols and cybersecurity as needed. These modules allowed communication systems to work with any inverter. However, there were instances that the technical specifications of each inverter limited interoperability. For example, a control system that attempted to send a control curve with four points to all DER in a group, would see some failures due to the differences in each inverter's number of Volt/VAR curve points. This underscores the need for grid codes and associated functional tests like UL 1741 to be specific in terms of capabilities within required functions.

Cybersecurity: Cyberattack vulnerability increases as DER become more widespread and communication networks expand to integrate with building automation or IT networks. In addition, DSOs may be unable to monitor the security of SIs owned by third parties.

The California Common SI Profile specifies IEEE 2030.5 as the communications protocol between the DER aggregator and the utility. However, communication between the aggregator and individual SI control unit is specifically out of scope for the standard, and no mechanism

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[109] *PG&E EPIC Project 2.03A*, PG&E (2018).

[110] *Standard Communication Interface and Certification Test Program for Smart Inverters*, EPRI (2016).

exists to ensure end-to-end cybersecurity between the utility and SI-enabled DER. Furthermore, while the IEEE 2030.5 communications standard (covers utility-aggregator interactions) includes a requirement for transport layer security, no certification or test procedure exists to guarantee that it is adequately implemented by vendors.[111]

Researchers at Argonne National Laboratory have identified quantitative metrics to measure the effect of a cybersecurity attack based on:

- Amount of load lost
- Number of feeders tripped
- Fraction of components not surviving a given attack
- Voltage or frequency violations
- Decreased system stability margins
- Time to recover a given fraction of network functionality
- Average propagation of cascading failures
- Safety violations[112]

DSO/transmission system operator (TSO) interaction: Using smart inverters to support transmission system operation without considering distribution system requirements, leads to risks of PV or other DER technology with a smart inverter affecting the downstream distribution system reliability or power quality. If solar PV-fed smart inverters were used to support voltage at the substation level, this control would need to be coordinated between the system operator and the DSO. To resolve conflicting requests from the TSO and DSO, the costs and benefits of each scenario need to be better understood. This understanding is limited by the accuracy of voltage modeling at service points.[113]

? Uncertainty

Reactive power priority requirement: To support grid stability, the Rule 21 Phase 2 requirements mandate reactive power priority from customer inverters; in the case that voltage needs correcting while the inverter is fully utilized, the new requirements reserve a portion of the capacity for reactive power support, partially limiting customer generation. The compensation structure and expectations for grid support need to be communicated clearly to customers.

Benefit uncertainty: Uncertainty surrounds the cost-benefit ratio of SI adoption or retrofit. PG&E's Smart Inverter[109] EPIC project performed a cost-benefit analysis of SIs on PG&E's system as compared to traditional distribution grid upgrades; the project will evaluate of the cost-effectiveness of the Smart Inverter Working Group Phase 1 and Phase 3 functions and

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[111] *Enabling Smart Inverters for Distribution Grid services*, California IOUs (2018).

[112] *Cybersecurity for distributed energy and Smart Inverters*, Argonne National Laboratory (2018).

[113] *Reactive Power Support of Distribution and Transmission Systems by Active Distribution Networks*, Energy Central (2018).

determine incremental benefits of autonomous SI functions. The costs of customer adoption versus benefits to the distribution operator should be assessed further.

Distribution Grid Management - Research Needs

Sensors for Circuit De-Energization

Research Description

This research aims to develop high fidelity, low-cost sensors and controls to de-energize select circuits based on electrical conditions. The effort could also address whether a circuit that has been proactively shut off for safety reasons is able to be re-energized without ground or aerial visual inspection, limiting the duration of customer outages. This project could expand upon the Monitoring, Communication and Control Infrastructure section of the SDG&E EPIC 2.03 project, particularly in looking at installing adapters to allow existing assets with limited communications to coordinate with the utility network.[114]

Barriers Resolved

- Localized de-energization of circuits
- Physical network model quality: Provides data on grid conditions at a higher level of temporal and geographical granularity to inform physical network models.

Metrics Impacted

- Reliability
  - Number of distribution grid device operations
  - Reduced Customer Average Interruption Duration Index (CAIDI) for FLISR-related activations
  - Reduced System Average Interruption Duration Index (SAIDI)

Benefits to Ratepayers

- Maintain/reduce operations and maintenance costs
- Improved system operation efficiency from increased flexibility
- Improved public safety
- Improved utility worker safety

Metrics and Targets (Technology Advancement)

- Performance
  - Reduce response time to de-energization
  - Measurement accuracy within +/- 0.5 percent
- Price
  - Reduce three-phase unit cost from $10,000 to $8,000[115]

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[114] *EPIC 2.03 Final Report*, SDG&E (2017)

[115] Target based on stakeholder comment, providing rough estimate as device functionality varies.

Priority

- Medium

Time Horizon

- Medium-Term

Funding Category

- Applied Research and Development

Local DER Transaction Platform

Research Description

This project would demonstrate a platform for local distributed energy transactions, allowing local energy sources and sinks to schedule and conduct transactions to meet local energy, capacity, and other grid needs. This project would specifically investigate capabilities for a resilient multi-customer microgrid that can continue to function in the event the bulk grid is unavailable for safety or technical reasons. The project would operate in two stages: first to develop and model and software controls for the local market and second to perform a physical demonstration if the first stage was completed successfully. Potential complexities to study include coordination of sharing energy storage resources with limited energy capacity across different customers and different levels of load criticality. The results would inform policymakers and grid operators about the challenges and opportunities of decentralizing the electric grid. The recently concluded Retail Automated Transactive Energy System (RATES)[116] project made significant progress developing such a transactive energy platform but identified several opportunities for improvement including: a more robust data interface between the end customers, distribution utility and system operator; promoting the importance of available flexible loads; and a push for a subscription transactive tariff to be provided by the distribution operators.

Barriers Resolved

- Benefits of grid modernization investments limited to a subset of customers: A customer-centric transactive energy platform would mitigate the issue of ratepayer-funded grid upgrades disproportionately benefiting certain subsets of the customer base.

Metrics Impacted

- Flexibility and Sustainability
    - DER penetration
    - DER adoption
- Resiliency

Benefits to Ratepayers

- Number and total nameplate capacity of distributed generation facilities
- Total electricity deliveries from grid-connected distributed generation facilities
- Number and percentage of customers on time-variant or dynamic pricing tariffs
- Customer bill savings

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[116] *Complete and Low-Cost Retail Automated Transactive Energy System.* California Energy Commission (2020).

- Nameplate capacity (megawatts) of grid-connected energy storage
- Energy security
- Reduced GHG emissions

Metrics and Targets (Technology Integration)

- Performance
  - System satisfies IEEE 2030.5 cybersecurity requirements
  - Demonstration system coordinates at least three business entities with multiple devices per entity
- Price[117]
  - The RATES project estimated a per participant cost of roughly $230 at the scale of 1,000 customers. The target would be to reduce participation costs to $200 per customer at that scale.
  - The RATES project estimated annual maintenance costs at 15 percent of installed costs. The target would be to reduce annual maintenance costs to 12% of installed costs
  - The project will identify any additional costs incurred to implement a fully functioning transactive energy pilot program

Priority

- Long

Time Horizon

- Medium-Term

Funding Category

- Technology Demonstration and Development

Real-Time Estimation of Photovoltaic Power

Research Description

This study would provide additional visibility into behind-the-meter customer generation and storage to allow distribution operators to make informed decisions on switching operations. Research has been conducted on methods to identify behind-the-meter resources in PG&E EPIC 1.21 (solar) and is proposed for PG&E EPIC 3.06C (storage), but real-time visibility is still needed to make switching decisions. For example, distributed generation on a distribution circuit may mask the total load when measured at the substation and result in more load being picked up than expected during a switching operation. The project would develop and evaluate both hardware-based and estimation-based methods. Effective adoption of functioning technologies by the grid operator would be a component of project success.

Barriers Resolved

- Physical network model quality: Mitigates situational awareness issues from the prevalence of unmonitored behind-the-meter PV systems and provides visibility into grid

[117] *Complete and Low-Cost Retail Automated Transactive Energy System.* California Energy Commission (2020).

conditions at a higher level of temporal and geographical granularity to inform physical network models.

Metrics Impacted

- Flexibility and Sustainability
  - Increased DER penetration

Benefits to Ratepayers

- Improved system operation efficiency from increased flexibility
- Improved forecast accuracy improvement
- Increased system monitoring capabilities

Metrics and Targets (Technology Integration)

- Performance
  - Mean absolute percentage error of estimate less than 10% each day
  - Estimation and data transfer able to provide predictions to system operator within five minutes

Priority

- Low

Time Horizon

- Medium-Term

Funding Category

- Technology Demonstration and Development

Hosting Capacity Expansion Planning and Operational Controls

Research Description

Utilities are learning how DER can offset the need for traditional infrastructure upgrades. Unfortunately, no distribution planning process exists that focuses on expanding the hosting capacity of a distribution feeder or customer service node to enable DER interconnection without an upgrade. In other words, the distribution planners have assumed fixed behavior of DERs rather than considering operational limitations that would allow additional interconnection. Ideally, operational controls would be used by interconnecting DER (PV, battery, EV) to manage operations and limit wiring upgrades within the home as well as the distribution system. The proposed focus of this research is to analyze how certified operational controls can safely interoperate with devices to offset the need for a traditional wires upgrade at the utility service node and investigate how this same approach can be used to expand the hosting capacity of the distribution system. Existing DER operating profiles will be modified to evaluate storage use for maximum grid benefit and customer economics. This research would allow greater DER integration by more efficiently using the capacity of the distribution system.

Barriers Resolved

- DER circuit saturation: Distribution planning processes do not currently enable rapid interconnection as feeders become saturated. This research will enable additional DER to be interconnected in a constrained feeder without triggering costly physical upgrades.

- Benefits of grid modernization investments limited to a subset of customers: This research demonstrates a method to mitigate hosting capacity issues without relying on traditional wires upgrades, which may disproportionately benefit certain customers.

Metrics Impacted

- Flexibility and Sustainability
  - Total potential DER installed capacity

Benefits to Ratepayers

- Number and total nameplate capacity of distributed generation facilities: Quantification and research optimization will highlight benefits, leading to policies and programs that enable larger quantities of DER to interconnect.
- Avoided procurement and generation costs: Non-wires solutions will lower utility costs for end users and change utility planning practices to better align with California's RPS.[118]
- Nameplate capacity (megawatts) of grid-connected energy storage: Non-wires solutions will increase storage adoption and use within multiple power system domains.

Metrics and Targets (Technology Integration)

- Performance
  - Use controls to increase estimated hosting capacity by 20%[119]

Priority

- Low

Time Horizon

- Medium-Term

Funding Category

- Technology Demonstration and Development

Estimating Distributed Inertia Requirements

Research Description

The shift toward distributed, inverter-based generation from centralized generation could create inertia problems on the overall T&D grid, because no spinning masses are associated with most inverter-based generation. As public safety power shutoffs may disconnect transmission lines, the amount of system inertia available in subsets of the grid may become a more granular concern than the amount of inertia in the entire system. This project would

[118] *California Renewables Portfolio Standard Program (SB 100),* CPUC (2018).

[119] Based on conversations with industry stakeholders and the expertise of the project team.

study these granular constraints to understand where and when this problem might occur and what can be done to mitigate it.

Barriers Resolved

- Barriers to DER providing grid benefits: An increase in inverter-based generation may end up causing inertia problems that could restrict additional DER penetration in lieu of centralized generation; this research aims to foresee and mitigate these issues.

Metrics Impacted

- Reliability and Resiliency
  - Frequency and voltage on transmission system after outage and restoration

Benefits to Ratepayers

- If a lack of system inertia becomes an issue, it may hinder the number of DER that provide generation to the distribution grid. Synthetic distributed inertia would ensure the distribution system can operate without the support of typical centralized generation units.

Targets (Additional Data)

- Performance[120]
  - Provide distributed inertia requirements for at least 60% of distribution circuits in IOU service areas
  - Provide distributed inertia requirements for 100% of distribution circuits in high-risk wildfire zones and areas affected by Public Safety Power Shutoffs

Priority

- Medium

Time Horizon

- Medium-Term

[120] Based on conversations with industry stakeholders and the expertise of the project team.

CHAPTER 5: Distributed Energy Resources Planning and Strategy

Distributed Energy Resources in Grid Planning

Like conventional grid operations, legacy grid planning processes have been centralized and driven primarily by utilities with oversight from the CPUC. The transformation to higher penetrations of distributed resources has opened the process to many more stakeholders and required significant increases in transparency. Efficiently allowing distributed resources to participate in the grid planning process requires tight communication and coordination across these many parties, accurate predictions of upcoming grid constraints, and a shared understanding of DER capabilities. This section discusses opportunities to create further transparency, standardize expectations, and reduce barriers to DER participation in grid planning processes.

Distributed Energy Resources in Grid Planning - Technical Assessment

In the early 2010s, initiatives like net energy metering (NEM) and the CPUC's Self-Generation Incentive Program were driving the adoption of distributed resources, but they did not provide significant direction for the most effective way to integrate these new resources with the existing grid. Among other components like time-of-use rates, modifications to NEM, and renewable portfolio standard clarifications, California AB 327 (2013)[121] required utilities to submit distribution resources plans (DRPs) that would help direct DER to optimal locations and help to assess their contributions to the grid. This led to CPUC Distribution Resource Plan rulemaking[122] (R.14-08-013), establishing requirements for two new analyses and a series of demonstration projects to put these analyses into practice:

- Recurring integrated capacity analysis (ICA) that would publicize maps showing how open different areas of the distribution system were to the addition of different DER
- Locational net benefits analysis (LNBA) to assess exactly how much DER contributed to different value streams

These new assessments opened the mechanics of the distribution planning process to the wider range of DER stakeholders. Even in the areas where consensus was not achieved on the best implementation, the assessments provided significant understanding of the complexities of moving to a multi-participant planning process. The lessons learned from the initial DRPs led to the 2018 CPUC Decision D.18-02-004. [123] This decision established the Distribution Investment Deferral Framework (DIDF) to allow a public assessment of upcoming grid needs and identification of opportunities that third-party distributed resources could compete against conventional grid investments to provide. After initial rounds of solicitations, some larger, front-of-the-meter DER bids were successfully chosen as more cost-effective than conventional

[121] *AB 327*, California Legislature (2013).

[122] *R.14-08-013*, CPUC (2013).

[123] *Distribution Investment and Deferral Process*, CPUC (2018).

grid investments, but many others were deemed not cost-effective by the Distribution Planning Advisory Group and independent professional engineers.

These issues applied particularly to aggregated behind-the-meter DER where: coordination of many customers in a specific region, cost-effective measurement and verification protocols, and alignment with the timelines of a competitive solicitation have proven difficult.[124] The following section discusses these barriers and the research opportunities to more effectively allow distributed resources to participate in the grid planning process.

Distributed Energy Resources in Grid Planning - Barriers

Cost

Difficulty combining resources from multiple participants: The solicitation and contracting costs from combining multiple smaller offers to meet a single identified grid need have proven complex despite the creation of a technology-neutral pro forma contract.

Timing of investments: DER projects cannot make significant progress constructing new assets until a CPUC decision approves the DER contract. This creates aggressive project timelines and requires resources to be on call for specific DER projects, in some cases coordinated across a range of different companies to do the design, procurement, installation and testing. In contrast, the personnel and supplies for a conventional project are all under the coordination of the distribution utility and can be re-assigned to another project if there are any delays in a project approval process.

Valuation

Difficulty separating value streams: Non-wires alternatives may provide benefits across a variety of market mechanisms. Distribution planners may identify a need for generation capacity from distributed resources in an area but have no identified need for other potential benefits provided by those distributed resources. Consequently, the provider of the resources may not be able to aggregate and sell the additional services in the market.

Lack of explicit valuation of reliability, resiliency and social benefits: Recent California wildfires and public safety power shutoffs have highlighted the importance of a reliable and resilient grid. There is limited research into and consensus on the value of resiliency to different ratepayers. Clear values are necessary to making efficient decisions about grid investments.

High utilization grid needs limit multiple-use applications: For grid needs like load reduction, the duration, frequency, and magnitude of the projected overload are relevant. For example, a one-megawatt load reduction required for two peak hours during a few weeks in the summer would allow a participating DER to seek alternate revenue streams outside of those hours; a similar one megawatt reduction required 12 hours per day year-round would heavily limit the DER's ability to pursue other revenue streams. However, the traditional wires investment being deferred would be the same cost in either case, regardless of whether the wire is in use two hours or 12. Additionally, the types of resources most effective at providing longer-duration

[124] *Distribution Deferral Opportunity Report*, PG&E (2018).

peak reduction may be less effective at achieving ancillary sources of revenue more suited to short-duration resources.

Capability

Operational flexibility of aggregated DER: Aggregating many behind-the-meter resources in an area involves greater customer acquisition costs and longer timelines. Aggregated DER may also be less adaptable to swings in assessed need than a single DER or wires solution. Furthermore, the participants in aggregation must be collected and confirmed to participate in a grid need solicitation with no guarantee of success.

Coordination

Customer acquisition challenges: Because DER can provide services only when present in enough quantities, at the optimal locations, at the time and duration required by the grid, and when they are more cost-effective than other approaches, barriers to customer adoption lead to uncertainty in forecasting and planning efforts. Coordinating with many customers coupled with a requirement for a critical mass creates greater organizational overhead than a single conventional grid upgrade.

Uncertainty

Uncertainty in customer and behind-the-meter resources behavior: Without a clear understanding of how customers behave and how behind-the-meter DER will respond to different types of grid signals, it is difficult for grid planners to have sufficient confidence in behind-the-meter DER availability and responsiveness to favor DER over traditional infrastructure upgrades.

Uncertainty in load forecast: The distribution planning process is driven by net load forecasts, including both demand growth and behind-the-meter generation. Potential grid needs are identified several years in the future and tracked in successive planning years, with investments made once planning criteria are exceeded. The timing and magnitude of a forecast capacity deficiency can change year to year, altering the characteristics of the grid need. Additionally, while the capability to switch portions of the overloaded network to adjacent substations allows for increased flexibility and more efficient operation, it makes it more complex to forecast grid needs at specific locations.[125] For example, PG&E's 2018 DIDF process identified a combined 3.2 megawatt need for a bank at the Santa Nella substation with 82 maximum calls of the resource per year. An update to the requirements in 2019[126] looks for a combined 6.7 megawatt need and 122 calls per year, representing a significant increase that participants may not be able to achieve with their planned projects. This document also cited expressions of interest in new high-speed vehicle charging on this substation as an example of unpredictable potential new load, and states that load applications for demand in the two-megawatt to five-megawatt range are not uncommon.

[125] *Distribution Deferral DER Procurement Advice Letter*, PG&E (2018)

[126] *Approval of Contracts Resulting from 2019 DIDF RFO*, PG&E (2019)

Distributed Energy Resources in Grid Planning - Research Needs

Behind-the-Meter Distributed Energy Resources Load Flexibility

Research Description

This project would perform a field study of the ability of behind-the-meter DER in IOU service territories to provide local load flexibility at given cost profiles. The research would include additional considerations required for effective DER adoption in disadvantaged communities and build on the Load Shift Working Group final report[127] and Demand Response Potential Study[128]. Potential research questions include:

- What combination of behind-the-meter DER (storage, smart appliances, PV, and smart inverter) provides how much load flexibility and at what cost?
- How do various customer segments respond to different incentive levels when deciding to adopt DER in the first place?
- What additional considerations should be made when working with behind-the-meter DER in disadvantaged communities?
- Once enrolled or enabled to participate, how do different customer segments respond to different levels of incentives when deciding the extent to which they want to participate?
- How much local load flexibility is available at different times of day?
- What is the locational availability of third-party or customer-owned DER at the times required to participate in distribution planning processes?

Barriers Resolved

- Uncertainty in customer and behind-the-meter resources behavior: Sheds insight on how customers of different types respond to different levels of incentives to develop more reliable estimates of load flexibility.
- Difficulty separating value streams: Helps identify value of load flexibility for various behind-the-meter DER configurations.

Metrics Impacted

- Reliability
    - Duration of load response provided by different technologies (hours)
- Flexibility
    - Amount of responding behind-the-meter load provided by different technologies (kilowatts)

Benefits to Ratepayers

- Peak load reduction (megawatts) from summer and winter programs
- Number and percentage of customers on time-variant or dynamic pricing tariffs
- Improved system operation efficiency from increased flexibility

Metrics and Targets (Technology Integration)

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[127] *Load Shift Final Report*, CPUC (2019).

[128] *Demand Response Potential Study*, Berkeley Lab (2017).

- Performance
    - Quantify total flexible load available in timeframe required by distribution planning process (two years for smaller upgrades, up to five for larger ones)
- Price
    - Provide bulk energy shifting at less than $0.05 per kWh shifted[129]
    - Total price sufficient to be cost-competitive participant in Distribution Investment Deferral Framework (varies by grid opportunity)

Priority

- High

Time Horizon

- Short-Term

Funding Category

- Technology Demonstration and Development

Distributed Energy Resources Controls to Minimize Integration Costs

Research Description

Instead of installing new conductors or operating system devices, this research will explore ways that behind-the-meter controls can be implemented to avoid distribution system upgrades. It will also identify ways to use onsite controllers to curtail or shift DER production and consumption based on specific problems (such as overproduction of solar) that would otherwise trigger required grid upgrades. The effort will demonstrate small changes to DER operation and controls that alleviate integration costs, potentially using existing smart inverter hardware. It will demonstrate that load management technology solutions (for example, PV curtailment control) can operate reliably enough that utilities do not need to make worst-case assumptions when performing interconnection studies. While these ideas are discussed in Rule 21 and ICA proceedings, they can be supported by demonstration. The effort will consider controls for aggregations of DER such as commercial EV chargers to avoid distribution system upgrades that would otherwise be needed.

Barriers Resolved

- Uncertainty in customer and behind-the-meter resources behavior: Improves confidence in the reliability of behind-the-meter resources to self-regulate and eliminate the need to implement costly upgrades.

Metrics Impacted

- Sustainability
    - Increases rate of DER upgrades in support of 100% clean energy (SB 100)
    - Reduces timeline for DER interconnections
- Affordability
    - Reduces ratepayer costs for upgrades associated with DER

Benefits to Ratepayers

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[129] Price target aligning with DAYS goal referenced in the Energy Storage section.

- Number and total nameplate capacity of distributed generation facilities
- Total electricity deliveries from grid-connected distributed generation facilities
- Avoided procurement and generation costs
- Nameplate capacity (megawatts) of grid-connected energy storage
- Maintain/reduce operations and maintenance costs
- Maintain/reduce capital costs
- Reduced overall upgrade costs, increased renewable energy integration, increased participation in DER adoption

Metrics and Targets (Technology Integration)

- Performance
    - Demonstrate capability to curtail generation on distribution operator or DER aggregator signal within five minutes
- Price
    - Reduce cost of additional control and communication hardware to less than $0.30/W to provide additional functionality at current inverter prices (installation size dependent)[130]
    - Quantify cost of lost DER revenues due to altered operation (installation dependent)
    - Quantify cost savings of reduced integration requirements for interconnection

Priority

- High

Time Horizon

- Medium-Term

Funding Category

- Technology Demonstration and Development

Sociotechnical Demand Response Impact

Research Description

Demand response is based on people or institutions doing or experiencing something different than they would have otherwise, even when responses are automated. If much higher levels of DR are required to implement renewable-dominated DER, people will need to make big changes.

The suggested research would perform a paper study to extend the current framework for DR to recognize how social and technological factors combine to create DR capacity and DR strategies to achieve higher levels of flexibility in timing, quantity, and type of energy use. This research is necessary because the existing technology-price model of DR conceals this activity in market mechanisms, giving little consideration on how to foster flexibility or how to manage the risks and unintended effects of such DR strategies. The results will include examples and an initial set of tools to more strategically plan DR, tackle risks, and anticipate problems,

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[130] *Q3/Q4 2019 Solar Industry Update*, NREL (2020).

including those related to equity. This research will investigate what changes to the technological landscape (such as low- or no-electricity alternatives) can enable people and organizations to be more willing and able to provide DR, as well as shift societal load patterns in such a way that complements generation. The research will also investigate how DER barriers summarized in the roadmap look from the perspective of the parties who are expected to provide DR.

The research method should rely on a combination of empirical case studies analyzed quantitatively and qualitatively; consultations with DR responders and non-responders in residential, commercial, and industrial sectors to understand their barriers and motivations; and collaboration with existing DR, DER, energy supply, and technology innovation stakeholders. Beyond increasing DR capacity, this extended framework can also increase societal resilience during outages. The framework would help steer development to ensure that more critical systems can work longer with little or no grid energy, which can decrease the costs of planned and unplanned outages.

Barriers Resolved

- Customer acquisition challenges: Simplifies the activities required by people and institutions to provide load reduction by strategically providing lower and no-energy alternatives, which can be more reliable and useful for planning purposes.
- Uncertainty in customer and behind-the-meter resources behavior: Informs realistic identification of risks associated with specific DR/DER strategies using empirical analysis of past and current DR efforts.

Metrics Impacted

- Flexibility
  - Increases capacity for DR
- Resiliency
  - Providing no- and low-energy alternatives helps society function during outages.

Benefits to Ratepayers

- Improved in system operation efficiency from increased flexibility: Highlights the real-world mechanisms of energy use flexibility, so that the capacity for flexibility can be built into energy demand.
- Support for energy system resiliency in the face of de-energizations: Fosters development of no- and low-energy alternatives that can be readily used during de-energizations.
- Non-energy economic benefits: Recognizes DR as more than a simple economic transaction and helps reduce the economic and non-economic costs of flexibility.
- Avoided customer energy use (kilowatt-hours saved): Low- and no-energy alternatives to standard higher-energy systems save kilowatt-hours.

Metrics and Targets (Additional Data)

- Performance
  - Provide written report on accounting for socioeconomic impacts on DER usage participation patterns
  - Produce database of demand response program participation rates at the census track level

- Match geographic demand response program participation rates to socioeconomic and demographic data to help segment market to target future outreach activities
- Provide guidelines for better enabling DER participation in demand response programs

Priority

- Medium

Time Horizon

- Medium-Term

Funding Category

- Technology Demonstration and Development

Distributed Energy Resources Integration in Low-Income Communities

Research Description

Census data show that in California 15 percent of the population (currently six million persons) have incomes below the federal poverty level and an additional 18 percent have incomes between poverty and 150 percent of the poverty line.

It will be challenging for DER integration to take place in low-income populations across the state. Affluent households with new housing, highly integrated digital systems, and technical savvy occupants are the natural audience in the residential sector for DER adoption. While in low-income communities, issues of poor housing quality, old and inefficient technologies, lack of digital communications infrastructure, and a host of other constraints mean that DER configurations working elsewhere may not be as readily adopted. In addition, high peak rates, distant load control, outages, exposures to heat events, increased air pollution, and so on, are a more significant burden on households in disadvantaged low-income communities that do not have the resources to deal with the requirements of DER integration. This project would build on the SB 350 Barriers Study[131] to find additional ways for low-income communities to apply DER to improve energy service quality and reduce costs.

A special emphasis on low-income communities in DER integration research, design, and development is needed to address unique conditions and challenges. This project would carefully examine DER in the low-income context, using quantitative, qualitative, simulation, and collaborative analyses. The work would be conducted in the following four stages.

1. Conduct reviews of existing literature, including scientific research on energy, programs, and policies; and low-income, minority, and other disadvantaged energy-user populations.
2. Inventory the current energy, technology, and DER status for California disadvantaged communities in terms of housing stock, technology, energy use and demand levels, drawing on a variety of quantitative data sources. Interview local experts and community members to flesh out and refine characterizations.

[131] *SB 350 Barriers Study*, California Energy Commission (2019).

3. Collaborate with local governments and community members to assess plausibility, including issues and barriers to different DER configurations. The effort should focus on issues in human-device and household-grid interactions.
4. Identify areas where redesigning DER configurations to better suit various low-income community cases would be appropriate and assess needs for new technologies and policies. These results would be used by state policymakers to refine state energy policy relating to low-income communities.

Barriers Resolved

- Customer acquisition challenges: Identifies challenges that disadvantaged communities face regarding technology adoption to optimize strategies that enable optimal and equitable siting of DER.
- Uncertainty in customer and behind-the-meter resources behavior: Identifies key factors and processes that highlight patterns and differences among disadvantaged communities related to consumer understandings, localized social and cultural practices, equity issues, and implications for technology design and policy.

Metrics Impacted

- Affordability
- Flexibility
    - Technology adoption
- Reliability
    - Effective performance

Benefits to Ratepayers

- Peak load reduction (megawatts) from summer and winter programs
- Support for energy system resiliency in the face of outages
- Improved system operation efficiency from increased flexibility: Encourages technology and program designers to account for and support energy consumer flexibility.

Metrics and Targets (Additional Data)

- Performance
    - Provide written report on accounting for socioeconomic impacts on DER installation patterns
    - Provide guidelines for better enabling DER adoption in low-income communities
    - Produce database of DER installation rates at the census tract level
    - Match geographic installation rates to socioeconomic and demographic data to help with market segmentation and in targeting future outreach

Priority

- Medium

Time Horizon

- Medium-Term

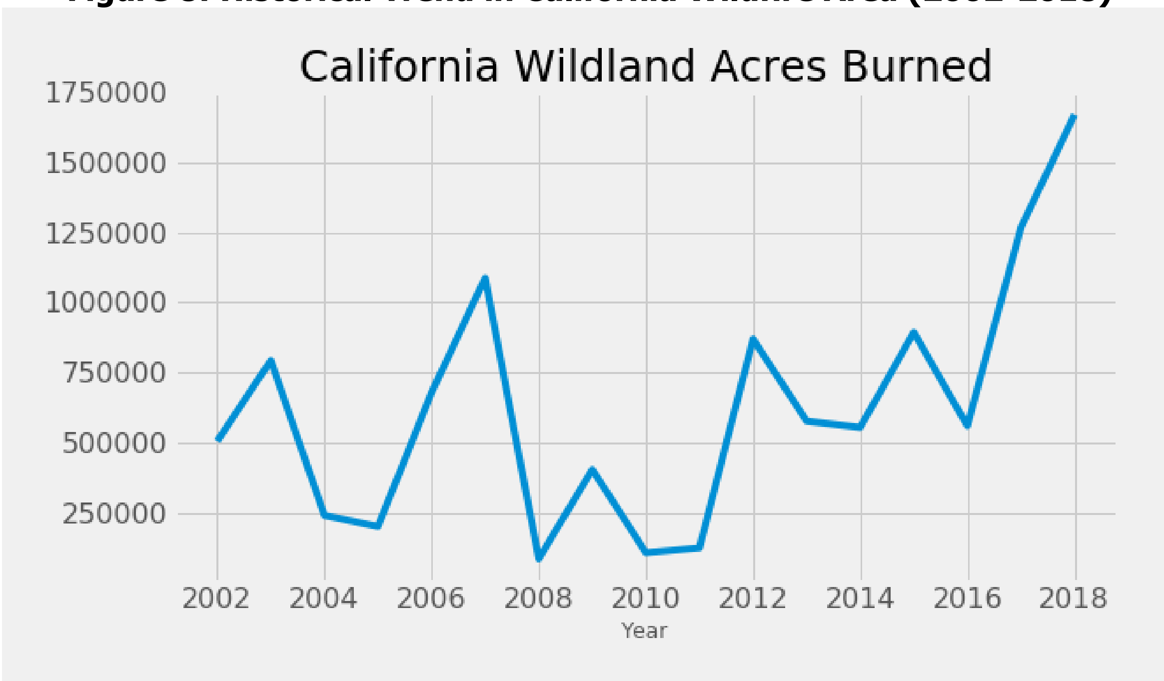
Funding Category

- Applied Research and Development

DER for Reliability and Resiliency

The electrical grid has been experiencing increasingly difficult environmental conditions, from more extreme temperatures and wind speeds to longer periods of low rainfall that combine to increase the risk of severe wildfires. Figure 8 shows the current trend in California wildfires. In 2019, broad public safety power shutoff events were called across the state, helping to limit wildfire risks but leaving millions of people without electricity for days. This section reviews the potential for DER to support safe, reliable, and sustainable power in the face of these challenging new conditions.

Figure 8: Historical Trend in California Wildfire Area (2002-2018)



California saw significant wildfires in 2017 and 2018. Results are not yet available for 2019.

Source: National Interagency Fire Center

DER for Reliability and Resiliency Technical Assessment

Electric system reliability is a standard performance indicator for electric utilities. Established metrics like SAIDI, System Average Interruption Frequency Index (SAIFI), and CAIDI measure the ability of the grid to deliver electricity in the quantity and quality required by customers.

Electric system resilience is a more recent metric, characterized as the ability of the system to resist failure, reduce the magnitude of events, and to recover from those events.[132] The industry is still developing quantitative metrics for resilience.

Many changes can be made to the grid itself to improve reliability and resiliency, such as undergrounding distribution lines and replacing wooden electric poles with stronger composite-based materials. These improvements are often called grid hardening. However, solutions like undergrounding are expensive and time-consuming; PG&E estimates costs of $3 million per

[132] *Smart Grid Annual Report to the Governor*, CPUC (2018).

mile and operates around 81,000 miles of overhead distribution lines.[133] Furthermore, investing in these solutions depends on the utility and does not provide the opportunity to pursue additional value streams and grid services while the capacity of the upgrade is not needed.

In contrast, deploying DER provides an opportunity to deliver safe and reliable power to customers while allowing more flexible grid operation during high-risk conditions. This could take many forms: single customer resources, single meter microgrids for community support, multiple customers sharing resources, or even a distribution substation islanded from the transmission network and operating on local generation. The most commonly cited DER solution for reliability and resiliency is the microgrid.

California's microgrid bill[134] was enacted in September 2018 and directed the CPUC to undertake a series of activities to facilitate the commercialization of microgrids, defined as interconnected systems of loads and DER within a clearly defined electrical boundary that can be operated independently of the larger grid. This led to CPUC rulemaking 19-09-009, which was split into three tracks in December 2019:[135]

- Track 1: Immediate Resiliency Planning for Wildfire and Outage Prone Areas
- Track 2: Standards, Protocols, Methods, Rates and Tariffs to Reduce Microgrid Barriers
- Track 3: Future Resiliency Planning

Interest in microgrids for resiliency purposes has sharply increased following the devastating 2017 and 2018 wildfire seasons, both from customers and grid operators. For example, PG&E launched an accelerated solicitation for distributed generation-enabled microgrids to support substation islanding in December 2019, identifying 20 different sites (shown in Figure 9).[136]

This section identifies the barriers and potential research solutions to enable these important DER solutions to most efficiently integrate with the conventional grid.

DER for Reliability and Resiliency Barriers

Cost

High project costs: In many cases, the cost to develop a microgrid can be higher than customer bill savings and other benefits. In addition to the hard costs of the installed generation, storage, and power electronics; there are significant soft costs for permitting, insurance, interconnection, and labor. Historically, microgrids have been designed as unique system configurations that require customization. Delays during different parts of the implementation process can have cascading effects and lead to significant timing risks. The interconnection process remains a major challenge for microgrids as utilities must review each custom system and perform several field tests before approving permission to operate.

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[133] *Facts about Undergrounding Electric Lines*, PG&E (2017).

[134] *SB No. 1339*, California Legislature (2018).

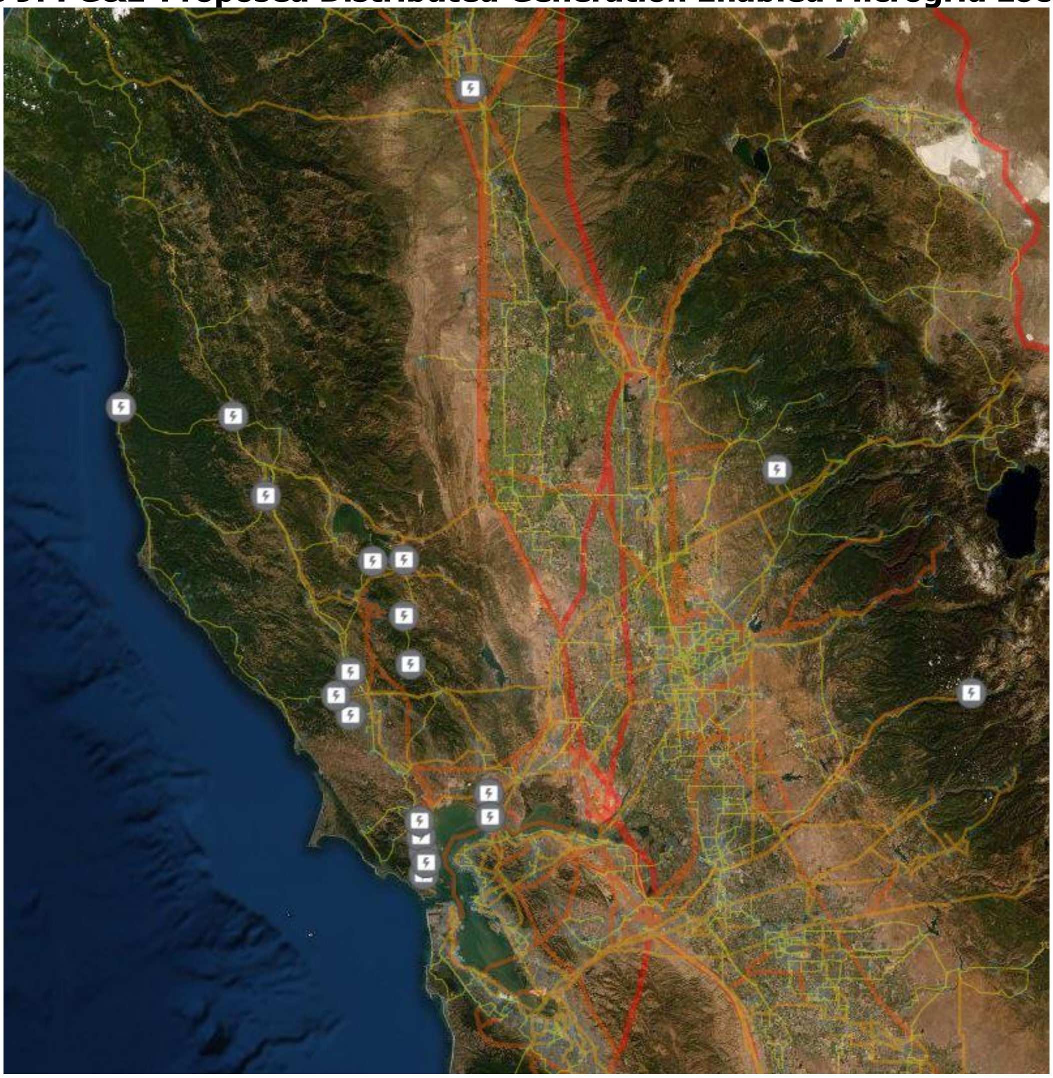
[135] *R.19-09-009 Scoping Memo*, CPUC (2019).

[136] *Distributed Generation Enabled Microgrid Services Solicitation*, PG&E (2019).

Finally, cost and performance tradeoffs between fossil-fuel-based or renewable-generation-based microgrids also exist.

Operations and maintenance costs for Special Facilities: Electric Rule 2[137] contains provisions to assign to facility owners the operations and maintenance costs of additional distribution infrastructure supporting a facility like a microgrid as they are above and beyond standard service. The Berkeley Energy Assurance Transformation pilot project funded by the CEC reported these costs being prohibitively expensive at 6.36 percent per year of the cost of ownership.[138]

Figure 9: PG&E-Proposed Distributed Generation Enabled Microgrid Locations



Potential locations for distributed generation backed microgrids that could power local areas during transmission grid outages.

Source: Navigant

[137] *Electric Rule No. 2 Description of Service*, PG&E. This rule also applies to SCE and SDG&E.

[138] *Berkeley Energy Assurance Transformation Presentation*, City of Berkeley (2019).

Valuation

Valuation of resilience is elusive: In the United States, there is no finalized process for quantifying and monetizing resilience in regulatory proceedings nor is there a standard industry approach. Not including a value stream for resilience means that the benefits of DER projects are significantly understated for both customers and utilities and that the playing field between DER and traditional electricity investments remains uneven.

Capability

Continued reliance on overhead distribution infrastructure for multi-customer microgrids: The same high-risk conditions that would require public safety power shutoffs events on the conventional grid (for example, high winds) would also apply to overhead lines in larger multi-customer microgrids. Those projects would only be able to operate and add resilience benefits when high-risk conditions were present around the transmission lines serving the area but not the area itself.

Islanding function: During a grid outage, distributed solar with grid-tied inverters will be disconnected for safety precautions. Customers must install additional local energy storage with the appropriate disconnect switches to continue to power their homes with local generation.

Clean backup generation: Mobile and emissions free back-up generators do not appear to be available in the market. Modular microgrids and mobile storage are new options but do not meet the timing and performance requirements of generation to backfill in the case of distribution asset failure.

Coordination

Conflicts with utilities: Multi-customer microgrids typically require the use of existing distribution lines or the construction of new distribution lines within the defined zone, which may infringe on utility franchise rights. When microgrid operation would involve the exchange of power between parties or the transmission of power across streets or public areas, the operators would be subject to prohibitive public utility regulations.

Management of intermediate distribution infrastructure for community microgrids: If a community microgrid consists of multiple customers with multiple meters, it will need to provide connecting distribution wires itself or use the conventional grid. The conventional grid is not constructed to allow partial energizations, and this configuration would create significantly more complexity relative to the standard division of responsibilities at the customer meter.

Coordination with third-party microgrid customers: For microgrids that would include multiple customers, there is limited guidance to rate structures around sharing microgrid-generated power during normal conditions and limited battery capacity during outage conditions. There are also significant technological challenges to metering and operating such a configuration.[139]

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[139] *Berkeley Energy Assurance Transformation Project Report*, California Energy Commission (2019).

Building code requirements: Customers looking to install backup generation may encounter challenges with building codes relating to generator placement and may need to have an additional architectural review performed to ensure the weight of the battery installation does not destabilize the building.

? Uncertainty

Interconnection rules: The lack of clarity regarding interconnection rules and who pays for necessary equipment or network upgrades is another major barrier. Standards for interconnection procedures and costs would relieve these uncertainties and facilitate deployment.

Design parameters for DER robustness: Designing to current building code does not guarantee DER robustness against extreme weather or disaster conditions.

Equity concerns of ratepayer-funded resilience investments: The benefits of localized resilience investments tend to be greater for customers closer to the site, which raises concerns about spreading the costs equally across all ratepayers when the facility is purchased by the distribution utility. There are uncertainties as to how the benefits of DER resiliency propagate throughout the service territory.

Distributed Energy Resources for Resilience and Reliability Research Needs

Valuing Resiliency for Microgrids

Research Description

This research effort would survey residential, commercial, and industrial customers to answer the following questions:

- How can existing Berkeley Lab research[140] on power system interruption costs be extended to provide guidance on reasonable storage/microgrid incentives?
- What is the market for reliability services?
- What marginal cost are customers willing to pay for various outage durations?
- What are the anticipated levels of fossil-fuel-based back up generation required to meet different levels of system resiliency?

This project would further survey of the effects of power system resiliency decisions on the elderly, disadvantaged, or customers with medical conditions. These results would inform grid planning decisions between resources that provide different levels of resiliency.

The California Public Utility Commission initiated Rulemaking R.19-09-009 to design a framework around microgrid commercialization associated with SB 1339 (Stern, 2018). The associated Microgrids and Resiliency Staff Concept paper[141] identifies a framework for characterizing the contributions of microgrids to resiliency. This framework will be used as the basis for assessing the monetary value associated with these operational impacts. This project aims to create baseline resiliency values for different customer categories that are not yet

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[140] *Estimating Power System Interruption Costs*, Berkeley Lab (2018).

[141] *Microgrids and Resiliency Staff Concept Paper*, CPUC (2020).

publicly available so that future targets may be set against these values. The project will also consider how the need for resiliency is expected to shift as a result of climate change.

Barriers Resolved

- Valuation of resilience is elusive: This research provides insight into understanding the value of resilience, which can be used to justify investments in DER projects that support resiliency.

Metrics Impacted

- Resiliency and Reliability
    - Information available to make decisions regarding resiliency and reliability

Benefits to Ratepayers

- Maintain/reduce operations and maintenance costs
- Improved system operation efficiency from increased flexibility
- Energy security
- Reduced GHG emissions
- Improved public safety
- Support for energy system resiliency in the face of outages

Metrics and Targets (Additional Data)

- Performance
    - Project will characterize microgrid resiliency based on:
        - The system functions that are supported
        - The type of disruptive events that are being protected against
        - The aspects of resiliency that are affected:
            - Magnitude of disruption;
            - Duration of disruption;
            - Duration of adaptation; and/or
            - Duration of recovery
        - The amount by which each aspect of resiliency is expected to improve
- Price
    - Benchmark and set targets for year over year improvements in cost per hour of backup service for each service class
    - Benchmark and set targets for year over year improvements in cost per level of service quality guarantee for each service class
    - Benchmark the value of resiliency for different customer categories across California

Priority

- High

Time Horizon

- Medium-Term

Funding Category

- Applied Research and Development

Residential Resilience – Outage Backup

Research Description

Multiple devastating wildfires in recent years have highlighted the need for backup power for safety applications. This project would develop small battery backup systems for wildfires (and other power outages) to seamlessly operate garage doors, phone, internet, safety lighting, and other life safety devices. These systems are particularly important for customer populations where manually operating garage doors and moving in the dark could present safety hazards. The project would demonstrate a system that connects these safety devices, estimates required battery capacity, and possibly integrates with a small PV system. Research can also review load prioritization technology that would allow critical loads to be powered much longer for the same solar plus storage capacity.

Barriers Resolved

- High costs: The ability to prioritize critical loads means that fewer generation resources are required, which will reduce the total microgrid cost.

Metrics Impacted

- Resiliency
  - Distributed energy storage's ability to be a key fire-safety component, which is linked to the effect of wildfires and other power interruptions

Benefits to Ratepayers

- Support for energy system resiliency in the face of outages

Metrics and Targets (Technology Advancement)

- Performance
  - Provide at least eight hours of service for average customer critical load
  - Count of customers served with improved backup capabilities
- Price
  - Decrease all-in backup battery costs from $750/kWh to $500/kWh[142]

Priority

- Medium

Time Horizon

- Short-Term

Funding Category

- Technology Demonstration and Development

Direct Current Microgrid with Plug-In Electric Vehicle Integration

This project would develop a small modular DC microgrid using storage, PEV and PV generation for critical loads to allow for more efficient solar generation use. The project would study the impacts and optimal sizing for different levels of reliability. It could also assess

[142] Target based on combination of price quotes for residential backup storage systems.

customer adoption of grid-islanding hardware to determine the grid's current resiliency status. For additional research value, this project could be located in a more remote area in the wildland urban interface to assess viability relative to the conventional grid once resiliency and safety concerns are considered.

Barriers Resolved

- Customer research: Understanding customer adoption of grid-islanding hardware can inform market facilitation efforts and enable market actors to improve the value proposition of resiliency.

Metrics Impacted

- Sustainability
  - GHG emissions
- Affordability
  - Cost reduction

Benefits to Ratepayers

- Avoided procurement and generation costs
- Peak load reduction (megawatts) from summer and winter programs
- Avoided customer energy use (kilowatt-hours saved)
- Customer bill savings (dollars saved)
- Reduced electrical losses
- Support for energy system resiliency in the face of de-energizations

Metrics and Targets (Technology Integration)

- Performance
  - Improve net facility energy savings from DC architecture from 3% to 5%[143]
  - Facility microgrid uptime at or above equivalent AC microgrid
- Price
  - Benchmark and improve year over year cost of additional power control hardware to enable direct DC charging

Priority

- Low

Time Horizon

- Long-Term

Funding Category

- Technology Demonstration and Development

Outage Grid Support Fuels

Research Description

To recover from unplanned outages or reduce effects from planned outages, utilities will sometimes use diesel primary-connected generators. Many communities are concerned about

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[143] *Direct Current as an Integrating and Enabling Platform*, California Energy Commission (2019).

the GHG emissions and noise of primary-connected temporary generators, prompting a need for a more environmentally friendly solution. With public safety power shutoff events, utilities may be required to use more temporary generators to reduce public safety power shutoff-related effects on their customers. Despite a preference for clean solutions, no mobile clean back up generation options are available in the marketplace that meet the 72-hour duration and space requirements - this research will identify cleaner fuels for temporary generator solutions that would allow reduced use or replacement of current mobile diesel back up. Existing research at the CEC on mobile biomass gasifiers[144] presents a promising solution that may need market facilitation rather than technology demonstration support.

Barriers Resolved

- Lack of clean backup generation: Temporary generators currently require diesel fuel.

Metrics Impacted

- Sustainability
  - GHG emissions/kilowatt-hours: Can be measured by reducing the GHG emissions and kilowatt-hours produced by temporary power generators.

Benefits to Ratepayers

- Reduced GHG emissions
- Local air pollution reduction

Metrics and Targets (Technology Advancement)

- Performance
  - Decrease CO2 emitted per MWh of generation using backup fuel by at least 5%[145] year over year
  - Develop metrics to improve availability and resilience of backup fuel supply chain
- Price
  - Capital costs + non-fuel operations and maintenance from $1,200 to $1,000/kW[146]

Priority

- High

Time Horizon

- Short-Term

Funding Category

- Market Facilitation

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144 EPC-14-051, California Energy Commission (2020).

145 Based on conversations with industry stakeholders and the expertise of the project team

146 A Comparison of Fuel Choice for Backup Generators, National Renewable Energy Laboratory (2019).

CHAPTER 6: Conclusion and Research Roadmap

Because there are many different types of technologies and strategies under the broad umbrella of distributed energy resources, there are interactions with the full range of electric grid planning and operations. Technologies in each of the DER categories can support the more efficient operation of the grid and significant research and policy work is ongoing in each subject matter area. This roadmap presents the high-level barriers and research opportunities across all these areas to place individual impacts in the context of the wider system.

Different types of DER can provide similar functionality from the perspective of the grid; for example, a need for load reduction at a peak time could be provided by discharging a battery, curtailing the charging of a PEV or calling a building demand response resource. However, each of those resources would have different considerations when deciding whether to participate in the load reduction, such as the battery state of charge, the vehicle's location, and the temperature preferences of the building occupants. In order to integrate these resources efficiently, there must be awareness of the different capabilities and limitations, and an ability to compare resources. This roadmap aims to present research opportunities across these different technologies and strategies so that all can be evaluated according to their contributions to a shared set of energy system goals.

There were 87 proposed research ideas, 41 of which passed the initial go/no-go screening. Of the eliminated research ideas, many had high overlap with a passing idea and were merged rather than rejected. The original submittals can be found on the website for this roadmap.[147] Based on the results of the prioritization screening and input from the Technical Advisory Committee and CEC staff, the 46 research opportunities deemed appropriate for this initiative were assigned high, medium and low priorities. Chapter 1 details the criteria used for the go/no-go and the prioritization screen.

The project team evaluated the potential research activities based on their priority level, complexity, and estimated duration; the team then identified prerequisite research and assigned each activity to short (one to three years), medium (three to five years), and long (five-plus years) time horizons. Tables 5-9 show the high (green), medium (yellow) and low (gray) priority opportunities for each of the subgroups. Priority level is influenced by the estimated level of impacts as well as the level of urgency driven by state policy and electrical system conditions.

[147] *DER Roadmap Website*, California Energy Commission (2019).

Table 5: Energy Storage Research Opportunities

Priority	Short Time Horizon	Medium Time Horizon	Long Time Horizon
High	Evaluate Alternate Storage Technologies	Green Electrolytic Hydrogen for Long-Duration Storage	
High	Next Generation Lithium-ion Storage		
High	Distributed Thermal Energy Storage Aggregation		
Medium	Storage Safety Standards		Energy Storage Recycling
Low	Battery Performance Testing Protocols for Grid Applications		

Energy Storage Research Opportunities

Source: Navigant

Table 6: Energy Flexible Load Asset Research Opportunities

Priority	Short Time Horizon	Medium Time Horizon	Long Time Horizon
High		Assess Costs of Demand Response Automation in New Buildings	Assess Device-Level Lifespan Effects of Load Flexibility
High		Develop National Electric Code-Approved Home Energy Management System to Reduce Panel Upgrade Costs	Enhance Commercial Buildings Monitoring and Control
High		Derive Capacity Value of Variable Distributed Energy Resources	Coordinate Residential Loads with Commercial Home Automation Hubs
High		Enable Load Flexibility Alongside Fuel Shifting	
High		Study Load-Modifying Participation Models	
High		Coordinate Water Heater Design and Controls	
High		Evaluate the Effect of Demand Response on Market Decisions	
Medium		Evaluate Distributed Resources Performance in New Construction	Improve Building-to-Grid Coordination

Energy Flexible Load Asset Research Opportunities

Source: Navigant

Table 7: Vehicle Grid Integration Research Opportunities

Priority	Short Time Horizon	Medium Time Horizon	Long Time Horizon
High	Vehicle-to-Building for Resiliency	Assess Second Life PEV Batteries	
High		Assess PEV Charging Technology Efficiencies	
Medium	Model PEV Charging and Price Responsiveness		VGI Data Program
Low		PEV Charging Device Performance Standards	

Vehicle-Grid Integration Research Opportunities

Source: Navigant

Table 8: Distributed Energy Resource Communications and Controls Research Opportunities

Priority	Short Time Horizon	Medium Time Horizon	Long Time Horizon
High	Secure Communications for DER	Low-Cost Telemetry for Aggregated DER	
Medium		Standardization of Device Protocols and Data Transparency and Availability	Local DER Transaction Platform
Medium		Estimating Distributed Inertia Requirements	
Medium		Sensors for Circuit De-energization	
Low		Hosting Capacity Expansion Planning and Operational Controls	
Low		Real-Time Estimation of PV Power	

DER Communications and Controls Research Opportunities

Source: Navigant

Table 9: Distributed Energy Resource Planning and Strategy Research Opportunities

Priority	Short Time Horizon	Medium Time Horizon	Long Time Horizon
High	Behind-the-Meter DER Load Flexibility	DER Controls to Minimize Integration Costs	
High	Outage Grid Support Fuels		
High	Residential Resilience - Outage Backup	Valuing Resiliency for Microgrids	
Medium		DER Integration in Low Income Communities	
Medium		Sociotechnical Demand Response Impact	
Low			Direct Current Microgrid

DER Planning and Strategy Research Opportunities

Source: Navigant

GLOSSARY AND LIST OF ACRONYMS

Term	Definition
AC	Alternating Current. Electrical current that switches direction at regular intervals or cycles.
ADMS	Advanced Distribution Management System. Software platform that integrates multiple distribution operations functionalities.
AMI	Advanced Metering Infrastructure. Measures interval customer electricity consumption and reports back to the distribution operator.
Ancillary services	Range of services necessary to support the transmission of electric power including frequency regulation, spinning reserves and operating reserves.
Apparent power	Combination of real and reactive power that determines power losses and capacity requirements.
Behind-the-meter	Resources connected to the electrical grid at the premise on the customer side of the electric meter.
Big data	Data whose large scale require changes to processes or computer hardware in order to store and analyze efficiently.
Black start	Capability to restart part of an electric grid following an outage without relying on the external transmission network.
Bulk power system	The potion of the grid including large power plants and transmission lines that moves electricity across large distances at high voltage to substations.
CAISO	California Independent System Operator. Manages transparent wholesale energy market and transmission grid.
CAIDI	Customer Average Interruption Duration Index. Reliability metric measuring the average outage duration a customer would experience.
Carbon neutral	A system with a net zero carbon footprint, that is, all emissions have been offset with carbon removal.
Centralized generation	Large-scale generation resources, usually located farther away from end users.
CO_2	Carbon dioxide. Greenhouse gas often produced by thermal generation units.
CPUC	California Public Utilities Commission. State agency responsible for regulation of public utilities.
Curtailment	Reduction in the production of a generator beyond what it could have otherwise produced.
DC	Direct Current. Unidirectional flow of current.

Term	Definition
DER	Distributed Energy Resource. Assets connected to the distribution grid including generation, energy efficiency, electric vehicles and demand response.
DERMS	Distributed Energy Resource Management System. Software platform that communicates with and controls DER.
DIDF	Distribution Investment Deferral Framework. Procedure adopted by the CPUC to compare DER solutions to conventional wires alternatives for meeting distribution grid needs.
Dispatch order	Ranking of power generators in order of bid cost. An out of order dispatch would be buying power from a more expensive generator for reliability reasons.
Dispatchable	Generation resources whose output can be modulated up and down across a range on demand.
Distribution Grid	The portion of the grid where electricity is distributed from substations to individual customers.
Distribution system operator	Entity that coordinates power flow on the distribution grid.
DMS	Distribution Management System. Software platform that distribution operators use to manage power flow.
DOE	Department of Energy. United States government agency responsible for policies regarding energy.
DR	Demand Response. Reduction in electricity use at the request of a grid operator to help balance electricity supply and demand.
DRP	Distribution Resource Plan. Annual regulatorily required report from distribution operators about upcoming investments in the distribution grid.
DSO	Distribution System Operator. Entity responsible for planning and operations of the medium voltage electric grid between customers and substations.
EIA	Energy Information Administration. United States agency responsible for collecting, analyzing and disseminating energy information.
EM&V	Evaluation, Measurement and Verification. Process to assess the impact of electric programs.
EMS	Energy Management System. Software platform that coordinates electricity use. Can refer to the distribution grid or smaller systems like buildings or microgrids.

Term	Definition
EPIC	Electric Program Investment Charge. CEC program to invest in scientific and technological research to accelerate electric sector transformation.
EPRI	Electric Power Research Institute. Independent nonprofit organization that conducts research related to the generation, delivery and use of electricity.
EV	Electric Vehicle. Mode of transport that utilizes electric motors for propulsion.
EVSE	Electric Vehicle Supply Equipment. Hardware that supplies electric vehicles with electricity.
FERC	Federal Energy Regulatory Commission. United States agency that regulates the transmission and wholesale sale of electricity.
FLISR	Fault Location, Isolation and Service Restoration. Scheme for partitioning the electric distribution grid to restore power to indirectly affected customers in an outage.
Frequency regulation	Modulation of resource power output in response to transmission operator signals to balance system frequency.
Frequency response	Primary frequency responses are actions to arrest and stabilize frequency in response to deviations. Usually provided by generator governor response, load response and other devices that provide immediate response based on local control.
GHG	Greenhouse gas. A gas that absorbs radiant energy and contributes to changing global temperatures.
GIS	Geographic Information System. Software platform that stores and analyzes spatial data.
Grid-hardening	Changes can be made to the grid itself to improve reliability and resiliency, such as undergrounding distribution lines and replacing wooden electric poles with stronger composite-based materials
Grid modernization	Changes needed in the power grid to accommodate new technologies to improve reliability and efficiency.
GW	Gigawatt. Unit of power equal to one billion watts.
Headend	Centralized software platform that collects signals from advance meters.
HEMS	Home Energy Management System. Software platform responsible for coordinating electricity use within a residence.
HVAC	Heating, Ventilation, and Air Conditioning. System that regulates temperature.
IT	Information Technology. Study or use of systems for storing, retrieving, and sending information.

Term	Definition
kVA	Kilovolt-Ampere. Unit of apparent power equal to one thousand volt-amperes.
kW	Kilowatt. Unit of real power equal to one thousand watts.
kWh	Kilowatt-hour. Unit of energy equal to power consumption of one thousand watts for one hour.
Last mile	The component of a network between higher capacity backbone infrastructure and end nodes.
Load following	Market product that requires resources to modulate their output in a medium timeframe in order to match supply and demand.
MW	Megawatt. Unit of real power equal to one million watts.
MWh	Megawatt-hour. Unit of energy equal to power consumption of one million watts for one hour.
Nameplate capacity	Intended full production sustained output of a power generator.
NEC	National Electrical Code. Regionally adoptable standard for the safe installation of electrical wiring and equipment.
NEM	Net Energy Metering. Electricity billing mechanism that credits consumers for electricity they produce at retail rates.
Non-wires alternative	DER solution that is used in place of a conventional distribution infrastructure investment.
Operating reserves	Resources with flexibility to increase and decrease generation available to be used in contingencies of the bulk power system.
OT	Operational Technology. Hardware or software that detects or causes a change through the direct monitoring and control of industrial equipment.
Peaker plant	A power plant which is expected to run rarely to meet the highest peaks of customer demand.
PEV	Plug-in Electric Vehicle. Vehicle that can be recharged from an external source of electricity.
PG&E	Pacific Gas and Electric. Investor-owned utility responsible for much of Northern California.
Power factor	Ratio of real to apparent power representing the efficiency of the system. A ratio of one would mean there are no extraneous losses and voltage and current waveforms are in sync.
Power factor management	Actions take to improve the power factor of a system to enable more efficient operation.
PV	Photovoltaic. Electricity generation from light.

Term	Definition
Reactive power	Measure of inefficiency in the power system due to current and voltage waveforms being out of sync.
Real power	Electric power consumed by equipment to do useful work.
Resource adequacy	A CPUC requirement that load serving entities demonstrate procurement of generation capacity of at least 115% of their projected peak loads.
SAIDI	System Average Interruption Duration Index. Reliability metric equal to the average outage duration per customer.
SAIFI	System Average Interruption Frequency Index. Reliability metric equal to the total number of power outages a customer would experience.
SCADA	Supervisory Control and Data Acquisition. Software platform for gathering and analyzing real-time data from industrial equipment.
SCE	Southern California Edison. Investor-owned utility responsible for much of Southern California.
SDG&E	San Diego Gas and Electric. Investor-owned utility responsible for the city of San Diego.
SI	Smart Inverter. Device that converts direct current to alternating current and has some advanced grid functions like voltage regulation and frequency support.
Submetering	Individual metering of specific loads to allow tariff differentiation.
System inertia	Ability of the power system to oppose changes in frequency due to resistance provided by the momentum of rotating masses in synchronous generators.
T&D	Transmission and Distribution. Electrical infrastructure responsible for moving electricity large distances at high voltages and small distances at medium voltages.
TSO	Transmission System Operator. Entity responsible for operation of the transmission grid.
V1G	Unidirectional power flow to vehicle from grid.
V2G	Bidirectional power flow between vehicle and grid.
Value stacking	Participating in multiple different markets or applications in order to achieve maximal benefit.
VAR	Volt-Ampere Reactive. Unit of measurement of reactive power.
Voltage support	Service provided by generating units or other equipment capable of producing or absorbing reactive power to keep system voltage within standards.

Term	Definition
Volt/VAR optimization	Process of modulating voltage and reactive power levels to achieve more efficient grid operation.

APPENDIX A: Policy Drivers

Table A-1: Summary of Relevant Policies and Legislation

Policy or Legislation	Year Adopted	Function
California Assembly Bill		
AB 1144	2019	Requires use of a portion of the Self-Generation Incentive Program, which provides incentives for battery storage, to provide additional benefits for community resiliency.
AB 2514	2010	Requires 1.3 GW of energy storage by 2020.
AB 2868	2016	Requires 500 MW of storage, in addition to AB 2514.
AB 32	2006	Economy wide-wide goal of reducing GHG emissions to 1990 levels by 2020.
AB 3232	2018	Reduce GHG emissions from California's building stock by 40 percent below 1990 levels by 2030.
AB 327	2013	Requires reform of utility distribution planning, investment, and operations by investing in preferred resources and advancing time- and location-variant pricing and incentives to support DER. One way is developing a NEM tariff. It also directs the CPUC to identify alternatives designed to increase adoption of renewable generation in disadvantaged communities.
AB 38	2019	Establishes a 5-year pilot program to support at-risk communities by proposing the first statewide fire retrofit program.
AB 523	2017	Dedicates at least 25 percent of available EPIC funds for clean energy projects in disadvantaged communities and an additional 10 percent in low-income households.
AB 693	2017	Creates Multifamily Affordable Housing Solar Roofs Program and requires that funding be put aside to implement solar roofs on qualified multifamily buildings, starting in 2017; goal of at least 300 MW installed by 2030.
AB 758	2008	Develop program to achieve more energy efficiency in existing buildings

Policy or Legislation	Year Adopted	Function
California Senate Bill		
SB 100 (RPS)	2018	100 percent carbon-free electricity by 2045. 50 percent renewable by 2025. 60 percent renewable by 2030.
SB 1369	2018	Green Electrolytic Hydrogen specified as energy storage technology to be targeted for increased use.
SB 1339	2018	Requires the CPUC, CAISO, and CEC to facilitate the commercialization of microgrids for customers by developing standards, reducing barriers, and developing rates and tariffs.
SB 1371	2014	Requires utilities to reduce methane emissions from natural gas by using more advanced technologies.
SB 1382	2016	Establishes methane emissions reduction targets in a statewide effort to reduce emissions of short-lived climate pollutants.
SB 1477	2018	$50 million per year from gas cap-and-trade for low-carbon heating programs; directs CPUC to investigate new low-emissions affordable homes.
SB 150	2017	Requires consideration of climate change in regional planning, leading to better designed neighborhoods that facilitate lower carbon transportation modes.
SB 32	2016	Builds upon AB 32 by setting GHG emissions reduction goal of 40 percent below 1990 levels by 2030.
SB 338	2017	Requires California utilities to rely on energy efficiency, demand management, energy storage, and other strategies to meet peak electricity needs.
SB 350	2015	Requires doubling energy efficiency by 2030; establishes IRP requirements; requires energy plans focused around GHG emissions reductions; directs CEC to identify some of most critical barriers for low-income energy customers accessing clean energy opportunities.
SB 49	2019	Advancing the development and use of smart appliances that can shift demand for electricity when renewable energy production is at its highest
SB 535	2012	Directs 25 percent of proceeds from the Greenhouse Gas Reduction Fund go to projects that provide a benefit to disadvantaged communities.

Policy or Legislation	Year Adopted	Function
SB 676	2019	Aims to optimize EV grid benefits by streamlining V2G strategies across load-serving entities.
SB 70	2019	Requires utilities to include information about consideration of undergrounding utility lines in their wildfire mitigation plans.
SB 700	2018	Allows for a five-year extension of the Self Generation Incentive Program, with as much as $700 million in funding for energy storage systems.
SB 901	2018	Requires all state utilities to submit wildfire mitigation plans. The overwhelming focus of those plans is to reduce wildfire risks around existing grid infrastructure.
AB 38	2016	Provides mechanisms to develop best practices for communitywide resilience against wildfires through home hardening, defensible space, and other measures.
SB 167	2019	Requires investor-owned utilities to improve their wildfire mitigation plans by including specified requirements to mitigate the effects of public safety power shutoffs.
California Executive Order		
Executive Order B-48-18	2018	Sets a target for 5 million EVs by 2030.
Executive Order B-55-18	2018	Sets a target for carbon neutrality by 2045 and maintain net-negative carbon emissions thereafter.
Executive Order: Petroleum Use Reduction	2015	Sets a target for reducing California's petroleum use by up to 50 percent by 2030.
CEC		
CEC Mandate: Solar on New Construction	2018	Beginning in 2020, new residential construction must have solar panels.
Clean Energy in Low-Income Multifamily Buildings Action Plan	2018	Identifies current programs and policies, remaining challenges, and concrete actions that California can take to accelerate the implementation of DER in multifamily buildings.
Energy Innovations Small Grant Program	1997	Provides funding for modeling projects to small businesses, nonprofits, individuals, and academic

Policy or Legislation	Year Adopted	Function
		institutions to conduct research that establishes the feasibility of new, innovative energy concepts.
California Code		
Title 20 Load Management Standards	1982	Establishes electric load management standards pursuant to Section 25403.5 of the Public Resources Code to encourage the use of electrical energy at off-peak hours and encourage the control of daily and seasonal peak loads. Updated standards expected in 2021.
Title 20 Appliance Standards	2018	See SB49. New standards expected 2023.
Title 24 Building Standards	2019	Part 6 – Energy efficiency standards for residential and nonresidential buildings, new construction, remodels and additions. Part 11 - CALGreen is the mandatory green building standards code established in an effort to meet the goals of Assembly Bill 32.
CPUC		
Alternative Fuels Vehicles (R. 13-11-007)	2013	Implements policy around the equipment and infrastructure required for electric and low-emissions vehicles to proliferate.
California Long-term Energy Efficiency Strategic Plan	2008	Specifies ambitious zero net energy goals. Roadmap to achieve maximum energy savings across all major groups and sectors in California
CPUC DER Action Plan	2016	Provides a vision and action to develop the market opportunities and remove unnecessary barriers to unleash the full value that DER can provide.
Decision 18-02-004	2018	Requires investor-owned utilities to file grid needs assessment and distribution deferral opportunity report. These documents will present the prime candidate grid needs that non-wires alternatives can be proposed to solve.
Demand Response (R. 13-09-011)	2013	Proceeding instated to enhance the role of DR in meeting the resource planning and operation requirements in California.
DER Interconnection (R. 17-07-007)	2017	Creates rules and regulations around the interconnection of all distributed resources.

Policy or Legislation	Year Adopted	Function
Distributed Generation (R.12-11-005)	2012	Encapsulates all rules and procedures pertinent to small-scale distributed generation.
Net Energy Metering (R. 14-07-002)	2014	Allows customers who generate their own energy to serve their energy needs directly onsite and to receive a financial credit on their electric bills for any surplus energy fed back to their utility. The rulemaking is a response to AB 327 and investigates the best path forward for NEM.
Rates and Infrastructure for Vehicle Electrification (R. 18-12-006)	2018	Successor to R. 13-11-007.
Rule 21	1982	Mandates 100 percent adoption of smart inverters for new installations within California beginning February 2019. Smart Inverter Working Group will specify future communications requirements.
Self-Generation Incentive Program	2000	Provides incentives to support existing, new, and emerging DER.
Federal		
Build America Investment Initiative	2015	Promotes increased investment in U.S. infrastructure, particularly through public-private partnerships.
Department of Energy's Grid Modernization Initiative	2019	Includes funding of $220 million per year for three years.
Energy Independence and Security Act of 2007	2007	Establishes national policy for grid modernization to maintain a reliable and secure electricity infrastructure. Outlines cybersecurity requirements for the smart grid.
FERC Order 719	2008	Required the operators of competitive wholesale electricity markets (for example, regional transmission organizations and ISOs) to treat DR bids as comparable to generators' bids in hourly energy markets.
FERC Order 745	2011	Requires regional grid operators to pay wholesale market rates for dispatchable, cost-effective DR resources.

Policy or Legislation	Year Adopted	Function
FERC Order 755/784	2011/2013	Requires public utility transmission providers to consider two additional parameters—speed and accuracy—while assessing regulation resources. The rule aims to increase competition and transparency in ancillary service markets.
FERC Order 792	2013	Modified rules for small generator interconnection. Informs the rules by which storage can interact in the wholesale generation market.
FERC Order 841	2018	Directs regional grid operators to remove barriers to the participation of electric storage in wholesale markets.
Partnership for Energy Sector Climate Resilience	2015	Owners and operators of energy assets will develop and pursue strategies to reduce climate and weather-related vulnerabilities.
Solar Investment Tax Credit	2005	Applies federal tax incentive to solar projects. Phase out begins in 2020, but industry is calling for an extension.
Other		
Net Zero Carbon Buildings Commitment	2018	Calls on signatories to enact regulations and planning policies to ensure that all new buildings operate at net zero carbon emissions by 2030 and for all buildings to do so by 2050. Administered by the World Green Building Council for the Global Climate Action Summit.
Pacific Coast Collaborative Greenhouse Gas Reduction Target	2016	Sets a target to reduce Pacific Coast GHG emissions by at least 80 percent by 2050.

APPENDIX B: Research Need Policy Mappings

Table B-1: Energy Storage Relevant Policies and Legislation

Policy	Distributed Thermal Storage Aggregation	Storage Safety Standards	Evaluate Alternate Storage Tech	Next Generation Lithium-ion Storage	Battery Testing Protocols for Grid Applications	Energy Storage Recycling	Fuel Cells for Long Duration Storage
California Assembly Bills							
AB 1144		x	x	x	x		x
AB 2514	x	x	x	x	x	x	x
AB 2868	x		x	x		x	
AB 32		x	x	x			x
AB 3232			x	x		x	x
California Senate Bills							
SB 100 (RPS)			x	x			x
SB 32			x	x			
SB 338	x						
SB 350			x	x			
SB 49	x						
SB 700		x	x	x	x		
SB 1369							x
CA Executive Order							
Executive Order B-55-18			x	x			
CPUC							
CPUC DER Action Plan	x						x

Policy	Distributed Thermal Storage Aggregation	Storage Safety Standards	Evaluate Alternate Storage Tech	Next Generation Lithium-ion Storage	Battery Testing Protocols for Grid Applications	Energy Storage Recycling	Fuel Cells for Long Duration Storage
Distributed Generation (R.12-11-005)	x						x
Self-Generation Incentive Program			x	x			
Federal							
FERC Order 719	x						
FERC Order 745	x						
FERC Order 755/784	x						
FERC Order 792	x						
FERC Order 841	x						
Partnership for Energy Sector Climate Resilience					x		
Other							
Net Zero Carbon Buildings Commitment			x	x			
Pacific Coast Collaborative Greenhouse Gas Reduction Target			x	x			x

These were the identified policy drivers that are addressed by each of the proposed research needs.

Source: Navigant

Table B-2: Energy Flexible Load Assets Relevant Policies and Legislation

Policy	Auto DR in New Building Cost	Load Flexibility Alongside Fuel Shifting	Grid-Conscious Heat Pump Water Heater	Evaluate Effect of DR on Market Decisions	Reduce Residential Panel Upgrade Costs	Improving Building-to-Grid Coordination	Enhancing Commercial Buildings	Residential Loads with Commercial Home Automation	DER Performance in New Construction	Device-level Lifespan Impacts	Capacity Value of Distributed Resources
California Assembly Bill											
AB 1144	x	x	x								
AB 32	x	x	x								
AB 3232		x	x		x	x	x	x	x		
AB 693						x	x				
California Senate Bill											
SB 100 (RPS)		x	x								
SB 1477		x									
SB 32		x	x								
SB 338			x	x			x	x	x		
SB 350		x	x				x				
SB 49			x						x		
CA Executive Order											
Executive Order B-55-18		x	x								
CEC											
CEC Mandate: Solar on New Construction						x	x				
Clean Energy in Low-Income Multifamily Buildings Action Plan					x			x			
Energy Innovations Small Grant Program	x										
California Code											

Policy	Auto DR in New Building Cost	Load Flexibility Alongside Fuel Shifting	Grid-Conscious Heat Pump Water Heater	Evaluate Effect of DR on Market Decisions	Reduce Residential Panel Upgrade Costs	Improving Building-to-Grid Coordination	Enhancing Commercial Buildings	Residential Loads with Commercial Home Automation	DER Performance in New Construction	Device-level Lifespan Impacts	Capacity Value of Distributed Resources
Title 20 Load Management Standards			x							x	
Title 24						x			x	x	x
CPUC											
Alternative Fuels Vehicles (R. 13-11-007)	x										
CPUC DER Action Plan	x				x						
Decision 18-02-004	x							x			
Demand Response (R. 13-09-011)			x	x					x		
Federal											
Energy Independence and Security Act of 2007	x										
FERC Order 719				x							
FERC Order 745				x							
Other											
Net Zero Carbon Buildings Commitment		x	x								
Pacific Coast Collaborative Greenhouse Gas Reduction Target		x	x								

These were the identified policy drivers that are addressed by each of the proposed research needs.

Source: Navigant

Table B-3: Vehicle-Grid Integration Relevant Policies and Legislation

Policy	Vehicle-to-Building for Resiliency	Model PEV Charging and Price Responsiveness	Assess PEV Charging Technology Efficiencies	PEV Charging Device Performance Standards	Vehicle-Grid Integration Communication Standards	Second Life PEV Batteries	Vehicle-Grid Integration Data Program
CA Assembly Bill							
AB 1144	x						
AB 2514						x	
AB 2868						x	
CA Senate Bill							
SB 100 (RPS)	x						
SB 167	x						
SB 676		x	x	x	x		x
SB 700						x	
SB 901	x						
CA Executive Order							
Executive Order B-48-18		x	x	x	x		x
Executive Order: Petroleum Use Reduction			x				
CPUC							
Alternative Fuels Vehicles (R. 13-11-007)		x	x	x	x		
CPUC DER Action Plan		x					
DER Interconnection (R. 17-07-007)						x	

Policy	Vehicle-to-Building for Resiliency	Model PEV Charging and Price Responsiveness	Assess PEV Charging Technology Efficiencies	PEV Charging Device Performance Standards	Vehicle-Grid Integration Communication Standards	Second Life PEV Batteries	Vehicle-Grid Integration Data Program
Distributed Generation (R.12-11-005)						x	
Other							
Partnership for Energy Sector Climate Resilience	x						

These were the identified policy drivers that are addressed by each of the proposed research needs.

Source: Navigant

Table B-4: DER Communications and Controls Relevant Policies and Legislation

Policy	Low-Cost Telemetry	Secure Communications for DER	Standardization of Device Protocols
CA Senate Bill			
SB 338	x		
CPUC			
CPUC DER Action Plan	x	x	x
Demand Response (R. 13-09-011)	x		x
Federal			
Energy Independence and Security Act of 2007		x	
FERC Order 719	x		
FERC Order 745	x		
FERC Order 755/784	x		
FERC Order 792	x		
FERC Order 841	x		
Other			
Partnership for Energy Sector Climate Resilience		x	

These were the identified policy drivers that are addressed by each of the proposed research needs.

Source: Navigant

Table B-5: Distribution Grid Management Relevant Policies and Legislation

Policy	Sensors for Circuit De-Energization	Local DER Transaction Platform	Real-Time Estimation of PV Power	Hosting Capacity Expansion Planning and Operational Controls	Distributed Inertia Requirements	DER to Support Outage Management
CA Assembly Bill						
AB 1144				x	x	
AB 32				x		
AB 3232				x		
AB 38						
AB 693			x			
CA Senate Bill						
SB 100 (RPS)	x			x	x	x
SB 167	x					
SB 32				x		
SB 338			x	x	x	
SB 350				x		
SB 676						
SB 901	x					
CA Executive Order						
Executive Order B-48-18						
Executive Order B-55-18				x		
CEC						
CEC Mandate: Solar on New Construction		x	x	x		
Clean Energy in Low-Income Multifamily Buildings Action Plan		x				
CPUC						
Alternative Fuels Vehicles (R. 13-11-007)						
CPUC DER Action Plan		x			x	x
DER Interconnection (R. 17-07-007)						

Policy	Sensors for Circuit De-Energization	Local DER Transaction Platform	Real-Time Estimation of PV Power	Hosting Capacity Expansion Planning and Operational Controls	Distributed Inertia Requirements	DER to Support Outage Management
Distributed Generation (R.12-11-005)						
Rates and Infrastructure for Vehicle Electrification (R. 18-12-006)						
California Code						
Rule 21			x			
Federal						
Build America Investment Initiative				x		
DOE's Grid Modernization Initiative	x			x		
Partnership for Energy Sector Climate Resilience	x				x	x
Other						
Net Zero Carbon Buildings Commitment				x		
PCC GHG Reduction Target				x		

These were the identified policy drivers that are addressed by each of the proposed research needs.

Source: Navigant

Table B-6: DER in Grid Planning Relevant Policies and Legislation

Policy	Behind-the-Meter DER Load Flexibility	DER Controls to Minimize Integration Costs	Socio-technical DR Impact	DER Integration in Disadvantaged Communities
CA Assembly Bill				
AB 1144		x		
AB 32		x		
AB 3232		x	x	
AB 327				x
AB 523	x			x
AB 693				x
AB 758		x		
CA Senate Bill				
SB 100 (RPS)	x	x	x	x
SB 1339	x			
SB 1371	x			
SB 1382	x			
SB 150	x			
SB 32		x		
SB 338	x		x	
SB 350	x	x		
SB 49	x	x	x	
SB 535				x
SB 676	x			
CA Executive Order				
Executive Order B-55-18		x		
Clean Energy in Low-Income Multifamily Buildings Action Plan				x
CEC				
Energy Innovations Small Grant Program				x
California Long-Term Energy Efficiency Strategic Plan		x		
CPUC				
CPUC DER Action Plan		x	x	x

Policy	Behind-the-Meter DER Load Flexibility	DER Controls to Minimize Integration Costs	Socio-technical DR Impact	DER Integration in Disadvantaged Communities
Decision 18-02-004				
Demand Response (R. 13-09-011)	x		x	
DER Interconnection (R. 17-07-007)		x		
Distributed Generation (R.12-11-005)		x		
California Code				
Rule 21		x		
Other				
Net Zero Carbon Buildings Commitment		x		
Pacific Coast Collaborative Greenhouse Gas Reduction Target		x		

These were the identified policy drivers that are addressed by each of the proposed research needs.

Source: Navigant

Table B-7: DER for Reliability and Resiliency Policies and Legislation

Policy	PV Resilience Needs	Valuing Resiliency for Microgrids	Residential Resilience	DC Microgrid w/ EVs	Clean Backup Generation Fuels
CA Assembly Bill					
AB 1144			x	x	
AB 38			x		
AB 693				x	
CA Senate Bill					
SB 100 (RPS)	x	x			
SB 1339		x		x	
SB 70		x			
SB 901	x	x	x		x
CEC					
Solar on New Construction				x	
CPUC					
CPUC DER Action Plan		x			
Other					
Partnership for Energy Sector Climate Resilience	x	x			

These were the identified policy drivers that are addressed by each of the proposed research needs.

Source: Navigant

APPENDIX C: Expert Interviews

Table C-1: List of Experts Consulted for the Literature Review

Area of Expertise	Individual
Energy Efficiency	Lawrence Orsini, CEO, LO3
DER Integration	Rich Barone, HECO
Energy Storage Performance and Cost	Jay Paidipati, Director, Navigant
DER Integration, Solar + Storage	AJ Perkins, Sun Energy
DER Integration, EV Integration	Sunil Chhaya, EPRI
Building Technologies and Standards	Mark Frankel and Jim Edelson, New Buildings Institute
Demand Side Management and Standards	Rolf Bienert, Technical Director, OpenADR Alliance
Storage Analytics / Grid Support	Polly Shaw, VP Regulatory Affairs, Stem
Bulk Power System Coordination	Clyde Loutan, Senior Advisor, CAISO
Energy Efficiency / Demand Response	Mary Ann Piette, Director DRRC, Berkeley Lab

Source: Navigant

APPENDIX D: List of All Proposed Research Needs

As part of the stakeholder engagement process, the team solicited research needs from CEC staff, the technical advisory committee, and the public stakeholders. Many of these proposed research needs are integrated into the report, however, several research ideas were screened out or modified. **Error! Reference source not found.** lists out the research needs proposed by stakeholders and provides the rationale for the ideas that were screened out or modified.

Table D-1: List of All Proposed Research Needs

Topic Name	Section	Included in Roadmap?	Notes
Low Cost Telemetry	Communications	Yes	
Secure DER Communication Protocol	Communications	Yes	
Standardization of Device Protocols and Data Transparency and Availability	Communications	Yes	
DER Controls to Minimize Integration Costs	DER Aggregation	Yes	
Assess Flexibility of Coordinated Customer DER	DER Aggregation	Yes	
DAC DER Integration	DER Aggregation	Yes	
Sociotechnical DR Impact	DER Aggregation	Yes	
Research DER to Improve FLISR	Distribution Grid Management	Yes	
Local DER Transaction Platform	Distribution Grid Management	Yes	
Valuing Operational Flexibility	Distribution Grid Management	Yes	
Sensors for Circuit De-energization	Distribution Grid Management	Yes	
Hosting Capacity Expansion Planning & Operational Controls	Distribution Grid Management	Yes	Similar to "DER Controls to Minimize Integration Costs"
Realtime Estimation of PV Power	Distribution Grid Management	Yes	
Auto DR New Cost	Energy Flexible Load Assets	Yes	

Topic Name	Section	Included in Roadmap?	Notes
NEC-Approved HEMS to Reduce Upgrade Costs	Energy Flexible Load Assets	Yes	
Assess Device-Level Lifespan Effects of Load Flexibility	Energy Flexible Load Assets	Yes	
Derive Capacity Value of Variable DR	Energy Flexible Load Assets	Yes	Similar to "Assess Flexibility of Aggregated Customer DER" but contains sufficient differentiators.
Enhancing Commercial Buildings Monitoring and Control	Energy Flexible Load Assets	Yes	
Load Shift with Fuel Shifting	Energy Flexible Load Assets	Yes	
Load Modifying Participation Models	Energy Flexible Load Assets	Yes	
Grid Conscious Heat Pump Water Heater Design	Energy Flexible Load Assets	Yes	
Evaluate Impact of DR on Market Decisions	Energy Flexible Load Assets	Yes	
Explore Residential Grid-Responsive Systems	Energy Flexible Load Assets	Yes	
DER Performance in New Construction	Energy Flexible Load Assets	Yes	
Improving B2G Coordination	Energy Flexible Load Assets	Yes	
Green Electrolytic Hydrogen for Long-Duration Storage	Energy Storage	Yes	
Evaluate Alternate Storage Technologies	Energy Storage	Yes	
Next Generation Lithium-ion Storage	Energy Storage	Yes	
Distributed Thermal Storage Aggregation	Energy Storage	Yes	
DER Recycling	Energy Storage	Yes	

Topic Name	Section	Included in Roadmap?	Notes
Storage Safety Standards	Energy Storage	Yes	
Battery Testing Protocols for Grid Applications	Energy Storage	Yes	
PSPS Grid Support Fuel Research	Reliability / Resiliency	Yes	
Risk Metrics for Extreme Events	Reliability / Resiliency	No	
Valuing Resilience for Microgrids	Reliability / Resiliency	Yes	
Residential Resilience	Reliability / Resiliency	Yes	
Residential DC Microgrid	Reliability / Resiliency	Yes	
PV Resilience Needs	Reliability / Resiliency	Yes	
Dynamic PV Modeling	Smart Inverter	No	Similar to "DER Controls to Minimize Integration Costs" but focused on modeling different inverter behaviors rather than directly changing inverter behaviors.
V2Building for Resiliency	VGI	Yes	V2G has already been done, but net new focus on resiliency
Second Life EV Batteries	VGI	Yes	
Submetering for EVs	VGI	No	Already covered per staff
Assess EV Charging Technology Efficiencies	VGI	Yes	
VGI - Comm Standards	VGI	Yes	
Model EV Charging and Price Responsiveness	VGI	Yes	
VGI Data Program	VGI	Yes	

Topic Name	Section	Included in Roadmap?	Notes
EV Charging Device Performance Standards	VGI	Yes	
DER Procurement Assistance Platform	DER Aggregation	Yes	Solar already covered, but not other DERs
Demonstrate DER Grid Balancing Services	Distribution Grid Management	Yes	
DER Ramping Research	Distribution Grid Management	Yes	
Secure Communications for DERs	Communications	No	Combined with "Secure DER Communication Protocols"
PV Resiliency Needs	Reliability / Resiliency	No	Considered already covered on second review.
Fencing for PV Resiliency	Reliability / Resiliency	No	Merged with "PV Resilience Needs"
EV Load Management System	VGI	No	Combined with "DER Controls to Minimize Integration Costs"
PV Hardware Resiliency (Weather)	Reliability / Resiliency	No	Merged with "PV Resilience Needs"
PV Hardware Resiliency (Fire)	Reliability / Resiliency	No	Merged with "PV Resilience Needs"
Plug-and-Play Power Distribution	Reliability / Resiliency	No	Combined with "Assess Flexibility of Coordinated DER"
DER Impact Modeling Tools	DER Aggregation	No	Rate design studies outside the scope of this roadmap
DER Contribution to Bulk Flexibility	Distribution Grid Management	No	Merged with "Assess Flexibility of Coordinated DER"
Bottom Up Integrated Planning	DER Aggregation	No	Changes to planning process out of scope for technical roadmap

Topic Name	Section	Included in Roadmap?	Notes
Load Shift Participation / Adoption	Energy Flexible Load Assets	No	Combined with "Assess Flexibility of Coordinated DER"
DER and Load Coordination @ Local Level	DER Aggregation	No	May be covered by existing DRP pilots
Removing Barriers to Biogas	DER Aggregation	No	Need to make sure technologies fall under DER
Bioenergy for Local Resilience	DER Aggregation	No	Not DER specific currently
Monetize Bioenergy	DER Aggregation	No	Not DER specific currently
Assess Office Lighting Solutions	Energy Flexible Load Assets	No	Not DER specific currently
Evaluating EV Adoption in DAC	VGI	No	EV rebate program outside of scope for DER research
Power Flow Controllers Development	Distribution Grid Management	No	Is this different than remote controlled switches?
VGIWG Support + Funding	VGI	No	CEC staff noted this is not appropriate for this roadmap
VGIWG Use Case Demonstration	VGI	No	CEC staff noted this is not appropriate for this roadmap
Residential EMS for Panel Upgrade Deferral	Energy Flexible Load Assets	No	Combined with "NEC-Approved HEMS..."
Building Decarbonization ideas	Energy Flexible Load Assets	No	Combined with "Assess Flexibility of Coordinated ..."
Understanding Occupant Comfort in DR	Energy Flexible Load Assets	No	Combined with "Load Shift Participation/Adoption"
Price API for Device Makers	Energy Flexible Load Assets	No	Believe exists through CAISO OASIS

Topic Name	Section	Included in Roadmap?	Notes
Biomass for Energy Recovery	DER Aggregation	No	Biomass generation is commercially mature
Economic Value of Resiliency	Reliability / Resiliency	No	Combined with "Valuing Resilience for Microgrids"
Design Guidance for Resilience	Reliability / Resiliency	No	Combined with "PV Resilient Racking"
Utility Upgrade Review Process	Distribution Grid Management	No	Changes to planning process out of scope for technical roadmap
Load Management Solutions Demonstration	DER Aggregation	No	Combined with "DER Controls to Minimize..."
DER Aggregation Demonstration	DER Aggregation	No	Combined with "Assess Flexibility of Coordinated..."
Connected Controls for Load Management	Energy Flexible Load Assets	No	Combined with "Load Shift with Fuel Shifting"
DER Security Framework	Communications	No	Combined with "Secure Communications for DERs"
Protecting Medical Baselines	Reliability / Resiliency	No	Combined with "Systems Integration for Power Outage Life Safety"
Modeling DER Price Response	DER Aggregation	No	Combined with "Assess Flexibility of Coordinated..."
Communication Protocols for Local Capacity Management	DER Aggregation	No	Combined with "DER Controls to Minimize Integration Costs"
Improve DER Visibility	Distribution Grid Management	No	Combined with "Low Cost Telemetry"
Fuel Efficient Tire Standards	VGI	No	Not DER specific
Consumer Engagement and Response to DER/Flex Load	DER Aggregation	No	Combined with "Assess Flexibility of Coordinated DER"

Topic Name	Section	Included in Roadmap?	Notes
VGI Valuation Framework and Methodology	VGI	No	Appears to be covered by DRP demonstration projects. Need to identify net new

Source: Navigant