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DER Integration Technical Assessment

Prepared for:

California Energy Commission

Submitted by:
Navigant Consulting, Inc.
101 California Street
Suite 4100
San Francisco, CA 94111

415.356.7100
navigant.com
Reference No.: 200060

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Introduction

California has embraced the adoption and grid integration of Distributed Energy Resources (DER)[1] as a strategic priority, supported by a robust suite of policies. These policies have been effective at spurring uptake of DER among customers and energy providers. Meanwhile, grid operators and load serving entities have made significant progress toward grid integration, resource planning and operations. As a result, today DER are meeting a larger share of California's energy needs than ever before.

While acknowledging this progress, there is still much to do. Fulfilling all of California's energy and climate goals, including safety, emission reductions, affordability, reliability, equity and emission reductions, will require further improvements in DER technologies. Improvements are needed in DER themselves, as well as the tools used by grid operators and load serving entities (LSEs) to integrate them. And some of these improvements will require strategic investments through the Electric Program Investment Charge (EPIC) Program, California's primary means of funding "applied research and development, technology demonstration and deployment, and market facilitation to create new energy solutions, foster regional innovation, and bring clean energy ideas to the marketplace."[2]

DER Research Roadmap Overview

The purpose of the DER Research Roadmap is to provide the California Energy Commission insight and recommendations as it considers these questions. This Technical Assessment provides the first step toward that end, identifying what further EPIC investments may be needed in order for DER to support California's energy and climate goals. The following Technical Assessment characterizes the current state of DER technologies, answering the following questions about key technologies and strategies:

1. What is the technology?
2. What does the technology do?
3. What do we know about the limits of the technology?
4. What don't we know about the technology?

The Technical Assessment was supported by a Literature Review of the technologies and strategies, as well as a series of expert interviews with stakeholders from around the industry. It has also been guided by a Technical Advisory Committee including representatives from utilities, research institutions, community choice aggregators, regulators, and the Energy Commission. After identifying the gaps between the current status of DER technologies and strategies and what is required to reach California's energy vision, a methodology will be developed to prioritize the possible research opportunities and determine the appropriate course of action in the short (1-3 years), medium (3-5 years) and long (5+ years) time horizons.

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[1] Defined by California code as distribution-connected distributed generation resources, energy efficiency, energy storage, electric vehicles, and demand response technologies

[2] *EPIC Program Description*, California Energy Commission (2019)

Technical Assessment Structure

After performing an initial literature review, and through consultation with the project Technical Advisory Committee, a range of load impacting and coordinating technologies and strategies were identified:

DER Functional Technology

- Energy Storage
- Electric Vehicle Integration and Smart Charging
- Energy Flexible Load Assets
- Smart Inverters

DER Enabling Technology

- Distribution Grid Communications
- Distributed Grid Management
- DER Aggregation as Non-Wires Alternatives

For each of these topical areas, the following discussion is provided in this Technical Assessment:

- Technology and Strategy Review
    - Characterization of technology and strategy
    - Discussion of advantages and disadvantages
    - Description of technical specifications and requirements
    - Review of recent RDD&D activities
- Critical Success Factors
    - Description of commercial readiness level, including market participation
    - Federal and/or state policy drivers
    - Assessment of barriers to further adoption
- Identified RDD&D needs
    - Actions to bring key, high-impact technologies and strategies to market

The following sections cover each of the topical areas. In addition, the Appendix provides a comprehensive listing of the Literature Review sources.

Guiding Energy Vision Metrics

This document also identifies potential metrics that can be used to measure progress in a topic area, tied to the categories proposed by the Grid Modernization Laboratory Consortium Metrics Analysis from the Department of Energy. Alignment with these categories helps California to stay synchronized with grid modernization and DER integration policy across the country to most effectively deploy its research resources. The overall categories are shown below, and metrics in the later sections are aligned with them graphically with matching icons. To the extent that information on the current status of these metrics was available from the literature review it is included in this document; it is the intent of the Research

Roadmap process to fill in the unknowns in an iterative process with industry stakeholders or to identify research gaps to be addressed.

Figure 1. Grid Modernization Metric Categories

Categories of Barriers to DER Integration

In a similar fashion, the barriers to efficient DER adoption are grouped into the categories in Figure 2. Particular DER barriers may align with multiple categories, though they have been listed with their closest match for clarity. The following table includes selected barrier examples; detailed descriptions are included in the body of the assessment. The Research Roadmap development process will solicit input from stakeholders as to what potential research could be pursued to alleviate the identified barriers.

Figure 2. DER Barrier Categories

Cost
The component, production or operational costs of the resource are above what is required for adoption.

Uncertainty
Limited information on the immediate or future performance of the resource restricts potential uses.

Valuation
The resource is not adequately compensated for benefits it is providing to the power system.

Coordination
Complexity of the interactions between various participants in the ownership and utilization of the resource limits adoption.

Capability
The performance characteristics of the technology are not sufficient to replace existing solutions.

Table 1. DER Barriers by Functional and Enabling Technologies

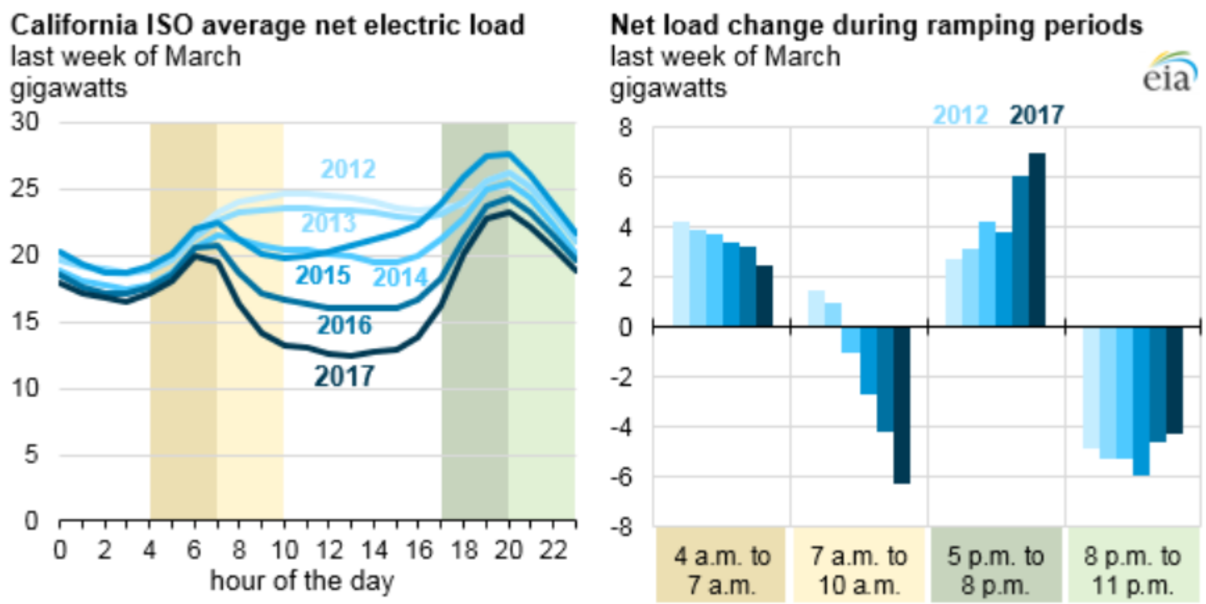
	Cost	Valuation	Capability	Coordination	Uncertainty
Storage	• Capital costs high • Competition for components	• Not all benefits compensated • Artificially low alternate customer costs	• Low energy density • MUA controls difficult • Duration limited	• Specialized installation and maintenance • Permitting and safety • Customer acquisition	• Battery life concerns • Third-party controls visibility
Electric Vehicles	• V2G vehicle costs • V2G EVSE costs • Incentives needed for multiple stakeholders	• Not all benefits compensated		• Aggregation required for feasible participation	• Battery warranty impacts • Vehicle battery availability
Energy Flexible Load Assets	• Building control hardware costs • Lack of financing	• Value stacking difficult	• Inadequate data synthesis • Communication unreliability • Lack of M&V protocols	• Lack of useful grid signals • Limited interoperability • Customer acquisition	• Value to customer is uncertain • Value to utility is uncertain
Smart Inverters			• Insufficient utility controls • Communication unreliability	• Customer acquisition • Limited interoperability	• Value to customer is uncertain • Value to utility is uncertain
Grid Comms				• Assignment of cybersec obligations • Lack of clear architecture	
Grid Operations	• Enabling platform cost allocation	• Cost-of-service ratemaking • Uneven customer reliability value	• Physical network model quality • Limited DER inclusion • Limitations of cloud analytics	• Integration with conventional grid systems • Insufficient communications standards • Impact on critical systems	
Grid Planning		• Limited regulatory incentives • Difficult separating value streams		• Complex coordination between resource types	• DER performance not guaranteed to planner

Section 1: Energy Storage

Increasing penetration of DERs and larger-scale intermittent resources leads to increasing 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 level in order to smoothly balance supply and demand.

The grid currently experiences high periods of imbalance between load and generation at two points during the day: during the early evening when solar power drops off as load rises; and more recently close to mid-day when solar generation is high and load is relatively low. This has led to a phenomenon known as the "duck curve," where price inversions have been noted by the California Independent System Operator (CAISO) and Arizona Public Service interconnect points and have resulted in California paying Arizona to purchase excess power.

Figure 3. California Duck Curve



Source: US Energy Information Administration, based on ABB Energy Velocity

Analysis of CAISO data by California Energy Commission staff[3] shows a maximum 3-hour ramp in 2018 of 14,777 MW, requiring significant generation to be brought rapidly online to match demand as renewable generation drops simultaneously with increasing customer load. These ramping requirements will increase as the net generation minus wind and solar discrepancy grows.

Energy storage can help flatten out 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, reducing reliance on fast reacting fossil fuel peaker plants. Additionally, energy storage solutions can be used as reserve capacity to lower the requirements of traditional spinning capacity, and increase efficiency of running generators, resulting in reduced fossil fuel use and associated emissions. Energy storage is applicable to today's flexibility concerns and will be increasingly important to provide dispatchability as California transitions to a fully de-carbonized power system. In

[3] Resource Flexibility Tracker, California Energy Commission (2018)

March 2018 CAISO curtailed 94,778 MWh of wind and solar generation compared to 81,776 MWh in the same month the previous year.[4]

There has been an increase in ramping requirements to support the fluctuations in generation from renewables and to support 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 for their ability to quickly start and ramp but can increasingly be met with alternative resources.

Technology and Strategy Review

Characterization of Technology and Strategy

Commercial and community-based energy storage has been deployed in the following three use cases:

- Reducing electricity cost by storing energy during off-peak hours to be used at more expensive peak hours
- Improving reliability of the power supply
- Improving power quality, frequency, and voltage.

Storage in the context of this review focuses on distribution and customer grid domains, defined by CPUC D.14-10-045[5] by the point of device interconnection.

Construction of storage systems differ in design depending on the technical needs of either a power-oriented system or an energy-oriented system. Power oriented systems are shorter duration and designed to provide instantaneous power output for a short time. Energy-oriented systems are designed 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 4 hours
- **Long-duration:** energy oriented, more than 4 hours.

In California, long-duration energy-oriented systems are expected to be important to shift the bulk of the solar generation peak into the evening hours when that resource is unavailable. As displayed in Figure 4, longer duration, energy-oriented systems have higher average costs per kW and lower costs per kWh, and vice versa for shorter duration, power-oriented systems.

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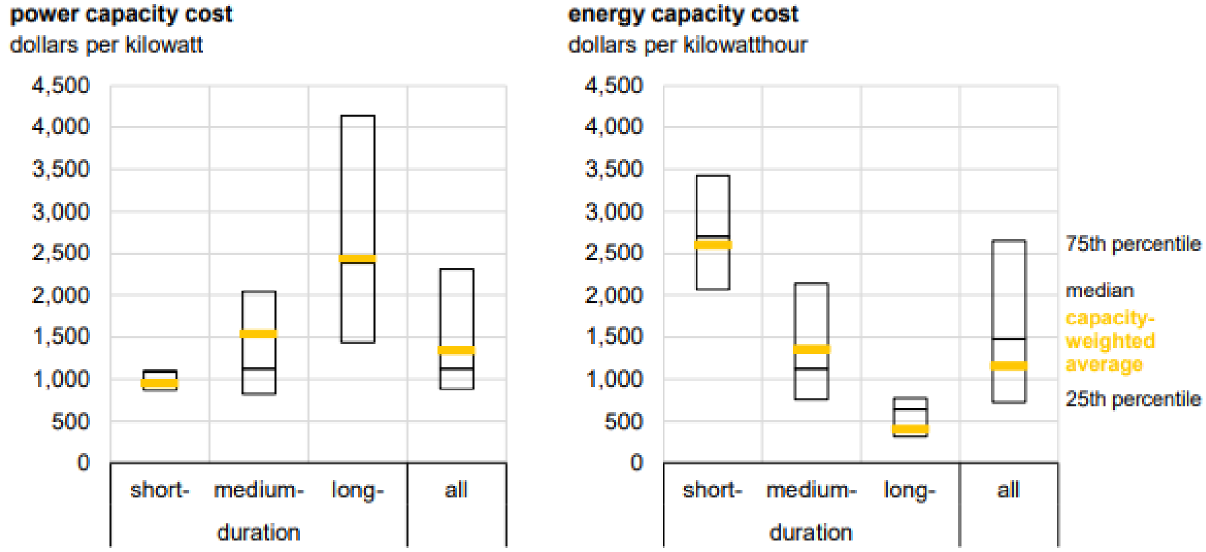
[4] *Managing Oversupply*, CAISO (2019)

[5] *Energy Storage Procurement* (D.14-10-045), CPUC (2014)

Figure 4. Estimated Capital Cost of Battery Storage Systems (2018)

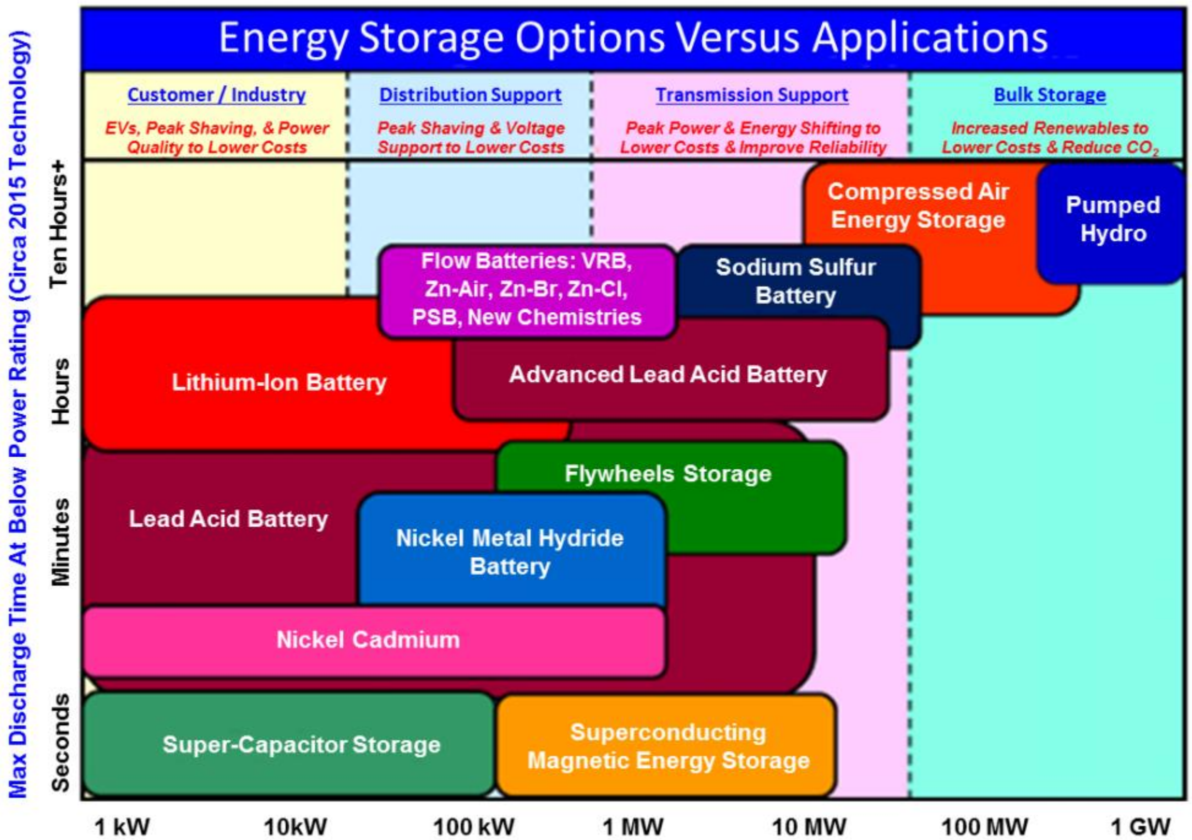


Source: EIA, Form EIA-860

Users have several types of battery technologies to choose from, each with their own inherent strengths and weaknesses. Typically, the optimal battery technology is selected based on the economic impact of the technology's designed operational use-case.

The relative discharge time and power capacities of different energy storage technologies is presented in Figure 5.

Figure 5. Energy Storage Technologies by Discharge Time, Size and Use



Source: EPRI

i. **<u>Lead Acid Batteries.</u>** Lead acid batteries are one of the most mature energy storage technologies, though the perceived deficiencies in some performance characteristics have driven development of newer battery chemistries. They are still in use for uninterruptible power applications where high energy density and significant number of charge cycles are not requirements. Estimated costs for a 1 MW, 4 MWh lead acid battery installation are in Table 2.[6]

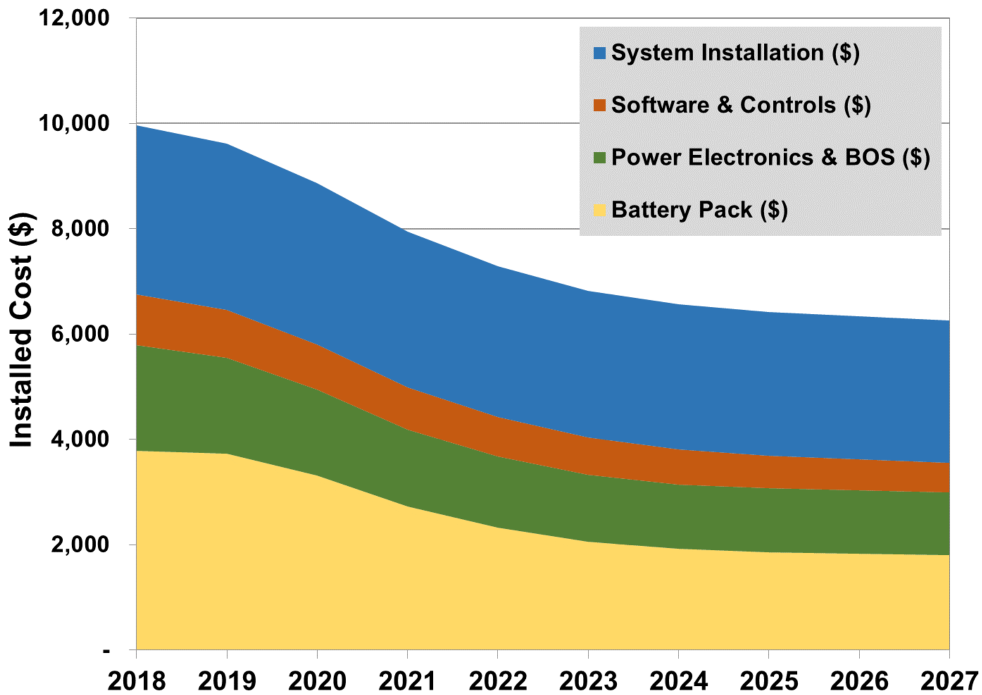
Table 2. Summary of Lead Acid Battery Costs (1 MW / 4 MWh) (2017)

Component	Lead Acid Cost
Battery Pack	$0.8M - $2M
Power Electronics	$0.23M – $0.47M
Balance of Plant	$0.12M - $0.25M
Systems Integration & Installation	$0.6M - $0.72M
Installed Cost	**$1.75M – $3.44M**

[6] *Energy Storage Report (Draft)*, Public Service Corporation of New Mexico (2017)

ii. **Lithium Ion Batteries.** Driven by consumer electronics and electric vehicle performance requirements, lithium ion battery chemistries have seen significant research and development, as well as dramatic increases in production scale. Lithium ion chemistries have been proposed and implemented for both distribution and transmission scale opportunities; the California Public Utilities Commission approved 567.5 MW of lithium ion batteries for Pacific Gas & Electric in January 2018[7], 10 of which will be located behind the customer meter. Lithium ion chemistries are popular for their high energy density, high-cycle efficiency, and fast response times.[8] Projected price curves of component categories for lithium ion chemistry batteries for distribution utility-scale (1 MW, 4MWh), small commercial and industrial (100 kW, 200 kWh), and residential (5 kW, 13 kWh) are below, sourced from Navigant Research interviews with storage developers and end customers.

Figure 6. Projected Lithium Ion Residential Storage System Costs (5 kW, 13 kWh)

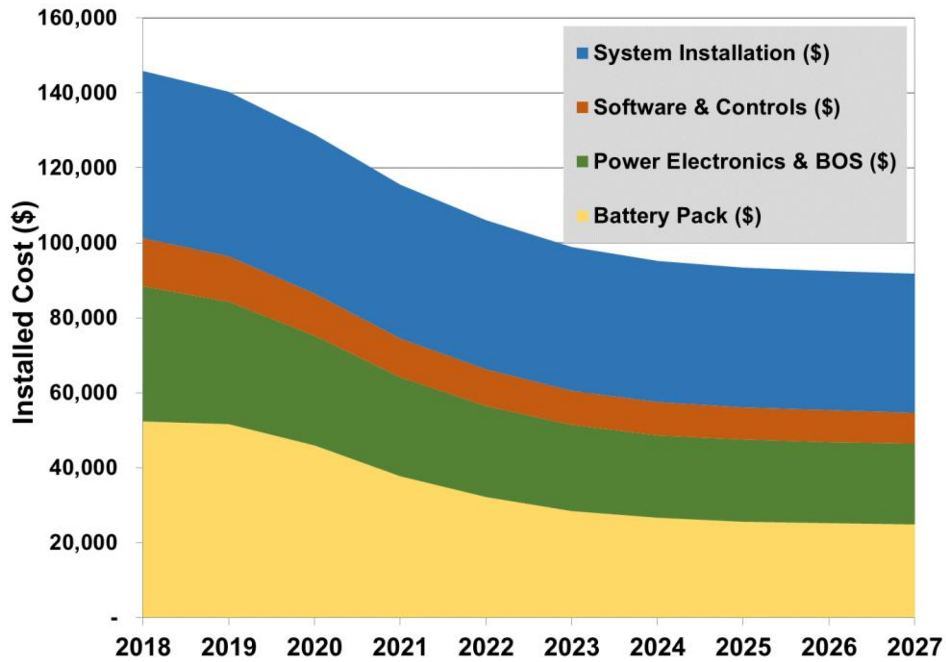


Source: Navigant Research

[7] *PG&E Storage Soliciation Resolution*, CPUC (2018)

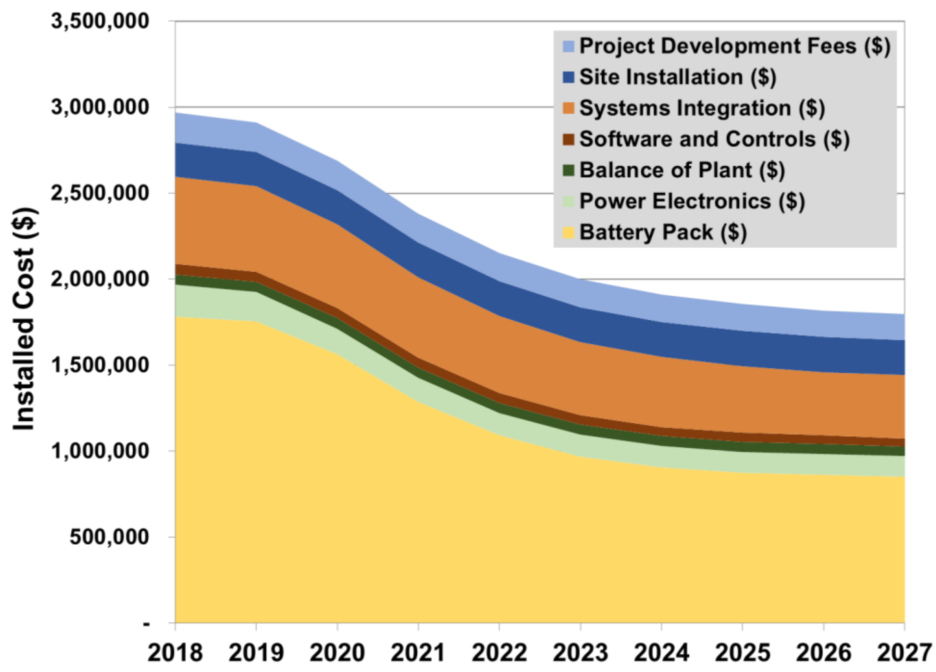
[8] *U.S. Battery Storage Market Trends*, EIA (2018)

Figure 7. Projected Lithium Ion Commercial System Costs (100 kW, 200 kWh)



Source: Navigant Research (2019)

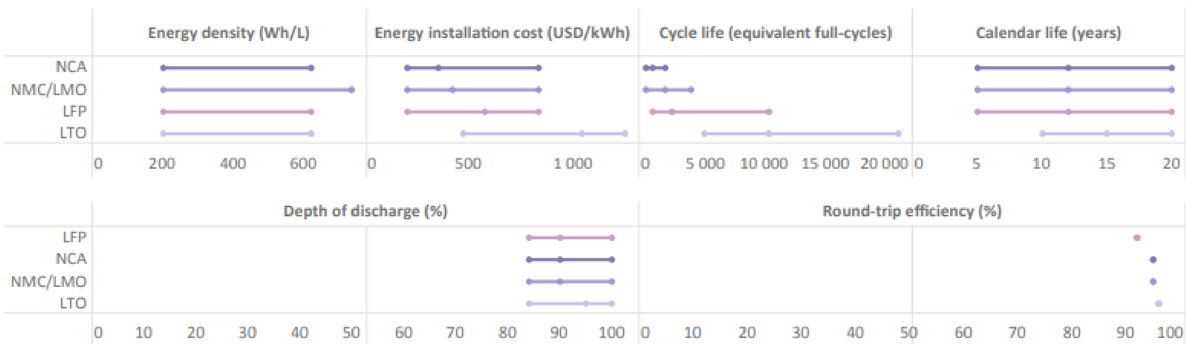
Figure 8. Projected Lithium Ion Utility-Scale System Costs (1 MW, 4 MWh)



Source: Navigant Research

Additional cost and characteristics data are available in the robust International Renewable Energy Agency Electricity Storage and Renewables report, published in 2017.[9] Figure 9 details performance characteristics for Nickel Cobalt Aluminum (NCA), Nickel Manganese Cobalt Oxide (NMC), Lithium Iron Phosphate (LFP) and Lithium Titanium Oxide (LTO) chemistries. Additional detailed description of these technologies can be found in that report. As noted previously, the per unit energy and power costs of energy storage are sensitive to the specific configuration of that unit and should be evaluated with that in mind.

Figure 9. Lithium-ion Battery Chemistry Performance Characteristics



Source: International Renewable Energy Agency

iii. **<u>Flow Batteries.</u>** Flow battery systems use separate liquid anodes and cathodes rather than a single electrolyte. Though the energy capacity of an installation is scalable with the amount of electrolyte provided and can be adapted to meet the requirements of individual projects, the industry is moving towards containerized systems with pre-determined storage durations. Though it is a relatively new technology, flow batteries are projected to have long cycle life and operational lifespan[10]. Several different chemistries are in development; notably Vanadium Redox (VRB), Zinc-Bromide (Zn-Br), and Zinc-Air (Zn-Air). Estimated costs for a 1 MW, 4 MWh system are presented below.[11] However, per a 2019 Electric Power Research Institute report, there is a significant uncertainty over future costs for flow batteries. Many of the systems installed to date are custom-built and the cost of components like the electrolyte has quadrupled in some cases over the last decade.[12]

Table 3. Summary of Flow Battery Costs (1 MW / 4 MWh) (2017)[13]

Component	Vanadium Redox	Zinc Bromide	Zinc Air
Battery Pack	$2.19M - $3.6M	$2.1M - $2.9M	$0.8M - $1.6M
Power Electronics	$0.73M - $1.2M	$0.6M - $0.9M	$0.45M - $0.64M
Balance of Plant	$0.1M - $0.125M	$0.1M - $0.125M	$0.08M - $0.1M

[9] *Electricity Storage and Renewables Report,* IRENA (2017)

[10] *U.S. Battery Storage Market Trends*, EIA (2018)

[11] Costs initially documented for a 4 MW, 16 MWh and scaled down to 1 MW, 4 MWh system for comparison purposes. Actual costs may not scale linearly.

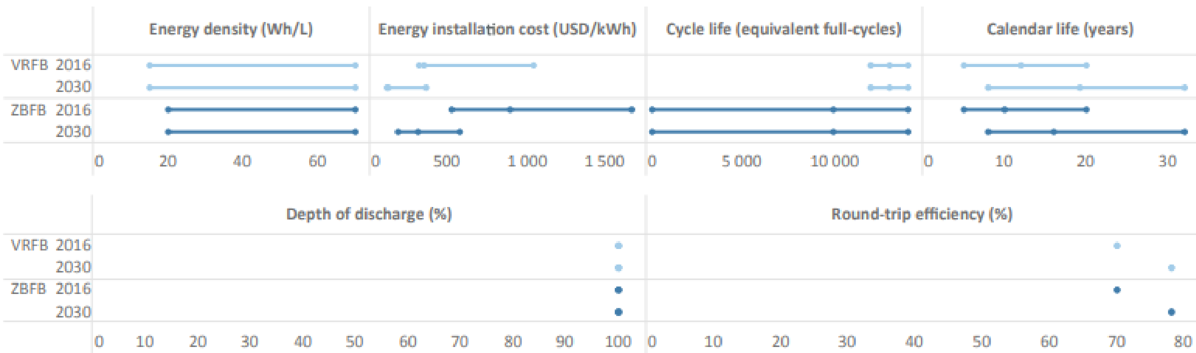
[12] *Energy Storage Technology and Cost Assessment*, EPRI (2019)

[13] *Energy Storage Report (Draft)*, Public Service Corporation of New Mexico (2017)

Systems Integration & Installation	$0.56M - $0.8M	$0.56M - $0.8M	$0.48M - $0.72M
Installed Cost	**$3.58M - $5.73M**	**$3.36M - $4.72M**	**$1.81M – $3.06M**

Performance metrics of Vanadium Redox Flow Batteries (VRFB) and Zinc Bromide Flow Batteries (ZBFB) from IRENA are shown in Figure 10.

Figure 10. Flow Battery Performance Metrics by Chemistry



Source: International Renewable Energy Agency

iv. <u>**Electric Vehicle (EV) Energy Storage.**</u> Plug-in electric vehicles are expected to become much more common in upcoming decades. Governor Brown's Executive Order B-48-18 aims to put 5 million zero-emission vehicles (ZEVs) in California by 2030, representing hundreds of GWh of potential storage. With about 17.5 million sales of light-duty vehicles sold annually in the United States,[14] this presents a tremendous challenge for grid operators, and a tremendous opportunity to take advantage of the expanding grid storage. This is a tremendous opportunity for utilities and balancing authorities to provide renewable storage for the grid if a strategy for connecting these batteries to the grid is executed.

Problems relying on EVs for storage do exist. Concerns with using personal vehicles to provide energy storage exist, especially because cycling batteries reduces the overall life of the battery. Timing can also be problematic. Typically, EV charging is performed at the owners' residence at night and during weekends, when electricity value and prices are relatively low. One potential challenge to overcome is the scenario of limited workplace charging stations for commuter EVs to connect to the grid during peak solar production hours.

A simple strategy for the implementation of EV charging is to encourage the promotion of workplace and residential EV charging in conjunction with peak renewable energy production times. Utilizing favorable rate structures and reducing or "throttling" charging of EVs during higher demand periods, such as in the early evening, can incentivize EV charging during curtailment periods. This can be accomplished with minimal impact to the consumer by implementing charging control technology with multiple settings for prioritized charging times. For example, a "quick charge" setting could be used when the EV operator has an immediate transportation need, while an "economic" setting could be used to align charging with lower rates during curtailment periods, such as during the mid-day solar generation peak. Two-way power flow could provide additional support for grid services but would also subject the consumer to the same

[14] *Light Weight Vehicle Sales,* Federal Reserve Bank of St. Louis

regulatory safety requirements as on-site generation. The considerations of EV charging are discussed further in the EV section of this report.

v. **Flywheel Energy Storage**. Mechanical energy storage systems using rotating masses predate the technologies in the previous category and excel in some applications. To store energy, a motor is used to impart rotational mechanical energy to a large mass; to produce energy, the rotating mass is used to power a generator. One provider, Amber Kinetics, claims >88% round trip efficiency, zero energy losses over time, and 30-year design life and resiliency to a wide range of temperature ranges. They did demonstrate a self-discharge rate of 0.8% of battery energy capacity per hour on average in a CEC pilot[15] and may be complex to site and permit. Thus, their competitive advantage is in higher-frequency use cases, such as grid ancillary services and industrial processes, and not in reliability or resiliency applications.

vi. **Long Duration Energy Storage.** While many of the existing commercial battery products focus on the short to medium term applications, the grid is expected to need longer duration energy that can go beyond intra-day load shifting. The ARPA-E branch of the Department of Energy launched the Duration Addition for Electricity Storage (DAYS) program[16] in 2018 to research applications from 10 to 100 hours, including a $3.5M grant to Primus Power to pursue a zinc-bromide flow battery solution aiming for < $35/kwh DC battery cost and 10 to 20 hours of storage.[17]

Discussion of Advantages and Disadvantages

Table 4. Advantages and Disadvantages of Various Methods of Energy Storage

Strategy	Advantages	Disadvantages
Electrochemical Energy Storage	• Known storage values • Relatively expensive method of delivering energy • Reliable source of energy storage	• Fluid regulatory environment • Takes a large amount of space • Hazardous chemicals are often involved • Specialized maintenance • Tariffs and rates needed
EV Storage	• With infrastructure upgrades, can reduce or eliminate renewable energy curtailment • May provide a significant source of storage to grid operators • Can be used to provide emergency power	• Infrastructure upgrades are expensive • Requires private sector investment and adoption • Consumers hesitant to adopt policies that reduce battery life • Primary use is transportation, not storage • Storage sources maybe connected and disconnected without grid operator control • Regulatory issues surrounding vehicle to grid transmission

[15] *Amber Kinetics Demonstration Project Report*, CEC (2015)
[16] *DAYS Program Overview*, ARPA-e (2017)
[17] *Primus Power Presentation*, Primus / California Energy Commission (2018)

Strategy	Advantages	Disadvantages
Flywheel Storage	• High lifespan • High roundtrip efficiency • Fast response • Low environmental impacts • High power density • High energy density	• High self-discharge rate limits applicability for medium and long duration use cases • High potential energy spinning mass can be dangerous if installed incorrectly; permitting difficulties may reflect this

Description of Technical Specifications and Requirements

i. Electrochemical Energy Storage

a. Land use and Zoning laws – Municipalities and counties may have specific regulations that limit or prohibit the use of battery storage systems in residential or commercial locations.

b. NEPA Review – National Environmental Policy Act (NEPA) may prohibit the development of battery storage in certain areas that are Federally protected.

c. Local Safety/NFPA – Local fire ordinances have jurisdiction over many storage sites due to the use of hazardous chemicals and the production of hazardous gas during battery operation. Often ventilation and fire suppression systems must be upgraded to accommodate battery storage installation.

d. Net Energy Metering (NEM) – Most of California's customer-sited storage is connected under NEM, and the storage component is subject to non-export requirements.

ii. EV Energy Storage

a. No current programs exist for EVs to provide grid storage that require a simple "plug-in" charger.

b. Local electrical and fire inspections may be required for EVs that have upgraded chargers installed in residences or commercial buildings, such as Tesla's Wall Connector which require a licensed electrician to install.[18]

[18] *Model S/X/3 Wall Connector*, Tesla (2018)

Figure 11. Tesla Wall Charger

Recent and Current RDD&D Activities

Research into energy storage has been well represented in previous EPIC projects and in federally funded projects. Over time, research focuses have shifted from demonstrating the feasibility of energy storage to provide grid services (e.g. ARPA-E CHARGES program, which provides a testbed to test ARPA-E-funded battery technologies in the context of the electric grid) to enhancing the business case for stand-alone or integrated storage. The research surveyed broadly fell into the following categories:

i. **Energy Storage Performance in an Integrated System.** These projects demonstrate the feasibility of and assess the benefits of integrating energy storage with other DERs for grid reliability and customer value. Projects include solar+storage demonstrations and microgrids. Potential metrics could include potential of the integrated technology to reduce costs, ease of permitting and interconnection, effectiveness of control algorithms, effectiveness of storage to increase hosting capacity,

ii. **Assessing and Enhancing Cost-Effectiveness of Storage.** These projects demonstrate innovative systems, strategies, and frameworks to characterize and/or improve the cost-effectiveness of adopting solar. This area explores value-stacking, wholesale market participation, and valuation methods, demonstrating successful strategies for project developers and customers to maximize the .value of their storage system. Potential metrics include project cost-effectiveness, value from market participation, and the impact of financial structures and tariffs.

iii. **Testing Viability of Emerging Storage Technologies.** Research in this area characterizes the performance of early stage storage technologies (e.g. flow batteries) in context of the grid. There has been less of a focus in this space due to the prevalence of Li-ion batteries.

Metrics for the evaluation of the progress of energy storage technologies are presented in Figure 12. These are focused on the characteristics of the technology themselves, while metrics dependent on the energy and ancillary service market clearing mechanisms such as reduced renewable curtailments, distribution investment deferral and production and operating cost impacts are reserved for a different document.

Figure 12. Metrics for Energy Storage

Storage Metrics	Unit
Installed capacity	MW, MWh
Capacity participating in wholesale markets	MW, MWh
Device cycle life	count
Device efficiency	%
Outage customer-minutes avoided	Customer-minutes
Charge / discharge rates	MW/min
Standby losses	%/hour

A selection of research projects is provided below, and a full list of surveyed research is presented in Appendix A.

i. **Peak Demand Lithium-Ion Battery Storage (2015).** Sacramento Municipal Utility District (SMUD) demonstrated a 500kW advanced lithium-ion battery storage system developed by Mitsubishi Heavy Industries to evaluate the technology's ability to support integration with non-dispatchable renewable generation, specifically solar PV generation. The battery was tested for its ability to provide peak electricity demand shaving, ramp rate control, and simulated frequency regulation support. SMUD identified that reliance on third party telecommunications proved problematic, causing issues with control and monitoring systems including fire protection monitoring.[19]

ii. **Pacific Gas and Electric EPIC Project (2018).** PG&E utilized the Electric Program Investment Charge (EPIC) funding for a project that plans to demonstrate the functionality of customer-sited behind-the-meter PV Smart Inverters and storage integration to determine the grid impacts of their use. The EPIC funded demonstration will assess the basic technical functionality of smart inverter autonomous functions that mitigate local voltage issues commonly found with high DER penetration in both residential rooftop and commercial applications. The EPIC project successfully integrated two battery systems: Vaca Dixon (2 MW Vacaville) and Yerba Buena (4 MW San Jose) to participate in real-time and day-ahead CAISO markets, and are the first batteries to participate in the Non-Generator Resource (NGR) market.[20] The project found that the observed CAISO Day-Ahead and Real-Time Energy revenues were not financially viable given the measured average 75% round trip efficiencies of the battery systems. The most financially viable use case was frequency regulation, though it was noted that demand for this service was more limited than energy.

iii. **Integrating System to Edge-of-network Architecture and Management for SHINES (SEAMS) Technologies on High Penetration Grids.** Hawaiian Electric Company received a DOE grant of $2,437,500 to demonstrate the benefits of:

[19] *Storage Procurement Report*, SMUD (2014)

[20] *Electric Program Investment Charge project's battery storage systems*, PG&E (2016)

a. Deploying distributed PV energy, storage, and dynamic load control with enhanced system-level utility visibility and distribution system control,

b. Offering more plug-and-play customer options for grid participation

c. Providing cost-effective “grid response” capabilities to system operators.

HECO explored a new solution called System to Edge-of-Network Architecture (SEAMS) to better integrate and manage the impact of PV and storage systems connected to the grid. SEAMS utilized an interdisciplinary team to design and demonstrate new system logics to “see and interface” with distribution-system level, customer-hosted electricity resources. Advanced communication and forecasting intelligence systems aim to manage distribution level issues introduced by high penetration PV and solar variability, while also evaluating cost effectiveness of distributed assets integrated with SEAMS capabilities.

iv. **SDG&E and AES Battery Storage Partnership.** San Diego Gas & Electric and AES Energy Storage installed the world’s largest Lithium Ion Battery-Based Energy storage installation in 2017 totaling 37.5 MW to maximize renewable energy use in Southern California. The project was fast-tracked by SDG&E in 2016 to enhance regional grid reliability, proving that utilities, municipalities, and private sector storage providers can work quickly to deploy storage where needed in a short period of time. The batteries are located at SDG&E substations in Escondido and El Cajon and serve as a 37.5 MW power source and a 75 MW flexible resource to the grid. This is enough capacity to power approximately 25,000 homes for 4 hours.[21]

Critical Success Factors

Description of Commercial Readiness Level, Including Current Market Participation

i. **Electrochemical Energy Storage**

a. Currently commercially viable for limited use cases such as customer demand reduction and wholesale frequency regulation markets, though the value needs to be evaluated on a case by case basis. If the spread between high and low wholesale energy prices increases, potentially due to increased zero marginal cost renewable generation, participation in additional use cases may become financially viable.

b. Significant commercial storage has been procured by Southern California Edison and San Diego Gas & Electric to address reliability risks because of constraints on natural gas supply due to Aliso Canyon leak in Los Angeles, and by Pacific Gas and Electric to replace peaking generation at Moss Landing. There are also several smaller distribution scale projects.

c. At the end of 2016, more than half of existing U.S. battery storage capacity was owned by independent power producers and investor owned-utilities.

d. Lithium-ion batteries account for approximately 83% of battery storage installations by capacity.

ii. **EV Energy Storage**

a. No reliable data was identified in the literature review concerning current EV Energy Storage in the market.

b. EV sales continue to trend higher and implementing policies and strategies to take advantage of increased EVs will be critical before mass proliferation of this technology

[21] *SDG&E, AES bring world's largest lithium ion battery storage online in California*, Utility Dive (2017)

creates an environment where minor policy changes may have major unintended impacts on the grid.

iii. Flywheel Energy Storage

a. Limited market participation aside from pilot projects in California.

b. Need to improve cost efficiencies to meet electric energy storage under the performance characteristics required by the California energy system.

c. Necessary to reduce self-discharge losses; demonstrate lab-tested performance characteristics in a field setting.

iv. Long Duration Energy Storage

a. While there are some examples of four to eight-hour systems in California, multi-day duration systems are not currently commercially viable.

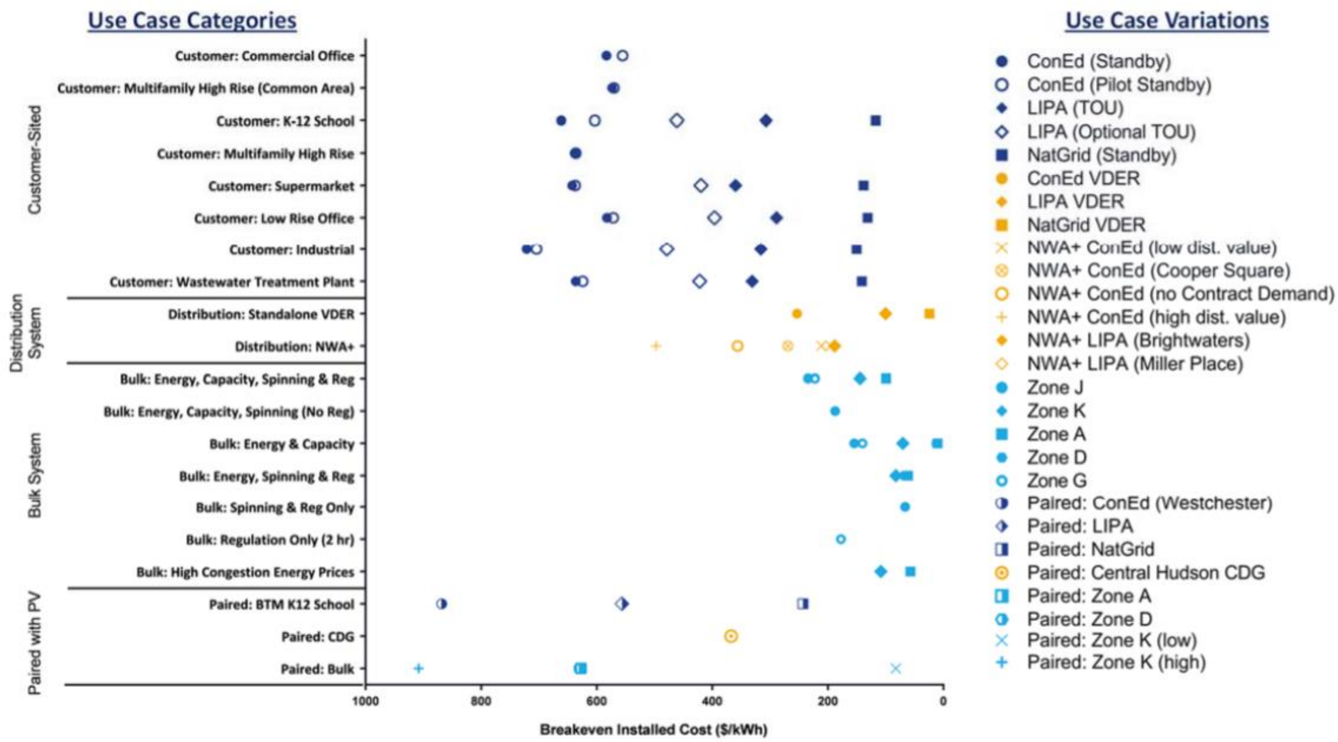
b. Programs like ARPA-e's Duration Addition to electricity Storage (DAYS) are providing research funding for additional demonstrations and development of multi-day storage.

Currently, the economics of storage are highly dependent on use case and the ability of the resource to capitalize on multiple value streams. Regulatory and market rules, operating constraints, and physical impacts limit value stacking. California and New York are both developing regulatory policy to value and define the participation options for distributed energy storage, with the Multiple Use Applications (MUA)[22] and Value of Distributed Energy Resources (VDER)[23], respectively. The MUA decision focuses primarily on defining which domains within the energy system distributed storage may provide services in, while VDER provides a more explicit valuation framework. Figure 13 shows the breakeven installed cost of storage (BICOS) over the system lifetime for several use cases across New York. Benefits were calculated based on the individual value stream components, driven by projected market revenues in some cases and by the VDER framework as described on the NYSPSC site in the footnotes. Efforts are needed to drive down non-hardware costs to accelerate adoption of energy storage technologies.

Figure 13. Breakeven Installed Cost of Storage for Various Storage Use Cases

[22] *Multiple-use Applications Decision D.18-01-003*, California Public Utilities Commission (2018)

[23] *Value of Distributed Energy Resources*, New York State Public Service Commission (2019)



Federal and/or State Policy Drivers

i. Federal Regulatory

a. **FERC RM16-23-000, Order No. 841.** This rule, effective 2018, requires ISOs and RTOs to remove barriers to the participation of electric storage resources in their capacity, energy, and ancillary service markets.[24]

ii. California State Government

a. **California AB 2868.** This bill requires investor-owned utilities (IOUs) to file applications with the California Public Utilities Commission (CPUC) for programs and investments that accelerate widespread deployment of distributed energy storage systems. It requires the PUC to prioritize programs and investments that provide distributed energy storage systems to public sector and low-income customers. The IOUs submitted applications to meet the mandated storage, but were directed by the CPUC to instead pursue an open request for offer (RFO) "without any bias towards ownership model".[25]

b. **California AB 2514.** This 2011 Assembly Bill refined policies and program details that set minimum storage procurement targets for state investor owned utilities (IOUs) and established California's Energy Storage Roadmap. This legislation was

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[24] *Electric Storage Participation in Markets Operated by Regional Transmission Organizations and Independent System Operators*, FERC (2018)

[25] Proposed Decision A.18-02-016, CPUC (2019)

a critical driver for behind-the-meter energy storage resources as a supply-side participant.[26]

c. **California Clean Vehicle Rebate Project.** California residents can apply for a purchase rebate up to $7,000 when they purchase a new, eligible zero-emission or plug-in hybrid light duty vehicle, with amount varying by vehicle model.[27] This project supports California's goal of having 5 million zero-emission vehicles on the road by 2030, and 250,000 electric vehicle charging stations by 2025. Nearly $350 million in rebates have been issued since the program started in 2009.

d. **California SB 1339.** This bill directs the development of a microgrid tariff, allows for third-party owned microgrids, and directs actions to support and streamline deployment of microgrids, where energy storage may play a major role.

iii. California Regulatory

a. **CPUC E-4791.** 2016 CPUC decision that directed expedited energy storage procurement to address the emergency grid reliability situation caused by the Aliso Canyon natural gas moratorium.[28]

Figure 14. Energy Storage Procurement as of August 2018

Pacific Gas and Electric					
	Target	On-Line Storage	Approved, Some Are in Progress	Pending Approval	TOTAL PROCURED
Transmission	310	0	0	692.5	692.5
Distribution	185	6.5	10	20	36.5
Customer	85	26.1	0	20	46.1
Southern California Edison					
	Target	On-Line Storage	Approved, Some Are in Progress	Pending Approval	TOTAL PROCURED
Transmission	310	20	100	0	120
Distribution	185	56	65.5	10	131.5
Customer	85	110	195	0	305

Source: CPUC

b. **CPUC D.18-01-003.** This decision provided 11 rules to structure the behavior of storage resources across multiple domains (Customer, Distribution, Transmission, Wholesale Market, and Resource Adequacy), directing that resources interconnected in the domains closer to customer are able to provide grid services to higher up domains. It also clarified how resource could perform multiple use cases, as long as the appropriate capacity was available when time-differentiated (different services at different times) and capacity-differentiated (different services at the same time with individually reserved portions of device capacity).[29]

c. **Self-Generation Incentive Program (SGIP).** SGIP is responsible for supporting the deployment of hundreds of megawatts of BTM energy storage by providing upfront

[26] *Energy Storage Roadmap*, CAISO (2014)

[27] *California Clean Vehicle Rebate Project*, Clean Vehicle Rebate

[28] *Resolution E-4791*, CPUC (2016)

[29] *Decision 18-01-003*, CPUC (2018)

and performance-based incentives. Recently, with the passage of SB 700, Over $400 million in incentives is available through 2019 for BTM storage systems, including a 20% Equity Budget set-aside, and with the recent passage of SB 700, program funding will be extended with $166 million per year through 2024.

d. **Distribution Investment Deferral Framework (DIDF).** The DIDF was adopted in February 2018 to establish an annual planning process to consider potential deferral opportunities for third-party DERs such as energy storage.

Assessment of Barriers to Further Adoption

Cost

Capital costs higher than conventional generation. While the costs of electrochemical energy storage have droped significantly over the last decade, the cost of providing a set amount of power is in circumstances greater than conventional natural gas generation when emissions and environmental impacts are not considered.

Competition for limited energy storage components. While the increases in scale of production of consumer electronics and electric vehicle batteries have driven down the cost of grid battery technology, increasing demand for non-grid batteries may eventually cause costs of certain technologies to increase. Alternative storage technologies not suitable for transportation applications may have less competition.

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 components may have direct opportunities to participate. CPUC's Multiple-Use Applications proceeding has provided clarity on how storage resource in different domains can participate in multiple use cases, but the market products are still in development.

Artificially low alternative customer costs. Customer cost of utility electric service to outlying and potentially fire prone areas of the state is intentionally limited in the existing market design and utility compact. 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 there are increasing public safety grid power shutoffs due to potential fire risk.

Capability

Hardware requires too much physical space. Especially in the dense urban areas where potentially-replaceable distribution grid infrastructure improvements have the highest cost, the space required for the lower energy density energy storage technologies may be too great.

Complexity of scheduling multiple applications with imperfect foresight. While regulations recently permit time-differentiated and capacity-differentiated participation in multiple applications across multiple domains and some vendors market solutions capable of optimizing storage controls, the facilities reviewed in the literature review for this document showed limited capacity-differentiated optimization and rather focused on a primary use case, potentially with additional secondary use cases.

Multi-day storage duration. While the currently available battery chemistries are approaching market readiness for several shorter-term applications, they are not ready to support upcoming multi-day durational energy shifting applications. While the difference in energy prices at different times is not currently high enough to justify energy storage-based arbitrage, reaching California's high renewable targets may increase this spread and provide additional economically viable applications if the technology is ready.

Coordination

Requires specialized installation and maintenance. Relatively new technologies require specialized skillsets in installers and maintainers. Limited familiarity with new code requirements has anecdotally created difficulties with storage adoption, but specific cost figures were not able to be identified during the literature review.

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.

Difficulty in customer acquisition. PG&E encountered customer acquisition challenges during the EPIC 2.19c BTM Storage project. The key reasons include: vendor lack of access to customer information, customer solar fatigue, improper incentives, and lack of clear strategy. Furthermore, there was misunderstanding of what existing solar system inverters can be retrofitted, because most of the existing residential vendor's solar lease contracts prohibited solar generation curtailment (one of EPIC 2.03 project use cases).[30]

? Uncertainty

Vehicle-to-grid battery life concerns. Customers may be hesistant to participate in grid services that entail increased charging or discharging their vehicle battery for concerns on the impact on the battery life, or direct violations of its warranty.

Third-party controls visibility. Distribution system operators do not have control over or visibility into behind the meter storage resources, and potential negative impacts 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 operated more efficiently.

Resiliency valuation. There is no current framework to quantify the potential resiliency benefits of energy storage. Demonstration and evaluation of of storage being used for some of these additional use cases would support certainty in deployment decisions.

Identified RDD&D Needs

Actions to Bring Key, High Impact Technologies and Strategies to Market

i. **Near-term**
   a. Standard system design. Research and deploy standardized solutions, which can reduce engineering and development costs and hardware costs, and dramatically reduce labor, installation, and overhead costs. Tesla Power Pack technology has taken the lead on the modular approach to energy storage.
   b. Standard interconnection designs. Standard designs that directly tap three-phase feeder circuits instead of substations can reduce interconnection hardware and labor costs, while maintaining safety and power quality. By negating the requirement for a substation interconnection, this approach also allows for greater flexibility in the location of a community solar plant, further reducing development costs.

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

c. Technology-enabled interconnection approaches. Rapid advancements in battery-storage and smart-inverter technology have expanded interconnection options. Battery storage installed in conjunction with smart inverters can be cost-effectively used to maintain energy quality and avoid reverse power feeding in situations where maximum community solar output is close to minimum circuit load.

d. Hybrid energy storage configurations. Combinations of technologies such as solar plus storage, lithium-ion batteries paired with flow batteries, and storage plus gas generation can be researched to provide a wider range of capabilities.

ii. Medium-term

a. Assess benefits of distributed storage. As California moves to a fully decarbonized grid, energy storage will become increasingly important component to help balance increasing penetrations of variable energy resources. Some of this functionality will be provided by large utility-scale installations, but there is potential value in a more distributed system that decreases reliance on transmitting power large distances.

b. Investments in modeling tools. There are a limited range of models currently available that allow for multi-day or seasonal storage optimization dispatch, particularly under uncertainty. This will miss opportunities to value long-duration storage technologies.

c. Assess the capability of second-life electric vehicle batteries to provide grid services. As vehicle batteries degrade through use, the overall energy capacity decreases. A partially degraded battery may no longer provide the range required by its primary application but can still be effective in secondary applications. Initial research has been conducted at the UC Davis RMI Winery Microgrid Project[31] and by the Honda Research and Development Company[32], but further investigation and outreach is merited to assuage customer concerns..

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[31] *RMI Winery Microgrid Project*, UC Davis (2014)

[32] *Deployment of Vehicle-to-Grid Technology and Related Issues,* Honda (2015)

Section 2: Electric Vehicle Integration and Smart Charging

Electric vehicles (EVs) represent a critical path to de-carbonizing the transportation sector, as well as one of the major new sources of electric load. EVs can have a wide range of impacts on the distribution grid, from negative to positive depending on how thoughtfully they are integrated. This section reviews the status of electric vehicles and smart charging, and identifies opportunities to enable their effective management for the benefit of the grid. While the focus of this document is to provide a high level review of how different DERs are being integrated; there is a more specific effort in progress that will provide greater detail in the Vehicle-Grid Integration Roadmap Update.[33]

Technology and Strategy Review

Characterization of Technology and Strategy

i. **Vehicle Grid Integration.** Vehicle grid integration (VGI) is the process that enables plug-in EVs (PEVs) to participate as load supply or demand assets for grid operators. Of late, VGI has become of increasing interest to automotive and electric power sector industry stakeholders for its potential to use PEVs for grid stabilization support. VGI is best framed between two technology formats: unidirectional and bidirectional vehicle grid integration, also known as V1G and V2G.[34]

   a. V1G: V1G is a unidirectional method where a PEV modulates the rate at which the battery is charged in line with grid operator signals.[35]

   b. V2G: V2G is a bidirectional method where a PEV can both consume power from the grid when charging as well as supply power to the grid by discharging. In practical terms, the difference between the two is that V2G capable PEVs are able to participate in grid services far more than PEVs that are only V1G capable. While V2G is technologically viable in most applications, it is not yet cost effective for personal-use PEVs from the perspective of the vehicle owner. V2G has seen the most traction in fleet vehicles in which the added costs of the technology can be recouped through aggregate participation in grid services that currently require a minimum level of participation. [36]

      i. V2B: In this scenario, the behind-the-meter structure (Building – V2B, or Home – V2H) is able to receive power from a PEV that is connected to it. The power management system of this building is able to draw energy from the PEV's battery to avoid demand charges or provide aggregate building-level grid services.

   c. Regulation and Demand Response: Both V1G and V2G have the capability to participate in regulation and/or DR services in addition to energy-focused services.

      i. Regulation: An ancillary service in which an asset is automatically controlled by an operator to provide frequency balancing services. Some markets break regulation into separate frequency increasing and decreasing products. Other

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[33] *California Vehicle-Grid Integration Roadmap Update*, CEC

[34] Navigant Research, *Vehicle Grid Integration*, 4Q 2017

[35] Navigant Research, *Vehicle Grid Integration*, 4Q 2017

[36] Navigant Research, *Vehicle Grid Integration*, 4Q 2017

advanced markets consolidate both services into one; these are known as symmetrical markets.[37] This market product requires rapid changes in power output; PEVs are well-suited to meet this need.

ii. Demand response (DR): An event or pricing scheme designed to alter consumer demand. Simple forms of DR include time-of-use (TOU) programs that incentivize off-peak charging; advanced forms include real-time pricing schemes. Often, DR is realized by events wherein the operator signals the asset to defer consumption. [38]

Numerous pilot VGI projects have been conducted, including BMW's iChargeForward program in San Francisco and the Maui Smart Grid project in Hawaii. With the new generation of PEVs coming to market now, improved capabilities for VGI are possible. For example, the 2019 Nissan LEAF is capable of bi-directional charging. In fact, Nissan states that it is using new LEAFs to partially power some of its facilities in California and Tennessee. As more vehicles are capable of bi-directional charging become available to consumers, the opportunity for utilities to utilize these mobile batteries will increase.

Discussion of Advantages and Disadvantages

Table 5. Advantages and Disadvantages of Vehicle-Grid Integration Methods

Strategy	Advantages	Disadvantages
V1G	• V1G can supply load flexibility required to balance supply and demand in the power system as much of the generation capacity is becoming non-dispatchable. • If implemented correctly, provides value to grid without negative impact to customer.	• Some level of communications and control software and hardware is needed to enable. • Customer may be uncertain about battery having expected amount of charge at a given time.
V2G	• V2G provides more flexibility to the power grid than V1G by allowing discharging.	• Installation that allows discharge to grid requires additional infrastructure. • Requires aggregation and control of many small resources. • V2G operation may not be within customer battery warranties. • Customer may be concerned about accelerated degradation of vehicle battery.

Description of Technical Specifications and Requirements

i. **IEC 62746-10-1 ED1**. Championed by the OpenADR Alliance, this communication standard can enable V2G capabilities. This standard can enable end-to-end communication from the energy utility to the end users.

[37] Navigant Research, *Vehicle Grid Integration*, 4Q 2017

[38] Navigant Research, *Vehicle Grid Integration*, 4Q 2017

ii. **ISO 15118.** This standard specifies the communication protocol between an EV and the Electric Vehicle Supply Equipment (EVSE). This protocol is being used to enable "plug and charge" capabilities, where the vehicle can authenticate itself with the EVSE without any additional actions by the consumer. The latest revision of this standard, ISO 15118-8:2018, includes standards information for inductive charging systems.[39]

iii. **Open Charge Point Protocol (OCPP).** Creates a universal language for the communication between charging stations and operators, enabling easier access for PEV owners to stations outside of subscribed networks.

iv. **IEEE 2030.1.1.** Specifies the design interface of electric vehicles and direct current (DC) quick chargers that promote rapid charging of battery electric vehicles.

v. Selected applicable standards are listed in Table 6.

Table 6. Additional Standards Affecting VGI

Name	Description
SAE J1772	Physical connection between PEV and EVSE, includes power line control communications enabling rate changes (via IEEE 1901 standard: broadband communications by power line)
SAE J2836	Technical information/use cases for messaging between vehicle, utility, and other players such as 3rd party billing organizations
SAE J2847	Recommended practices and message information between PEVs and grid
SAE J2931	Requirements of physical layer communications using power line carrier between PEV and EVSE. Enables communications to smart meter or home area network
SAE J3072	Requirements for utility interactive inverter system integrated into PEV ensuring safe interconnection
ISO/IEC 15118-2	Technical protocol description and open systems interconnection layer for V2G communications
ISO/IEC 15118-3	Physical and data link layer requirements for V2G communications
IEC 61850	Design of electrical substation automation and communications system for DER
IEC TC69	Technical protocol, use case, and Open Systems Interconnection (OSI) layer for V2G communications
UL 9741	Requirements covering both AC and DC bidirectional EVSE

Source: Navigant Research 2017

There are numerous elements that comprise a VGI system in order to provide grid services. The selected standards listed in Table 15 exemplify the complexity that stakeholders (including utilities, infrastructure suppliers, and equipment manufacturers) are attempting to address.

Recent and Current RDD&D Activities

There is a wealth of research already completed regarding vehicle-to-grid integration and smart charging through EPIC funding, EPRI research, National Lab research and pilots, and other sources. Primarily, research has been focused on: the technological capabilities of VGI, the value of VGI to the market, and the development of communication protocols for VGI.

[39] *ISO 15118*. Organisation Internationale de Normalisation

i. **Technological Capability.** Consists of projects that test or implement new VGI functionalities. This includes technologies associated with the EVSE framework for bi-directional charging, grid infrastructure requirements, power electronics testing, and vehicle requirements.

ii. **Value of Technology and/or Service.** Consists of projects that attempt to quantify the value of services VGI is capable of providing and projects that examine the inherent costs in VGI enabling product streams.

iii. **Communication Protocols.** Consists of projects that test the refinement of communication protocols and security, including network architecture design.

In general, the research reviewed attempted to quantify the value of VGI in current available markets, measure the efficacy and responsiveness of large scale VGI grid management, develop standards for cybersecurity protocols, and to identify new technologies capable of making VGI more accessible and effective.

The focus of ongoing research is to implement an end-to-end DER system. There will be numerous challenges associated with implementing such a system. These challenges include obtaining and integrating compatible hardware and software, and demonstrating value for all stakeholders.

Figure 15 identifies potential metrics that would be useful in assessing VGI as smart charging becomes more prevalent. Primarily the metrics that would be most useful for VGI enablement are those that define the *potential* and *value* of VGI. A quantified understanding of potential and value of VGI would provide the necessary information needed for policymakers and market participants to create a pathway for implementation. There are pilots in progress that begin to address some of these metrics. For example, the LAAFB EPIC project provides revenue and revenue per vehicle associated with their pilot. More projects and/or studies evaluating this metrics in practice are needed.[40]

[40] *Los Angeles Air Force Base Vehicle-to-Grid Demonstration*. EPIC (2018)

Figure 15. Potential VGI and Smart Charging Metrics

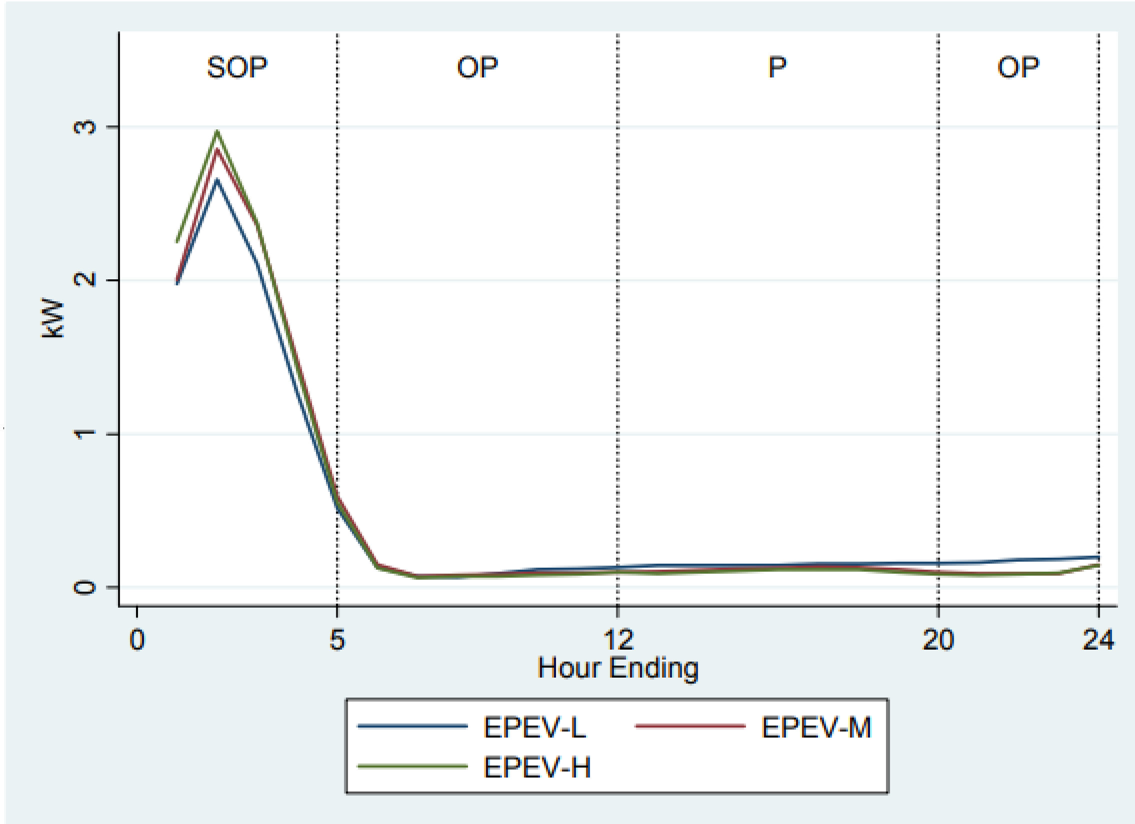
EV Integration Metrics	Unit
Percentage of electric vehicles capable of bi-directional charging	percent
Revenue opportunity available on average in the market per kWh energy for a given vehicle	$/kWh
Average number of electric vehicles plugged in to a charger during peak events	count
Number of chargers currently installed capable of bi-directional charging	count
Maximum MW output of all bi-directionally capable EVs at current penetration as a percentage of current peak.	percent
Maximum MW consumed of all EVs/available chargers at current penetration as a percentage of current peak.	percent

A selection of vehicle grid integration research and demonstration projects is presented below. A full list of identified work can be found in the Appendix.

i. **SDG&E PEV Pricing and Technology Study.** This study, approved by the CPUC, used a randomized control trial framework of EV tariffs applied in the SDG&E territory to determine customer change in behavior based on a variety of rate structures. This study found a high level of responsiveness to "super off-peak period" charging rates by employing charging timers. This trend intensified the longer participants were on the tariff showing some "learning behavior" in study participants. Finally, this study showed that particpants were sensitive to the intensity of price signals, responding more strongly to price signal as the on-peak rates increased. Figure 16 shows the load profile for the customers in this study, in which the majority of charging happens during "super off-peak" (SOP) periods.[41] Tailored EV charging tariffs like these can shift customer load to reduce the impacts of "duck curve" flexibility issues.

[41] *Final Evaluation for San Diego Gas & Electric's Plug-in Electric Vehicle TOU*, SDG&E, Nexant (2014)

Figure 16. SDG&E PEV Pricing and Technology Study – Average Daily EV Load Shapes for All Customers on Experimental Rates

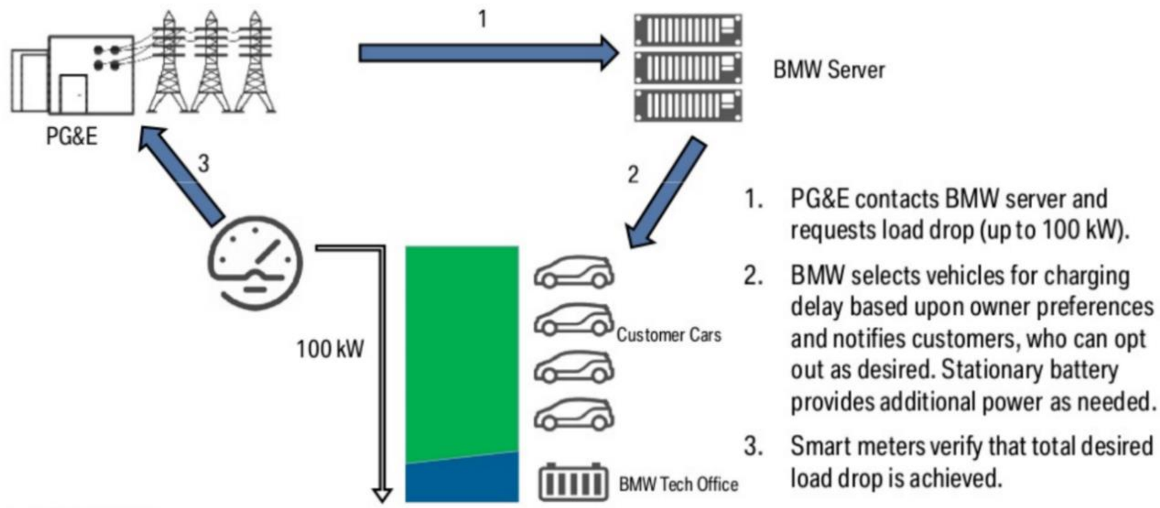


Source: Nexant 2014

ii. **BMW iChargeForward.** Based in the San Francisco Bay Area, the iChargeForward program was launched in July 2015 by BMW and PG&E to test the value proposition of residential V1G business models to the utility, the aggregator, and the PEV owner. The first phase of the program aimed to provide a minimum of 100 kW of capacity to PG&E and was backed up by a 100kW / 225 kWh stationary battery storage unit located at the BMW Technology Office in Mountain View, California. The first phase of the project (completed in December 2016) demonstrated a high level of consumer willingness to participate: 92% of participants were very satisfied with the pilot, and 86% indicated they would likely recommend it to others. There was a total of 192 DR events and the program successfully achieved full grid load reduction of 100 kW in 94% of events. In total, more than 19,000 kWh were shifted. The pilot was extended and expanded after receiving a grant from the California Energy Commission (CEC). The program plans to incorporate at least 250 eligible BMW i3, i8, and iPerformance (Series 2, 3, 5, 7, and X5 plug-in hybrid EVs [PHEVs]) owners, who can receive up to $900 for participation through December 2018. The program is the first attempt by an automotive OEM to act as an aggregator for its own vehicles. The pilot hopes to prove that a profitable business model exists for aggregators to organize PEVs for grid services and a reduction in total cost of PEV ownership is possible.[42]

[42] *iChargeForward Report*, PG&E and BMW (2017)

Figure 17. BMW iCharge Forward Program



Source: BMW 2017

In the span of the pilot, there were relatively few technical barriers that the pilot team were not able to solve internally. These performance issues typically were isolated to a specific provider and was able to be quickly solved.

- There were issues with communication that caused response latency that proved to be a fundamental problem in the GSM-based Telemetry Services. The project team worked through a solution with the wireless provider.
- There were minor communication issues with OpenADR that caused certain DR events to be missed by the program.
- The metering services had minor technical issues in power value reporting.
- Battery cell replacement took longer than expected but issue was resolved by changes in operations.

iii. **Zero Emission Mobility to All (ZEM2All).** ZME2All was a 4-year, €60 million ($70.9 million) project that studied the effects of transportation electrification in Malaga, Spain through a fleet of 200 PEVs, and 243 charging stations, six of which were bidirectional direct current (DC) fast charge units.[43] This project was notable for its “close-to-real-world” implementation with all services commonly paid for actually charged to participants, providing insight into customer behaviors.

iv. **V2G School Buses.** School buses may be particularly well suited to serve as V2G assets due to their long downtimes during school and evening hours. Two projects in the US, one in California and one in Massachusetts, are currently testing the feasibility of V2G school buses. The California project plans to build and deploy six V2G capable school buses to determine if the cost premium for the PEV V2G technology for each bus can be paid back within the buses’ useful life (15 years). Details of the estimated return on investment can be found in Figure 18 All vehicles are expected to be in use by the end of 2017.[44] \

[43] *ZEM2All Report*, IEEE (2015)

[44] *ZEV School Bus Report*, Clinton Global Initiative (2016)

Figure 18. California School Bus V2G Economic Modeling Program

	Diesel	EV	Key Assumptions
Initial Vehicle Price	$110,000	$230,000	Type C bus; includes cost of charging infrastructure for EV bus
Annual Expense for			
Fuel	$5,000	$3,024	12K miles/year; diesel at $2.50/gal; electricity at $0.18/kWh
Propulsion System Maintenance	$5,743	$1,306	Oil change, brake replenishment major drivers of cost
Accrual for Battery Replacement	--	$3,061	$500/kWh to start; 2% annual rate of cost decrease
Annual V2G Revenues	--	$6,100	Based on actual electric market parameters
Years to Breakeven	**13**		

Source: CGI V2G EV School Bus Working Group, PJM Interconnection 2017

v. **SDG&E Power Your Drive Program.** With a budget of $45 million, SDG&E is deploying up to 3,500 chargers. These chargers are designed, permitted, constructed, commissioned and owned by SDG&E. SDG&E also handles the billing, provides customer support and maintenance. Per CPUC Decision D.16-01-045, SDG&E submits a semi-annual report, with the most recent in September 2018 and the final program report expected in April 2019 as the program ramps down. As of the last report[45], 238 customers have signed easements or license requirements, which will include 2,746 charging ports. The total spend as of the last report is a little under $41M with 932 ports energized so far. The increased costs relative to original estimates were driven by software customizations required to accomdate the innovative hourly rate, complex electric vehicle supply equipment (EVSE) vendor approvals, significant Americans with Disabilities Act (ADA) compliance issues, and delays in acquiring easements. In addition, a special rate class was introduced for these charging stations that incorporated dynamic pricing. Some technical challenges encountered were:

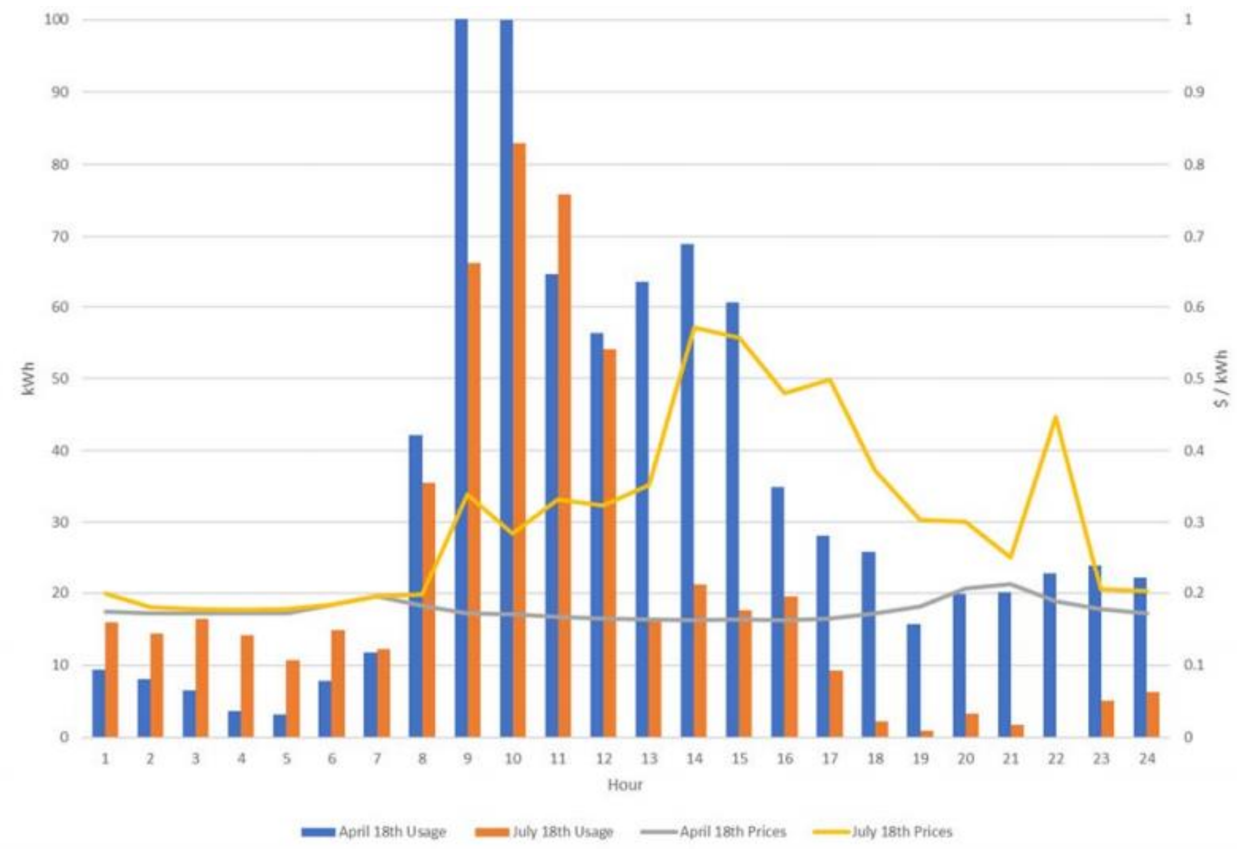
- EVSE meter accuracy unable to meet +/- 0.5% requirements
- Electric Vehicle Service Provider (EVSP) struggled to communicate accurate consumption to the backend vs reported locally by the EVSE and/or standard meter
- EVSP struggled to display pricing on the charger, mobile application, or web portal accurately
- EVSP unable to pass daylight savings time shift requirements
- EVSP split sessions across days to meet SDG&E billing requirement
- EVSP struggled to connect to webservice security using two-way Secure Socket Layer (SSL)
- Despite SDG&E using industry integration standards, it took EVSP time to meet requirements

[45] *Power Your Drive September 2018 Semi-Annual Report*, SDG&E (2018)

- EVSP had to adjust to SDG&E customer enrollments model

The two billing options available were rate-to-driver, where the EV driver receives the separately meterd rate directly and is billed to the EV driver's SDG&E account, and rate-to-host, where the site host is billed to its commercial SDG&E account. The rate implemented variable hourly pricing, and demonstrated an ability to incent charging away from SDG&E peak hours, as shown in Figure 19.

Figure 19. SDG&E Power Your Drive Charging Example



Source: SDG&E Charge Ready September Report 2018

vi. **SCE Charge Ready Pilot.** With a budget of $22 million, SCE is planning to deploy 1,500 charge ports. By the end of the third quarter of 2018[46], SCE reserved funding for 1,280 charge port commitments across 79 sites. SCE does not directly own the EVSE, but does provide the make-ready stub serving the EVSE, involving electric distribution infrastructure such as transformers, service lines and meters. SCE is not implementing an associated rate structure because they are not retaining ownership of the chargers. SCE has additionally filed for a full scale implementation with an additional 48,000 chargers for $760 million over four years.[47] Details on the challenges encountered were not presented in the quarterly reports.

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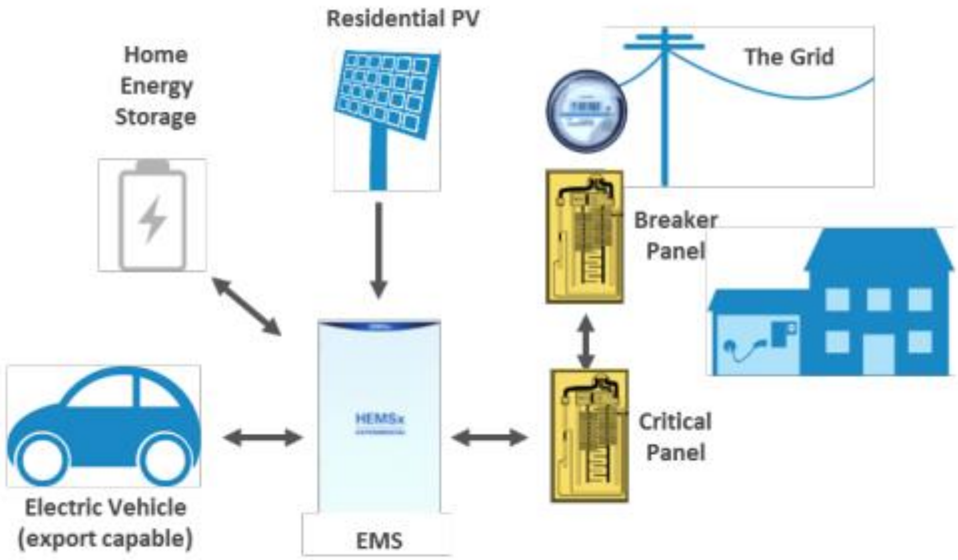
[46] *Charge Ready Quarterly Report*, SCE (Q3 2018)

[47] *Charge Ready Description*, SCE

vii. **PG&E EPIC Test Smart Inverter Enhanced Capabilities Pilot.** From 2016 to 2018, PG&E conducted a pilot for Vehicle to Home (V2H) use of EVs in VGI. The test was aligned to EPIC piloting framework and was set up to test efficacy and cost-effectiveness of a V2H system.[48]

Figure 20. Demonstration of V2H System Diagram



Source: EPIC 2.03b – Test Smart Inverter Enhanced Capabilities – Vehicle to Home, PG&E 2018

Table 7. V2H System Test Results

Scenario	Primary Resource(s)	Success Criteria Tested				
		Islanding (Outage / Demand Response)	Paralleled Resources	Cold Load Pickup	Rule 2 Voltage Range	Load Following
Verification	SS	Pass	Pass	Pass	Pass	Pass
	SS + PV	Pass	Pass	N/A	Pass	Pass
Validation	EV Islanded	Pass	N/A	N/A	Pass	Pass
	EV Islanded + Grid Support	Pass	N/A	Pass	Pass	N/A
	EV Islanded + PV	Pass	Pass	Pass	Pass (7-13) Fail (70)	Pass
	EV + SS	Pass	Pass	Pass	Pass	Pass
	Nanogrid[7]	Pass	Pass	Pass	Pass	Pass

Source: EPIC 2.03b – Test Smart Inverter Enhanced Capabilities – Vehicle to Home, PG&E 2018

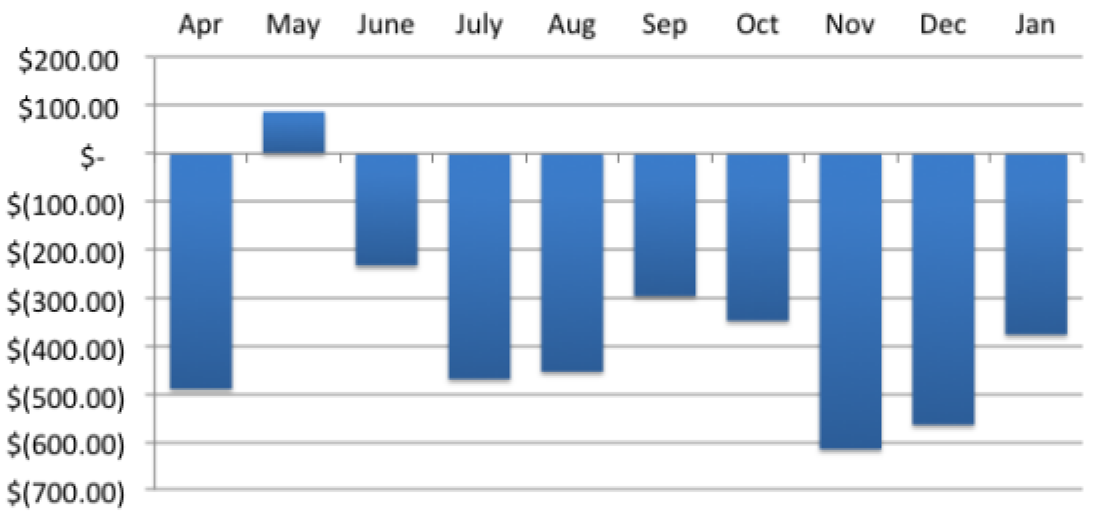
viii. **EV Subtractive Billing EPIC Pilot.** The California IOUs have begun to implement pilots that test the subtractive metering process – the pilot is ongoing. By leveraging EV Meter Data

[48] *EPIC 2.03b – Test Smart Inverter Enhanced Capabilities – Vehicle to Home*, PG&E (2018)

Management Agents (MDMA) to deliver submetered EV data to the IOU, the utility is able to subtractively meter electric vehicles, producing separate household and electric vehicle consumption value and bill. The opt-in pilot will provide data on MDMA accuracy and could potentially provide a cost-effective avenue for EV submetering.[49]

ix. **<u>Los Angeles Air Force Base (LAAFB) V2G Demonstration</u>.** This demonstration project aimed to pilot V2G technology in a microgrid environment. Twenty-nine EVs with V2G apability were tested for use grid services, demand management, and demand response in addition to the vehicles priority base transportation services. LBNL provided scheduling software for V2G services. The project provided 373 MWh of frequency regulation to CAISO in 20 months. The fleet was capable of producing up to 80 hours of backup power to the base. The program generated between $25 to $72 per vehicle per month, excluding market participation fees. The fleet did not have the power output/input minimum to participate in demand response services. Figure 21 shows the monthly settlement over the project period with fees included.[50]

Figure 21. Monthly CAISO Settlement with Reg Up and Reg Down



Source: Lawrence Berkeley National Lab, October 2018

Critical Success Factors

Description of Commercial Readiness Level, Including Current Market Participation

i. **<u>V1G</u>.** One-way grid to vehicle connections are currently viable in the market. Companies have reported leveraging value streams from V1G, though the figures of total payments achieved were not available in the secondary research. In California, smart charger companies can participate in the DR market and the wholesale energy market. Individuals with vehicles connected to the grid can participate in time-of-use rates and DR aggregation.[51]

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[49] *Electric Program Investment Charge (EPIC) 2017 Annual Report*, PG&E (2017)

[50] *Los Angeles Air Force Base Vehicle-to-Grid Demonstration*, EPIC (2018)

[51] *Utilities and Electric Vehicles*; Smart Electric Power Alliance (2017)

ii. **V2G**. Two-way vehicle grid integration is still in a relatively early stage. This technology has seen market participation in pilots, but not yet in private company operation. [51]

Federal and/or State Policy Influences

i. **Federal Regulatory**

a. FERC Order 745. Outlines DR compensation in wholesale markets, providing revenue stability to new providers.[52]

b. FERC Order 755/784. Also known as pay-for-performance, mandates grid operators in competitive markets, include within frequency regulation markets, compensation metrics for asset response time and accuracy. Expanded by Order 784 to account for speed and accuracy.[53, 54]

c. FERC Order 792. Modified rules for small generator interconnection. Informs the rules by which storage can interact in the wholesale generation market.[55]

d. FERC Order 841. Grants energy storage equal footing as other resources in wholesale energy markets. ISOs and RTOs have a year after the decision (February 2018) to implement rules that would allow storage to participate in energy sale markets, frequency regulation, ancillary services and transmission and distribution deferral.[56]

ii. **California Regulatory**

a. Executive Order B-48-18. The executive order signed by Governor Brown sets a Zero Emission Vehicle (ZEV) target penetration of 5 million vehicles by 2030. The order also sets goals to support and plan ZEV infrastructure development including vehicle integration and EVSE support.[57]

b. Alternative Fuels Vehicles (R. 13-11-007). Implements policy around the equipment and infrastructure required for electric and low-emission vehicles to proliferate. This is relevant to VGI in that electric vehicles are a primary target of the proceeding.[58]

c. Rates and Infrastructure for Vehicle Electrification (R. 18-12-006). Proceeding instated as successor to R. 13-11-007. Both the prior and current rulemaking are aimed at working with the investor-owned utilities to develop the necessary infrastructure and rate tarrifs that will enable electrification of transport as aligned to state goals.[59]

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[52] *Order 745*, Federal Energy Regulatory Commission (2011)

[53] *Order 755*, Federal Energy Regulatory Commission (2011)

[54] *Order 784*, Federal Energy Regulatory Commission (2013)

[55] *Order 792*, Federal Energy Regulatory Commission (2013)

[56] *Order 841*, Federal Energy Regulatory Commission (2018)

[57] *Executive Order B-48-418,* State of California (2018)

[58] *Order Instituting R. 13-11-007*, California Public Utilities Commission (2013)

[59] *Order Instituting R. 18-12-006*, California Public Utilities Commission (2018)

d. Demand Response (R. 13-09-011). Proceeding instated to enhance the role of demand response in meeting the resource planning and operation requirement in California. DR will be one of the main value streams of VGI.[60]

e. Distributed Generation (R.12-11-005). Encapsulates all rules and procedures pertinent to small scale distributed generation. In some definitions of VGI, the electric resource will be considered in the generation market.[61]

f. DER Interconnection (R. 17-07-007). This proceeding intends to create rules and regulation around the interconnection of all distributed resources, which would include the integration of vehicles into the grid as a resource.[62]

Assessment of Barriers to Further Adoption

Cost

V2G vehicle costs. V2G is more expensive than V1G, as most EVSE is not bidirectional, and current PEVs do not natively support bidirectional power flow through AC ports. Theoretically, costs can be low, but availability of such units is limited to few manufacturers. Costs have historically been high, around $1,000 per kW. Commercialization of DC V2G systems, as achieved by Enel and Nissan, is likely to drive cost reduction through economies of scale. As most hardware is currently proprietary, cost and price information is not publicly available. With the adoption of standards discussed in Technology and Strategy Overview Section, it is expected that hardware and software will become standardized, resulting in reduced costs and prices.

The majority of V2G systems are likely to be DC based because of higher power capabilities. AC V2G or DC vehicle-to-home are available but less likely to be widely adopted. The benefit of an AC V2G system is that the cost is low (if vehicles come AC V2G capable). However, it requires OEMs to place a bidirectional charger on the PEV, which many mass market OEMs have not. Demand to enable AC bidirectionality is primarily aimed at fleets as it is easier and less costly to enable it through the DC charging port (from the OEMs' perspective). It is unlikely OEMs adopt onboard bidirectional chargers in the near term. Values for the difference in cost between AC and DC based V2G systems were not available in the secondary research.[63]

In their V2H EPIC pilot, PG&E calculated VGI cost-effectiveness using the five tests defined in the California Standard Practice Manual. is included for reference. Across most costs tests, VGI proves not to be cost-effective. [6448]

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[60] *Order Instituting R. 13-09-011*, California Public Utilities Commission (2013)

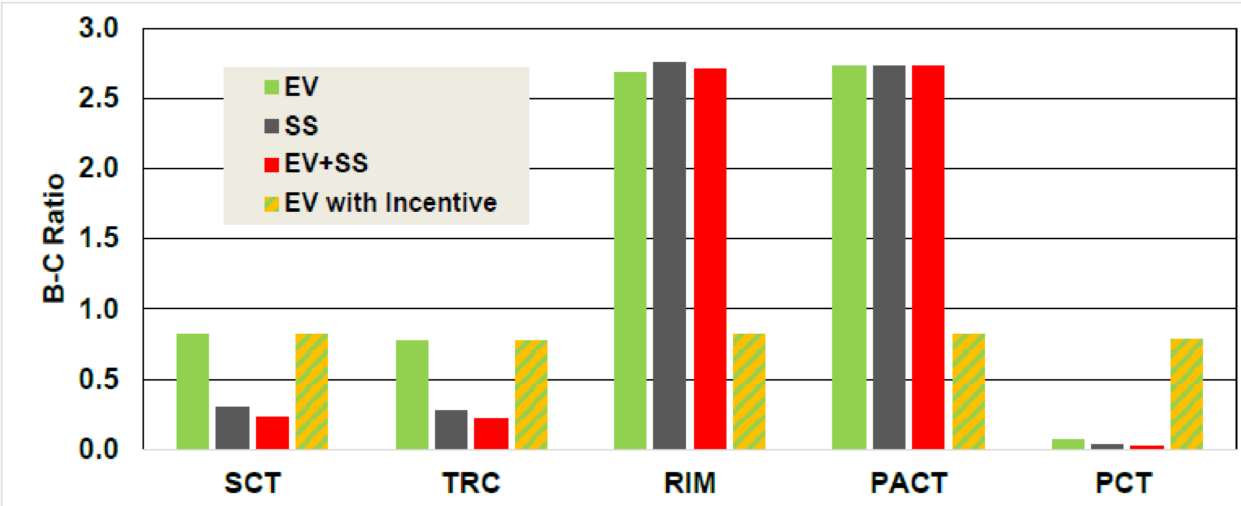
[61] *Order Instituting R. 12-11-005*, California Public Utilities Commission (2012)

[62] *Order Instituting R. 17-07-007*, California Public Utilities Commission (2017)

[63] Navigant Research, *Vehicle Grid Integration*, 4Q 2017

[64] Navigant Research, *Vehicle Grid Integration*, 4Q 2017

Figure 22. Summary of Cost-Effectiveness Measured by Cost-Benefit Ratios



Source: PG&E V2H EPIC Pilot, February 2018

V2G EVSE costs. An EVSE may require upgraded infrastructure at the premises to either enable higher-capacity electricity flow or enable the necessary upstream interconnection to the grid. At rates above 10 kW, utilities may have to replace the connected transformer (if rated at 25 kVA or lower) or add a higher-capacity service drop line. Commercial entities looking to aggregate power from several vehicles and deliver it to the grid may have installation costs exceeding $10,000.[65] Bi-directional EVSEs may have additional infrastructure requirements to ensure applicable non-export requirements are met.

Incentives required for multiple components of chain. PEV owners must be compensated to ensure PEV participation, which reduces the revenue potential for aggregators. Relative to other competing technologies, where one or a few assets may meet minimum capacity requirements with ease, the VGI solution is complex. VGI pilot programs are more likely to emerge in markets with low minimum capacity requirements.

Valuation

The full value of V1G/V2G is still relatively uncompensated. As is the case with many DER technologies, there are markets V1G could participate in, such as wholesale frequency regulation or voltage management, that are still closed to this resource and thus difficult to build business plans around. This is the case for the V2G as well. While certain manufacturers have announced the capability and intention to develop V2G enabled vehicles, they still do not have a significant market penetration and as such have not meaningfully participated in existing market structures and demonstrates real market value. However, this problem will subside as V1G and V2G pilots become more prevalent and new markets open to these technologies. For example, the value of V1G has been quantified in select markets. Companies in California have already started incorporating vehicles in the demand response market and day ahead wholesale market. Further, a majority of California electricity providers already have EV-specific rate classes. As such, a portion of the value associated with V1G assets in these markets is defined and creates value confidence for new market participants. V2G will require similar increases in market participation and prevalence to create market confidence in the value of the technology.

[65] Navigant Research, *Vehicle Grid Integration*, 4Q 2017

Coordination

Aggregation required for feasibility. To deliver sufficient value to grid services markets, aggregators need to connect and manage a large number of vehicles. A single vehicle can only provide limited value to grid services and major grid services markets have minimum capacity requirements, as shown in Table 8.[66] From the perspective of a grid operator or planner, this coordination represents additional complexity relative to conventional grid resources.

Table 8. Minimum Capacity Requirements of Major Grid Services Markets

Grid Network	Service	Capacity
California Independent System Operator (CAISO)	Ancillary Services	500 kW
ISO New England	DR	100 kW
Federal Energy Regulatory Commission (FERC) Proposed Rules	Electric Storage and Distributed Energy Resources	100 kW
Electric Reliability Council of Texas (ERCOT)	Frequency Response	100 kW
New York Independent System Operator (NYISO)	Emergency DR / Day-Ahead DR	100 kW/1 MW
National Grid (UK)	Frequency Response by Demand Management	3 MW
Midwest Independent System Operator (MISO)	DR	1 MW

Source: Navigant Research 2017

Interoperability. Coordination across drivers, manufacturers, aggregators and grid operators is complex and would benefit from additional testing of devices and communications standards between different parties. There are multiple pathways to connect VGI devices across a range of stakeholders. For example, approaches can be EV-centric or EVSE-centric, and there are multiple pathways for EV/EVSE interaction with building management systems. Paths need to be clearly defined, and consensus needs to be achieved to efficiently integrate electric vehicles with the grid.

Varying design standards for EVSE. Much of existing EVSE technology lacks seamless two-way communication between vehicles and the grid. Non-uniform communications protocols also exist across EVSE provider, with many viable options but no consensus across EVSE manufacturers, electric vehicle platform providers and automakers.

Incomplete standards. To date, there is no existing standard that meets all potential functional requirements. For example, ISO/IEC 15118 does not fully address some of the business and technical aspects of the EV charging framework that has been installed throughout North America. This includes considering the roles and motivations of site owners and service providers.

[66] Navigant Research, *Vehicle Grid Integration*, 4Q 2017

? Uncertainty

Battery warranty uncertainty. Unclear battery warranty conditions may limit customer interest in participation, particularly in V2G implementations. The effect of and associated cost of battery degradation in V2G application is still not well understood and is thus not typically covered under OEM battery warranty. Efforts to quantify the extent of battery degradation have been inconclusive.

One University of Hawai'i study found that grid participation of V2G enabled vehicles can reduce the battery life to less than five years,[67] another found no impact[68], and a third 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.[69] In practice, the LA Air Force Base V2G Epic project found that it was too difficult to isolate the source of battery degradation in their EVs, though they assumed that grid services contributed to degradation.[70] More research is needed to understand the cost-benefit balance of V2G as it pertains to EV battery life.

Vehicle battery availability. PEVs are vehicles first and grid assets second. Vehicles are mobile assets and given their primary function of moving people and/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, they 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 requires a much greater burden on technology to track their patterns of availability and having a total resource pool that is much larger than a resource that offers guaranteed availability.

Identified RDD&D Needs

Actions to Bring Key, High Impact Technologies and Strategies to Market

i. **V1G**. In general, V1G is well understood and there are already market participants.

a. Near-Term

i. More work could be done to explicitly value smart charging via V1G. As of now, V1G as a resource is valued based on its capacity to participate in DR and wholesale markets, but potential value to a business via demand charge reductions is still unclear.

ii. Work with Grid Needs Assessment and a Distribution Deferral Opportunity Report processes to clarify project value for precise load modification.

ii. **V2G**.

a. Near-term

i. In a similar case to energy storage, while the technological capabilities of V2G to modify load have been demonstrated in projects like the Power your Drive Pilot, the market mechanisms have not yet been solidified to take full advantage of

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

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

[69] *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)

[70] *Los Angeles Air Force Base Vehicle-to-Grid Demonstration*, EPIC (2018)

services V2G can provide.[48] Detailed study of the value of load modification is necessary to determine the appropriate level of subsidy.

ii. Current vehicle warranty policy is based on time/miles driven and the warranty is voided by vehicle use for other services. OEMs need regulatory support to update policies.[48]

b. Mid-term

i. The V2G market is in its nascent phase. Stakeholders generally agree that the potential benefits of V2G implementation are significant. As a result, substantial effort has gone into the development of communication standards. These standards have been included in many newer infrastructure projects, including the Electrify America charging network. The continued inclusion of these standards in hardware will create a network with the necessary critical mass to realize the value of V2G connectivity.[48]

ii. Security of V2G is expected to be a sticking point for adoption. OEMs, EVSE suppliers, and regulators will need to invest time and money into ensuring that the two-way connection is secure from malicious activity. [71]

c. Long-term

i. Currently, the markets for VGX lack standardization. If the technology is to become widespread, regulatory and market standards will have to be implemented to give assurance of market presence and reduce hassle of adoption.[48]

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[71] *VGI Overview*, International Energy Age*ncy* (2017)

Section 3: Energy Flexible Load Assets

Management of building loads represents a significant portion of California's potential carbon reduction potential. Many of the new distributed resources exist behind the meter and there are significant technical opportunities to use building assets and automation to support and increase the efficiency of grid operations. Additionally, as the electric grid shifts to a more significant penetration of non-dispatchable resources, the burden of balancing supply and demand falls increasingly on flexible resources like batteries and responsive loads. The LBNL 2025 Demand Response Potential Study[72] divides this load management into four categories depending on the time-scale to which it applies:

- **Shape** captures DR that reshapes customer load profiles through price response or on behavioral campaigns— "load-modifying DR"—with advance notice of months to days.
- **Shift** represents DR that encourages the movement of energy consumption from times of high demand to times of day when there is a surplus of renewable generation. Shift could smooth net load ramps associated with daily patterns of solar energy generation.
- **Shed** describes loads that can be curtailed to provide peak capacity and support the system in emergency or contingency events—at the statewide level, in local areas of high load, and on the distribution system, with a range in dispatch advance notice times.
- **Shimmy** involves using loads to dynamically adjust demand on the system to alleviate short-run ramps and disturbances at timescales ranging from seconds up to an hour.

Identifying how load-side resources can be managed to match the generation and distribution resources available in a location will be key to effective distributed resource integration, whether this management aims simply to reduce peak consumption or to include controls based on emissions rates and renewable curtailment reduction. This management will include building automation systems, controls for behind the meter photovoltaic installations, electric vehicle charging infrastructure, and be holistically controlled by advanced analytics and machine learning to optimize across grid needs and customer preferences.

Technology and Strategy Review

Characterization of Technology and Strategy

i. **Demand Flexibility.** Appliances like washers, dryers, HVAC, refrigerators, water heaters, and lighting can serve as controllable end uses for traditional DR strategies. Table 9 represents the selected end uses and enabling technologies that were modeled in LBNL's 2025 Demand Response Potential study. Passive DR strategies like daylighting or building thermal mass optimization can also provide demand flexibility. Additional potential load technologies include: electrification loads like dispatchable space and water heaters; thermal storage like ice, chilled water, and phase change materials; appliances like refrigerators, washers and dryers; and miscellaneous equipment like televisions and computers.

[72] *2025 Demand Response Potential Study*, Lawrence Berkeley National Lab (2017)

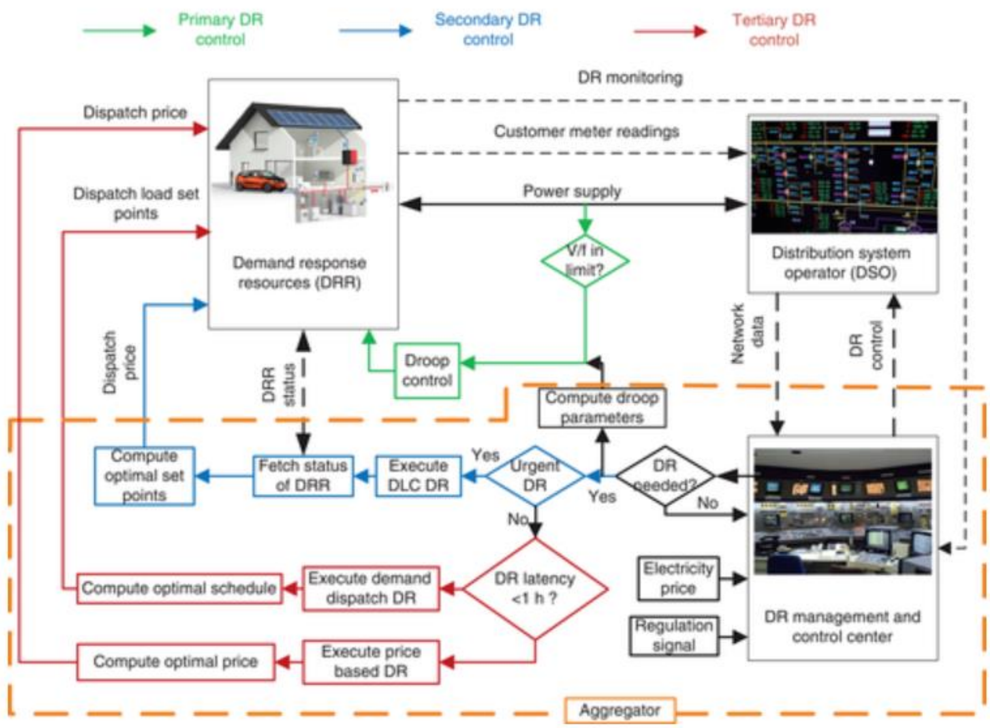
Table 9. Selection of Demand Responsive Technologies

Sector	End Use	Enabling Technology Summary
All	Battery-electric and plug-in hybrid vehicles	Level 1 and Level 2 charging interruption
	Behind-the-meter batteries	Automated DR (Auto-DR)
Residential	Air conditioning	Direct load control (DLC) and Smart communicating thermostats (Smart T-Stats)
	Pool pumps	DLC
Commercial	HVAC	Depending on site size, energy management system Auto-DR, DLC, and/or Smart T-Stats
	Lighting	A range of luminaire-level, zonal and standard control options
	Refrigerated warehouses	Auto-DR
Industrial	Processes and large facilities	Automated and manual load shedding and process interruption
	Agricultural pumping	Manual, DLC, and Auto-DR
	Data centers	Manual DR
	Wastewater treatment and pumping	Automated and manual DR

Source: 2025 Demand Response Potential Study, *LBNL*

ii. **Control Devices and Strategies.** In automated grid support service programs, a centralized programming control system is responsible for the coordination of different benefits. Effective algorithms should be able to optimize energy savings, cost, and user comfort and have a reasonable computation time. Load control devices (e.g. switches and smart thermostats) implement these algorithms and can be stand-alone and/or integrated into an EMS for large facilities. Figure 23 shows a possible control structure for DR system.

Figure 23. Hierarchical DR Control Structure

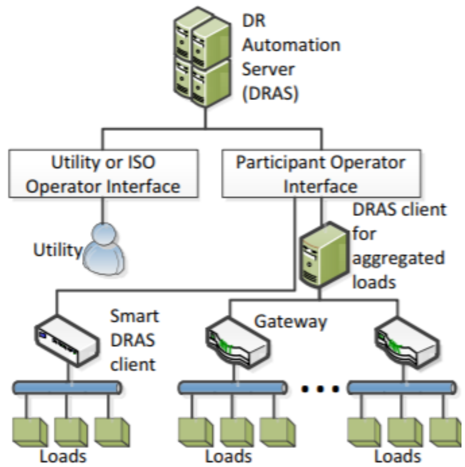


Source: [*Opportunities and challenges of demand response in active distribution networks,*] *Wiley Interdisciplinary Reviews: Energy and Environment*

iii. **Communications Architecture.** A general DR architecture supports the activation or deployment of load management algorithms by a utility in a client's designated appliances as determined by the DR program the client subscribes to.[73] Figure 24 depicts an OpenADR architecture, which consists of a DR Automation Server (DRAS), an Operator Interface where utilities manage programs and wholesale bidding, and a Participant Interface where participants can opt-out or perform automated bidding.

[73] *Opportunities and challenges of demand response in active distribution networks,* Wiley Interdisciplinary Reviews: Energy and Environment (2017)

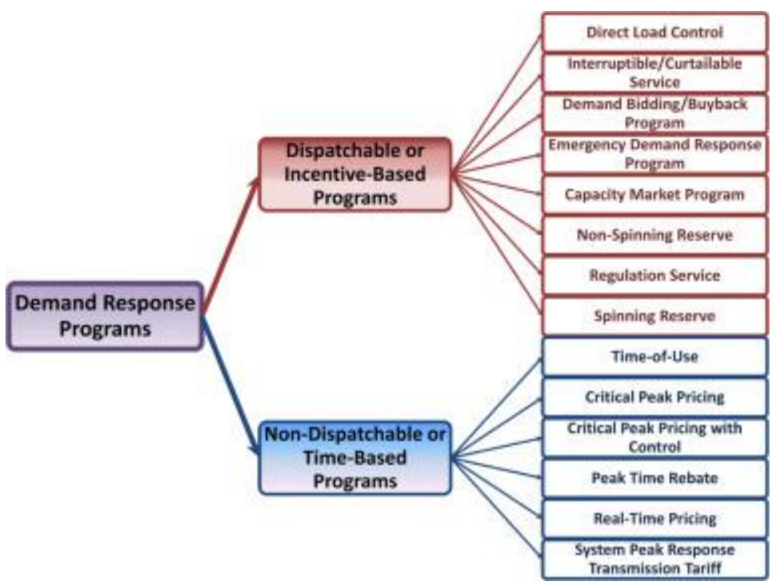
Figure 24. OpenADR Architecture



Source: [Demand Response Architectures and Load Management Algorithms for Energy-Efficient Power Grids: A Survey](), Law, Yee Wei, Tansu Alpcan, Vincent Lee, Anthony Lo, Slaven Marusic, Palaniswami Marimuthu

iv. **Program Strategies.** DR program strategies can be considered incentive-based or price-based. Figure 25 outlines strategies within each program type. Incentive-based programs pay incentives to customers in response to reduced consumption during the peak hours. In price-based programs, customers voluntarily modify their consumption based on dynamic electricity prices, shifting their electricity usage to lower-priced periods.

Figure 25. Classification of DR Program Models



Source: Demand response for sustainable energy systems: A review, application and implementation strategy, Renewable and Sustainable Energy Reviews

v. **Grid Services.** Demand side management can be used to provide voltage or reactive power support and could potentially be used to provide flexibility products at the wholesale level as well.

Discussion of Advantages and Disadvantages

Table 10. Advantages and Disadvantages of Flexible Load Technologies

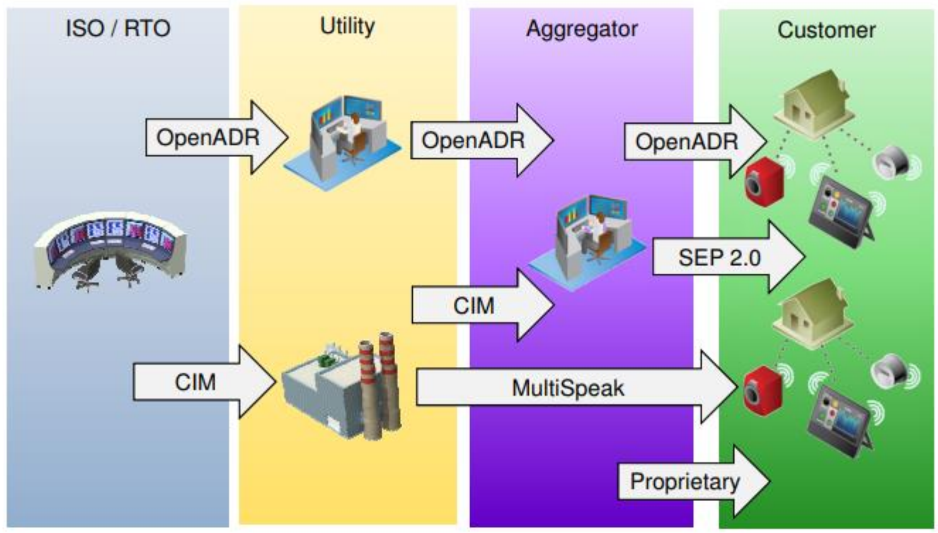
Strategy	Advantages	Disadvantages
Demand-Side Management	• Demand side management strategies have the potential to defer grid investments and provide grid services in a distributed, affordable manner. • The proliferation of IoT and connected devices will enable more control and flexibility of demand-side resources. • Provides another opportunity for flexibility to balance an increasingly non-dispatchable generation resource mix.	• Challenges with setting a fair baseline has led to unfair compensation, disincentivizing utilities and customers to continue DR programs. • Issues with cybersecurity arise when considering residential participation. • Most programs are designed to reduce demand during bulk system peak, which does not necessarily align with localized coincident peak demand at the primary or secondary feeder level. This leads to incentives and programs that are unable to harness DSM for distribution-level load relief. • Conflicting dispatch needs and lack of coordination between the bulk system and the distribution system limit the ability of customers to participate in multiple load reduction programs and be compensated fairly.

Description of Technical Specifications and Requirements

i. **CTA-2045.** Consumer Technology Association (CTA) and the Electric Power Research Institute (EPRI) developed a standard that defines a "modular communications interface" (MCI) for water heaters, air conditioning units, pool pumps, and electric vehicle chargers.

ii. **OpenADR.** Open Automated Demand Response (OpenADR) provides a non-proprietary, open, standardized and secure demand response (DR) interface that allows electricity providers to communicate DR signals directly to existing customers using a common language and existing communications such as the Internet. Figure 26 shows where OpenADR can be used in context of a DR strategy.

Figure 26. Use Cases for OpenADR



Source: Communications Standards for Demand Response and DERs, EPRI

iii. **IEEE 2030.5 (SEP 2.0).** Allows communications between energy-related devices in the Home Area Network (HAN) with zero-configuration.[74]

iv. **IEC 61850.** Communication networks and systems for power utility automation. Popular for DR aggregation and VPP applications.

v. **IEEE 1888.** The *ubiquitous green community control network* (UGCCNet) standard defines a data exchange protocol that enables interoperability and integration of multiple facilities, data storage, and application services such as central management, energy saving, environmental monitoring, and alarm notification systems. It also identifies a set of security requirements.

vi. **NA7.5.10.** This test ensures that central demand shed sequences have been properly programmed into the Direct Digital Control system for zonal HVAC required by Title 24.

Recent and Current RDD&D Activities

For Energy Flexible Load Assets, a significant amount of research has been done in previous EPIC projects and by entities like LBNL's Demand Response Research Center, LBNL's Demand to Grid Laboratory, EPRI, ARPA-E, and PNNL. A growing interest in microgrids for military sites has led DOD's Environmental Security Technology Certification Program (ESTC Program) to develop programs for distributed resources to participate in energy markets through demand response and other means. Across these different entities, the major directions that the research has taken include:

i. **Market and Program Innovation.** Projects in this area promote more effective DR and DSM programs and market structures by generating insights on cost-effectiveness, performance, and customer behavior to address complexities associated with the variability of DR technologies and customer participation. Potential metrics include:

   a. Cost effectiveness of programs for customers and program administrators;

   b. Participation levels;

[74] *PGE VGI working group for 2018 OpenADR Alliance meeting*, OpenADR (2018)

c. DR event energy reduction;

d. Technical incentive requirements;

e. Customer retention.

ii. **Control Strategies and Grid Coordination.** Many current research efforts focus on the design of price-based demand response models and control strategies. There has also been work done on scheduling flexible energy loads (e.g. HVAC, EV charging) for demand response. Research in this section also identifies the right set of capabilities to achieve the highest energy savings and overall value to the customer and then quantifies that savings potential. Potential metrics include:

a. Stability and predictability of resulting load profile;

b. Energy savings;

c. Grid responsiveness;

d. Cost effectiveness;

e. Ability to address system needs (e.g. duck curve);

f. Reliability of customer's DR performance, persistency of reliable response, computation time, and user comfort.

iii. **Communications and Interoperability.** Projects in this area demonstrate the usage of open-source information exchange systems and promote interoperability of heterogeneous technologies. Potential metrics include:

a. Reduced transaction costs;

b. Ability of systems to be vendor agnostic;

c. Security of interfaces.

iv. **Grid Optimized Loads.** Projects in this area enable a simple, uniform, and technology-agnostic method to characterize a technology's ability to contribute to grid needs. The aim is to provide independently validated metrics of device performance for consumers, manufacturers, and grid operators.

The goals of the reviewed research include enabling flexible loads to support customer and system needs, enhancing market and program designs, and developing standardized metrics to assess grid-readiness of devices. Figure 27 presents potential metrics to assess the research in this topic.

Figure 27. Potential Energy Flexible Load Assets Metrics

EFLA Metrics	Unit
Device Response Time, including Communications	time
Load Ramp Speed	%capacity/sec, MW/min
Data Granularity	Temporal, Geographic
Participation in DR	MW, MWh, Customers
DR Enablement Costs	$/customer, $/kW
Number of Connected Devices	count
Amount of Modifiable Load by Sector	MWh
Ramp Rate of Modifiable Load	MW/min
Availability of Modifiable Load	Various

A selection of Energy Flexible Load Assets research and demonstration projects is included below; a full list of identified work is contained in the Appendix.

i. **Transactive Control Demand Response.** This PNNL project developed a novel demand response system that is based on a bi-directional "transactive" response approach to control system demand peaks and create a stable and predictable load profile for the utility. This transactional-control demand response system was tested in PNNL's landmark Olympic Peninsula Smart Grid Demonstration Project that proved the ability and willingness of customers to respond to real-time price information.

ii. **The GridOptimal Initiative**. Led by New Buildings Institute, the objective of the GridOptimal Initiative is to build a rating system that defines buildings as grid citizens. The first step will be to define the value and the need to stakeholders and determine metrics that account for the complexities of optimally operating buildings while still providing a transparent, understandable, and useful rating system. The team seeks to find the balance between accounting for a multitude of factors and keeping things simple.

iii. **Synthetic Reserves from Aggregated Distributed Flexible Resources**. General Electric Global Research along with its partners will develop a novel distributed flexibility resource technology that aggregates responsive flexible loads and DERs to provide synthetic reserve services to the grid while maintaining customer quality-of-service. Key innovations include a forecast tool, an optimization framework, and a scalable control and communication architecture will enable coordination and control of the resources.

iv. **US Green Building Council.** USGBC is working on revisions to LEED 4.0 to integrate building assets which support and enhance grid operations. This includes appreciation for demand response participation and an increased focus on building performance measurement throughout the project lifecycle.

Critical Success Factors

Description of Commercial Readiness Level, Including Current Market Participation

A commercially available device that facilitates DR is the smart plug, which has sensing, control, and transmission capabilities, and can be used to transform regular appliances into smart appliances that respond to HEMS signals. Table 11 summarizes the costs of several smart plugs. While an individual plug may not seem expensive, the costs of retrofitting multiple appliances can add up.

Table 11. Costs of Smart Plugs

Manufacturer	Country	Some of their smart plug products and prices
BroadLink Network and Communication Pvt LTD.	China	• BroadLink SP3 Spcc control mini WIFI smart home socket $20.50. • BroadLink SP2 WIFI intelligent smart socket Automatic Remote Controller $40. • 12 Recievers + BroadLink RM Pro, i-phone WIFI + RF Automation Smart Home Controller $149.99 usd.
Insteon (Subsidiary of Smartlabs, Inc)	USA	• Insteon 2457D2 Lamp Dimmer dual band $34.99 usd. • New Insteon 1626 – 10 FilterLinc 10-Amp plug in Noise filter. $35.00. • Insteon 2457D2 plug in Dimmer $58.98.
Xiaomi Inc	China	• Xiaomi Android Smart Socket WIFI wireless control swiches Timer plug charge with 5 A USB support $15.74. • Xiaomi Mi Smart WIFI socket Intelligent App Remote Control Timer plaug. $19.99. • Xiaomi Mi Smart WIFI wireless Remote Control Switch Timer Smart Power Socket $46.61.
Belkin International Inc	USA	• Belkin Wemo Switch WIFI plug $39.99. • Belkin Wemo Switch and Motion Detector $59.95. • Belkin Wemo Insight WIFI Smart Plug. $59.99.
Shenzhen Orvibo Electronics Co. Ltd	China	• Orvibo EU S20 WIFI Remote Control Wireless Smart Power Wall Plug Switch $22.57. • Orvibo USB WIFI smart Home extension Sockets Switches Remote Control Timing Plug $31.99. • Orvibo Smart Home System Kit Door Window PIR Sensor Remote Control $124.99.

Source: *Application of load monitoring in appliances' energy management – A review*, Renewable and Sustainable Energy Reviews

Table 12 summarizes the load flexibility potential of various DR-capable systems.

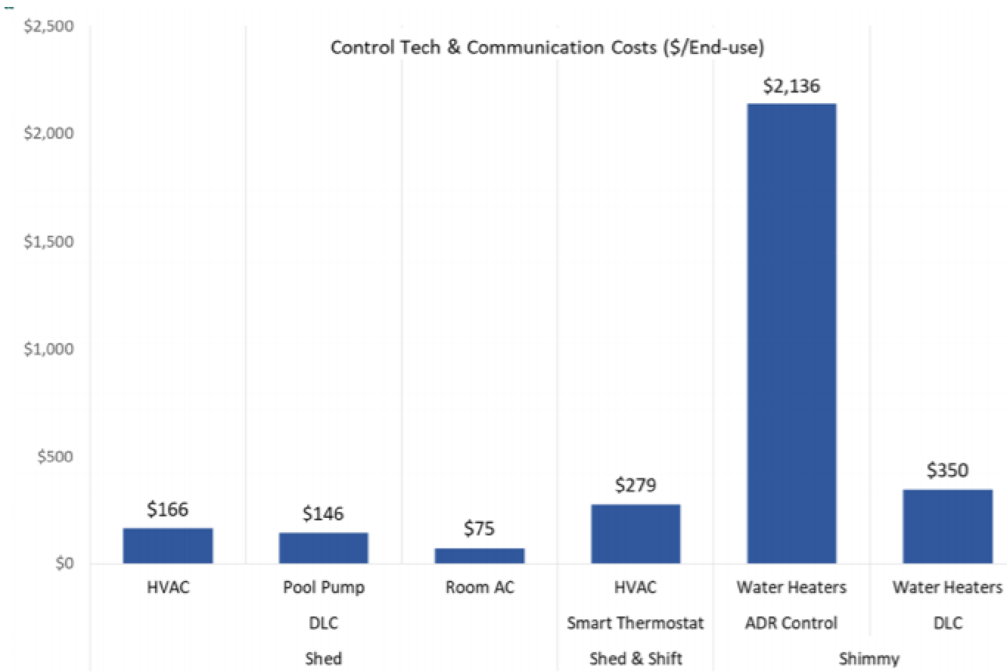
Table 12. DR Potential of Flexible Loads

Year	Building energy systems described	DR type	Load flexibility results
2014	Thermal energy storage	Price based	Maximum 18.7% total peak load shift to valley time
	Space heating with thermal storage	Price based	Reduce the energy payment of the house, and indirectly reduce the market power
2015	Fast demand response strategy using active and passive building cold storage	Incentive based	Up to 34.9% chiller power reduction
2016	PV and ice storage in building	Price based	The highest peak load reduction is about 89.51%
	Ventilation system in residential building	Price based	A single ventilation system can provide 4.5 kW for power increase and 1.0 kW for power reduction during DR time
	Smart building cluster with PV systems	Price based	The proportion of shiftable loads is 25% in the total load profile
	Compressed air energy storage	Price based	Shift 10% of load to other hours
	Fast demand response of HVAC system	Incentive based	Achieve 39% power reduction
	HVAC system and smart appliances	Incentive based	Reduce the daily peak load by 25.5%
	Electric vehicles planning in residential, commercial, and industrial areas	Price and incentive based	Achieve 20% peak load reduction and 40% aggregate cost reduction
2017	Home Energy Management System (HEMS) in residential building	Price based	Autonomously reduce peak load and reduce electricity cost up to 20% a day

Source: Application of load monitoring in appliances' energy management – A review, Renewable and Sustainable Energy Reviews

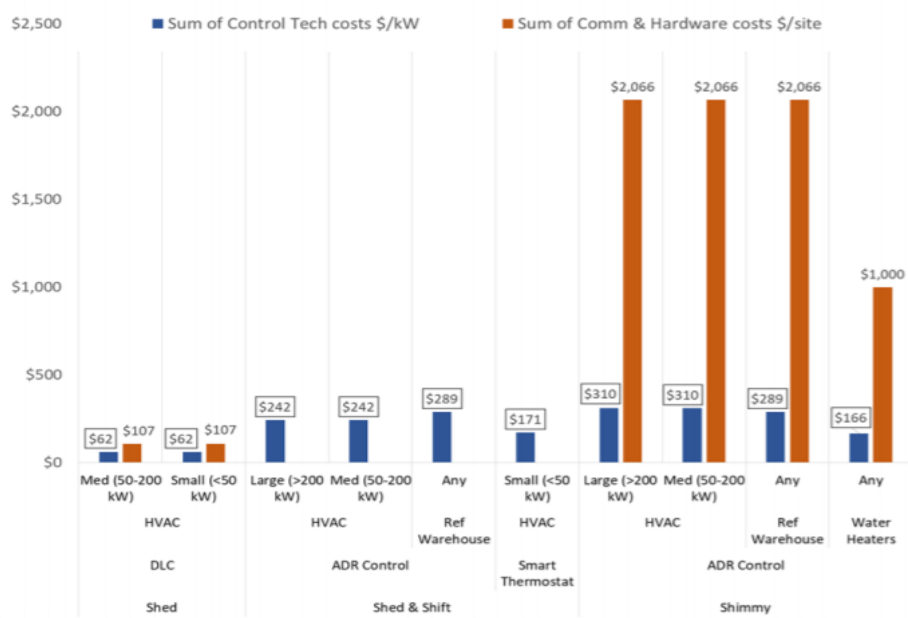
The following figures are from a LBNL study that assesses DR enablement costs for various sectors. Communication and hardware costs for achieving controllability "per site" are fixed costs and are reported in $/site. Costs included in this category are telemetry, communication resource interface, and installation costs. Variable initial costs for the control technology for achieving controllability "per kW" (e.g., HVAC and retail lighting controls) are reported in $/kW. Fixed end use controllability and communication costs for the residential sector are specified in $/end use.

Figure 28. Residential DR Enablement Costs



Source: LBNL[75]

Figure 29. Commercial DR Enablement Costs



Source: LBNL

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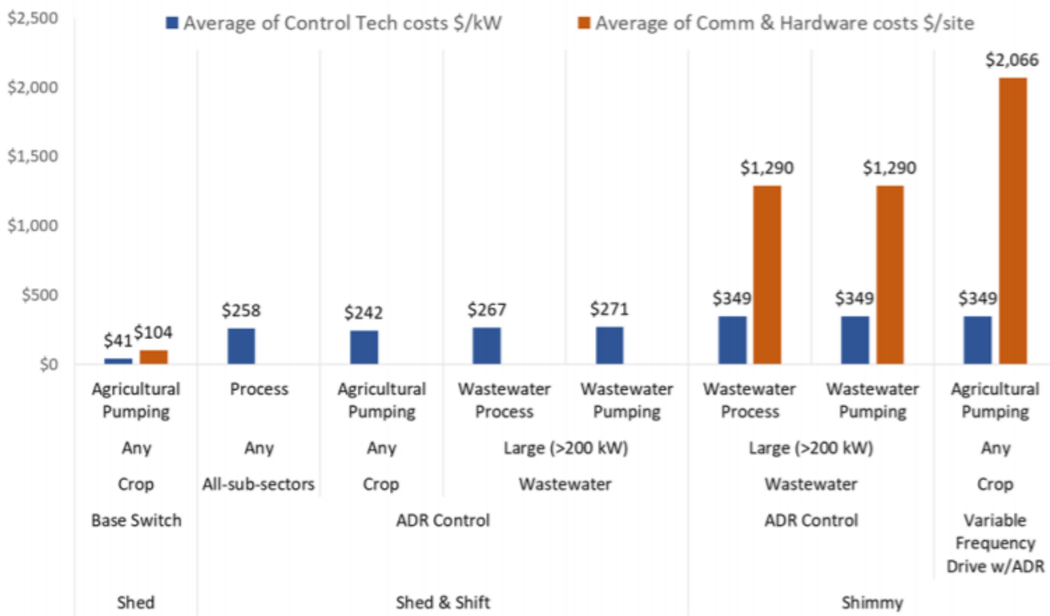
[75] Demand Response Advanced Controls Framework and Assessment of Enabling Technology Costs, LBNL (2017)

Figure 30. Industrial DR Enablement Costs



Source: LBNL

The following figures are from a 2015 LBNL report that considers the installation and configuration costs and includes the costs of owning and operating DR automation systems.[76] One key trend we see is lower $/kW for larger systems, likely due to economies of scale. Some of the more recent projects had a higher $/kW because they used the more advanced OpenADR 2.0 framework. Additional research is needed to update these costs to OpenADR 2.0 standards and implementations. This study shows that the costs of automating DR systems are complex and depend on multiple factors:

i. Scope of DR automation - Installation and configuration requirements. DR automation native to the controls tended to drive costs down for the whole site.

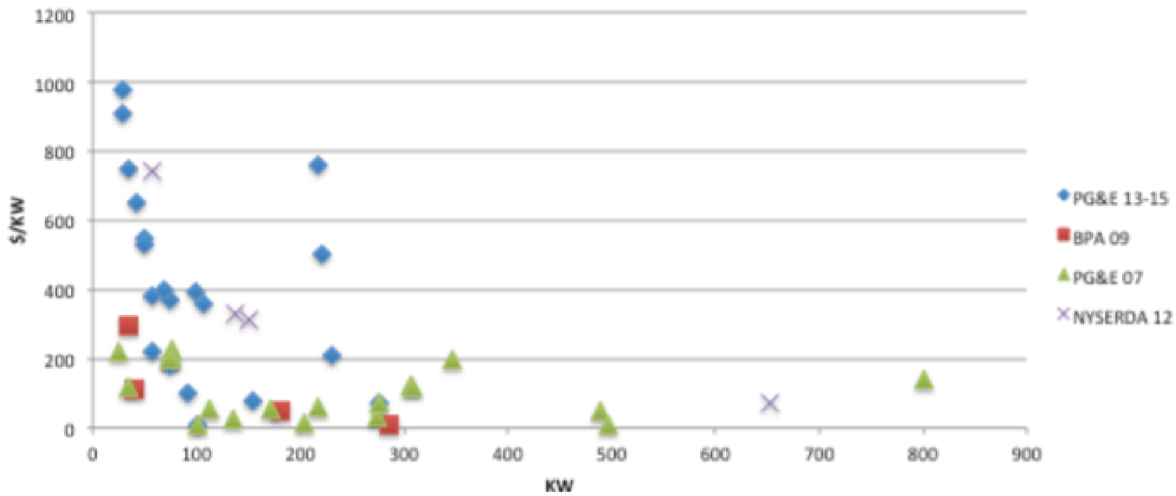
ii. Size of load reduction – Larger sites had lower $/kw.

iii. Version of DR automation protocol – OpenADR 2.0 costs have been higher but are expected to come down over time. The sample for the OpenADR 2.0 system costs are Small and the data are not well understood yet.

iv. Type of demand reduction – Seasonal grid stress vs ancillary services.

[76] *Costs to Automate Demand Response –Taxonomy and Results from Field Programs*, LBNL (2015)

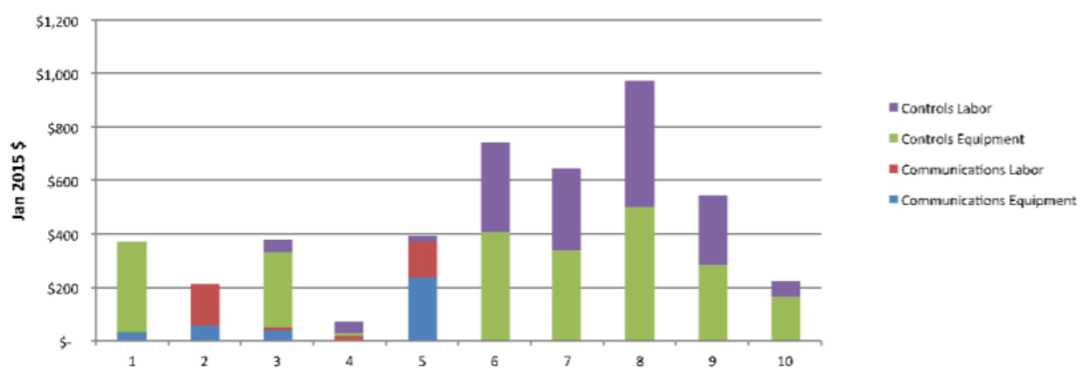
Figure 31. Comparison of AutoDR Costs



Source: LBNL

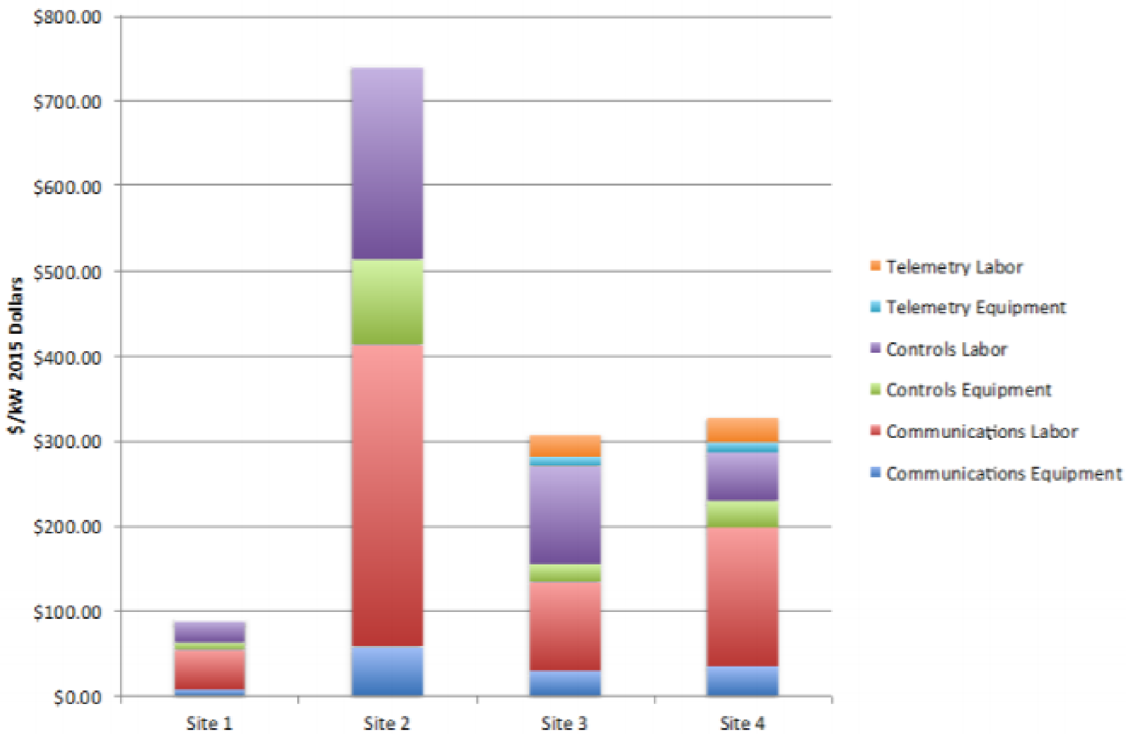
The cost breakdown shown below for PG&E and NYSERDA projects demonstrate that labor costs, which can include up-front engineering, installation by a technician, and commissioning tests, are a signifcant contribution to AutoDR enablement costs. This underscores the need to develop systems that can be simply and cost-effectively installed.[76]

Figure 32. Costs for recent PG&E AutoDR sites using OpenADR 2.0



Source: LBNL

Figure 33. Costs for AutoDR systems in NYSERDA territory, in 2015 dollars



Source: LBNL

Federal and/or State Policy Influences

i. **Federal Regulatory**

a. **FERC Order 719 (2008).** Required the operators of competitive wholesale electricity markets (e.g. RTOs and ISOs) to treat DR bids as comparable to generators' bids in hourly energy markets. [77]

b. **FERC Order 745 (2011).** Calls for economic demand response to be paid the full wholesale price if they are deemed to be more cost-effective than traditional generation options in wholesale energy markets. This mandate only applies to energy markets, but it is reasonable to expect this concept to extend to capacity markets as well.[78]

ii. **California Regulatory**

a. **R.02-06-001. Policies and Practices for Advanced Metering, Demand Response, and Dynamic Pricing (CPUC June 2002).** The aim of this rulemaking was to provide a broad spectrum of demand response programs and tariff options to customers who make their demand-responsive resources available to the electric system.

[77] *Order No. 719: Wholesale Competition in Regions with Organized Electric Markets – Final Rule*, FERC (2008)

[78] *Order No. 745, Demand Response Compensation in Organized Wholesale Energy Markets, 134 FERC ¶ 61,187*, FERC (2011)

i. D.03-06-032. adopted price-responsive demand response programs for large customers and set annual participation goals for utility demand response programs

b. **R.13-09-011. Enhance the Role of Demand Response in Meeting the State's Resource Planning Needs and Operational Requirements (CPUC Sep. 15, 2017).** This rulemaking established that demand response should be flexible and reliable to support renewable integration and emissions reductions, should evolve to meet changing grid needs, should be procured from third parties in open markets, and should be dispatched pursuant to wholesale or distribution market instructions, superseded only for emergency conditions.

i. D.17-10-017. Decided to hold a 2018 auction for 2019 deliveries through the Demand Response Auction Mechanism pilot.

c. **CAISO Resource Aggregation.** Organizations can now aggregate 500 kW and larger demand resources and participate with them in the wholesale market.

d. **Title 24 (2016).** Specifies requirements for demand responsiveness in HVAC, lighting, and digital signage.

Assessment of Barriers to Further Adoption

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 installation, and the cost of implementing communicating controls is a major barrier, particularly for smaller commercial buildings.

Lack of available financing. While the benefit-cost 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/value streams are currently limited by policy, market, and technical conditions. While policy changes are required to fully address this challenge, research into developing affordable submetering options can also enable customers to capture multiple value streams through DR.

Capability

Inadequate data synthesis capabilities. Many existing EMS solutions do not have the capacity to interface with a large and varied set of data sources.

Last-mile communication can be unreliable. DR aggregators have noted that reliability issues of Wi-Fi-based communication protocols have led to unmet commitments. Based on the reviewed research, communications reliability of DR systems has not been quantified.

Difficulties integrating DR with existing back-office systems. Most utilities 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 DR resources and programs in place. [79]

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

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

Data availability limitations. There is a need for higher quality and more readily available energy efficiency and DER data to assess energy and non-energy impacts and prioritize and support appropriate investments in these electricity resources. These data gaps are often due to consumer preference, security, and privacy issues. LBNL developed a report that pinpoints more specific issues within EMV of DERs.[80]

Lack of measurement and verification technology and protocols. There is a gap in technologies and strategies to verify the performance of control systems. The technology needs to be inexpensive, easy to install into existing buildings, and able to provide traceable data and reliable outcomes. Existing commissioning solutions are gaining traction but are not exhaustive and require customization. While many solutions exist at an equipment or component level, emerging solutions seek to cover buildings through a holistic assessment of the building's subsystems.

Coordination

Lack of useful grid signals. Grid signals that can inform energy consumption (e.g., price or incentive signal, cost effective feedback/response in buildings, etc.) as well as price discovery capabilities in buildings are lacking.[81]

Limited interoperability with proprietary systems. Uncoordinated installation and use of appliances and systems has led to independent operation of demand resources, limiting the development multi-objective optimization capabilities. While integration platforms such as home area networks exist, most of these systems are not currently supervisory or integrated to automate building components or systems.[82]

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.[83]

Existing and emerging solutions are inconsistent in the formats of their data, architecture, and interoperability, making it difficult to integrate and share across buildings, communities and for national use. As connected buildings and building systems become more prevalent, there is a need to standardize building data elements to reduce data processing loads and enable consistency in repositories.

Lack of uniformity in building IT infrastructure. The current lack of uniformity in buildings adds expense in retrofit applications that hinders the use of many analytics and optimization solutions and limits their applicability to new construction.

Lack of effective metrics for evaluating cost-effectiveness of integrated programs. Current outcome metrics like kW or kWh reductions do not sufficiently incentivize integrated DSM (IDSM). Utilities note that there is no framework to assess the holistic benefits of IDSM and that program evaluation currently consists of evaluating the component measures independently. EM&V and cost-effectiveness metrics will need to capture temporal and locational benefits associated with load flexibility.[84]

Uncoordinated implementation. Distinct program budgets and funding cycles for EE, DR, and distributed generation make it challenging to integrate multiple technology solutions.[84]

[80] *Electricity end uses, energy efficiency, and distributed energy resources baseline*, LBNL (2017)

[81] *Buildings-to-Grid Technical Opportunities: From the Buildings Perspective*, DOE (2014)

[82] *Drivers of Demand Response Adoption*, Brattle Group (2011)

[83] *Technology for Building Systems Integration and Optimization – Landscape Report*, BTO (2018)

[84] *Barriers and Opportunities for Integrated DSM*, LBNL (2018)

Customer acquisition challenges. Since DERs 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 can limit the ability of DERs to effectively provide grid services.[85]

Lack of T-D coordination. Coordinating multiple DR opportunities will require tighter coordination between transmission and distribution planning and operations.[86]

Lack of transparency into bidding prices. In California, bilateral agreements between utilities and generators put DR bids at a disadvantage. Bidders get paid what they offered and have no visibility into the value of the resource.[87]

? Uncertainty

Value to customer is uncertain. The National Forum on the National Action Plan on Demand Response (NAPDR) recommended a framework for evaluating cost-effectiveness, and the CPUC uses DR Cost-Effectiveness (C-E) Protocols when evaluating cost-effectiveness of DR programs. However, the costs and benefits to the customer for providing DR services in the context of dynamic prices are not well understood.[88] Additional work is necessary to quantify the costs associated with different types of demand response resources providing different types of bulk power system services.[89]

Value to utility is uncertain. There is a lack of a clear method to value DR, which limits the adoption of DR products and services at the utility side.

Interaction between demand response 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. On the other hand, a customer's adoption of energy efficiency measures may reduce the impacts of that same customer's participation in the demand response program.[90]

Identified RDD&D Needs

Actions to Bring Key, High Impact Technologies and Strategies to Market

i. There is a need to recognize and grant equivalence to non-utility grade submeters to enable more affordable submetering that can in turn facilitate value-stacking. Monitoring technologies need to be more precise, autonomous, cost competitive, and not labor intensive to install.

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85 *Coordinating Distributed Energy Resources for Grid Services: A Case Study of Pacific Gas and Electric*, NREL (2018)

86 *Future Opportunities and Challenges with Using Demand Response as a Resource in Distribution System Operation and Planning Activities*, LBNL (2016)

87 *Two Models, Two Outcomes for Demand Response in PJM, California*, Concentric Power (2018)

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

89 *Demand Response and Energy Storage Integration Study*, DOE (2016)

90 *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)

ii. Support the development and integration of low-cost sensors and actuators with open, secure, and scalable platforms that can facilitate the development of more sophisticated algorithms to dynamically aggregate and transact diverse loads and facilitate better measurements, verification, and settlement of these transactions.

iii. Promote open and secure access to demand and the state-of-device information.

iv. Continue to improve model-based predictive, agent-based, or learning-based control algorithms. Design hybrid control architectures that can reap the benefits of both centralized and decentralized control strategies.[91]

v. Research the interactive effects between multiple control systems, consumer behavior, appliance characteristics, electrical load dependency, and the distribution network. [91]

vi. Conduct holistic studies of DR in context of the whole electricity system (e.g. simulate DR providing multiple services and in competition with other resources)

vii. Support the development of more time-based and stochastic distribution system planning tools that can effectively model various types of demand response resources. [91]

viii. Characterize DR potential and load in response to dynamic prices, including how much it costs to install and configure automation and how long customers stay on DR programs and DR measures. Data needs to be publicized to provide a better understanding of any gaps between what is needed by the grid and what dynamic pricing can deliver.

ix. Characterize costs of DR automation in new buildings.

x. Demonstrate the implementation of DR and energy flexible loads in new construction to take full advantage of Title 24 compliance capabilities.

xi. Demonstrate machine readable electricity tariffs to better communicate the cost of electricity.

xii. Explore the value of the code requirements for grid optimization assets.

xiii. Further valuation research is required to clarify how to value distribution services such as real/reactive power for voltage control and DER use for switching operations. [85] Develop methodologies to quantify, monetize and socialize grid benefits, with focus on locational and temporal value.

[91] *Opportunities and challenges of demand response in active distribution networks,* Wiley Interdisciplinary Reviews: Energy and Environment (2017)

Section 4: Smart Inverters

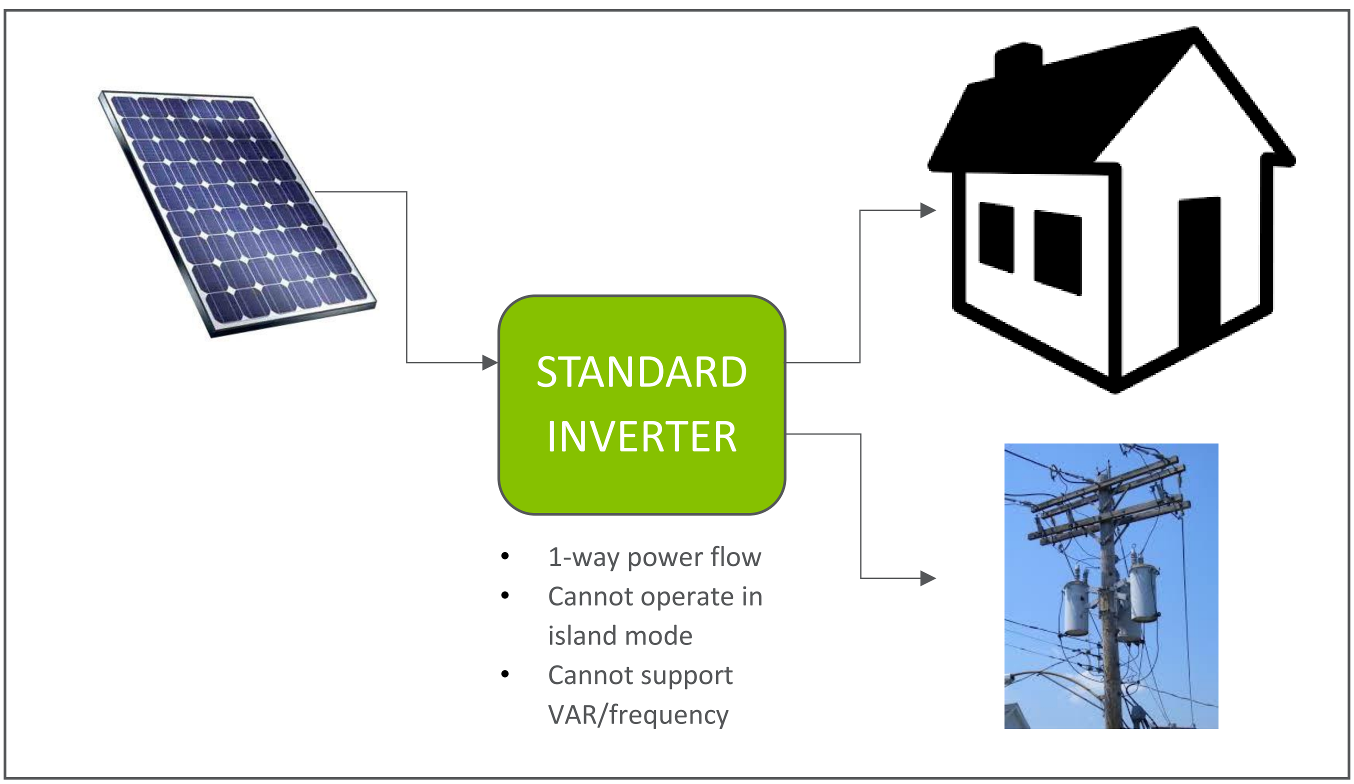
Technology and Strategy Review

Smart Inverters are advanced inverters that seek to perform innovative control strategies to match generation fluctuations with electricity consumption and enhance grid benefits in addition to the conventional conversion of DC to AC electricity. The additional functionality can help to address challenges associated with the integration of variable customer loads and generation by using advanced monitoring and communications strategies to assist with the power quality and/or support ancillary services to the grid. The majority of customer inverters help to convert photovoltaic generation, though they would also be required to connect electrochemical energy storage.

Characterization of Technology and Strategy

Standard inverters (see Figure 34) simply convert variable DC from an array of solar panels into useable AC that could be either used either locally on-site or fed to the grid. Systems may feed energy to the grid during overgeneration events (PV output exceeds the site load) or if the system is designed to provide grid support. Standard Inverters also lack the capability to support the grid by operating at a fixed power factor and typically disconnect the associated PV generation during grid disturbances. Furthermore, in the event the grid is disconnected from the solar panel power source, re-connecting that source to the grid can be problematic because the standard inverters operate fully “on” or “off”, presenting a sharper change in net load. This can present a significant source of power when reconnected, making restoration of the grid after an abnormal event problematic for grid operators. These sequences are also risk triggering additional system failures, which can extend restoration time and damage sensitive electronic equipment tied to the grid.

Figure 34. Standard Inverter Operation



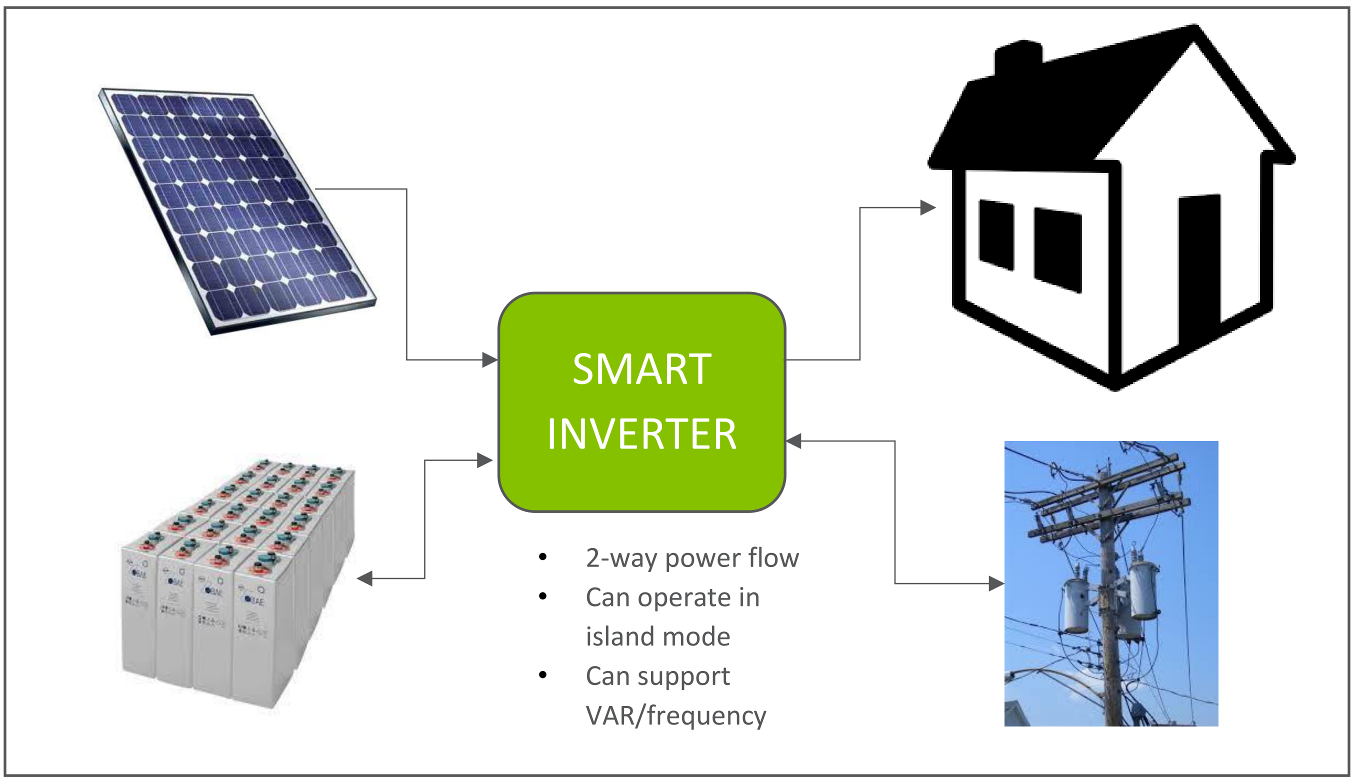
Source: Redhorse Consulting

Smart Inverters can stabilize the grid by providing voltage regulation through reactive power support, volt-var control, volt-watt functions, frequency-watt functions, active power curtailment, and low voltage ride through, given the appropriate settings. The advanced functionality of Smart Inverters enables PV generation to operate with additional flexibility and support the distribution grid rather than producing more challenging conditions. This not only makes PV generation less costly for the grid to integrate, but also makes PV generation a more reliable source of power for on-site or grid connected applications[92].

Smart Inverters (see Figure 35) can also utilize supplemental energy storage systems to store energy during mid-day generation and produce it during peak. In addition, Smart Inverter advanced functionalities, such as VAR/Volt support and two-way communications capabilities with utility and balancing authority networks, supports grid services. Smart inverters also differ from standard inverters in that they support on-site power delivery independent of the grid. While energy storage can be deployed alongside Smart Inverters, it is not a must-have requirement.

Standard inverters were required by IEEE standards to disconnect PV generation in the event of a grid failure or loss of power. Smart Inverters have the capability to "island", which allows continued delivery of PV generated electricity in the event of grid interruption or failure[93].

Figure 35. Smart Inverter Autonomous Operation



Source: Redhorse Consulting

i. Smart Inverters support the grid in the case of high solar adoption in the following ways:

   a. Features such as "riding through" and staying operable under a minor frequency or voltage disturbances on the grid.

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[92] *Smart Inverter Grid Support Functions and Potential Impact on Reliability*, NREL (2015)

[93] *Smart Grid, Smart Inverters for a Smart Energy Future*, NREL (2017)

b. Capability to absorb or provide electricity into or from the grid to provide support for grid system stability.

c. Provide "soft starts" after power outages by controlling the time of reconnected distributed generation. This capability to ease restoration of power to the grid after power failures by limiting the voltage fluctuations in active power after reconnection and provides for a smooth interconnection transition.

ii. Smart Inverters can be used in the following applications:

a. In an off-grid mode with no utility interconnection, also known as island mode.

b. In a grid-tie mode with utility interconnection, where the system provides site and/or grid power.

c. In a hybrid mode, with interconnection to both a battery bank and the grid, where the system can operate in a backup mode to provide power if the grid is interrupted.

California became the first U.S. state to require the use of Smart Inverters in solar projects, while Hawaii was the first U.S. State to allow Smart Inverters to be approved for interconnection. California adopted the smart inverter requirement under an updated Rule 21 approved by the California Public Utilities Commission (CPUC) on September 9, 2017. Interconnection requirements, along with other Rule 21 changes, seek to take advantage of Distributed Energy Resources (DER), such as on-site solar generation, by enabling their use as grid assets instead of being restricted to behind the meter use cases.

Smart Inverters also provide control of two-way power flow, which enables storage to be used alongside solar behind the same inverter. This feature helps grid operators better address the challenges of adding non-dispatchable renewables. This is of importance in California as the state makes progress in sourcing 100% of its electricity from renewables by 2045.

A Smart Inverter Working Group (SIWG) was formed in 2013 with collaboration between the CPUC and the California Energy Commission to examine advanced inverter functionality, with a focus on how it can help address issues with high penetration DER. The SIWG evaluated inverter functionality in three phases: 1) autonomous functions, 2) communication protocol, and 3) advanced functionality. Table 13 discusses the advantages and disadvantages of each phase of research.

Discussion of Advantages and Disadvantages

Table 13. Advantages and Disadvantages of Smart Inverter Functions

Strategy	Advantages	Disadvantages
Phase 1: Autonomous Functions	• More stable grid, especially in areas with high DER penetration • Increased ability of utilities to respond to grid fluctuations • Less waste due to power line losses related to power factor	• Limited utility and balancing authority control • Increased cost • No retrofit requirement

Strategy	Advantages	Disadvantages
Phase 2: Communication Protocol	• Increased capability to balance grid frequency, power factor, and voltage • Most Smart Inverters will have communication hardware installed, with firmware or software updates to enable communication • More real-time data available to grid operators on the health of the entire grid, not just Smart Inverters	• Increased cyber-security risks • Customer privacy may be compromised • Communication infrastructure will require significant capital costs to fully benefit from two-way communication • Increased operational funding required to maintain upgraded infrastructure • Potential difficulty in upgrading firmware on existing inverters
Phase 3: Advance Functionality	• Under development by SIWG	• Under development by SIWG

Description of Technical Specifications and Requirements

i. **Cybersecurity requirements.** Cyber security requirements are expected to include appropriately configured firewalls, role-based access control mechanisms, authentication and integrity of all messages, ability to provide confidentiality for some messages, key management requirements, communications channel performance requirements and monitoring, time synchronization across all systems, security monitoring, and audit logs of all significant alarms and events.[94]

ii. **Communications requirements.**

Table 14. Communications Requirements for SI Voltage Regulation

Metric	Voltage Regulation Requirement
Communication interval	Faster than delay on voltage regulator (30 sec)
Reliability	98%
Latency	<10 seconds

Source: Sandia National Lab[95]

iii. **California's Rule 21 Modification.** Removes barriers from legacy utility providers by providing all publicly owned utilities in California with guidance on:

a. Standardized technology and size-neutral requirements

b. Review process

c. Testing and certification procedures

d. Standard interconnection fees

e. Streamlined application process

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[94] *SIWG Phase 2 Recommendations for CPUC*, Smart Inverter Working Group (2015)

[95] *Evaluation of Communication Requirements for Voltage Regulation Control with Advanced Inverters*, Sandia National Lab (2016)

The modification was made to be in compliance with IEEE 1547-2018 which allows behind-the-meter Smart Inverters and storage systems to interact with the grid in two-way power flows to help keep the grid stable, while providing protection to the grid in the case of disturbances. The Rule 21 modification was made to help make the grid more resilient and stable as additional sources of solar generation are connected to the grid, which transitions these sources from making the grid more unstable to making the grid more stable. This is especially noticeable in line spurs and in areas of high solar penetration.

iv. **IEEE 1547-2018.** Provides technical specifications for the design, installation, and testing of interoperability between utility power systems and distributed energy resources. Requirements in the specification include: general requirements, response to abnormal conditions, power quality, islanding, design, production, installation evaluation, commissioning, and periodic testing. The standard encompasses technologies that include synchronous machines, induction machines, or power inverters/converters that is sufficient for most installations.

v. **IEC 61850.** An IEC communication standard adopted by the smart inverter working group (SIWG) as an alternate communication protocol that can be used upon mutual agreement.

Table 15. Additional Relevant Standards for Smart Inverters

	Standard	Description / Purpose	Current State/Upcoming Milestone
Interconnection	IEEE 1547-2018 - Standard for Interconnection and Interoperability of Distributed Energy Resources with Associated Electric Power System Interfaces	An IEEE standard of interconnection requirements.	Published in 2018 after a multi-year revision process.
Interconnection	IEEE P1547.1 - Draft Standard Conformance Test Procedures for Equipment Interconnecting Distributed Energy Resources with Electric Power Systems and Associated Interfaces.	An IEEE test standard under revision that tests to the interconnection requirements in IEEE 1547-2018.	With IEEE 1547-2018 published, a published revision of IEEE 1547.1 is expected in 2019.
Interconnection	UL 1741 - Standard for Safety - Inverters, Converters and Interconnection System Equipment for Use With Distributed Energy Resources	A UL standard that tests to the utility interactive inverter requirements of IEEE 1547 and IEEE 1547.1. The standard also includes product safety test procedures.	Revised in 2016 (Supplement A or "SA") to test to the inverter requirements of California and Hawaii. A future revision is expected following publication of the updated revision of IEEE 1547.1.
Interconnection	Rule 21 - Generating Facility Interconnections	A California tariff that governs the interconnection requirements of the IOUs.	Updated as required by the California Public Utilities Commission (CPUC).
Communication	IEEE 2030.5-2018 - IEEE's Adoption of the Smart Energy Profile 2.0 (SEP2) Application Protocol Standard	An IEEE communication standard adopted by IEEE 1547-2018 as an eligible inverter communication protocol and adopted by the CA SI Working Group (SIWG) as the default communication protocol for inverters.	Updated revision published in 2018. A new project authorization request (PAR) was recently opened for a future revision.
Communication	California Common SI Profile (CSIP)	An IEEE 2030.5 implementation guide and common communication profile for inverter communications developed to meet the needs of the IOUs.	CSIP 1.0 was issued in 2016 by the California SI Working Group (SIWG). CSIP 2.1 was issued in 2018 by SunSpec.
Communication	SunSpec Common SI Profile Test Procedures	Verifies compliance with the IEEE 2030.5 functionality and options specified in CSIP.	Published in 2018.
Communication	IEEE 1815-2012 – Standard for Electric Power Systems Communications-Distributed Network Protocol (DNP3)	An IEEE communication standard adopted by IEEE 1547-2018 as an eligible inverter communication protocol and adopted by SIWG as an alternate communication protocol that can be used upon mutual agreement.	Published in 2012.

Source: Pacific Gas & Electric[96]

Recent and Current RDD&D Activities

There has been significant amount of research into smart inverters, primarily from EPRI, utilities, and national labs. Collaboration between utilities and national labs have been common in smart inverter projects. A range of grid-serving smart inverter functionalities have been demonstrated, including local voltage support, PV impact mitigation, and some capacity service capability. However, current communication infrastructure, customer adoption levels, testing frameworks, and utility systems limit the deployment of advanced functionalities. The research we surveyed encompassed the following areas:

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[96] *Enabling Smart Inverters for Distribution Grid services*, PG&E (2018)

i. **<u>Communications and Cybersecurity.</u>** Projects in this area develop and demonstrate reliable and secure communications architecture. Potential metrics could include response times and scalability of solution. SNL, ANL, NREL, and EPRI are currently working on projects in this area.

ii. **<u>Interoperability and Standardization.</u>** Projects in this area enable standardized communications and interoperable systems by informing standards and developing testing procedures. Potential metrics could include test expenses, uniformity of grid behavior of compliant solutions, system integration and supply chain costs, and level of multivendor interoperability.

iii. **<u>Advanced Functionality Research and Demonstration.</u>** These projects develop and/or test autonomous features, communications, and control capabilities to improve inverter technologies, inform emerging industry standards, and define the operational and communication requirements to support the advancement and deployment of new inverter technologies.

Some metrics are shown in Figure 36.

Figure 36. Metrics for Smart Inverters

Smart Inverter Metrics	Unit
Number of third-party grid sensors	count
Number of communications-enabled Smart Inverters	count
Installed capacity of communications-enabled Smart Inverters	MW
Impact on distribution system – Annualized equipment operations	#
Impact on distribution system – Voltage challenges	% of customer minutes outside of desired voltage levels
Maximum power point tracking (MPPT) – Tracking Speed	Rate
Maximum power point tracking (MPPT) – Accuracy	Efficiency (ratio of the average output power to the power at the MPP)
Voltage Range[97]	V
AC/DC Conversion Efficiency	% (most systems are 96-97%)
Standby mode power losses	W per kW of capacity (most systems exhibit 0.11 to 0.22 W)

[97] *Response to Invitation to Submit Proposals - Solar Inverters*, CA IOUs (2017)

	Accuracy of active function implementation	%
	Availability to provide grid services when called for	%
	Response time to external signals	seconds

A selection of research projects is highlighted below. A more complete list can be found in the Appendix.

i. **Pacific Gas and Electric EPIC Project 2.03 (2018).** PG&E has initiated an Electric Program Investment Charge (EPIC) project that plans to demonstrate the functionality of customer-sited behind-the-meter PV Smart Inverters and the grid impacts of their use. PG&E findings demonstrated the basic technical functionality of smart inverter autonomous functions that mitigate local voltage issues commonly found with high DER penetration in both residential rooftop and commercial applications. The program is ongoing. The PG&E Grid Integration and Innovation group has concluded that smart inverters can be beneficial in addressing reliability and power quality issues common among high DER areas. The demonstration has also shown that more work is required to standardize the technology and improve communications reliability[98].

ii. **Salt River Project Advanced Inverter Study (2017).** Arizona-based Salt River Project (SRP) is currently conducting a study involving more than 750 SRP customers in conjunction with the Electric Power Research Institute (ERPI) to better understand how advanced inverters can help maintain grid reliability as solar installations increase. The utility has installed more than 750 smart inverters on new and existing residential solar installations on the customer side of the meter and began collecting data in July 2017. In one component of the study, SRP is specifically investigating how smart inverters work within a community to determine benefits in an area with a large penetration of solar. Already, SRP has noted that the smart inverters help smooth the intermittent solar power fluctuations and mitigate power quality issues commonly found in areas of high solar penetration[99].

iii. **Joint Lab Testing of Smart Inverters (2018).** A coalition of PG&E, SCE, and EPRI performed lab testing on autonomous volt/watt curves, frequency-watt curves, voltage and frequency ride though and several other advanced functionalities. The project found many issues with the state of commercial Smart Inverters – non-standard naming conventions, advanced functionalities defaulted to off and limited documentation on advanced functions.

Critical Success Factors

Description of Commercial Readiness Level, Including Current Market Participation

i. Smart inverters are currently required for future installations in California, although traditional inverters will not be required to be retrofitted at this time. Costs vary based on size and manufacturer, along with featured "smart" capabilities. German grid operators recently mandated that all inverters must be upgraded to include smart functionality at an expected upgrade cost of approximately US$20B. California has not mandated existing solar inverters to be upgraded and to date, no grid interruptions have been reported due to existing DER solar generation. While a

[98] *Discover the Electric Program Investment Charge Program*, PG&E

[99] *SRP advanced inverter pilot study examines solar's impact on the grid*, American Public Power Association (2017)

retrofit would provide some benefits to customers and support the integration of additional distributed solar, the grid support benefits are currently not economically compensated, and a retrofit is not mandated by California law. The intent is to expand functionality and improve system reliability with renewable power sources. Figure 37 and Figure 38 provide estimates of inverter costs from the National Renewable Energy Lab for inverters with module-level power electronics (MLPE) and non-MLPE. The data are sourced from public corporate filings for MPLE and from the PVinsights database for the non-MLPE.[100]

Figure 37. Non-MLPE inverter prices (USD/Wac)

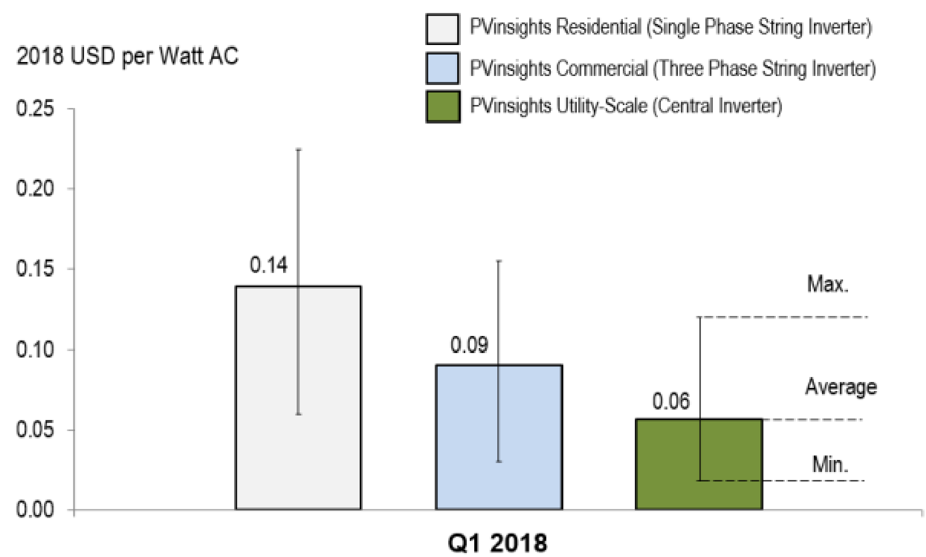
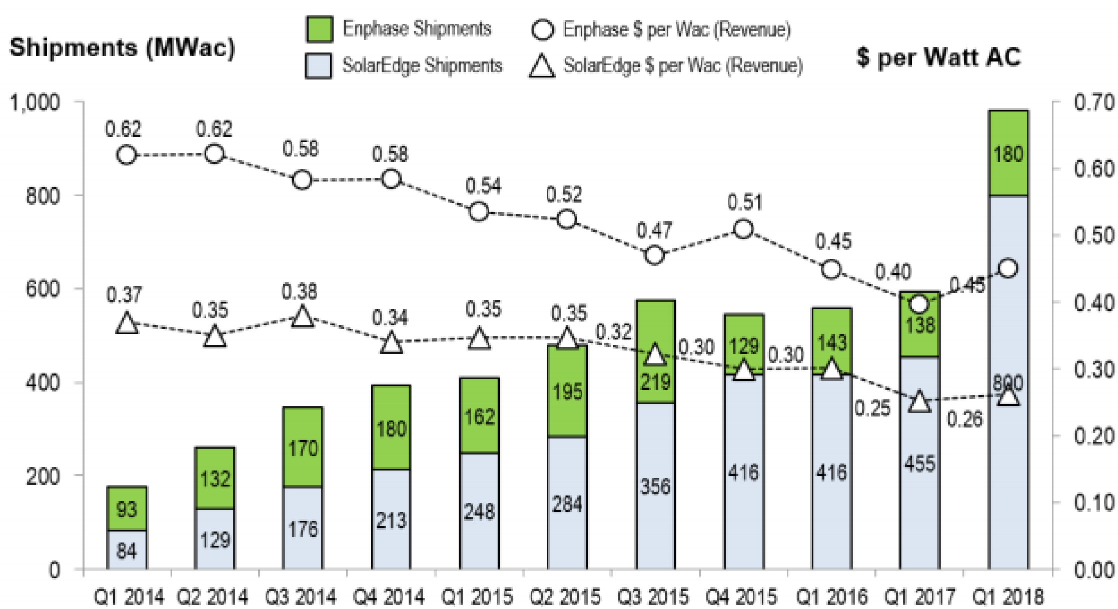


Figure 38. MLPE inverter shipments and prices (USD/Wac)



ii. Until recently, U.S. standards (IEEE 1547-2003) prohibited inverters connected to the grid from using advanced functionality, such as voltage support functions, instead requiring DERs to

[100] U.S. Solar Photovoltaic System Cost Benchmark: Q1 2018. National Renewable Energy Laboratory.

disconnect from the grid in the event of a grid disturbance. As a result, adoption rates of advanced inverters were low due to higher cost for advanced functionality. The new IEEE 1547-2018 standard contains requirements for advanced inverter feature use in grid-connected systems allowing smart inverters to perform support functions for the grid. No studies exist showing smart inverter adoption rates, however it can be assumed that adoption prior to 2018 has been minimal. However, as standards and policy decisions improve economics, it is expected that the market will expand.

iii. The ability of smart inverters to support the grid will be immediately available as smart inverters are installed. To realize the full benefits of smart inverters, supporting communications must be established between grid operators and the smart inverters. Such a communication system does not currently exist in California or the United States. The development and implementation of a communication system will further benefit grid stability and make smart inverters and their connected generation system more available to support grid stability as non-dispatchable renewables come on-line.

iv. Electric Power Research Institute (EPRI) demonstrated that smart inverters can increase the amount of solar PV that can be reliably installed on a utility feeder (i.e., increase the capacity of the feeder) and can potentially lead to higher penetration levels of PV DERs in the future. Adding smart inverters with volt-VAR control capability to the PV installations improved the reactive power and voltage at the local and substation level in this EPRI analysis. Based on the volt-VAR curve, the maximum voltage at the PV interconnection point was reduced by absorption of VARs from the grid following the volt-VAR curve and control algorithm.

Federal and/or State Policy Influences

i. Federal Government

a. **Solar Investment Tax Credit.** Federal tax incentive applies to solar projects, including inverters at 30% through projects commencing construction through the end of 2019, phasing out through 2021. Residential will drop to zero at that point, while commercial and utility credits move to a permanent 10 percent.

ii. California Regulatory

a. **Rule 21.** Mandates 100% adoption of Smart Inverters for new installations within California beginning February 2019. Future communications requirements are expected from the Smart Inverter Working Group. This would be an Alliance of Wide Area Communication Protocols, or a modification to another standard for communications. This standard is expected to be released soon.[101]

Assessment of Barriers to Further Adoption

Capability

Insufficient utility operational capabilities. Current distribution system modeling and analysis are insufficient for optimal DER asset utilization due to the lack of accurate phase identification information.

Utilities lack capabilities to dynamically realize SI value, which include both software solutions (such as a coordinating platform that provides SI visibility to the utility and then optimizes and dispatches DERS through the SI) and hardware solutions both on the distribution grid and at the DER facility (such as ADMS and additional visibility/monitoring devices on the distribution grid, e.g. line sensors, to supplement visibility at end devices). Utilities will need to invest in foundational capabilities and systems to enable 1)

[101] *Wide Area Communications Protocol*, SunSpec

real-time communication of distribution dispatch instructions to the aggregators/SIs (active control), and 2) automated optimization of grid operations leveraging both traditional distribution operations equipment and SI-equipped DERs.

Communications unreliability. In PG&E's EPIC 2.03A Location 2 demo, the IEEE 2030.5 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, SDG&E's SI Demo C experience and PG&E's EPIC 2.19C/EPIC 2.03A Location 1 demos showed that the reliability of SI communications was well below the average communication reliability for Supervisory Control and Data Acquisition (SCADA)-enabled devices, such as line reclosers. For distribution services, this creates challenges associated with performance since 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% reliable to not have an impact on the effectiveness of the inverter to provide voltage control.[102]

Coordination

Customer Acquisition. Often, residential PV systems aren't owned by the customers or DER vendors, but by 3rd parties. Since 3rd party ownership rights typically prevent any possibility to intentionally curtail power, which was part of the active power control use case, many existing inverters cannot be retrofitted with Sis.

In addition, the vendor faced difficulties acquiring new customers to participate in the technology demonstration, despite an incentive in the form of a $300 credit and a free residential energy storage device.[103,104]

Consistency and Interoperability. An EPRI project 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 cyber security as needed. These modules allowed communication systems to work with any inverter. However, there were instances where the technical specifications of each inverter limited interoperability. For example, a control system that attempted to send a common 4-point curve to all DER in a group would succeed with some but fail with others 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 UL1741 to be specific in terms of capabilities

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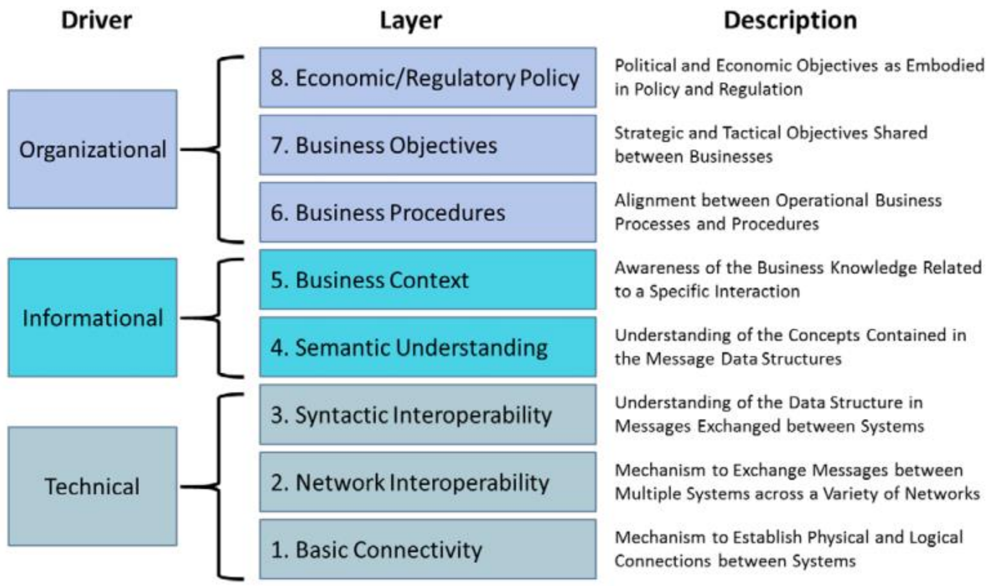
[102] *Evaluation of Communication Requirements for Voltage Regulation Control with Advanced Inverters*, SNL (2016)

[103] *PG&E-EPIC-Project-2.03a, PG&*E (2018)

[104] *PG&E-EPIC-Project-2.03a, PG&*E (2018)

within required functions.[105] Figure 39 provides a framework for organizing the various layers of interoperability.

Figure 39. GridWise Architecture Council's Eight-Layer Interoperability Model



Updates to IEEE 1547/1547.1 requirements and UL 1741 are underway. Upcoming challenges include alignment of industry players (manufacturers, installers and developers) to certification standards and consistent implementation and field verification that SIs are in compliance with Rule 21.

Cybersecurity. Cyber-attack vulnerability increases as DERs become more widespread and communications networks expand to integrate with building automation networks or IT networks. In addition, DSOs may be unable to monitor the security of SIs owned by third parties.

Currently, the California Common SI Profile (CSIP) specifies IEEE 2030.5 as the communications protocol between the DER aggregator and utility. However, communication between the aggregator and individual SI Control Unit (SMCU) is specifically out-of-scope for the standard, and no mechanism currently exists to ensure end-to-end cybersecurity between the utility and SI-enabled DER. Furthermore, while the IEEE 2030.5 communications standard which covers utility-aggregator interactions does include a requirement for transport layer security (TLS), no certification or test procedures exist to guarantee that it is adequately implemented by vendors.[106]

Researchers at ANL have identified quantitative metrics to measure the impact of a cybersecurity attack based on (i) the amount of load lost, (ii) the number of feeders tripped, (iii) fraction of components not surviving a given attack, (iv) voltage or frequency violations, (v) decreased system stability margins, (vi) time to recover a given fraction of network functionality, (vii) average propagation of cascading failures, and (viii) safety violations.[107]

DSO/TSO interaction. Use of smart inverters to support the operation of the transmission system without consideration of distribution system requirements leads to risks of PV or other DER technology with a smart inverter impacting the downstream distribution system reliability or power quality. If solar PV fed

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

[106] *Enabling Smart Inverters for Distribution Grid services*, CA IOUs (2018)

[107] Cybersecurity for distributed energy and Smart Inverters, ANL (2018)

smart inverters were used to support voltage at the substation level, this control would need to be coordinated between the system operator and the distribution system operator. To resolve conflicting requests from the TSO and DSO, there needs to be a better understanding of the costs and benefits of each scenario, but this understanding is limited by the accuracy of voltage modeling at service points.[108]

? Uncertainty

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

Benefit uncertainty. Uncertainty of cost-benefit of SI adoption or retrofit. PG&E's EPIC project 2.03A will perform cost-benefit analysis of SIs on PG&E's system as compared to traditional distribution grid upgrades, which will evaluate of the cost-effectiveness of SIWG Phase 1 and Phase 3 functions and determine incremental benefits of autonomous SI functions. Resolution will be required on the costs of customer adoption versus benefits to the distribution operator.

Identified RDD&D Needs

Actions to Bring Key, High Impact Technologies and Strategies to Market

i. **Near Term**

   a. On-going research is needed to quantify the benefits of smart inverters with advanced communications that enable multiple microgrids or other grid power sources to interact with each other and communicate with utilities. This can help justify the infrastructure costs required on a large scale to take advantage of these functions. An NREL study used distribution equipment operations and percent of time over or undervoltage as metrics to assess the impact of smart inverters on grid performance.[109]

   b. Test the appropriate incorporation of Smart Inverter capabilities in the DER interconnection screening process.

   c. Test the coordination of transmission and distribution requirements for smart inverter functions and settings.

ii. **Mid Term**

   a. Include Smart Inverter models in distribution planning to accurately assess future impacts.

   b. Perform the studies necessary to harmonize Smart Inverter requirements in Rule 21 to match IEEE 1547-2018.

   c. Standard communication protocols that can "speak" to each utility and the CAISO balancing authority should be developed to ensure that installed smart inverters do not become immediately obsolete upon adoption of a communication standard. Identifying

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108 *Reactive Power Support of Distribution and Transmission Systems by Active Distribution Networks*, Energy Central (2018)

109 *Feeder Voltage Regulation with High-Penetration PV Using Advanced Inverters and a Distribution Management System: A Duke Energy Case Study*, NREL (2016)

the IT infrastructure needs and comparing upgrade costs to the benefits of Smart Inverter communication will allow utilities to target areas economically optimal for communication infrastructure upgrades. Privacy and cyber security concerns should also be addressed.

iii. Long Term

a. Clarifying the functions and ownership of Smart Inverters with relation to grid interaction and sustaining continuous Smart Inverter functionality developments will enable a successful roadmap for future investment. Extended real-world demonstration of enabled use cases can help to define what value is able to be provided by coordinated Smart Inverters.

Section 5: Distribution Grid Communications

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

Technology and Strategy Review

Characterization of technology and strategy

i. **LTE:** In the US, public carriers like AT&T, Sprint, and Verizon are aggressively courting the utility vertical, pushing for the use of their networks for applications, including AMI and distribution automation (DA) as well as security monitoring, mobile workforce, and demand management. Because of its low latency, LTE may be considered for nearly all emerging DER and smart grid applications. Carriers are trying to win over utilities by touting higher speeds, greater capacity, and the ability to set message priority.[110]

ii. **5G.** While still some years away, 5G is the next evolution in public wireless networks. It aims to provide a network with dramatically improved function when compared to the 3G and 4G networks in use today. 5G is also expected to be less expensive than networking solutions available today, although it is too early to predict the specifics of the cost reduction with certainty.[111]

    a. Unlike earlier cellular generations, such as 2G and 3G networks, the 5G architecture will evolve over the next 5-10 years (and beyond) on top of the 4G networks in place today. 5G will offer backward compatibility as new spectrum bands and radio technology are integrated. Although100% backward compatibility will not be technically feasible, developments will be more advanced than previous generations. As such, network obsolescence in the 5- to10-year timeline, which has been a barrier to utility dependence on cellular networks, will no longer be a major factor.[112]

    b. The technical specifications 5G offers over 3G and 4G are impressive: up to a 1,000-fold increase in bandwidth per unit area, up to 100 times more connected devices, up to 10 Gbps connection speeds to mobile field devices, perceived network availability of 99.999%, perceived 100% network coverage, and a maximum of 1 ms end-to-end roundtrip delay (latency). This step change in functionality means a plethora of new devices and sensors will be able to collect, use, and send data at faster speeds and higher volumes than ever.[113]

    c. The 5G framework is designed to support three broad services: enhanced mobile broadband (eMBB), ultra-reliable and low latency communications (uRLLC), and massive machine-type communications (mMTC). In the context of IoT from a utility

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[110] Navigant Research, *Communications Technologies for DER Integration*, 1Q 2018

[111] Navigant Research, *Communications Technologies for DER Integration*, 1Q 2018

[112] Navigant Research, *Communications Technologies for DER Integration*, 1Q 2018

[113] Navigant Research, *DER Management Technologies*, 4Q 2016

perspective, both uRLLC and mMTC provide enhanced potential for utilizing analytics in asset monitoring, load forecasting, and DER integration.[114]

iii. **Public cellular connections** have been the primary networking choice for smart inverter applications, including DESS, solar, and wind installations. These networks are also leveraged for DR and EV charging communications.[115]

a. Cellular is widely used for EVSE networks, however, major carriers such as Verizon Wireless and AT&T Mobility are considered expensive by some EVSE network operators. Interviews indicate that service costs may be $20 or more per charging station per month, and high fees for static IP addresses may also be charged.[116]

b. Cellular components for charging stations range widely in price.; a simple modem will cost less than $100, but a router with an Ethernet port may cost between $250 and $300. The components also have to be hardened for extreme hot and cold temperatures for many locations, which can also add to cost. [117]

iv. **T-1/Time-Division Multiplexing Technology.** This refers to a method of transmitting and receiving independent signals over a single signal path by means of synchronized switches at each end of the transmission line. As a result, each signal appears on the line for only a fraction of time in an alternating pattern, which allows for greater signal efficiency. Some grid locations, especially substations, may use dedicated TDM services from the local carrier, which offer relatively high-speed data transmission. Typically deploying some kind of frame relay service over these links, this approach allows the basic transfer of monitoring data to be sent back to the utility headend at a low cost. However, to serve the needs of the more integrated network of the future, highly intelligent networks that efficiently manage available bandwidth and optimize its use for applications such as SCADA, IP-based mobile radio, video surveillance, and other advanced communication needs are likely to be phased in. These networks will require the use of higher-speed, IP-based networking technology that allows the bandwidth to be actively managed and optimized. The use of T-1/TDM technology, which may cost $500 to $700 per month, is also declining in the utility sector and being replaced by private fiber or other solutions.[118]

v. **Fiber optic communications systems.** Various forms of fiber optic communications systems are in use throughout the grid, primarily (but not only) in substation applications. The inherent bandwidth, noise immunity, and security associated with fiber are benefits, though it remains an expensive option due to the costs of laying private fiber any significant distance. [119] Construction costs associated with fiber optic installation vary widely depending on the installation environment.

vi. **Power line communications (PLC).** PLC solutions provide connectivity using existing power lines as the communications medium. Many different types of systems and terminologies are associated with this technology—and nearly as many standards. PLC systems make up a significant percentage of existing AMI systems in Europe, and PLC is being used in China and South Korea as well. In the US, PLC frequently has been deployed by cooperative utilities with

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[114] Navigant Research, *DER Management Technologies*, 4Q 2016

[115] Navigant Research, *Communications Technologies for DER Integration*, 1Q 2018

[116] Navigant Research, *Communications Technologies for DER Integration*, 1Q 2018

[117] Navigant Research, *Communications Technologies for DER Integration*, 1Q 2018

[118] Navigant Research, *Networking and Communications for Smart Grids and Smart Cities*, 3Q 2016

[119] Navigant Research, *Communications Technologies for DER Integration*, 1Q 2018

low meter density per square mile, where it is often the most cost-effective solution for AMI and DA applications.[120]

a. Due to relatively limited functionality and data speeds, PLC systems are seeing waning demand in North America, although PLC remains a commonly deployed system in the Pacific Northwest and Midwest. PLC is likely to find continued success in specific niches, such as in rural areas where the extended reach is valuable, as well as in emerging markets.[121]

b. PLC solutions remain the most cost-effective choice for some of these utilities, but increasingly, utilities are looking ahead to more advanced grid applications for which PLC may not be the ideal choice.[122]

vii. **RF-based mesh networks.** These networks have emerged as the leading technology for AMI deployments in North America. A mesh network forms a web-like network topology. Any node not in direct communication range of its target destination, such as a meter sending data to a concentrator, will have its data relayed by another node in the mesh (e.g., another meter).[123,124]

a. Effective mesh networks are self-configuring and self-healing. They automatically determine which nodes are in range and reconfigure when the topology changes, such as when a node is added or removed or an obstacle between two nodes is added or removed.[125]

viii. **RF point-to-multipoint (P2MP).** These systems use licensed radio spectrum allocations with greater allowed transmit power levels to enable communications between a centralized tower-based node and many meters (and other nodes) within the range of that tower.[126]

a. Private RF P2MP systems in North America leverage primary use US Federal Communications Commission licensing. As licensed spectrum, interference is much lower than in unlicensed, shared use frequencies. Licensed spectrum, however, can be expensive and difficult to obtain. Therefore, vendors of these private NAN systems usually acquire and manage the rights to this spectrum themselves, allowing the utility customers to use it without the associated initial costs or regulatory hassles.[127]

b. This technology has been successful across North America with over 11.5 million awarded endpoints according to Navigant Research's Global AMI Tracker 4Q17. Additionally, P2MP networks are currently being deployed across the northern region of the UK as a function of Sensus' major networking contract. Upon completion, this large-scale AMI network could potentially be leveraged for various DER applications, including distributed storage, solar, and wind.[128]

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[120] Navigant Research, *Communications Technologies for DER Integration*, 1Q 2018

[121] Navigant Research, *Communications Technologies for DER Integration*, 1Q 2018

[122] Navigant Research, *Networking and Communications for Smart Grids and Smart Cities*, 3Q 2016

[123] Navigant Research, *Communications Technologies for DER Integration*, 1Q 2018

[124] Navigant Research, *Networking and Communications for Smart Grids and Smart Cities*, 3Q 2016

[125] Navigant Research, *Communications Technologies for DER Integration*, 1Q 2018

[126] Navigant Research, *Communications Technologies for DER Integration*, 1Q 2018

[127] Navigant Research, *Communications Technologies for DER Integration*, 1Q 2018

[128] Navigant Research, *Communications Technologies for DER Integration*, 1Q 2018

ix. **Wi-Fi.** Wi-Fi is another aspirant to the smart grid communications market, primarily in distribution and/or AMI backhaul applications. In a mesh topology, Wi-Fi can provide robust wide area communications at a low cost, and such solutions have been deployed in numerous municipal utility smart grid deployments in the US. Generally, a Wi-Fi-based system may be more cost-effective in denser environments than a P2MP solution. In regard to DR communications, smart thermostats almost exclusively employ Wi-Fi communications.[129]

a. Several US utilities have deployed Wi-Fi in smart grid projects that cover AMI and DA. These include Avista Utilities, the city of Burbank Water & Power, DTE Energy, Duke Energy, Kansas City Power & Light, the city of Fort Collins (Colorado), the Public Service Company of Oklahoma, and Silicon Valley Power (SVP).[130]

b. Wi-Fi technology can be used for the charging station NAN to transmit data from the charging station to the collector or gateway, where the data is then transmitted over the WAN to the operations center. By gathering the data from multiple stations in a single gateway, the host can lower the number of cellular accounts needed for the location and dramatically reduce the service charges per month.[131]

c. The addition of Wi-Fi components to a charging station can add between $50 and $100 per station in costs.[132]

x. **Low power wide area (LPWA).** LPWA networks are set to play an important role in expanding the possibilities for Internet of Things (IoT) in cities, and although there has not been a great deal of utility use to date, there are those exploring this option. LPWA networks are targeted at applications that have low or infrequent data throughputs but benefit from low cost modems ($5-$10), cheap connectivity (a service cost of a few dollars per year), long-range access, deep penetration, and an extended battery life for devices (around 10 years on a standard battery).[133] A comparison of LPWA technologies is provided in Table 16.

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[129] Navigant Research, *Communications Technologies for DER Integration*, 1Q 2018

[130] Navigant Research, *Communications Technologies for DER Integration*, 1Q 2018

[131] Navigant Research, *Communications Technologies for DER Integration*, 1Q 2018

[132] Navigant Research, *Communications Technologies for DER Integration*, 1Q 2018

[133] Navigant Research, *Communications Technologies for DER Integration*, 1Q 2018

Table 16. LPWA Technologies Comparison

Technology	Proprietary/ Open Standard	Service Cost/Node Cost	Maturity	Spectrum Band	Battery Life	Max Data Rate	Packet Size
SIGFOX	Proprietary	$1/year – several $/month/ **~$2-$3**	Deployed widely in Europe; deploying in 29 countries worldwide	Unlicensed 900 MHz	~12 years	~100 bps	12 bytes
RPMA	Proprietary	~$1-several $/month/ **~$10-$15**	Deploying	Unlicensed 2.4 GHz	~5-10 years	~1 kbps	Flexible (6 bytes-10 kbytes)
LoRa	Open	$1/year – several $/month/ **~$5-$10**	150+ trials and deployments worldwide	Unlicensed 900 MHz (US) 863-870 MHz (Europe) 779-787 MHz (China)	~5-10 years	~1-50 kbps	10-100s of bytes
NB-IoT	Open (private spectrum/ cellular operators only)	<$1/month/ **~$5 (target node price)**	2018 launch	LTE cellular bands	~10 years	~170-250 kbps	N/A
LTE-Cat-M1	Open (private spectrum/ cellular operators only)	$1-several $/month/ **~$15 (target node price)**	Mid-2017 launch	LTE cellular bands	~10 years	~1 Mbps	100-1,000 bytes typical
Milli 5	IEEE 802.15.4g	~$1-several $/month/ **~$10-$15**	Commercially available	Unlicensed 900 MHz	Up to 20 years	~50 kbps	N/A
EC-GSM-IoT	Open (cellular operators only)	$1-several $/month/ **~$10 (target node price)**	2017 launch	GSM cellular bands	~10 years	100s kbps	N/A

Source: Navigant Research

The various communications technologies are compared in Table 17 and Table 18.

Table 17. Smart Grid Communications Technologies, Relative Comparison

Technology	Bandwidth	Latency (Amt./Variability)	Reliability	Security
Leased Lines	Low	Low/Low	Medium-High	Medium
Fiber	High	Low/Low	High	High
PLC	Low	Medium/Medium	Medium	Medium
RF Mesh	Low	High/High	Medium	Medium
Wi-Fi Mesh	Medium-High	Medium/High	Medium-High	High
Private Pt2MPt	Low	Medium/Medium	Medium	High
WiMAX	Medium-High	Medium/Medium	Medium	High
2G/3G Cellular	Low	Medium/Medium	Medium	Medium
4G	Medium-High	Medium/Medium	Medium-High	Medium
VSAT Satellite	Low-Medium-High	High/Medium	Medium-High	High

Source: Navigant Research

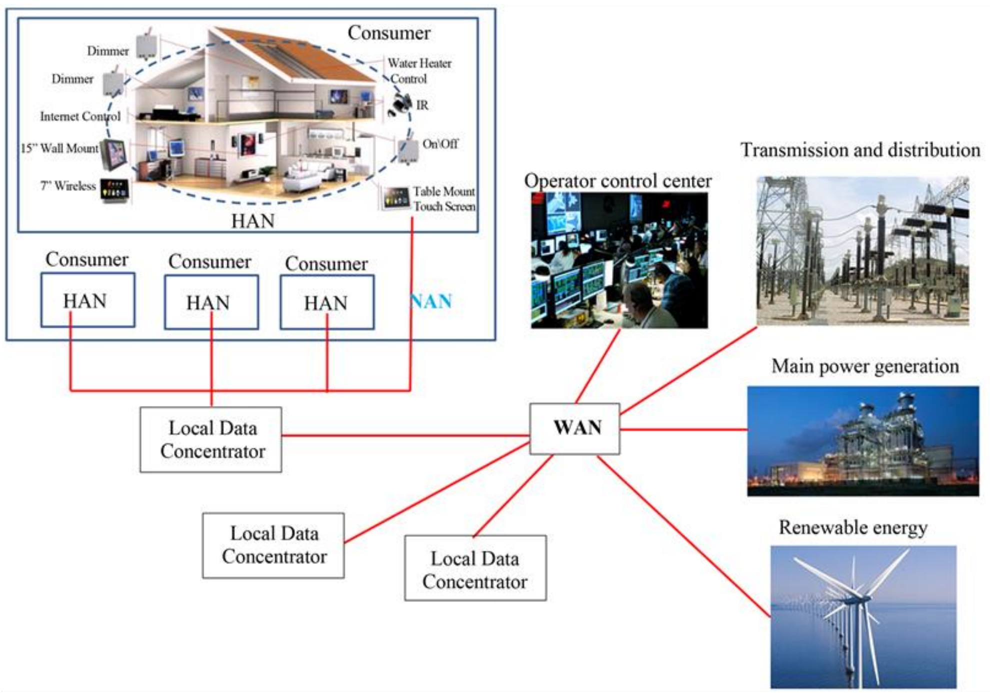
Table 18. Comparison of Communication Technologies for the Smart Grid

Technology	Standard/protocol	Max. theoretical data rate	Coverage range	Network		
				HAN/BAN/IAN	NAN/FAN	WAN
Wired communication technologies						
Fiber optic	PON	155 Mbps–2.5 Gbps	Up to 60 km			X
	WDM	40 Gbps	Up to 100 km			
	SONET/SDH	10 Gbps	Up to 100 km			
DSL	ADSL	1–8 Mbps	Up to 5 km		X	
	HDSL	2 Mbps	Up to 3.6 km			
	VDSL	15–100 Mbps	Up to 1.5 km			
Coaxial Cable	DOCSIS	172 Mbps	Up to 28 km		X	
PLC	HomePlug	14–200 Mbps	Up to 200 m	X		
	Narrowband	10–500 kbps	Up to 3 km		X	
Ethernet	802.3x	10 Mbps–10 Gbps	Up to 100 m	X	X	
Wireless communication technologies						
Z-Wave	Z-Wave	40 kbps	Up to 30 m	X		
Bluetooth	802.15.1	721 kbps	Up to 100 m	X		
ZigBee	ZigBee	250 kbps	Up to 100 m	X	X	
	ZigBee Pro	250 kbps	Up to 1600 m			
WiFi	802.11x	2–600 Mbps	Up to 100 m	X	X	
WiMAX	802.16	75 Mbps	Up to 50 km		X	X
Wireless mesh	Various (e.g., RF mesh, 802.11, 802.15, 802.16)	Depending on selected protocols	Depending on deployment	X	X	
Cellular	2G	14.4 kbps	Up to 50 km		X	X
	2.5G	144 kbps				
	3G	2 Mbps				
	3.5G	14 Mbps				
	4G	100 Mbps				
Satellite	Satellite Internet	1 Mbps	100–6000 km			X

Based on data rate and coverage range, several networks would qualify for multiple area network applications.

xi. **Network** <u>infrastructure.</u> Smart grid communications are usually structured around three major networks: Home Area Network (HAN), Neighborhood Area Network (NAN) and Wide Area Network (WAN). Figure 40 shows the coordination of the three area networks. Smart appliances and smart meters can be connected to a HAN via ZigBee, Wi-Fi, and Ethernet technologies to enable home automation and building energy management. Each HAN transmits information to NANs, which can be implemented with PLC, fiber optic, ZigBee mesh, Wi-Fi, and cellular technologies. NANs aggregate and store energy consumption data across multiple buildings to support applications such as smart metering, demand response and distribution automation. WANs consist of multiple NANs and support applications such as wide-area control, monitoring, and protection, requiring greater bandwidth, higher transmission frequency, and larger coverage distance. WANs can be implemented with cellular, fiber optic, and WiMAX.[134] Each area network level has different data rate and coverage range requirements, and these are represented in Figure 41.

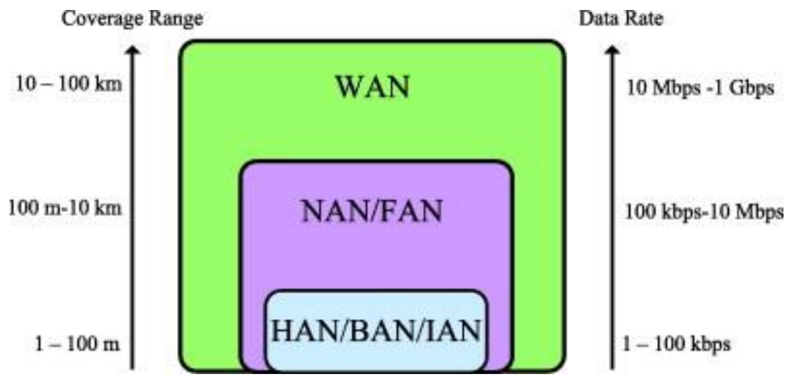
Figure 40. Representation of HAN, NAN, and WAN



Source: Smart Grid Communications Technologies, Journal of Power and Energy Engineering

[134] *Communication network requirements for major smart grid applications in HAN, NAN and WAN, Computer Networks* (2014)

Figure 41. Variation in Data Rate and Coverage Range



Source: Communication network requirements for major smart grid applications in HAN, NAN and WAN, Computer Networks

Discussion of Advantages and Disadvantages

Table 19. Advantages and Disadvantages of Various Communications Tech

Technology	Advantages	Disadvantages
Fiber	Fast and under operator control	Very expensive to lay new fiber
Power Line Communications	Inexpensive, good to low customer density areas	Limited performance for advanced applications
T1 Line	Effective and under operator control	Legacy, may not have capabilities required by future grid
LTE	Low latency, good coverage	Built on telecom provider networks; may have high costs
5G	Upcoming standard; high performance	Still under development; coverage currently limited
Public Cellular Connections	Simple and well-developed	Expensive; devices may not be robust enough for grid reliability
Mesh Networks	Robust and self-healing	Reliability good for customer data transfer but may not be sufficient for operations
Point to Multi-point	Centralized control, sufficient performance	Limited available radio spectrum; also desirable for other applications
Wi-Fi	Cost-effective; widely established technology	Performance concerns for critical operations
Low Power Wide Area	Cost-effective; high numbers of devices	Limited applications to date; primarily for infrequent communications

Description of Technical Specifications and Requirements

Criteria for communications requirements by attribute are presented in Table 20.

Table 20. Smart Grid Communications Requirements

Attribute	Requirements	Comments
Bandwidth	Low, Medium, or High	**Low:** <250 kbps; often as low as <20 kbps **Medium:** 250 kbps up to ~1 Mbps **High:** >1 Mbps Note that this definition attempts to generally convey the typical end-to-end throughput required as opposed to individual link speeds; this is meant as a loose and relative measure
Latency	Loose, Medium, or Tight	**Loose:** Can tolerate high latency in absolute terms and high variability in the latency **Medium:** Has some relative limits to the absolute amount or the variability of end-to-end latency **Tight:** Strict requirements for the absolute amount and/or the variability of the end-to-end latency
Reliability	Low-High	**Low:** No significant operational harm would result if connectivity were lost for a significant amount of time (minutes to a few hours) **Medium:** Operations would be affected but are unlikely to result in loss of service or a similar effect if connectivity were lost for a significant amount of time (minutes to a few hours) **High:** Significant harm might occur if connectivity were lost for a significant period of time Note that these are relative characterizations, as no one would want an unreliable communications link; these characterizations generally translate into how much investment should be made in communications link redundancy
Security	Medium-High	**Low:** No significant operational harm would result if link were intentionally compromised (i.e., data obtained or spoofed) **Medium:** Significant but limited harm would result if link were intentionally compromised (i.e., data obtained or spoofed) **High:** Highly visible and widespread harm could result if link were intentionally compromised (i.e., data obtained or spoofed) Note that these are relative characterizations, as no one would want an inherently insecure link

Source: Navigant Research[135]

i. **Security Controls**

a. Because substations can be concentration points for smart grid communications, they must have especially strong communications security. Often, several means for telecommunications exist to enter a substation (e.g., AMI, transmission, distribution, hotspots), coupled with a high bandwidth circuit back to the utility's central office.[136]

b. Device Controllers - Device controllers are devices, such as PLCs, RTUs, intelligent electronic devices, and data concentrators that communicate directly with sensors, flow meters, and other individual sources of process and distribution data. Device

135 Navigant Research, *Networking and Communications for Smart Grids and Smart Cities*, 3Q 2016

136 Navigant Research, *Cybersecurity for the Digital Utility*, 3Q 2017.

controllers may be brand new, with the capability to run modern cybersecurity, or old and run serial protocols, with no security ability at all. [137]

c. Utilities add Wi-Fi hotspots at substations so that their technicians can access central site software easily. Those Wi-Fi connections should use virtual private networks (VPNs) to ensure encrypted communications and secure data transfer from remote locations to core operations. [138]

d. Utilities are facing challenges with legacy RTUs running on ultra-low bandwidth networks, which make substation monitoring and standards compliance more difficult.[139]

ii. **DER Communications Basic Security Controls**[140] NREL and Sandia National Lab are leading a working group on DER cybersecurity standards, and presented the following requirements for DER communications:

a. Enforce role-based access controls.

b. Maintain network separation between IT, OT and Management networks.

c. Periodically update software security patches.

d. Encrypt selectively to minimize processing overhead.

e. Disable all unused ports to eliminate unauthorized access.

Recent and Current RDD&D Activities

A significant amount of DER Communications research has been previously conducted by EPIC projects as well as EPRI and the national laboratories. The Grid Modernization Laboratory Consortium (GMLC), a group of national labs coordinated through the Department of Energy and focused on general grid modernization, has also provided a significant amount of research in recent years. The GMLC efforts include high level DER communications strategy work, including: the Interoperability Strategic Vision and the Grid Sensing and Measurement Study. Across these different entities, key focus areas of DER communications research include:

i. **Advanced Functionality Demonstration.** Consists of projects that implement novel hardware configurations or testing network capabilities

ii. **Communications Protocols.** Consists of projects that define open access protocols for communicating between grid operators, third party providers, and end devices

iii. **Device Functionalities.** Consists of projects that identify functional and non-functional requirements for DER communications capabilities.

iv. **Cybersecurity.** Consists of projects that describe cyber-security requirements for DERs by actors, logical interfaces, and logical interface categories.

[137] Navigant Research, *Cybersecurity for the Digital Utility*, 3Q 2017.

[138] Navigant Research, *Cybersecurity for the Digital Utility*, 3Q 2017.

[139] Navigant Research, *Cybersecurity for the Digital Utility*, 3Q 2017.

[140] *DER Cybersecurity Standards*, SNL and NREL (2017)

The overarching goals of the research reviewed include:

i. Provide support for integration of many novel, low-cost sensors.

ii. Provide support for the incorporation of new data streams.

iii. Provide support for real-time data management and exchange frameworks.

iv. Provide support for maintenance of security standards through open protocols.

Work continues at the federal level to support the definition and direction of high-level communications architecture development, while state- and utility-level research focuses on testing and field implementation.

Metrics developed to assess the strength of DER communications networks include:

i. Number of connected devices.

ii. Total throughput of data per customer.

iii. Latency of communications between the grid operator and end nodes.

Additional metrics are presented in Table 21.

Table 21. Potential DER Communications Metrics

Communications Metrics	Unit
Number of utility SCADA monitoring points	count
Number of two-way utility monitoring and control points	count
Number of third-party grid sensors	count
Number of communications-enabled Smart Inverters	count
Installed capacity of communications-enabled Smart Inverters	MW
Number of communications-enabled Smart Buildings	count
Total load of communications-enabled Smart Buildings	MW
Number of certified devices (OCF, UPnP, AllJoyn)	count
Network cost per customer	$

A selection of DER communications research and demonstration projects is presented below. A full list of identified work is contained in the appendices.

i. **Fiber to the Meter (FTTM).** The most prominent example of a successful FTTM) deployment is that of Electric Power Board in Chattanooga, Tennessee. The use of fiber also enables utilities to potentially provide triple play services (voice, video, and data) to its customers.[141,142]

ii. **Germany Smart Inverter Retrofit.** Regarding smart inverters, Germany may be the most active market in the world, as the country is in the midst of a $300 million project to retrofit inverters on 315,000 solar systems, coming to a cost of $952 per system. Germany is taking this bold step in response to concerns over increased voltage fluctuations that threaten to destabilize the country's electric grid.[143]

iii. **Green Mountain Power LTE for smart grid applications.** In one early example of the use of private LTE for smart grid applications, Vermont-based Green Mountain Power partnered with Vermont Telephone Company, a regional incumbent local exchange carrier with a 700 MHz spectrum license, to share LTE network buildout costs. This partnership between a local utility and an incumbent local exchange carrier may serve as a model for other electric utilities, especially in rural and sparsely populated areas where a LTE communications network may be desired, but funding is unavailable for the capital construction costs and/or if the area lacks an adequate commercial revenue base.[144]

iv. **APS' Solar Partner Program.** The utility deployed 1,598 smart inverters to assess the effect of using this technology to incorporate solar PV and energy storage throughout the distribution system. Smart inverters were deployed across Verizon's public cellular and Landis+Gyr's AMI communications networks, the latter of which employs RF mesh communications. [145]

v. **SRP.** In 2015, Phoenix, Arizona-based SRP acquired the Phoenix-Mesa economic area license #158, covering an estimated 4.3 million population units (POPs) in central Arizona. The license includes two 1 MHz swaths of spectrum at 757 MHz-758 MHz and 787 MHz-788 MHz. Private equity firm Access Spectrum was the seller. The company, along with Columbia Capital and Beach Point Capital, has been marketing similar licenses nationwide for $0.75/MHz POP (POPs x MHz). This implies that SRP made an investment in the $6.5 million range for the license. Relatively speaking, for a company with annual revenue of roughly $3 billion, this is a rather small investment—but one with potentially great upside.[146]

Critical Success Factors

Description of Commercial Readiness Level, Including Current Market Participation

i. The cost of retrofitting is significantly higher than deploying smart inverters as part of new DG deployments. With smart inverters costing around $150 for new deployments, the cost benefit considerations against retrofitting are clear. To avoid the economic pitfalls experienced by Germany, and its electric customers, regulators in the US and beyond need to ponder the

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[141] Navigant Research, *Communications Technologies for DER Integration*, 1Q 2018

[142] Navigant Research, *Networking and Communications for Smart Grids and Smart Cities*, 3Q 2016

[143] Navigant Research, *Communications Technologies for DER Integration*, 1Q 2018

[144] Navigant Research, *Communications Technologies for DER Integration*, 1Q 2018

[145] Navigant Research, *Communications Technologies for DER Integration*, 1Q 2018

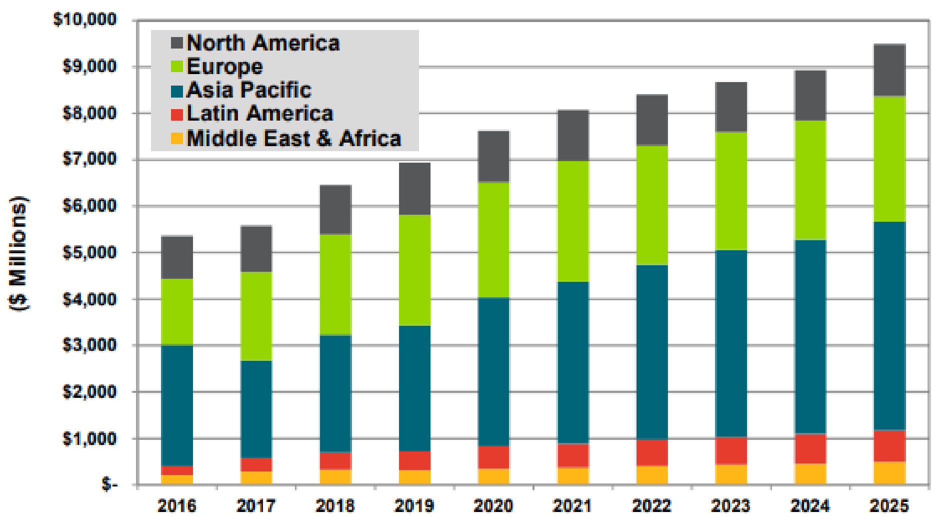
[146] Navigant Research, *Networking and Communications for Smart Grids and Smart Cities*, 3Q 2016

potential long-term benefits of incentivizing/mandating smart inverters as the penetration of DG continues to climb.[147]

ii. Navigant Research estimates that the utility market for communications nodes, infrastructure, and services will exceed $5.3 billion in 2016 (reference Figure 42). Note that these forecasts do not include the cost of devices into which nodes are integrated, but rather, the cost of the nodes alone. Meter nodes, distribution feeder automation device nodes, sensor nodes, collectors, base stations, towers, and substation equipment, including switches, routers, network interface cards, and network security devices, are all included in the equipment forecasts for smart grid applications.[148]

   a. Incremental utility investments in support of smart city applications are expected to grow at a CAGR of 34.0% between 2016 and 2025, when communications equipment and services for these application domains will reach $93.3 million.[149]

Figure 42. Total Utility Spend for Smart Grid and Smart City Networking and Communications by Region, World Markets: 2016-2025



Source: Navigant Research[150]

iii. Figure 43 presents the Navigant Research industry leaderboard for the AMI and/or DA networking space. Itron received high marks in both the Vision and Product Portfolio criteria for its patented Riva technology, which combines multiple protocols for dynamic selection of the most advantageous transport platform for the situation. Riva combines PLC, RF mesh, and Wi-Fi on the same chip, allowing for a flexible platform that can transition from urban to rural environments.[151]

Silverspring Network's (now iTron) IPv6-enabled platform has been used for approximately 25 million field devices worldwide (including street lights), giving it one of the larger market shares for

[147] Navigant Research, *Communications Technologies for DER Integration*, 1Q 2018

[148] Navigant Research, *Networking and Communications for Smart Grids and Smart Cities*, 3Q 2016

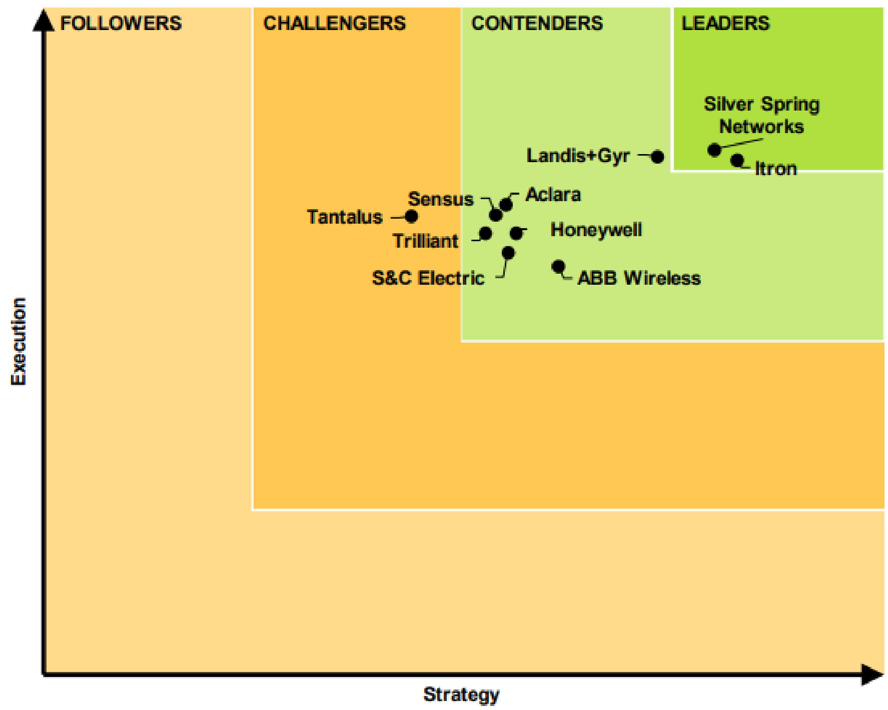
[149] Navigant Research, *Networking and Communications for Smart Grids and Smart Cities*, 3Q 2016

[150] Navigant Research, *Networking and Communications for Smart Grids and Smart Cities*, 3Q 2016

[151] Navigant Research, *Navigant Research Leaderboard Report: Utility Field Area Networking*, 4Q 2016.

AMI communications providers. Its Gen5 technology boasts throughput of up to 2.4 Mbps, the fastest among the large RF mesh system providers. In 2016, SSN introduced its Milli 5 power optimized mesh technology, which guaranteed a 20-year battery life and provided a more cost-effective method for connecting battery-operated devices in the field. Its focus on optimized communications technologies resulted in high scores in the Technology and Product Quality criteria, although its Product Portfolio was narrower than some of its rivals.[152]

Figure 43. Navigant Research Leaderboard Grid



Source: Navigant Research Leaderboard Report Utility Field Area Networking

iv. There was little to no data on costs for the various technology types, likely due to the variability depending on project specifics. **Table 22** compares costs for various HEM network enabling technologies, showing that ZigBee is the most affordable.

Table 22. Comparison of Costs for Home Energy Management Network (2014)

Network	Cost
ZigBee	Chip: ~$2.75-$3.5/unit Cable: $0 Access point/switch: $0
Wi-Fi	Chip: ~$8-$16/unit Cable: $0 Access point/switch: $20-$50
Ethernet	Chip: ~$1-$13/unit Cable: ~$1/meter Access point/switch: $20-$50

[152] *DER Cybersecurity Standards*, SNL and NREL (2017)

Source: Cost-Effective and Reliable Communication Infrastructure for Smart Grid Deployment, Prof. Saifur Rahman

Federal and/or State Policy Influences

i. **California Regulatory**

a. **Rule 21.** Under the revised Rule 21, it is mandated that all new inverters be capable of communicating with the utility using Institute of Electrical and Electronics Engineers (IEEE) Standard 2030.5 beginning in March 2018, or 9 months after the release of an industry recognized certification test standard (SunSpec or otherwise).[153]

b. **Data Privacy.** California requirements on personally identifiable information extend to customer interval data. Ensuring that communications remain secure is integral to providing DER services over internet rather than utility network channels.[154]

ii. **Standards Organizations**

a. **IEEE Standards.** Outside of Germany, and a few progressive US states, there has been little in the way of legislation around DER communications. To achieve proper economies of scale, some in the industry hope to see an adjustment to IEEE inverter standards that would mandate the installation of smart inverters for all new distributed solar projects.[155]

b. **California Inverter Standards.** Standards will also need to be established regarding utility data access and control of smart inverters during periods of grid disturbance, also referred to as reliability events. The majority of DER assets today are non-utility owned, meaning that adequate compensation and coordinate schemes must be developed in return for access to data from DER. A set of communications standards for Smart Inverters are being developed by the Smart Inverter Working Group.[156]

Assessment of Barriers to Further Adoption

Both distribution system operators and third parties are making advances in the deployment of advanced communications technologies; the difficulties arise in an efficient integration of all of the new technologies through appropriate communications protocols and a clear architecture to assign features and responsibilities to the various actors.

Cost

Attribution of Costs of Enabling Platform. Distribution communications assets are required for almost all grid modernization use cases, but it is difficult to justify the cost for a limited number of these use cases. This also makes staged implementations difficult, preferring large-scale unified implementations.

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153 Navigant Research, *Communications Technologies for DER Integration*, 1Q 2018

154 *Assembly Bill No. 1274*, California Legislature (2014)

155 Navigant Research, *Communications Technologies for DER Integration*, 1Q 2018

156 *SIWG Phase 3 DER Functions*, CPUC (2017)

Coordination

Limited assignment of cybersecurity responsibilities. While not directly a barrier to future adoption, devices may be coming on to 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, be they electric vehicles, end load automation portals or smart inverters. Finding an effective way for this data to be shared with the distribution grid operator could greatly increase the value and reduce the concerns of the operator, allowing greater adoption.

Lack of Clear Architecture. On one end of the spectrum, a centralized approach could require all participants in the future energy system obey the same standards and protocols, from electric vehicle charging systems to customer end loads to distributed generation. This would provide clarity, but significantly limit flexibility and interoperability between different types of devices. On the other end, translational protocols could be allowed that provide different types of end devices a *lingua franca*. This would enable many different devices types to develop separately, but could also lead to overwhelming complexity in the future.

Identified RDD&D Needs

Actions to Bring Key, High Impact Technologies and Strategies to Market

i. **Near-term.**

a. Third party communications capabilities *(TD&D).* Assess utility operations groups ability to efficiently communicate at scale with third party devices over a range of locations and conditions.

b. Large-scale capabilities of AMI networks *(TD&D).* Test capabilities of AMI networks to transmit large quantities of interval data. Consider the potential for analytics to be performed at the edge of the communications networks so that the full raw datasets are not required to be transmitted.

c. Testing of End Node Wi-Fi Communications Resilience *(TD&D).* Conduct research on how to make DER operations and controls resilient to end node communications. Many connected end-use loads use customer wireless networks for communications, which could result in lower reliability than usual for grid communications.

d. Addressing Home Area Network (HAN) Interference *(ARD).* The dense deployment of wireless HANs in urban areas can lead to issues with inter-HAN interference, and multiple devices within a HAN can cause intra-HAN interference.[157] Additional research is needed to understand these feedback mechanisms and develop mitigation strategies.

ii. **Mid-term.**

a. Standards Development Facilitation *(TD&D).* Standard communication protocols that can "speak" to each utility and the CAISO balancing authority should be developed to ensure that installed smart inverters do not become immediately obsolete upon adoption of a communication standard. Identifying the IT infrastructure needs and comparing upgrade costs to the benefits of Smart Inverter

[157] *Smart Grid Communication Technologies*, Journal of Power and Energy Engineering ((2018)

communication will allow utilities to target areas economically optimal for communication infrastructure upgrades. Privacy and cyber security concerns should also be addressed.

b. Coordinate Communications Standards across DERs *(TD&D).* Implement a pilot coordinating communications between solar or storage smart inverters and electric vehicle chargers to test intra-DER communications requirements.

iii. Long-term.

a. No long-term needs yet identified.

Section 6: Distributed 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 bi-directional distributed network controlled in parts 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 control of these distributed resources in a way that efficiently integrates them into the existing grid. The bulk of distribution grid management will rightfully fall under utility control, with grid management research correspondingly within utility EPIC research programs. However, a discussion of Distribution Grid Management is included in order identify any potential collaborative research areas.

Technology and Strategy Review

Characterization of Each Baseline Type of Technology and Strategy

i. **Sensing and Control Assets.**

a. Smart Meters. Originally designed to provide utilities with the sum total of the electric current that flowed through the meter over a given time period, these new meters are often equipped with sensing and measurement technology designed to increase system visibility and reliability. For example, many new AMI meters are equipped with software that enables the meter to locate outages at a high spatial granularity.[158] California was one of the first states to perform a territory-wide advanced metering infrastructure rollout, and has full coverage across non opt-out customers.

b. Line Sensing. Line sensors like Distribution Line Monitors (DLM) give utilities remote monitoring and condition assessment of devices and provide significant cost reductions over traditional monitoring techniques (line crews and bucket trucks). Line sensors come in many shapes and sizes and are equipped with a variety of sensing and measurement, data interpretation, and communication capabilities. Some sensors are mounted directly on distribution lines, while others can collect data without contact. DLMs are capable of feeder visualization, distribution substation load monitoring, and fault detection and analysis.[158]

c. Substation Monitoring. Substation assets can be equipped with intelligent controls, dynamically responsive communications, and remote and/or automated operation capabilities.

d. Distribution Transformer (DT) Monitors. DT monitors provide real-time intelligence for vault, pad-mount, and pole-top DTs. These sensors are particularly prevalent in North America due to the aging distribution infrastructure and can help to prolong the useful life of transformers and other system assets. DT sensors are often very sophisticated, which will result in most of the DT instrumentation being installed as an integrated device, rather than modular standalone sensors. [158]

e. Synchrophasor Technology. Synchrophasor technology uses phasor measurement units (PMUs) to measure voltage and current waveforms and calculate phasors at high speeds

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[158] Navigant Research, *T&D Sensing and Measurement Market Overview*, 1Q 2018.

in real-time, time-stamping those measurements against a time source such as the Global Positioning System (GPS). PMU data can be used for real-time situational awareness and operator decision support, generator model validation, forensic event analysis, and to provide additional visibility into system stability and oscillations.[159]

f. Legacy distribution grid assets. Equipment that has traditionally been used to manage and protect the grid (e.g. voltage regulators, capacitors, circuit breakers, relays, etc.) was designed for upstream power flow from centralized generation. These assets will need to be upgraded or replaced in order to mitigate equipment fatigue and/or malfunction issues that would be caused by high penetrations of variable DERs.

ii. Analytics

a. DER Analytics. Provides analysis of grid and DER data, to elicit insights on the state of the grid, and for forecasting and planning purposes in a DER-heavy environment. DER analytics support utilities in planning and forecasting, or micro-forecasting, DER. DER can cause tremendous disruptions to traditional supply and demand patterns and heavily affect the processes of resource, capital, and operational planning. Utilities need to be able to understand and forecast DER-affected demand and DER output, as well as understand and predict its locational effects on the grid in order to effectively perform these processes.[160]

b. Grid Operations Analytics. Grid operations analytics is a broad field that includes use cases for grid management and planning, system control, and outage management. Applications in this category include outage detection and prevention, damage assessment, system modeling, power quality optimization, real-time network operations and grid balancing, DER integration, state estimation, AMI network visualization, meter connectivity, outage notification, root cause analysis, and damage assessment. Some of these require data- and analytics-based decision-making beyond those supported in DMSs, OMSs, and meter data management and network management systems.[161]

c. Demand-Side Analytics. Demand-side analytics include applications for integrated demand-side management (DSM), DER information, and load analysis. Applications include DSM program management, load disaggregation, customer segmentation, pricing and DER programs (for energy efficiency, DR, energy storage and distributed generation), geo-targeting for grid-edge solutions, DER load forecasting, and demand analytics.[162]

iii. Distribution Management Systems (relating to DER integration).

a. Advanced Distribution Management System (ADMS). This platform usually comprises distribution management system (DMS) applications, supervisory control and data acquisition (SCADA), outage management system (OMS), and distributed energy resource management system (DERMS), maintaining a single as-operated model of the distribution network that is based off of the as-built model (typically from a geographic information system [GIS]). [163]

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[159] *Electric Power System Report*, PNNL (2017)

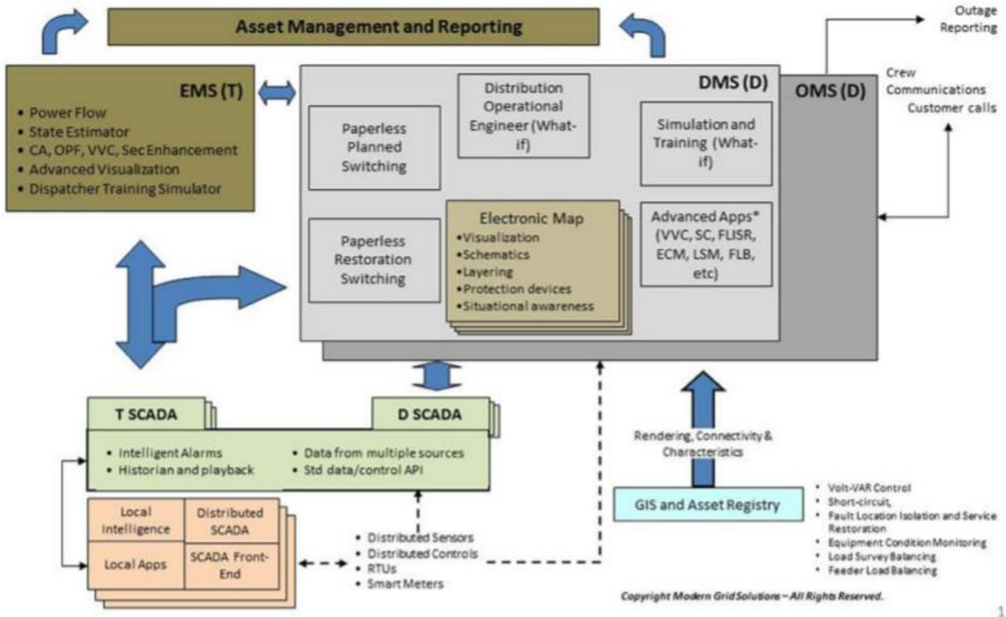
[160] Navigant Research, *Market Overview: DER Management Technologies*, 4Q 2016.

[161] Navigant Research, *Market Data: Smart Grid IT Systems*, 1Q 2017.

[162] Navigant Research, *Market Data: Smart Grid IT Systems*, 1Q 2017.

[163] Navigant Research, *Market Data: Smart Grid IT Systems*, 1Q 2017.

Figure 44. Conceptual ADMS Architecture



Source: Modern Grid Solutions

b. Supervisory Control and Data Acquisition (SCADA). SCADA refers to computer-based control systems that generally include specific types of sensing, control, and computing devices connected by some form of local or wide area network communications. Historically, SCADA solutions have been widely used within the HV transmission system, down to the substation where HV is stepped down to medium voltage. Increasingly, the utility deployment of SCADA and the requisite connectivity are now extending to distribution substations in order to improve visibility throughout the distribution network and to support a variety of DA applications such as Fault Location Isolation and Service Restoration (FLISR) or IVVC. Distribution SCADA communicates with substation Remote Technology Units (RTU, which are controllers), field intelligent electronic devices (IEDs), large DER and micro-grid controllers, and with large customer energy management systems (EMS). [164, 165]

c. DER Management Systems (DERMS). DERMS are monitoring and control systems that enable optimized control of the grid and DER (to the extent that a utility may be able to dispatch and control DER). To minimize disruptions and the presence of phantom loads, utilities need to manage the grid more proactively. Common use cases include Volt/VAR optimization (VVO), power quality management, and the coordination of DER dispatch (when possible) to support operational needs. DERMSs may include DR, but may also include resources like distributed generation (DG) and energy storage. [166]

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[164] Navigant Research, *Market Data: Smart Grid IT Systems*, 1Q 2017.

[165] *Distribution Grid Management,* EPRI (2010)

[166] Navigant Research, *Market Overview: DER Management Technologies*, 4Q 2016.

d. Demand Response Management System (DRMS). Demand response management systems (DRMSs) have been developed to help utilities manage their DR programs and improve program ROI. In general, it is a system that has a combination of DR program enrollment, device tracking, forecasting, dispatch, data communications, and settlement capabilities. It is also important to distinguish DRMSs from distributed energy resources management systems (DERMSs).[167]

e. Transmission-Distribution (T-D) Coordination. T-D "interfaces" are substations where the transmission and distribution grids interconnect. Coordination between system operators (TSO and DSO) is crucial to guarantee an efficient use of the flexible services offered by DERs.[168,169]

Discussion of Advantages and Disadvantages

Table 23. Advantages and Disadvantages of Select Grid Management Technology

Strategy	Advantages	Disadvantages
Sensing and Control Assets	• AMI supports two-way communication (automated meter reading (AMR) does not). Non-contact distribution line sensors, such as electromagnetic frequency sensors, have the ability to be deployed by both a utility inside the right-of-way, and by a third-party vendor outside of the right-of-way without diminishing accuracy of sensor data. This enables a simplified deployment process. • Non-contact distribution line sensors are typically less expensive, easy to install, and require less maintenance. [158, 170]	• Increased ratepayer costs, complexity of integration
Analytics	• Customer-Adoption Modeling helps account for many of the factors neglected in traditional DER forecasting, including the cost and performance of DERs, incentives, customer retail rates, peer-effects, and customer demographics.[171]	• Increased ratepayer costs, complexity of integration

[167] Navigant Research, *Market Data: Smart Grid IT Systems*, 1Q 2017.

[168] *Coordination between transmission and distribution system operators in the electricity sector: A conceptual framework*, Utilities Policy, Vol 50 (2018)

[169] *Coordination of Transmission and Distribution Operations in a High Distributed Energy Resource Electric Grid*, More Than Smart (2017)

[170] *Electromagnetic Sensors for Measurements on Power Lines*, Washington State University (201

[171] *Forecasting load on the distribution and transmission system with DERs,* LBNL (2018)

Strategy	Advantages	Disadvantages
Distribution Management Systems	• The ability for DERMS to operate independent of DMS allows operation at a much more granular level, where human decision-making is too slow. • ADMS integrates operations across numerous systems and applications that are typically isolated or, at best, loosely coupled in traditional DMS systems.[172]	• Increased ratepayer costs, complexity of integration

Description of Technical Specifications and Requirements

Functional and non-functional requirements of grid management technologies are usually determined by the utility using industry best-practices. Some features include:

i. **Sensing and Control Assets**

 a. Sensor Technology Recommendations

  i. Grid topology sensing

  ii. Inexpensive installation

  iii. Capable of lasting a day or two for without grid power [173]

 b. Electrical Measurement Requirements

  i. Fast waveform sampling

  ii. Magnitudes and phases (unbalanced)

  iii. High precision (small phase differences)

  iv. Timing/synchronization[172]

 c. Data Requirements

Table 24. Data Requirements for Protection, Control, and Monitoring Applications.

Application	Typical data size (bytes)	Typical data sampling requirement	Latency	Reliability (%)	Communication technologies
Wide-area protection					
Adaptive islanding	4–157	Once every 0.1 s	<0.1 s	>99.9	Wired:
Predictive under frequency load shedding		Once every 0.1 s	<0.1 s	>99.9	– Fiber optic
Wide-area control					
Wide-area voltage stability control	4–157	Once every 0.5–5 s	<5 s	>99.9	Wireless:
FACTS and HVDC control		Once every 30 s–2 min	<2 min	>99.9	– WiMAX

172 *Advanced Distribution Management Program*, SmartGrid (2016)

173 *Advanced Distribution Management System Testbed Development*, NREL (2017)

Application	Typical data size (bytes)	Typical data sampling requirement	Latency	Reliability (%)	Communication technologies
Cascading failure control		Once every 0.5–5 s	<5 s	>99.9	– Cellular
Precalculation transient stability control		Once every 30 s–2 min	<2 min	>99.9	
Closed-loop transient stability control		Once every 0.02–0.1 s	<0.1 s	>99.9	
Wide-area power oscillation damping control		Once every 0.1 s	<0.1 s	>99.9	
Wide-area monitoring					
Local power oscillation monitoring		Once every 0.1 s	<30 s	>99.9	
Wide-area power oscillation monitoring		Once every 0.1 s	<0.1 s	>99.9	
Local voltage stability monitoring		Once every 0.5–5 s	<30 s	>99.9	
Wide-area voltage stability monitoring	>52	Once every 0.5–5 s	<5 s	>99.9	
PMU-based state estimation		Once every 0.1 s	<0.1 s	>99.9	
Dynamic state estimation		Once every 0.02–0.1 s	<0.1 s	>99.9	
PMU-assisted state estimation		Once every 30 s–2 min	<2 min	>99.9	

Source:Communication network requirements for major smart grid applications in HAN, NAN and WAN, Computer Networks

d. Standards

i. IEC 61850 is an international standard defining communication protocols for intelligent electronic devices at electrical substations.

ii. Distribution Management Systems

a. Optimal ADMS operation.

i. The distribution grid needs to have a significant penetration of multi-functional Smart Meters available to frequently measure, store, and transmit kW, kvar, high accuracy Volts, voltage sags and swells, “Last Gasps”, and higher harmonics data. The meters also serve as gateways for two-way communications, enabling DR and control of customer-side DERs, ES, and PEVs.[174]

b. IEEE 1547.

i. Existing integration standards, including IEEE 1547, regulate the use of behind the meter DER as an ADMS application, or in integration with DERMS.

c. Transmission/Distribution coordination requirements.

[174] *Distribution Grid Management,* EPRI (2010)

i. DER data is required to be aggregated for each substation with indication of the mix of DERs and their capabilities.

ii. Default equivalent impedances must be established for various distribution grid types that can be used to choose adequate parameters for, e.g., WECC's PVD1 model for distributed PV systems.

iii. Consideration for relevant interconnection performance requirements based on national or regional standards.

iv. Development of distributed energy resources stability models and their voltage and frequency trip parameters; the regionally specific parameters Vt0, Vt1, Vt2, and Vt3.[175]

Recent and Current RDD&D Activities

There has been a significant amount of research regarding distribution grid management. Most of the research covers topics in advanced management systems, connected distributed resources, communication protocols, and enabling technologies.

- **Advanced Management Systems.** Consist of projects testing the implementation of advanced distribution management systems and aggregate building management systems.
- **Connected Distributed Resources.** Consist of projects aimed at implementing systems that coordinate the deployment of distributed resources, specifically smart inverters and battery storage
- **Communication Protocols.** Consist of projects testing standardized and open-source management systems (i.e. IEEE 2030.5)
- **Enabling Technologies.** Consist of projects, private business models, and research identifying and testing technologies that would enable robust and automated distribution grid management

The projects reviewed consisted of research in a variety of different topics. Research goals included: quantifying the cost-benefits of distributed system operation, matriculating privately-owned and utility-owned connected devices into the management framework, standardizing open-source communication platforms, and developing robust semi or fully automated management systems.

[175] *DER Connection Modeling and Reliability Considerations*, NERC (2016)

Figure 45. Potential Grid Management Metrics

Grid Management Metrics	Unit
Flexible load bids by aggregator/third party	MW/MWh
Total connected devices in territory	count
Number of DER customers participating in grid management	count
Percent distribution load visible to operator	percent
Percent of circuits with automated switches	percent
Data center throughput per connected device	bps/device
Cost-benefit ratio of solutions	Ratio

A selection of distribution grid management research and demonstration projects is included below; a full list of identified work is contained in the appendix.

i. <u>Sensing and Control Assets.</u>

a. DLM.

i. <u>Pacific Gas and Electric Case Study.</u> In 2016, Pacific Gas and Electric (PG&E), one of the largest utilities in the US, completed an evaluation of line sensor capabilities in a partnership with Sentient Energy, testing line sensor communications, fault and other grid event identification, and DER integration management. Sentient reported reductions of PG&E customer outage minutes of nearly 20% with fully integrated line sensors. Notably, PG&E included its first rollout of DLMs in its 2017 General Rate Case.[176]

b. AMI.

i. <u>Central Lincoln People's Utility District.</u> Central Lincoln used AMI data to monitor end-of-line voltages for a substation involved in a CVR pilot program. This pilot resulted in 2 percent energy savings for all customers. Based on these results, Central Lincoln plans to implement the CVR program system-wide.[177]

ii. <u>Xcel Energy</u>. In 2016, Xcel Energy proposed a $500 million upgrade of Colorado's electric meter infrastructure. A foundational piece of its use case was the ability to use the smart meter infrastructure to communicate with the utility about the status of

[176] Navigant Research, *T&D Sensing and Measurement Market Overview*, 1Q 2018.

[177] *<u>AMI Summary Report</u>*, DOE (2016)

the system. Using these signals, Xcel will be able to more quickly identify where an outage is and send a repair crew to the location to reduce outage duration. Xcel's proposed plan also included the addition of integrated Volt/VAR optimization (IVVO) sensing in metering functionality.[178]

c. Synchrophaser Technology.

i. ARPA-e, UC Berkeley. Demonstrated micro phasor-measurement unit (PMU) in lab settings and tested 4G communications capabilities. Analyzed requirements and use cases for a broad spectrum of diagnostic and control applications. Working through issues with sources of noise, and with finding a ground source of truth field data without other complex instrumentation. Challenges to create algorithms able to translate measured data to insight on grid conditions.[179]

ii. Distribution Management Systems.

a. DERMS

i. PG&E Pilot. In August 2016, GE and Pacific Gas and Electric Company announced their collaboration on a pilot project to demonstrate effective DER management in California. The project focuses on maintaining reliable operation of the distribution network with the increase in DER such as solar PV and battery storage, and leveraged GE's Grid IQ Insight framework for visualization and situational intelligence. The DERMS performance was evaluated across seven use cases:

- Situational awareness
- Manage system capacity constraints
- Mitigate voltage issues with real power output
- Mitigate voltage issues with reactive power output
- Enable economic dispatch of DERs
- Provide operational flexibility
- Enable limited MUA of DERs[180]

The project identified scalability, standardization, valuation, market design, and resource valuation as opportunities for improvement in DERMS implementation.[181,182]

ii. NV Energy. ABB is piloting its DERMS with NV Energy in Nevada. Currently, the project is exploring distribution management use cases with the DERMS, including VVO, energy efficiency, and line loss reduction. The project is focused specifically on managing distributed solar PV generation equipped with smart inverters, with the goal of automating dispatch of these resources as well as incorporating first-generation PV systems (without smart inverters) into the system-wide model.[183]

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178 Navigant Research, *T&D Sensing and Measurement Market Overview*, 1Q 2018.

179 *Micro-Synchrophasors for Distribution Systems.* ARPA-e, (2015)

180 DER Coordination Pilot, PG&E & NREL (2018)

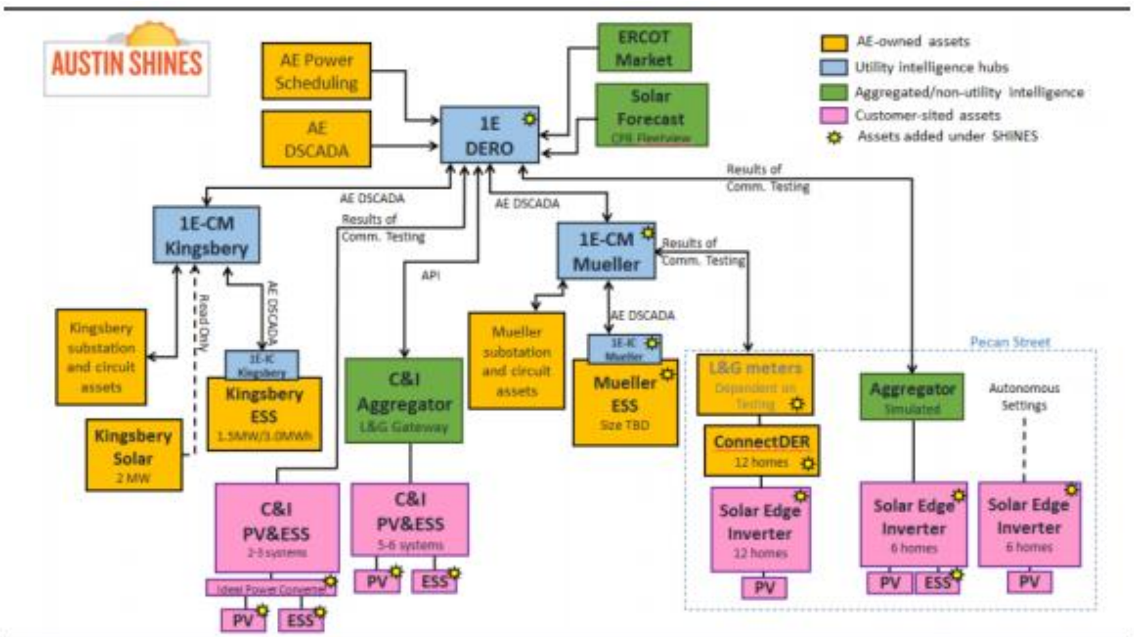
181 Navigant Research, *Market Overview: DER Management Technologies*, 4Q 2016.

182 DER Coordination Pilot, PG&E & NREL (2018)

183 Navigant Research, *Market Overview: DER Management Technologies*, 4Q 2016.

iii. Austin Energy PV+Storage. In January 2016, Austin Energy received $4.3 million in DOE funding under the SunShot Initiative/SHINES program to develop and demonstrate “a solution adaptable to any region and market structure that offers a credible pathway to a levelized cost of electricity (LCOE) of 14¢/kWh for solar energy when augmented by storage and other DER management options.” Austin Energy has procured a DERMS solution for the multiyear project, as well as local controls for storage modules from Doosan GridTech (formerly 1Energy). The company is in the process of integrating Doosan GridTech’s DER Optimizer (DERMS) directly with its recently installed ADMS, SCADA (at two substation sites), and aggregated residential and C&I solar PV plus energy storage assets via Landis+Gyr remote terminal unit (RTU)/gateway technology.[184]

Figure 46. Austin Energy SHINES Conceptual Network Architecture



Source: US Department of Energy

b. ADMS.

i. DOE-sponsored ADMS Testbed Development. The ongoing project aims to establish a national, vendor-neutral Advanced Distribution Management System (ADMS) testbed to accelerate industry development and adoption of ADMS capabilities for the next decade and beyond.[172]

ii. Austin Energy. Prior to rolling out the ADMS, Austin Energy conducted a pilot to assess the technical feasibility, as well as the costs and benefits of installing such a system. The pilot consisted of monitoring and control of various distribution automation devices over a Landis + Gyr mesh radio network. They found that the mesh radio network was able to handle the “last mile” of communication between the

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[184] Navigant Research, *Market Overview: DER Management Technologies*, 4Q 2016.

substation and various distribution automation devices, and that Austin Energy's GIS model provided sufficient data for the ADMS.[185]

c. DRMS.

i. NV Energy. Nevada's largest IOU, NV Energy, was one of the earliest implementers of DRMS. Its DR programs leveraged multiple proprietary systems control and communications systems. The utility engaged a consultant to help run workshops and create a matrix of DRMS requirements, which led to the release of a request for proposal (RFP) and the selection a vendor in 2009.The system includes a number of modules including a device management module, program tracking, optimization module, forecasting, strategy event execution, system load forecast, weather data, incentive handling/settlements, and real-time measurement and verification (M&V). It was released over three software phases in 3 years and required a lot of testing and integration work—including 23 utility systems integrations.[186]

Critical Success Factors

Description of Commercial Readiness Level, Including Current Market Participation

Distribution grid operators are taking various paths to implementing advanced distribution grid management technologies, from adding individual modules to their existing Distribution Management Systems to installing entirely new Advanced Distribution Management Systems in order to reduce integration issues between modules provided by different vendors.

The global market for smart grid IT and analytics for software and services is projected to reach approximately $12.8 billion in 2017 and surpass $13.6 billion in 2018. Navigant Research expects the market to grow at a compound annual growth rate (CAGR) of 5.9% through 2026 to more than $21.4 billion.[187]

By category of spend, managed services (or SaaS) is expected to be the fastest-growing category, increasing at a 16.0% CAGR through 2026. Ongoing maintenance fees (typically 20% of the original software license fee per year) are projected to account for the largest spend category as installed bases of IT systems grow.[188]

Navigant Research anticipates a healthy market for utility IoT analytics from 2018 to 2028 as the software and cloud solutions improve and utilities become more adept at using them to solve business issues and gain efficiencies. Revenue from annual global sales of these analytics solutions is expected to grow from $1.3 billion in 2018 to more than $5.1 billion in 2028 at a compound annual growth rate (CAGR) of 14.7%.[189]

In 2018, North America spending on utility IoT analytics for DER was $1.035 million, which was 0.2% of total utility IoT analytics spending (including asset performance and grid operations).[190]

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185 *Austin Energy: A real-life advanced distribution management system (ADAMS)*, Continental Automated Buildings Association (CABA) (2014)

186 Navigant Research, *Market Overview: DER Management Technologies*, 4Q 2016.

187 Navigant Research, *Market Data: Smart Grid IT Systems*, 1Q 2017.

188 Navigant Research, *Market Data: Smart Grid IT Systems*, 1Q 2017.

189 Navigant Research*, Market Overview: IoT and Analytics for Utilites Market Overview*, 2Q 2018.

190 *DER Connection Modeling and Reliability Considerations*, NERC (2016)

i. **Sensing and Control Assets.**

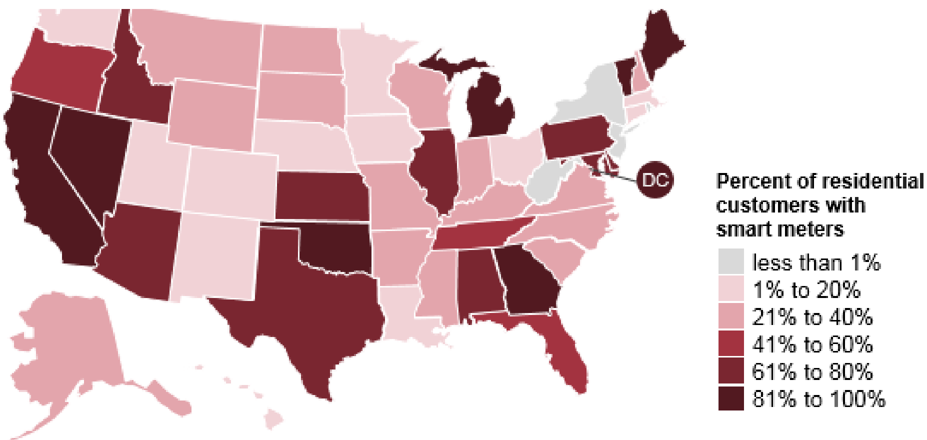
a. In 2017, Navigant Research estimates that just 20% of distribution substations in the US were equipped with TDSM technology, and less than 5% of distribution lines were monitored. By 2026, these numbers are forecast to increase to 85% for distribution substation monitoring and 38% for distribution line monitoring.

b. Low visibility into DER activity because telemetry is often not required.

c. Distribution Line monitors (DLMs) are scarcely deployed today, making up less than 1%-11.5% market penetration (based on the region)

d. By the end of 2016, over 80% of customers in CA had smart meters.

Figure 47. Residential Smart Meter Adoption Rates by State, 2016



Source: EIA

ii. **Supervisory Control and Data Acquisition (SCADA).**

a. Many distribution systems have little or no distribution SCADA, and most existing distribution sensing is low speed and low capability. Grid sensor installation is often cost-prohibitive.[191]

b. Some vendors believe that eventually SCADA will reach all devices in the medium and low voltage networks; for now, the clear trend is to extend SCADA to distribution substations.[192]

iii. **Synchrophaser Technology.**

a. Synchrophasors are a mature technology in transmission networks and are used in a variety of applications. However, synchrophasors are not used widely to observe power distribution networks. Although "distribution" PMUs may be deployed at distribution substations, their voltage angle measurements are usually referenced against angles elsewhere on the transmission grid, not the distribution feeder.

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[191] *Distribution System Evolution: Implications for Sensing and Measurement*, PNNL (2017)

[192] Navigant Research, *Market Data: Smart Grid IT Systems*, 1Q 2017.

iv. Analytics.

a. Commercially available software-as-a-service (SaaS) solutions can deliver on-demand adoption forecasts for distributed energy resource (DER) technologies and enable utilities to assess grid and bottom-line revenue impacts for a combination of DERs.[193]

b. Utilities are beginning to develop advanced customer adoption forecast models to forecast DER growth, but have difficulty assessing the predictive power of the models without historical data, as significant DER adoption is a new phenomenon. For the more complex resources, not only the device installation is required to be forecast but also how the customer intends to use it.

v. Distribution Management Systems

a. ADMS.

i. In 2016, less than 50 utilities (out of 3,000) U.S. were estimated to have some level of ADMS, with many of them implemented in part only. Each ADMS project has been a one-off learning experience. One could argue that ADMS vendor systems are not yet mature, so that even the vendors are learning what utilities need in ADMS.[194] Pacific Gas and Electric is in the process of installing a new ADMS, while Southern California Edison requested funding for a "system of systems" or Grid Management System in their initial Distribution Resource Plan filing.

ii. The current state of the art for ADMS is a large vendor-specific system that can only be afforded by the largest utilities. ADMSs are not available to the majority of utilities because of the time, cost, and need to commit to a single vendor across a range of systems.[195]

b. DERMS.

i. DERMS is in an early stage of operational demonstration with market and operational factors driving the various levels of maturity of DERMS products. The power industry grapples with a single, unified definition of DERMS. This is due to varying opinions of the operational and technical capabilities envisioned.[196] In order for DERMS to be efficiently integrated, the resources they coordinate must become more standardized and the market processes for paying customer participants must be defined.

c. DRMS.

i. Multiple vendors' commercial products are available in the market and have been operationally deployed over the past decade.[197] It should be noted that current solutions rarely coordinate with transmission system or distribution system operations technologies. [196]

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[193] *New DER Planning Software from Clean Power Research and SMUD Enables Utilities to Predict Bottom-Line Impacts in a DER World*, SMUD (2018)

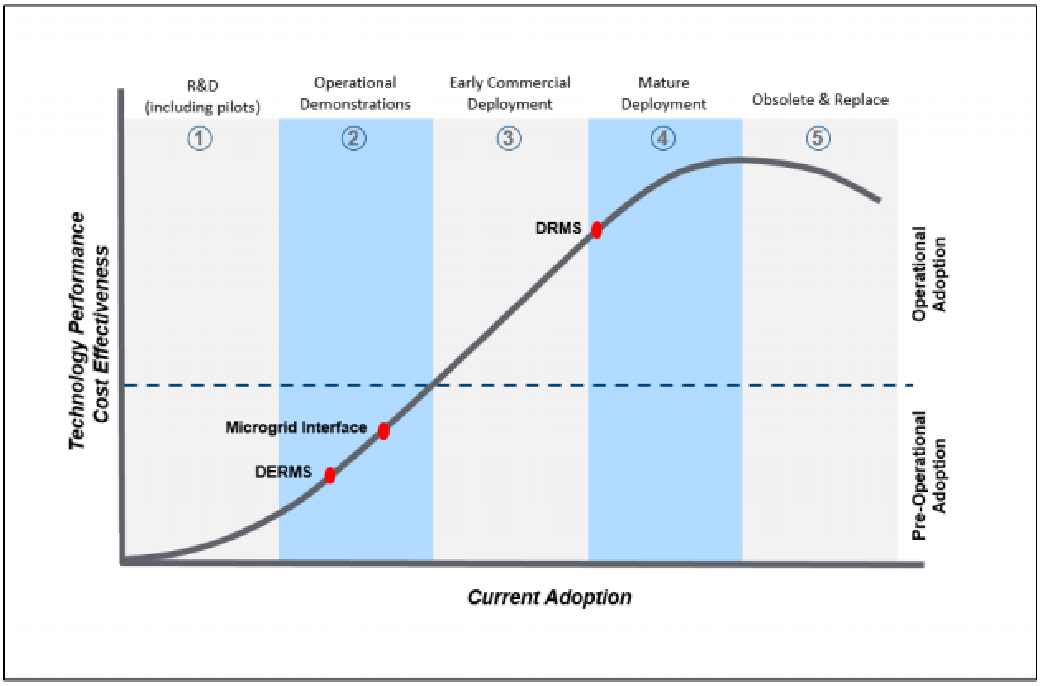
[194] *ADMS State of the Industry and Gap Analysis*, PNNL (2016)

[195] *Today in Energy*, EIA (2017)

[196] *Distribution System Evolution: Implications for Sensing and Measurement*, PNNL (2017)

[197] Navigant Research, *Market Overview: DER Management Technologies*, 4Q 2016.

Figure 48. DERMS and DRMS Adoption Maturity



Source: DOE[198]

vi. Transmission-Distribution Coordination

a. There is no current set of guidelines or reference implementation that can help decision makers develop needed holistic strategies for transmission and distribution coordination across planning, grid operations, and market operations. There is a tendency to move directly toward technology solutions for point concerns rather than starting with a set of overarching objectives. States and wholesale market operators that are enabling participation of DERs in wholesale markets, as well as pursuing DERs as non-wires alternatives, recognize the need to coordinate the use of DERs between distribution operations and bulk system operations and markets, and are taking steps to define this interface and coordinate their use.[199]

Federal and/or State Policy Influences

i. **Federal Government**

a. **Government-based financial support for pilots.** Until economic and market forces command proactive adoption of DER management technologies, many investments will be government subsidized. DER management technologies have been driven at the national, state/province, and local level in the United States and Canada, with the most proactive campaigns for DER integration taking place in California and New York.

ii. **California Regulatory**

a. **Regulators developing interest in new market frameworks.** Although at a slow pace, policymakers are becoming more invested in expanding the value proposition

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[198] *Modern Distribution Grid: Volume II*, DOE (2017)

[199] *The Transmission-Distribution Coordination*

, DOE (2018)

for DER. Though realization of transactive markets is a long way off, movements like New York's Reforming the Energy Vision initiative (NY REV) have started a significant policy conversation with respect to enabling distribution-level markets. The Distribution Infrastructure Deferral Framework mechanism in California is formalizing third party participation from non-wires alternative solutions.

b. **Data Privacy.** Utilities and their partners in California now have a framework for handling sensitive customer data. Some states have emulated these privacy regulations. In the absence of a federal mandate, the issue is likely to be resolved on a state-by-state basis. In Europe, the issue has more clarity. The new General Data Protection Regulation (GDPR) effective in May 2018 gives consumers greater control of their personal data. The GDPR scheme could become a model in other regions depending on how it plays out.[200]

Assessment of Barriers to Further Adoption

Cost

Attribution of Costs of Enabling Platform. The user must be able to justify the cost of the DERMS based on the expected benefits it will garner. DRMS solutions have a wide range of cost—from hundreds of thousands of dollars to several million. The cost varies with the type of DERMS solution (on-premises versus software as a service [SaaS]), the number and scale of programs to be integrated, the number of enrolled customers, and the extent of integration with the internal systems and the third-party equipment. In general, on-premise DRMSs cost more than the SaaS solution. Vendors charge a mix of fixed fees plus service fees or annual license fees.[201]

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 since 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 cutting-edge technology upgrades, as most are deemed too expensive.

Benefits of grid modernization investments are limited to a subset of customers. Utilities are using measures of customer interruption as a metric for justification of grid modernization investments. Some customers (such as large C&I customers manufacturing goods) have a much higher interruption cost than others (such as residential customers). However, while the benefits of improved reliability are disproportionately realized by a relatively small number of customers, utility investments in Fault Location and Service Restoration, automated switching, and other distribution automation investments are socialized. At the same time, these investments are unlikely to be made in areas with low population density, but likely high risk for outages; this is a situation which could be aptly addressed by DERs either within a microgrid or as standalone resources. How reliability is calculated in the Locational Net Benefit Analysis will impact what kinds of investments are made.[202]

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[200] Navigant Research, *Market Overview: IoT and Analytics for Utilities Market Overview*, 2Q 2018.

[201] Navigant Research, *Market Overview: DER Management Technologies*, 4Q 2016.

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

Capability

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

Limitations of cloud analytics. Data sent to the cloud has a latency issue that reduces its value when a fast, local decision is desired. Cloud downtime presents another problem in mission-critical situations. It needs a high degree of resilience. There are other limits to cloud services, too, such as paying for network bandwidth, data storage, and compute power. Security concerns hinder the use of cloud capabilities for risk-averse utility operators.[203]

Physical network model quality. ADMS requires physical network model to be extremely accurate. The data models currently residing in utility GIS systems are either incomplete, inaccurate, or both. The extensive model clean-up required before deployment is a barrier.[204,205]

Flexibility and interoperability limitations. Another challenge noted by the utilities is the limited flexibility of the DRMSs available in the market. Even though vendors claim that their DRMS solution is highly flexible, utilities note that several features/functionalities cannot be customized. Most utilities have a limited number of trained staff to operate these complex systems.[206]

Partial automation. PGE found that DERMS exhibited limited scalability of current partially-automated processes for load shedding, curtailing generation, and dispatching field crews for increasing penetration of DER and Demand Response (DR) assets (requiring human monitoring and analysis).[207]

Limited DER inclusion. PG&E found that DERMS is currently limited to a subset of Distributed Energy Resources (DERs), including Behind-the Meter Storage and Smart Inverters (PV). [208]

Coordination

Challenges of integrating grid management systems. The integration challenge between the component operational systems is the single largest challenge for ADMS/DMS/DRMS/DERMS design and deployment. Specific challenges include the piece-meal integration of existing systems with new systems, which may not be provided by the same vendors, and the integration of operational systems with back-office systems.[209]

Challenges of integrating sensing and control assets. Utilities face significant challenges integrating new capabilities into their existing asset management and condition monitoring software infrastructure, and it is difficult for utilities to justify the cost of such advanced sensing hardware without the accompanying asset management software framework. [210] Large-scale integration of new devices into legacy grid management systems often required additional, unplanned work as issues are identified.

Risk tolerance. Utilities are risk adverse and tend to avoid major system or process overhauls that would be required to adopt advanced grid management systems.

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[203] Navigant Research, *Market Overview: IoT and Analytics for Utilites Market Overview*, 2Q 2018.

[204] *Big Data Techniques to Address ADMS Data Quality Issues*, GridBright (2018)

[205] *Today in Energy*, EIA (2017)

[206] Navigant Research, *Market Overview: DER Management Technologies*, 4Q 2016.

[207] Navigant Research, *T&D Sensing and Measurement Market Overview*, 1Q 2018.

[208] *Joint IOU EPIC 3 Planning Workshop*, CA IOUs (2017)

[209] *ADMS State of the Industry and Gap Analysis*, PNNL (2016)

[210] Navigant Research, *Market Overview: DER Management Technologies*, 4Q 2016.

Transmission/Distribution coordination. Technological deficiencies across planning and operations undermine the readiness to support this transition. Respondents cited that not only were specific capabilities such as comprehensive modeling tools and DER forecasting lacking, but the ability to construct a system—including secure communications around the different grid devices to execute needed capabilities—was also not readily available. There is no clear or holistic direction of how organizations planned to address the T-D interface evolution needed related to planning, operations, and markets.[211]

Operational silos. DER-integrated forecasting and planning analysis needs to penetrate operational silos 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. At the same time, utilities are looking to consolidate their communications systems while prioritizing security and flexibility. This puts the pressure on 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 DERs, according to PG&E, the standard is not yet prescriptive or stable enough to enable consistent interpretation by aggregators for all desired functions.[85]

Identified RDD&D Needs

Actions to Bring Key, High Impact Technologies and Strategies to Market

i. **Sensing and Control Assets**

   a. Near-term

      i. Compatibility (TD&D). Develop systems compatible with a utility's existing asset management software system or communications and security protocols.[212]

ii. **Analytics**

   a. Near-term

      i. Integrate Dynamics Analysis into Distribution Planning (ARD). Dynamic studies will become increasingly important with higher levels of DERs, especially inverter-based DERs, and with microgrids, where dynamics can be used to investigate whether automatic control systems can maintain voltage and frequency when subjected to disturbances.[213]

      ii. Triangulate and Expand Forecasting Approaches (ARD). A number of utilities use only a single DER forecast or consider only a small range, which indicates an opportunity for these utilities to expand the scope of their forecasting approaches. Promotion of a wider deployment of strategies that use third-party forecasts and various forecast approaches is needed.

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[211] Navigant Research, *Market Overview: DER Management Technologies*, 4Q 2016.

[212] Navigant Research, *Market Overview: DER Management Technologies*, 4Q 2016.

[213] *Summary of Electric Distribution Analyses with a Focus on DERs*, Grid Modernization Laboratory Consortium (2018)

iii. Conduct Harmonic Studies on DERs (ARD). New loads such as electric vehicles may also cause harmonic distortion on a transformer or line section. These types of new loads may need to be studied, especially as these systems can be either a load or a source, depending on the system needs.[214]

b. Mid-term

i. Improving Representation of Customer-Adoption Decisions (ARD). Further research and development of customer adoption models to capture heterogeneity of population, non-economic factors, and regional descriptors to then develop geospatial forecasts for DER adoption and impact.[215]

ii. Automate hosting capacity calculations (TD&D). Tools currently available on the market are capable of conducting hosting capacity studies, but often require the addition of external scripts to automate the extensive analysis required in such studies. Built-in research and develop in automated hosting capacity analyses is needed to accelerate and establish consistency in DER interconnection processes.[214]

iii. Enhance Cloud and Edge Analytics Capabilities (ARD). Research to address latency and security concerns while driving down costs for network bandwidth, data storage, and computation power is needed.[216]

iii. Distribution Management Systems

a. Near-term

i. Integrable, interoperable ADMS applications. (TD&D). Enabling Deployment of interoperable, multi-vendor ADMS applications that can be easily integrated with existing systems needs to be enabled.[217]

ii. Data quality mitigation (TD&D). Development of methods to use data analytics in operational applications, such as those found in an ADMS, is needed to reduce the cost of addressing data quality issues.[209]

iii. Provide an open source platform (MF). Provision of a vendor agnostic interconnection layer to enable various DMS systems, their peripheral systems, and other applications is needed to effectively interconnect.[218] For example, Open Field Message Bus (OpenFMB™) is an existing standards-based solution that enhances integration with field devices and enables power systems field devices to interoperate.

iv. Simplification through standardization (TD&D). Standardize terms and terminology is needed to enable utility understanding and decision-making in the procurement process. Development of common requirements in distribution

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[214] *The Transmission-Distribution Coordination*, DOE (2018)

[215] *Planning for a Distributed Disruption: Innovative Practices for Incorporating Distributed Solar into Utility Planning*, LBNL (2016)

[216] Navigant Research, *Market Overview: IoT and Analytics for Utilities Market Overview*, 2Q 2018.

[217] *Forecasting load on the distribution and transmission system with DERs*, LBNL (2018)

[218] *Advanced Distribution Management Systems*, DOE (2015)

management system RFPs is needed to make it easier for vendors to respond and accurately compare systems.[219]

v. Transmission-Distribution Coordination (TD&D). The new planning and operational coordination functions will require assigning roles and responsibilities between transmission system operators (TSOs) and distribution system operators (DSOs). Development of a set of guidelines or reference implementation is needed to help decision makers develop holistic strategies for transmission and distribution coordination across planning, grid operations, and market operations.[220]

b. Mid-term

i. Transmission-Distribution Coordination (TD&D). Development of coordination schemes that predefine stakeholder roles and implementation guidelines is needed. Development of specific integrated resource, transmission and distribution planning, and detailed design and implementation of DER coordination architectures, including information flows, controls, and market design, is also needed. Lastly, identification of interactions with the regulatory framework and potential areas for improvement is needed. [220]

[219] Navigant Research, *Market Overview: DER Management Technologies*, 4Q 2016.

[220] *New DER Planning Software from Clean Power Research and SMUD Enables Utilities to Predict Bottom-Line Impacts in a DER World*, SMUD (2018)

Section 7: DER Aggregation as Non-Wires Alternative

In order to efficiently integrate DER into the electrical grid, a framework must be developed to measure and compare their contributions in conjunction to traditional utility infrastructure. To this end, California recently mandated its investor-owned utilities (IOUs) to submit annual Distribution Resource Plans (DRPs), including Grid Needs Assessments (GNAs) and Distribution Deferral Opportunity Reports (DDORs). These filings provide insight into how distributed resources can perform as non-wires alternatives (NWAs) to meet identified grid needs at a lower cost or in a cleaner or more reliable way.

Technology and Strategy Review

Characterization of Technology and Strategy Types

i. Non-Wires Alternatives (NWA)

a. Working definition. An electricity grid investment or project that uses non-traditional transmission and distribution (T&D) solutions, such as distributed generation (DG), energy storage, energy efficiency (EE), demand response (DR), and grid software and controls, to defer or replace the need for specific equipment upgrades, such as T&D lines or transformers, by reducing load at a substation or circuit level.[221]

b. Technologies. A Non-Wires Alternative (NWA) can include any of the following technologies: DR (e.g., smart controllable thermostats, direct AC load control, other customer-initiated load reduction), EE (e.g., LED lighting, smart appliances, efficient buildings), DG (e.g., solar PV, combined heat and power, battery storage), software and controls (e.g., smart grid, voltage control, distribution management system software).[222]

ii. DER Analytics

a. DER Analytics working definition. Used for analysis of grid and DER data, to elicit insights on the state of the grid, and for forecasting and planning purposes in a DER-heavy environment.[223]

b. DER Analytics purpose. DER analytics support utilities in planning and forecasting, or micro-forecasting, DER. DER can cause tremendous disruptions to traditional supply and demand patterns and heavily affect the processes of resource, capital, and operational planning. Utilities need to be able to understand and forecast DER-affected demand and DER output, as well as understand and predict its locational effects on the grid in order to effectively perform these processes.[224] It is especially important to be able to identify DER generation contributions to net load under abnormal conditions, for both safety and efficient grid operations.

[221] Navigant Research, *Non-Wires Alternatives*, 2Q 2017

[222] Navigant Research, *Non-Wires Alternatives*, 2Q 2017

[223] Navigant Research, *DER Management Technologies*, 4Q 2016

[224] Navigant Research, *DER Management Technologies*, 4Q 2016

iii. Virtual Power Plants

a. Virtual power plant (VPP) systems working definition. Used to facilitate the aggregation and dispatch of DER portfolios for capacity and energy services and to interface with energy markets.[225]

b. Virtual power plant (VPP) systems purpose. VPP control systems remotely and automatically optimize DER dispatch via an aggregation and optimization platform linking retail to wholesale markets. Though not fully mature, there is growing development in support of DER participation in capacity and energy services markets at the wholesale and retail level.[226] Contrary to DERMS, virtual power plant systems are generally operated outside of utility control and pursue market incentives.

c. Virtual power plant (VPP) systems capabilities. VPP technologies aggregate numerous DER services into a single entity that can participate within an energy market to either dispatch generation or bid into DR markets. From the outside, the VPP looks like a single power production facility that publishes one schedule of operation and can be optimized from a single remote site, enabling ease of access to wholesale markets through existing structures. From the inside, the VPP can combine a rich diversity of independent resources into a network via sophisticated planning, scheduling, and bidding of DER-based services. VPPs are an important component of a transactive energy (TE) market.

iv. Communications Technologies

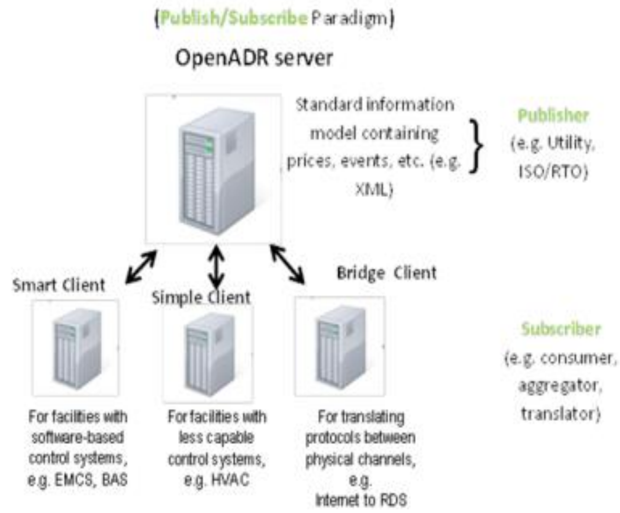
a. OpenADR 1.0. OpenADR has been in development for more than 10 years, and now has 160 members and over 100 certified products. The initial objective was to develop a low-cost, speedy, and reliable communications infrastructure that would allow electric utilities and ISOs to send DR signals directly to customers' existing Energy Management Systems (EMS) using a common language and an existing communications technology such as the Internet. OpenADR 1.0 was commercially launched in 2007 as a de facto standard in California. It included a standardized utility price, reliability, and event signals to support customers' energy management and conservation strategies for DR. A typical OpenADR client/server model is illustrated in Figure 49.[227]

[225] Navigant Research, *DER Management Technologies*, 4Q 2016

[226] Navigant Research, *DER Management Technologies*, 4Q 2016

[227] Navigant Research, *Virtual Power Plant Enabling Technologies,* 3Q 2016

Figure 49. OpenADR Client/Server Model



Source: Demand Response Research Center

b. OpenADR 2.0. In 2014, the International Electrotechnical Commission (IEC) approved the OpenADR 2.0b profile specification as a publicly available specification (PAS) called IEC/PAS 62746-10-1. The standard will be the basis for a new commission standard. The level of international support for the PAS validates the global importance of the OpenADR smart grid specification. There is now development of a 2.0c standard which would offer a higher level of support.[228]

c. MultiSpeak. The MultiSpeak specification is a protocol that is popular among municipal utilities and cooperatives. The protocol was created in 2000 by the National Rural Electric Cooperative Association and several vendors of software to electric cooperatives. The goal was to create a common platform for IT software (such as CIS and GIS) that would reduce software development and IT staffing costs for small utilities. The platform has since expanded to support supervisory control and data acquisition (SCADA) systems, outage management systems (OMSs), distribution automation, workforce management, advanced metering infrastructure (AMI), and DR. Using MultiSpeak provides peace of mind to small utilities since they know the software has been tested and verified by a third party, that the software will integrate with their existing enterprise software—as well as any software they implement in the future. The most recent version of MultiSpeak (version 5.0) was released in February 2015. According to the organization, MultiSpeak is in use by more than 725 utilities and public power districts, across 19 countries.[229]

v. NWA Business Models

a. Request for Proposal (RFP). NWA specific RFPs include detailed descriptions of the load reduction or other grid service needed, the location, characteristics of customers, and the time of day the service needs to be provided. Respondents develop a cost, plan, and timeline to address the need outlined in the RFP.

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[228] Navigant Research, *Virtual Power Plant Enabling Technologies,* 3Q 2016

[229] Navigant Research, *Virtual Power Plant Enabling Technologies,* 3Q 2016

The proposals are reviewed based on criteria that fall under four main categories. The first is economics, such as the total cost of the project, the unit cost per kilowatt of load reduced, and a cost-benefit analysis. The second relates to the implementer's capability, experience, and risk of execution. The third looks at the impact the project will have on the community and the timeliness of the impact. Finally, the proposal is reviewed based on reliability of the assets, applicability to the need, and the viability of the assets.

b. Procurement with current contractors. This business model seeks to alter current contracts between the utility and its existing implementation contractors. However, some regulators may not permit this option. Changes to an existing contract could do the following:

  i. Direct the contractor to target certain customers within a geographic region or a specific customer class

  ii. Develop specific measures, such as bundled EE programs, specifically targeted at reducing peak demand

c. Auction Models. Auction models are particularly well suited for price discovery into solutions and technologies deployed in an NWA. In addition, the speed of the auction compared to a RFP approach adds an element of flexibility in design, enabling the utility to shape the NWA on the basis of participation. The same can be done with an RFP, though typically in an extended period of time. An auction can be set up to cover all or part of a NWA project and can be divided into subcomponents, such as years and time-of-day periods. See the Brooklyn Queens Demand Management (BQDM) case study below for an example of this business model.

d. Internal utility resource deployment. The final option consists of the utility using in-house resources to meet the NWA need. This allows the utility to maintain full control of operations and minimize costs. Examples of this business model include: utility-scale storage, utility-run DG, and utility solar. This business model is only an option if the regulatory structure permits.

Discussion of Advantages and Disadvantages

Table 25. Advantages and Disadvantages of Non-Wires Alternatives

Strategy	Advantages	Disadvantages
Non-wires Alternatives	• In the right circumstances, non-wires solutions can be a more flexible, cost-effective, and lower emissions alternative to conventional grid investments. They can also provide a more robust local electrical grid, enabling a higher degree of climate risk mitigation than conventional strategies. • Non-wires alternatives enable a wider range of participants to support the needs of the electric grid, facilitating market-based solutions that provide service to the end consumer at a lower cost.	• Contrary to conventional solutions, non-wires alternatives are relatively new and unproven. Relying on a portfolio solution for critical needs may expose the grid to a higher level of uncertainty. Additionally, the coordination costs of involving a wide range of participants may negate what could be a natural monopoly in grid planning and operations. • Current incentive structures may not place non-wires alternatives on equal footing with standard solutions, leading to inefficiencies in procurement. Uncertainty as to the appropriate valuation of particular grid needs like resource adequacy, or uncertainty in the ability of non-wires alternatives to meet future grid needs leads to difficulty in comparison.

Description of Technical Specifications and Requirements

i. <u>Non-Wires Alternatives Standards</u>.

Non-wires alternatives are comprised of a range of different hardware devices or collections of modifiable loads and these assets are covered individually in their own sections. The requirements for the integration of non-wires alternatives as a whole are covered by the Locational Net Benefits Analysis[230], and Distribution Investment Deferral Framework, covered in Sub-Track 3 of Track 3 of CPUC Decision 18-02-004[231]. These proceedings are exploring how to appropriately measure and value the contributions of NWAs and characterize their ability to replace conventional distribution assets.

Review of Recent RDD&D Activities

While there are multiple EPIC-funded projects improving renewables forecasting, research into NWA and the integration of DERs into utility planning processes has received less representation. The research surveyed can be categorized in to the following themes:

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230 *LNBA Final Report*, CPUC (2018)

231 *Decision 18-02-004*, CPUC (2018)

i. **Multi-Use Case and Valuation.** These initiatives are developing frameworks to fairly assess the complete stream of value that DERs can provide to the grid, which is an important input into planning tools and NWA feasibility evaluations. This area addresses the lack of transparency in current valuation methodologies. The GMLC is funding some research in this space, for example Definitions Standards and Test Procedures for Grid Services and the Grid Services and Technologies Valuation Framework.[232] The Competitive Solicitation Framework Working Group identified potential valuation components that could be used for future solicitations, but they did not reach consensus on how the valuation process would be implemented, including selecting which valuation components would apply and the level of transparency in making that decision.[233]

ii. **Planning Tools.** These projects aim to address the lack of measured data to calibrate and validate models and the lack of visibility into customer behavior and DER adoption by developing advanced tools and strategies to facilitate DER integration into utility planning processes and reduce interconnection costs. Several projects are funded by DOE SETO's System Integration program and the GMLC. Some relevant metrics include the reduction of interconnection costs, increase in interconnection processing speed, forecast accuracy improvement, and scalability and modularity of developed tool.

iii. **NWA Demonstrations.** These projects demonstrate the ability of DERs to defer traditional grid upgrades and meet projected load growth. Most of the NWA demonstration projects are utility-led and exhibit promising results. Some relevant project metrics include timeline, size, and cost-benefit ratio

The research reviewed aimed to integrate DERs into distribution planning processes on equal footing with conventional solutions, identify rigorous metrics to assess the contribution of DERs in grid planning, and to demonstrate the ability of DERs to defer traditional grid upgrades.

Figure 50 shows some potential metrics for Non-Wires Alternatives.

Figure 50. Potential Metrics for NWA Research

Non-Wires Metrics	Unit
NWA Capacity installed	MW
Total Deferred Conventional Asset Costs	$
Frequency of hosting capacity analysis update	Months
Percent of distribution deferral opportunities with NWA bids	%

A selection of research and demonstration projects is included below. A full list of identified work can be referenced in the appendix.

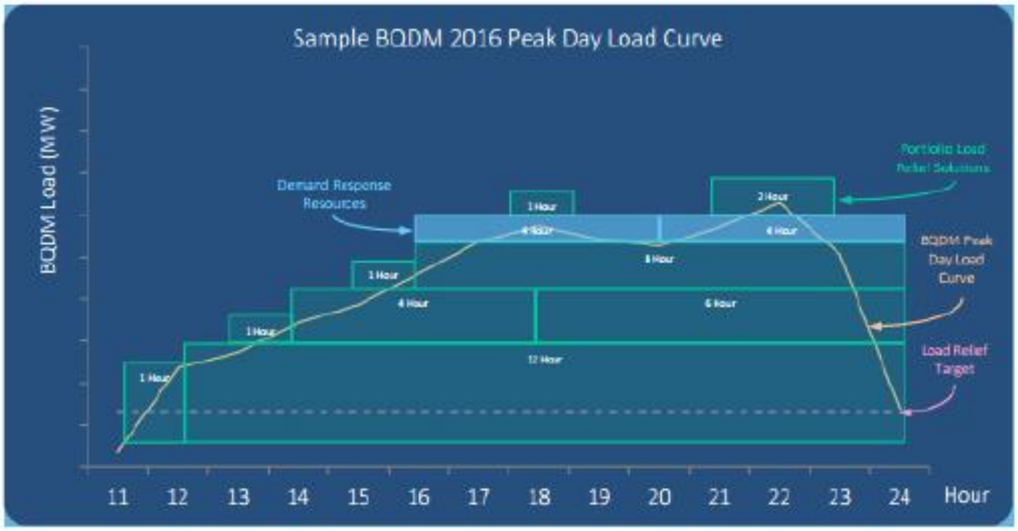
i. **Project Case Study: Brooklyn Queens Demand Management (BQDM).** After an extended heat wave placed sever capacity pressure on Brooklyn and Queens in 2013, Con Edison submitted an RFP for approximately $200 million in investments to defer distribution upgrades

[232] Institutional Support: Portfolio Overview, GMLC (2018)

[233] Joint IOU Competitive Solicitation Framework Working Group Final Report.docx, CSFWG (2016)

related to these capacity constraints. Con Edison filed a proposal with the New York Public Service Commission titled the BQDM program. This targeted program intends to use many forms of DER to defer or avoid costly T&D infrastructure projects, namely a new $1 billion substation for the Brooklyn/Queens area, a region expected to grow significantly with businesses and housing, as shown in Figure 51.

Figure 51. Con Edison BQDM Sample 2016 Peak Day Load Curve

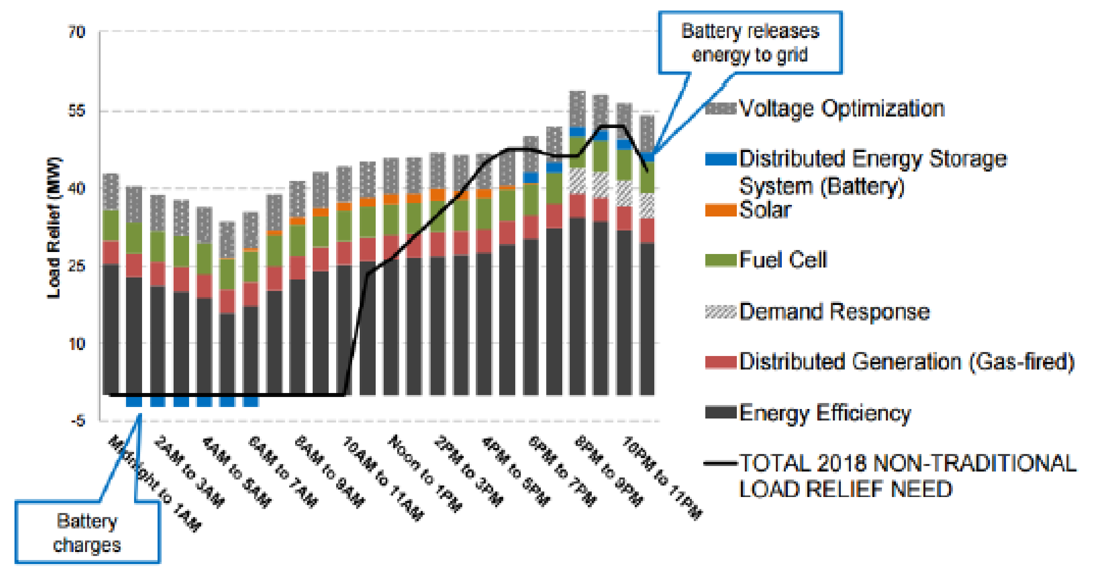


Source: Consolidated Edison

The BQDM program will spend $200 million in demand-side load management programs to shed 52 MW of load—41 MW from the customer side and 11 MW from non-traditional utility-side measures. It will also spend an additional $300 million in infrastructure investments such as substation upgrades by 2018. In 2015, Con Edison worked with 3,100 small businesses in neighborhoods across Brooklyn and Queens to lower energy consumption by around 12 MW. Additionally, 550 multi-family properties and over 4,300 individual residential apartment customers reduced electricity consumption by almost 1.3 MW. These combined efforts reduced electricity usage by 13.3 MW, amounting to 63,648,211 kWh of energy savings.

The program relies largely on EE measures, ranging from traditional incentives for replacing inefficient appliances and AC units to more nascent incentives for new building management systems, battery systems and microgrids. However, the program also relies on other unique DER such as fuel cells, DR, and energy storage. In addition, the program focused on improving customer engagement by reaching out to small and medium-sized businesses to gain insights to the challenges that accompany customer participation. The utility faced challenges in customer acquisition, vendor contracting, permitting, and municipal planning and coordination. The anticipated resource portfolio is shown in Figure 52.

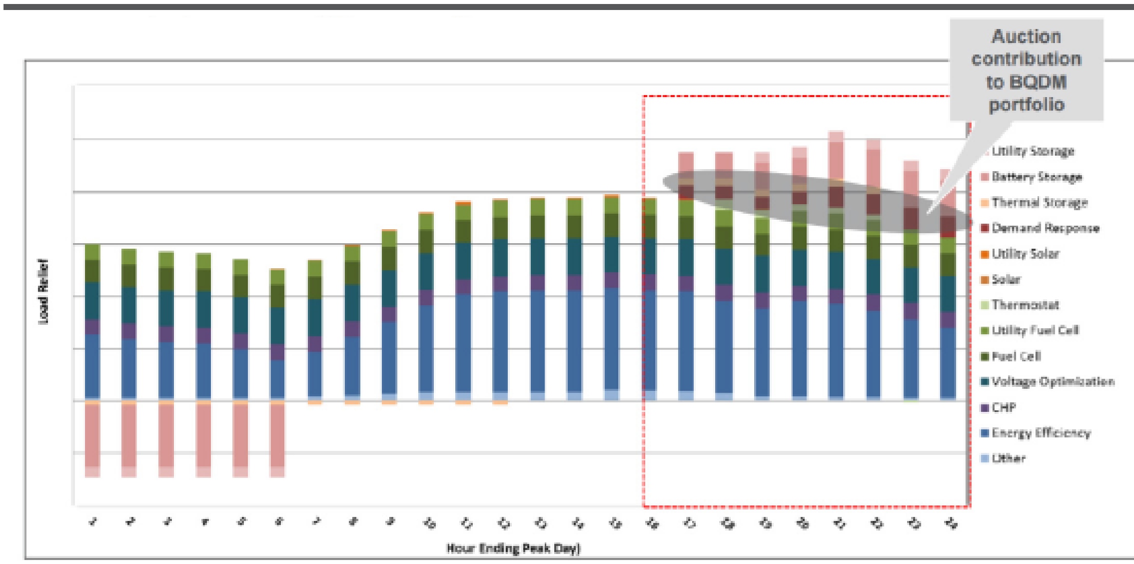
Figure 52. Anticipated BQDM 2018 Portfolio



Source: Consolidated Edison

Con Edison used an auction to procure part of the BQDM resource base (depicted in Figure 53). In its petition to the New York Public Service Commission for approval of the BQDM program, Con Edison acknowledged that per-megawatt unit costs are generally higher than previous network-oriented programs due to the complicated nature of the network conditions and the demographics of the area. Con Edison also noted that the network peak is significantly longer than the peak durations of other targeted programs. The auction mechanism was therefore a tool to create a market event, drive participation, and enable price discovery.

Figure 53. BQDM Auction Contribution



Source: Consolidated Edison

The auctions for 2017 and 2018 were held in July 2016. Con Edison accepted offers for 22 MW of peak hour DR from 10 providers. Payments ranged from $215/kW/year to $988/kW/year depending on the amount of power reduction and the demand management technology used. Con Ed met its reliability needs for 2016 and plans to continue to progress with future NWA investments.[234]

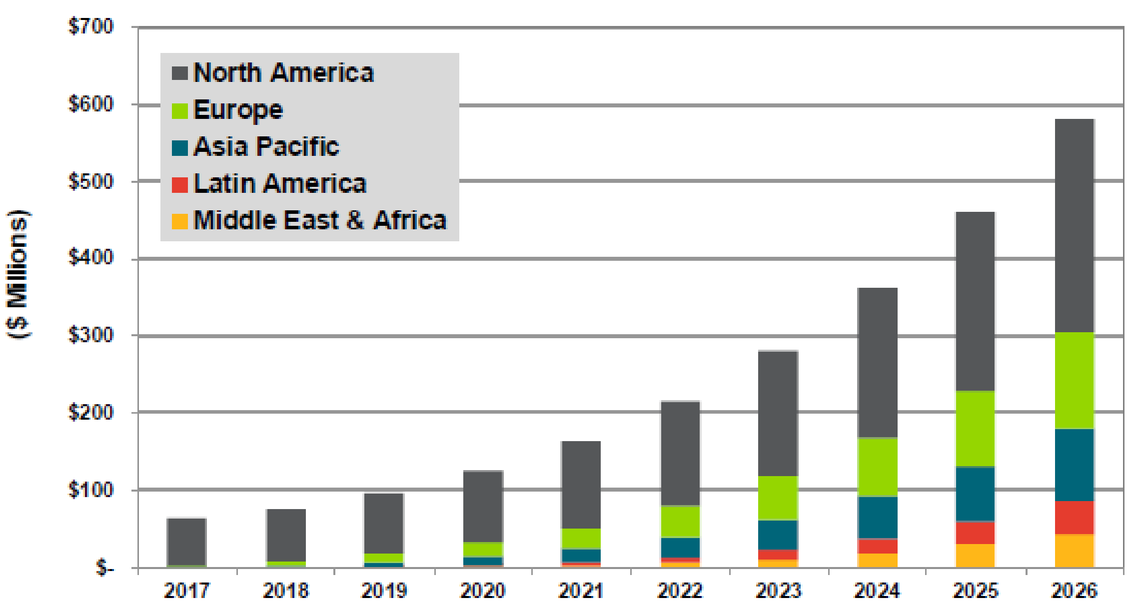
ii. **Virtual Power Plants (VPPs).** Over the last decade there have been a growing number of pilot projects to test and validate the VPP platform concept. Early VPPs were designed to aggregate and integrate demand resources in the absence of affordable energy storage. As energy storage costs decline over time, there is a growing trend of integrating fleets of solar PV plus energy storage into mixed asset VPPs to displace generation and centrally-provided services. These projects have predominantly taken place in the United States, Germany, Australia, South Africa, and Japan.[235]

Critical Success Factors

Description of Commercial Readiness Level, Including Current Market Participation

i. **NWA Growth Forecast.** Navigant Research expects roughly $63 million to be spent on NWA on a global basis in 2017. NWA project costs in developing countries are expected to be less than those in developed nations due to the generally lower costs of goods and services. Figure 54 shows, growth is expected to be robust during the forecast. By 2026, a global total of $580 million in spending is anticipated. The largest region of spending is expected to be North America, reaching $275 million in 2026, primarily centered in the United States. This trend is expected to hold true throughout the forecast, though other regions eventually start to implement NWA programs. Other regions, like Europe, tend to take a more holistic approach to grid management rather than location-specific measures like NWAs.[236]

Figure 54. NWA Spending by Region, World Markets: 2017-2026



[234] Navigant Research, *Non-Wires Alternatives*, 2Q 2017

[235] Navigant Research, *DER Management Technologies*, 4Q 2016

[236] Navigant Research, *Non-Wires Alternatives*, 2Q 2017

Source: Navigant Research

Federal and/or State Policy Influences

i. **California Regulatory**

a. **CPUC Decision 18-02-004.** The annual Grid Needs Assessment (GNA) and Distribution Deferral Opportunity Report (DDOR) are new exercises required of the California IOUs by CPUC Decision 18-02-004[237]. Relevant information is to be provided as available through the 2018 process, with the first official documents required in the 2019 cycle. These will present the prime candidate grid needs that non-wires alternatives can be proposed to solve.

ii. **California Government**

a. **California SB 100.** Mandates 100% zero-carbon by 2045. Attention to non-wires alternatives was the primary reason SB 100 did not pass in the 2017 session. However, the bill passed in 2018 with attention to non-wires alternatives still within.[238] The bill mandates that retailers take "reasonable measures" to procure cost-effective distribution generation.[239]

b. **California AB 2868/ Decision 13-10-040.** 500 MW of behind the meter storage. This assembly bill adds 500 MW storage procurement mandate to the 1,325 MW procurement mandate defined in AB 2514.[240,241]

c. **AB 2514/Decision 10-03-040.** 1,325 MW storage by 2020. This assembly bill mandates the California IOU's to procure 1,325 MW of energy storage by 2020.[242,243]

d. **2018 State of the State address.** 5M ZEV by 2030. The executive order signed by Governor Brown sets a Zero Emission Vehicle (ZEV) target penetration of 5 million vehicles by 2030. The order also sets goals to support and plan ZEV infrastructure development including vehicle integration and EVSE support.[244] The effect of a ramp on electric vehicles on the opportunities for NWAs is twofold:

   i. Electric vehicles can in some capacities act as distributed resources that can be aggregated to create non-wires solutions for grid needs.

   ii. Electric vehicles represent a potentially massive and in part unpredictable increase in demand for utilities which could strain the transmission and distribution infrastructure

Assessment of Barriers to Further Adoption

California is identifying local value to distributed resources in the Locational Net Benefits Analysis section of the Distribution Resource Plans proceeding, but barriers in the framework still exist. The LNBA working group agrees that the current methodology, which estimates the T&D avoided cost of a DER project, is

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[237] Page 4, Paragraph k

[238] *On to Governor Brown's Desk: What 100% Clean Energy Means for California*,, Greentech Media (2018)

[239] *California Senate Bill 100*,, California State Senate (2018)

[240] *Assembly Bill 2868*,, California State Assembly (2016)

[241] *Decision 13-10-040*,, California Public Utilities Commission (2013)

[242] *Assembly Bill 2514*,, California State Assembly (2010)

[243] *Decision 10-03-040*,, California Public Utilities Commission (2013)

[244] *Executive Order B-48-418*,, California Governor's Office (2018)

not yet ready for system-wide rollout due to the lack of updated, location-specific information and exclusion of costs. Ideally, the methodology would serve as a sourcing mechanism to help determine payments for DERs, however, additional refinements are still needed to provide more granular insights.

Valuation

Lack of regulatory incentives. Without regulatory pressure in place, reasons for a utility to pursue NWA over traditional upgrades are limited. There is higher perceived risk associated with these types of short measure life projects compared to traditional upgrades that are built to last 20 years or more. In addition, a T&D upgrade is aligned with historical utility experience, creating comfort in, which can make implementing poles and wires upgrades.

Difficulty of 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 a particular area but have no identified need for other potential benefits provided by those distributed resources. However, the provider of the resources may not be in a position to aggregate and sell the additional benefits in the market.

Coordination

Complexity of coordination across distribution operators. For technical management of DER, many vendors report that the value of their solutions cannot be maximized if IT, planning, and operations organizations remain siloed within utilities. The potential benefits of DER management technologies are undervalued when they are limited to fewer users and one-off use cases.[245]

The focus on standards slows investments. The majority of the vendors interviewed for this report held lukewarm opinions on standards and technology frameworks for DER integration and management. Some stated that these hinder innovations by overly prescribing implementation standards. Others labeled them as a necessary evil— important to increase the level of comfort around an obtuse technology problem, but not necessary when most new technologies are designed to be interoperable and/or highly secure through multiple formats.[246]

Identified RDD&D Needs

Actions to Bring Key, High Impact Technologies and Strategies to Market

Projects identified in the Distribution Deferral Opportunity Report need implementation support to demonstrate the full range of potential non-wires alternatives called out. The conventional planning and implementation process for grid needs is not well designed for complex resource portfolios currently available. Project accounting needs to be carefully examined to accurately identify the actual cost of non-wires alternatives upon pilot completion

[245] Navigant Research, *DER Management Technologies*, 4Q 2016

[246] Navigant Research, *DER Management Technologies*, 4Q 2016

Appendix: Literature Review Sources

Energy Storage

Energy Storage Performance in an Integrated System

U.S. Battery Storage Market Trends, *Energy Information Administration, 2018.*

This paper explores trends in U.S. battery storage capacity additions and describes the current state of the market, including information on applications, cost, and market and policy drivers.

Demonstration of Community Scale Generation System at the Chemehuevi Community Center, *Primus Power, 2015.*

This project deploys and demonstrates an integrated system consisting of two pre-commercial solar technologies with flow-battery energy storage and an energy management system.at the Chemehuevi Indian Tribe Community Center. This effort will demonstrate the commercial feasibility to deploy many megawatt hours of dispatchable energy integrated in a photovoltaic/battery storage configuration.

Demonstration of Community Scale Low Cost Highly Efficient PV and Energy Management System, *UC Davis, 2016.*

This project is demonstrating that the combination of advanced PV generation, a smart electrical energy storage system that integrates retired electric vehicle batteries, and an energy management system can reduce the community's average daily power and daily peak energy demand by more than 10%.

Integrating Building-Scale Solar + Storage Advanced Technologies Maximizing Value to Customer and the Distribution Grid, *EPRI, 2017.*

EPIC is funding the assessment of performance and benefits of integrated solar photovoltaic (PV) and storage along with advanced energy efficiency (EE) and demand response (DR) / distributed energy resources (DER) management technologies in a commercial building setting. The goal is to leverage the synergies of integrated and controllable components to improve distribution grid stability and reliability while also enabling the commercial customer to reduce both capital costs and operational and management costs for optimal value.

Integrating Front-of-the-Meter Energy Storage with Smart PV Inverters and Solar Forecasting. *EPRI, 2017.*

EPIC is funding demonstration and research of an integrated, interoperable, cost-effective, and scalable solution that integrates distributed front-of-meter energy storage with smart PV inverters and solar forecasting to address grid readiness limitations and enable multi-tiered value stacking for DER.

Las Positas Community College Microgrid, *Chabot-Las Positas Community College District, 2015.*

This project will demonstrate the ability of a commercial-scale microgrid to optimize distributed energy resources for customers, distribution utilities, and the California ISO by using advanced energy management tools to coordinate a high penetration of customer renewable energy assets with multiple energy storage technologies on a community college microgrid.

The Potential for Energy Storage to Provide Peaking Capacity in California under Increased Penetration of Solar Photovoltaics. *NREL, 2018.*

NREL examines the potential for energy storage to perform functions currently met by the conventional generators that serve peak electricity demand, and they find that PV affects the technical potential of energy storage to meet peak demand in different ways, depending on how much PV is deployed.

Assessing and Enhancing Cost-Effectiveness of Storage

Energy Storage Technology and Cost Assessment, *EPRI, 2019.*

This report provided detailed cost and performance estimates for lithium ion and flow battery technologies. It proposed four main cost categories: Upfront Owner Costs; Turnkey Installation Costs; Operations and Maintenance Costs; and Decommissioning costs.

Advanced Renewable Energy Storage and Recycled Water Project, *Victor Valley Wastewater Reclamation Authority (VVWRA), 2016.*

This project is demonstrating an advanced, pre-commercial flow battery storage and control system at VVWRA's existing Regional Wastewater Treatment Plant, located in a disadvantaged community outside of Victorville. This project could reduce grid power demand and reduce energy costs to wastewater treatment plants and alleviate disruptions in recycled water production due to high variability of on-site power loads which can cause partial treatment shutdowns.

Advanced VGI Control to Maximize Battery Life and Use of Second-Life Batteries to Increase Grid Service and Renewable Power Penetration. *LBNL, 2017.*

This project demonstrates an automated control system for a fleet of plug-in electric vehicles and repurposed second-life batteries that reduces the overall cost of ownership by maximizing battery lifetime, shifting load to reduce electricity and demand charges, and providing V2G and V2B services, including those supporting the use of onsite solar generation. The demonstration is adding a stationary second-life battery installation to the existing PEV fleet site at Los Angeles Air Force Base.

Cost-Effective Islanding of Grid-Tied PV Using Advanced Energy Storage, *Lockheed Martin, 2014-2016.*

The demonstration results are expected to validate the cost and performance benefits of the system providing economic capabilities such as peak shaving, demand response, utility ancillary services, and energy arbitrage while improving a site's energy security through improved utilization of installed renewable energy resources during grid independent operations.

Identifying Potential Markets for Behind-the-Meter Battery Energy Storage: A Survey of U.S. Demand Charges, *NREL, 2017*

This paper presents the first publicly available comprehensive survey of the magnitude of demand charges for commercial customers across the United States to identify regions where there may be an economic case for behind-the-meter battery storage investment and estimate the potential size of the market for storage across these regions.

Load Archetypes: A Cross-Sectional Analysis of New York City's Largest Users to Help Accelerate the Deployment of Battery Storage, *GridMarket LLC, 2016*

To support the growth of the BESS across New York, this paper seeks to explore how variation in buildings' energy demand categorizes them into distinct "load archetypes", and how those archetypes can inform the design of BESS for managing peak demand and optimizing load at a given site.

Mercedes_Benz at a Low-Income Mobile Home Park - Integrated Community Solar and Storage. *Mercedes Benz, 2016*

By developing an integrated community solar and storage energy system at a low-income mobile home park, this project will identify strategies for storage to provide clear value propositions to customers under existing tariff structures and demonstrate additional opportunities to increase the value of storage to the customer and better meet distribution system operational goals.

Meeting Customer and Supply-side Market Needs with Electrical and Thermal Storage, Solar, Energy Efficiency and Integrated Load Management Systems. *Center for Sustainable Energy, 2016*

This project develops co-optimization strategies for distributed energy resources (DERs). The purpose is to maximize customer and system value under existing CPUC-approved retail and California Independent System Operator (California ISO) wholesale tariff structures, future market structures and pricing, and the transactive energy pricing signals developed under agreement.

Pilot Testing of Eos' Znyth Battery Technology in Distributed Energy Storage Systems. *Eos Energy Storage, 2016.*

The goal of this project is to develop and test behind-the-meter residential and commercial battery storage applications, each on both a stand-alone basis and integrated with solar PV. The project team is testing the impact of rate designs on customer load profiles; developing VPP control algorithms; and modeling, simulating, and extrapolating the economic impacts of installed systems and quantifying the benefits to CA utilities and ratepayers.

Santa Monica Advanced Energy District, *City of Santa Monica, 2016.*

The city of Santa Monica is designing a microgrid that will integrate a suite of local renewable energy sources, energy storage, and controllable loads into a single system that will later be scaled up. This project pilots innovative planning, permitting, and financing approaches and tools to help improve the business case for DER adoption at the community-scale.

Third Party Valuation of Grid and Microgrid Energy Storage Technologies, *DNVGL, 2014.*

Provide a unique combination of third-party testing facilities, testing and analysis methodologies, and expert oversight to the evaluation of ARPA-E-funded energy storage systems. This testing of ARPA-E-funded storage systems could identify performance issues and assess the economic value of systems for end-users. The development of economically optimized testing protocols can have an industry-wide impact as it may reduce the testing and validation cost burden faced by young companies with new technologies.

Transportable Microgrid with Energy Storage, *EPRI, 2016-2019.*

The project will obtain the necessary credible capital cost reductions, operating cost, real-world test data, safety features, reliability data, economic benefit data, and a tractable technology transfer plan that shows that the microgrid can be commercialized in a timely and cost-effective manner via a collaboration between the US DoD and US research institutes, electric utility industry, and engineering companies.

Validated and Transparent Energy Storage Valuation and Optimization Tool (StorageVET™), *EPRI, 2016.*

This EPIC-funded research developed and demonstrated analytical methods to produce credible estimates of energy storage project value for site-specific cases. It also provided an accessible, transparent, and validated platform for regulators, utilities, energy storage developers, and other stakeholders to engage in clear dialogue about the potential financial outcomes for energy storage projects and optimal operations.

The Value of Energy Storage for Grid Applications, *NREL 2013.*

This analysis used a commercial grid simulation tool to evaluate several operational benefits of electricity storage, including load-leveling, spinning contingency reserves, and regulation reserves. Overall, the results followed previous analyses that demonstrate relatively low value for load-leveling but greater value for provision of reserve services.

Vacaville Sodium-Sulfur Battery Storage, *PG&E, 2014.*

2 MW/28 MWh battery provides services to PG&E and CAISO energy markets. Research goals are to gain experience and data from participating in CAISO's Non-Generator Resource market, deploy an automated communications and controls solution, and quantify value from participating in markets.

Testing Viability of Emerging Storage Technologies

Advanced Energy Storage Modeling, Performance Evaluation and Testing, *UC San Diego, 2015-2020.*

The University of California, San Diego (UC San Diego) will conduct testing of ARPA-E energy storage technologies in both laboratory and grid-connected conditions. This approach will allow UC San Diego to achieve test results that represent a wide spectrum of applications, determine system performance under a variety of conditions, and eventually generate initial performance data that can be shared with electric utilities and other potential grid storage buyers to inform them of the promise of early-stage storage technologies.

Advanced Implementation of Energy Storage Technologies. *DTE, 2010-2015.*

DTE Energy will demonstrate the use and benefits of Community Energy Storage (CES) systems to strengthen grid reliability and test the ability to integrate secondary-use electric vehicle (EV) batteries into the CES demonstration effort. The performance data of the CES devices and control systems under in-service operating conditions will be analyzed and used to identify gaps and facilitate how the devices can be standardized for use across the U.S.

A Life Cycle Assessment of the Environmental and Human Health Impacts of Emerging Energy Storage Technology Deployment, *UC Irvine, 2017.*

This project investigates whether flow batteries are a viable option for providing grid energy storage at the large scale, either in place of or alongside lithium-ion battery technology.

Utility demonstration of Znth Battery, *Eos, 2017.*

Evaluate zinc hybrid cathode battery to cost-effectively provide the grid: peak shaving, ancillary services, load following, and frequency regulations Eos and project team members will test the storage system against a variety of utility specific use cases and will illustrate the technology's ability to achieve the Energy Commission's performance targets and financial targets of keeping costs under $200/kWh when manufactured at scale.

A Review of Flywheel Energy Storage System Technologies and Their Applications, *University of London, 2017*.

Review paper covering characteristics and applications of flywheel energy storage, including detailed descriptions of device configurations. The main applications are explained and commercially available flywheel prototypes for each application are described.

Low-Cost Flywheel Energy Storage Demonstration, *CEC 2015.*

Grant-funded demonstration through the PIER program at CEC to test the Amber Kinetics 6.25 kW, 25 kWh flywheel system. The project reports the potential for low system costs, high lifespan, and high efficiency. Self-discharge was estimated in laboratory tests to be 0.8% of battery energy capacity per hour on average, though this appeared to have a positive linear correlation with rotational speed.

HECO / Amber Kinetics Flywheel Pilot, *HECO 2018.*

HECO and Amber Kinetics are testing an 8 kW / 32 kWh kinetic energy storage system for local grid reliability and support. The five-ton flywheel stores electricity as rotational kinetic energy and lists a 30-year lifespan.

Vanadium Flow Battery Pilot, *SDG&E and Sumitomo Electric 2017.*

SDG&E will be testing a 2MW/8MWh pilot vanadium redox flow battery storage for voltage frequency, power outage support and the shifting energy demand abilities. This is the largest flow batter of its kind in the US.

Electric Vehicle Integration and Smart Charging

Technological Capability

Intelligent Electric Vehicle Integration (INVENT). *Nuvve Corporation, UCSD, 2017 - 2020.*

EPIC project demonstrating the real-world benefits of advanced Vehicle-Grid Integration (VGI) applications for electric vehicles (EVs), including smart charging and bi-directional sharing of EV batteries.

California E-Bus to Grid Integration Project. *Zero Net Energy (ZNE) Alliance, 2017 - 2020*.

EPIC project demonstrating a real-life operating context and inform best practices for commercial-scale procurements of electric buses throughout the state. This project is mainly aimed at developing actionable and fleetwide best practices for E-Bus integration into the grid.

Adaptive Onboard Chargers for Delivery Customers Demonstrating California Advances in Charging. *Motiv Power Systems, Inc., 2017 - 2020.*

EPIC project aimed at developing an onboard smart charger solution and an onboard bi-directional charger solution to enable vehicle grid integration options for medium- and heavy-duty fleet vehicles. The technology will be demonstrated using existing zero emissions delivery trucks at four AmeriPride Services locations within disadvantaged communities in Fresno, Bakersfield, Merced, and Stockton.

Open Vehicle to Building/Microgrid Integration Enabling ZNE and Improved Distribution Grid Services. *Electric Power Research Institute (EPRI), 2017 - 2019.*

EPIC project aimed at developing a local energy management system that integrates bidirectional plug-in electric vehicle charging, photovoltaic energy generation, and stationary battery storage to provide greater grid stabilization capabilities.

U.S. Dept. of Defense, LA Air Force Base V2G Pilot. *National Labs (LBNL), 2012.*

At a high level, this project seeked to employ V2G in the LA Air Force base microgrid to test the technology capability of a V2G control system, the V2G hardware, and prospects for EV participation in current energy markets.

Integrated Systems Modeling of the Interactions between Stationary Hydrogen, Vehicle, and Grid Resources. *National Labs (LBNL, NREL, INL), 2018.*

This project seeked to quantify the opportunity of utilizing flexibility from hydrogen systems to support the grid, to develop and implement methods to assess optimal system configuration and operating strategy for grid-integrated hydrogen systems.

iChargeForward V1G . BMW, PGE, Olivine, 2016.

BMW partnership with PG&E to create charging system for fleet pilot of BMW vehicles.

Bi-Directional, Wireless Truck Charging. *National Labs (ORNL), 2016*.

Oak Ridge National Laboratory partnered with UPS on a DOE-funded project focused on developing high-power, bidirectional wireless charging for electric delivery trucks. The goal is a V2G mode, with 6.6 kW wireless power transfer to building or grid loads providing grid support functions or ancillary services that can strengthen grid resilience

Enhancing Grid Resilience with Integrated Storage from Electric Vehicles. *DOE/FERC, 2018.*

Examines the ability of integrated storage from EVs to enhance grid resilience. Modes of integration discussed: G2V, V2B, V2G. Provides recommendations for DOE funding

Impact of Uncoordinated Plug-in Electric Vehicle Charging on Residential Power Demand. *National Labs (NREL), 2018.*

A computer simulation to explore the effects of in-home charging on the grid. Muratori found that as more PEVs are added to a neighborhood, and a higher charging power is adopted, "the distribution infrastructure might no longer reliably support the local electricity demand." He also noted the higher demand could shorten the expected life of a transformer.

Multi-Lab EV Smart Grid Integration Requirements Study: Providing Guidance on Technology Development and Demonstration. *National labs (General), 2015.*

A study aimed to define plug-in electric vehicle (PEV) grid integration scenarios and suggest the opportunities they support along with the necessary system implementation requirements.

Demonstrating Plug-in Electric Vehicles Smart Charging and Storage Supporting the Grid *CEC, 2018.*

Paper that presented the development and deployment of an electric vehicle (EV) charging system in Santa Monica, California, consisting of smart charging, vehicle-to-grid, vehicle-to-building, demand response and power quality sustainable capabilities to achieve grid resiliency and economic benefit to EV fleet owners. The research team from the University of California, Los Angeles (UCLA) Smart Grid Energy Research Center used its wireless network communication system and bi-directional EV charge infrastructure technologies to demonstrate the grid needs such as peak shaving, load leveling, and renewable source smoothing.

Understanding and Managing the Impacts of Electric Vehicles on Electric Power Distribution Systems. *University of Vermont, 2014.*

Estimated the Impact of Electric Vehicle Smart Charging on Distribution Transformer Aging. This paper describes a method for estimating the impact of plug-in electric vehicle (PEV) charging on overhead distribution transformers, based on detailed travel demand data and under several different schemes for mitigating overloads by shifting PEV charging times (smart charging). The paper also presents a new smart charging algorithm that manages PEV charging based on simulated transformer temperatures.

Smart Grid Demonstration Project in Maui Island of Hawaii State. *Hitachi, 2017.*

Projected aimed at installing and operate charging infrastructure. Conduct V1G and V2G demonstrations in Maui.

Vehicle-Grid Integration (VGI) Roadmap. *CAISO, 2014.*

CAISO paper that maps a way to develop solutions that enable electric vehicles (EV) to provide grid services while still meeting consumer driving needs.

Improving Commercial Viability of Fast Charging by Providing Renewable Integration and Grid Services with Integrated Multiple DC Fast Chargers. *Zeco Systems dba Greenlots, 2017*.

Developed an integrated hardware + software platform to control distributed DC fast chargers and energy storage to offer site benefits, and evaluate grid services potential from the aggregated DCFC loads to offer utility on-peak demand response, renewable integration and fleet scheduling.

Plug-In Electric Vehicle Commercial Charging Station Usage Pattern Assessment. *National Labs (LBNL), 2018.*

Evaluating how electric vehicles can be utilized as a grid resource.

Scaled Smart Charging Pilot. *Avista, 2016 - 2019*.

The purpose of the pilot is to determine how much PEV load can be shifted from peak load times to off-peak times without using TOU rates. This pilot is expected to provide Avista with a holistic view of scaling EV infrastructure sustainably with the grid and inform intelligent longer-term programs with utility owned EV charging infrastructure.

Durability and reliability of electric vehicle batteries under electric utility grid operations: Bidirectional charging impact analysis. *Hawaii Natural Energy Institute, SOEST, University of Hawaii at Manoa, 2016.*

Laboratory testing on commercial Li-ion cells to investigate the impact of bidirectional charging on Panasonic 18650 NCA batteries. The additional cycling to discharge vehicle batteries to the power grid in a vehicle-to-grid (V2G) scenario, even at constant power, is detrimental to EV battery cell performance. This additional use of the battery packs could shorten the lifetime for vehicle use to less than five years.

Characterization of In-Use Medium Duty Electric Vehicle Driving and Charging Behavior (Dec. 2014). *National Labs (NREL), 2014.*

In this paper, the authors present an overview of medium duty EV operating and charging behavior based on in-use data collected from both Smith and Navistar vehicles operating in the United States.

Value of Technology and/or Service

Smart Charging of Plug-in Vehicles with Driver Engagement for Demand Management and Participation in Electricity Markets. *National Labs (LBNL), 2018.*

EPIC project that developed and demonstrated a smart charging control system for electric vehicle supply equipment that demonstrated both minimized utility costs through managed charging of fleet vehicles and developed approaches to engage the non-fleet PEV owners and managed their charging station loads to further reduce electric utility costs.

U.S. Dept. of Defense, China Lake Naval Air Weapons Station and LA Air Force Base V2G demonstration (rate schedule). *U.S. Department of Defense, 2014.*

SCE provided a special rate schedule for these military bases to support a V2G pilot. CAISO’s market functionality supported participation by non-generator resources (NGRs) on these military bases, such as batteries from plug-in electric vehicles (PEVs), in both the energy and ancillary services markets. These resources served both generation and load and were dispatched to any operating level within their entire capacity range but were also constrained by a megawatt-hour (MWh) limit to (1) generate energy, (2) curtail the consumption of energy in the case of demand response, or (3) consume energy.

EV Demand Response Pilot. *PEPCO, 2015.*

Demonstrated “passive” incentives (lower rate) to achieve positive customer behavior towards off peak charging and demonstrated “active” incentives (demand management) towards off peak charging, while providing the customer “opt out” alternatives.

Clinton Global Initiative V2G School Buses. *PJM Interconnection LLC, National Strategies, LLC (NSI), EY, 2014.*

Initiative aimed at moving EV school buses toward full, unsubsidized commercial availability by demonstrating vehicle-to-grid as the “missing link” of economic competitiveness

EV providing DR Services in Wholesale Markets. *EMotorWerks, CA IOUs, 2018.*

Enel X's eMotorWerks subsidiary is rolling out its smart grid electric vehicle (EV) charger as a virtual battery that can participate as a demand response resource in the California wholesale power market.

Managing PEV Charging: Optimization of Pricing & Resource Allocation. *SDGE, 2016*.

SDG&E developed and implemented a pilot program to aggregate and bid distributed energy storage and PEVs into the CAISO’s Energy, Spinning and Non- Spinning Reserve markets.

A Test of Vehicle-to-Grid (V2G) for Energy Storage and Frequency Regulation in the PJM System. *University of Delaware, NRG, PJM, 2013.*

A University of Delaware and PJM case study illustrated the ability of EVs to bid frequency regulation services into competitive markets. In a simulation assessment, Shinzaki, Sadano, Maruyama, and Kempton estimated that a vehicle could generate between $623 and $1,014 in V2G service revenue streams.

Communication Protocols

Demonstration of Electric Vehicle Smart Charging and Storage Supporting Grid Operational Needs. *Regents of the University of California, Los Angeles, 2018.*

EPIC project that demonstrated potential applications for smart grid technologies that enable smart charging, integration of renewable energy, and vehicle-to-grid (V2G). These scenarios will use bidirectional power flow infrastructures, deployed at various sites within the Southern California Edison territory, to measure a range of variables including the behaviors of PEV users captured via smartphone applications, system integration with smart grids using a test bed of OpenADR signals, power levels, and power quality.

Distribution System Aware Vehicle to Grid Services for Improved Grid Stability and Reliability. Electric Power Research Institute (EPRI), 2018.

EPIC project that developed a vehicle-to-grid (V2G) communication system that will demonstrate grid awareness, self-regulation, and interoperability. The communication technology and interfaces supported V2G information processing to better leverage plug-in electric vehicles and improve renewable generation penetration.

Advanced VGI Control to Maximize Battery Life and Use of Second-Life Batteries to Increase Grid Service and Renewable Power Penetration. *National Labs (LBNL), 2017 - 2020.*

EPIC project aimed to demonstrate an automated control system for a fleet of plug-in electric vehicles and repurposed second-life batteries that reduces the overall cost of plug-in electric vehicle ownership by maximizing battery lifetime, shifting load to reduce electricity and demand charges, and providing vehicle-to-grid and vehicle-to-building services including those supporting utilization of on-site solar generation.

Modeling and Control Software Tools to Support V2G Integration. *National Labs (LBNL), 2018.*

Outcome 1: Development of open-source toolsets for VGI planning, analysis, and operations

Outcome 2: Application of toolsets to address critical knowledge gaps and barriers to VGI

Vehicle to Building Integration Pathway. *National Labs (PNNL), 2016.*

Developed and demonstrate pre-normative methods needed to develop a standardized and interoperable communication pathway and control system architecture between Plug-in Electric Vehicles (PEVs), Electric Vehicle Support Equipment (EVSE) and Building/Campus Energy Management Systems (BEMSs)

Diagnostic Security Modules for Electric Vehicles to Building Integration. *National Labs (INL, ANL, NREL, PNNL), 2016.*

Developed a Diagnostic Security Module (DSM) framework for creating an end-to-end security architecture for the integration of modern Plug-in Electric Vehicle (PEV) with Electric Vehicle Supply Equipment (EVSE) and a BEMS.

Open Vehicle Grid Integration Platform (OVGIP) Proof of Concept. *EPRI, utilities, OEMs, 2018.*

The project objective is to advance the open platform concept into the product development and testing stage. It will assess the effectiveness of an open standards-based platform to seamlessly integrate PEV charging with grid objectives through DR and DSM mechanisms.

Grid Communication Interface for Smart Electric Vehicle Services Research and Development. *Andromeda Power, LLC, 2016 - 2019.*

EPIC project that developed an advanced bidirectional, smart, fast charging system to enhance the integration of plug-in electric vehicles into the electricity grid using real time monitor and control to efficiently enable automated demand response.

Next-Generation Grid Communication for Residential PEVs. *ChargePoint, Inc., 2018.*

EPIC project aimed at developing a grid-vehicle-charging station connectivity methodology and assess the real-time potential for residential smart chargers to respond to utility signaling for grid stabilization.

Open Source Platform For Plug-in Electric Vehicle Smart Charging in California. *The Regents of the University of California, Berkeley, 2016 - 2019.*

Microgrid project focused on open source platform VGI through local building control.

Augmenting AMI with Broadband: A Smart Charging Pilot Demonstration. *SCE, 2016*.

A report summarizing the Smart Charging pilot conducted by SCE that evaluated some technologies that could be deployed by SCE and vendors in order to achieve smart charging to realize the benefits of electrification.

Systems Research Supporting Standards and Interoperability. *National Labs (ANL, INL, LBNL, NREL, ORNL, PNNL), 2017 - 2019.*

The objective of the proposed project is to address the considerable uncertainty regarding the degree to which PEVs can provide grid services and mutually benefit the electric utilities, PEV owners, and auto manufacturers. This project will answer this question by leveraging capabilities of multiple national laboratories with vehicle/grid integration (VGI) to perform hardware-in-the-loop (HIL) studies that integrate communication and control system hardware with simulation and analysis activities.

Smart Grid, Electric Vehicles And Demand Response Collaboration With UCLA. *National Labs (LBNL), 2018.*

Using OpenADR to mediate residential demand response and grid storage using electrical vehicles.

Energy Flexible Load Assets

Market and Program Innovation

Demand Response and Energy Storage Integration Study. *DOE, 2016.*

This report represents an initial effort in analyzing the potential integration value of demand response and energy storage, focusing on their operational value providing bulk power system services and barriers to deployment.

Demonstrating “Fast Demand Response” and Integrating Intermittent Renewable Energy*. HECO, Honeywell, 2012-2014.*

The pilot is designed to validate the technical design and tariffs for a full-scale demand response program to support Hawaii’s renewable energy goals

Does Real-Time Pricing Deliver Demand Response? A Case Study of Niagara Mohawk's Large Customer RTP Tariff. *LBNL, 2004.*

This study examines the experience of 130 large (over 2 MW) industrial, commercial, and institutional customers at Niagara Mohawk Power Corporation that have faced day-ahead electricity market prices as their default tariff since 1998. It was shown that default RTP does deliver modest DR benefits, but is best viewed as part of a portfolio of DR options.

Driving Towards Fast and Flexible Demand Response Leveraging Distributed Resources. *EPRI, 2017.*

The report highlights key trends in market and policy developments impacting demand response (DR) evolution and resulting implications on DR programs and enabling technology alternatives. The report distills literature reviews and industry interviews to identify promising DR strategies for providing fast and flexible services in select industrial customer sectors, including refrigerated warehouse and data centers.

Evaluation Framework for Sustainable Demand Response Implementations: A Framework for Evaluating Demand Response Implementation Alternatives for Sustainability. *EPRI, 2011.*

The DR evaluation framework provides a structured, systematic approach to assist utility personnel (e.g., program designers) in evaluating program design options to achieve sustainable DR implementations, supportive of utility objectives, regional policies, and other drivers for DR.

Empowering Proactive Consumers to Participate in Demand Response Programs. *Ohmconnect, 2016-2019.*

First, this EPIC-funded project will determine prosumer (proactive consumer) interest in a third-party demand response market by testing user acquisition via direct and non-direct engagement strategies. Second, experimentation with behavioral and automated users will allow analysis of user yield under a variety of conditions and extract a set of shadow curves that can inform how much energy load shifting can be expected under various price incentives. Finally, this project will create a novel solution for using residential telemetry to connect prosumers and their Internet of Things (IoT) devices to the market operators.

Home Energy Management System Savings Validation Pilot. *Lockheed Martin Energy (LM Energy), 2017.*

NYSERDA collaborated with LM Energy to provide an integrated HEMS solution to a pilot group of single-family homes and to analyze potential energy and cost savings. The Base-Load Simulation method was successfully demonstrated as a valid approach for HEMS measurement and verification (M&V) while minimizing the impact on homeowners.

Identifying Effective Demand Response Program Designs for Small Customer Classes.
UCLA, 2016-2019.

This pilot study will test the effectiveness of innovative design strategies a.k.a. "treatments" for residential DRPs using a behind-the-meter customer engagement platform.

PGE Test Bed. *Portland General Electric, 2018.*

This project aims test a number of hypotheses and critical assumptions about the potential of flexible loads in the Northwest that are difficult or impossible to obtain. Additionally, the Test Bed will gather data on achievable potential informed by participation and saving rates, test customer engagement approaches, develop experience and program management best practices, moving from direct load control to pricing program to coordinated transactive management of flexible loads and distributed energy resources.

Control Strategies & Grid Coordination

Customer-centric Demand Management using Load Aggregation and Data Analytics. *EPRI, 2016.*

This EPIC-funded project aims to develop, deploy and operate a software aggregation platform (tool) that combines the response from multiple residential and small commercial customers and loads in a manner that both stabilizes and verifies the response from individual loads while enhancing grid stability and reliability.

Dynamic Building Load Control to Facilitate High Penetration of Solar PV Generation, *ORNL, 2017-Present.*

This project will create an open-source control framework for exploiting variability and dispatchability of electric power loads. It will demonstrate low-cost, low-touch sensing and control retrofits to distributed PV generation and building loads that can provide the load-shaping response needed to integrate high-levels of renewable penetration.

GridBallast - Autonomous Load Control for Grid Resilience. *National Rural Electric Cooperative Association (NRECA), 2016-2019.*

This project aims to develop GridBallast, a low-cost demand-side management technology. Devices based on GridBallast technology will monitor grid voltage and frequency and control the target load in order to address excursions from grid operating targets.

Grid-Interactive Water Heaters. *HECO, 2014.*

HECO commissioned a yearlong project to assess how grid-interactive water heaters could provide grid services by using software and controllers to manage the units. HECO found the project was able to provide sustained and precise voltage regulation and had a minimal impact on customer energy use or comfort.

Highly Dispatchable and Distributed Demand Response for the Integration of Distributed Generation, *AutoGrid Systems, National Labs, 2012-2014.*

This project designed and demonstrated a highly distributed Demand Response Optimization and Management System for Real-Time (DROMS-RT) to show that 10 "personalized" DR signals could be sent to millions of customers in extremely short time frames.

Improving Distribution Transformer Efficiency and Lifetime through Product Selection and Dynamic Load Control. *SRNL, 2017.*

Develop and evaluated transactive load control strategies for distribution and building level transformers that improve the efficiency of integrated electric energy system and extend the service life of utility and building assets.

Irvine Ranch Water District Load Shifting and Demand Response Pilot Project. *Advanced Microgrid Solutions, SCE, 2017.*

This EPIC-funded project aims to develop, test, and validate a pre-commercial load shifting and demand response (DR) platform for industrial water treatment, pumping, storage, and recycling facilities. The project will include: a) real time monitoring, b) automated load control, c) a pre-commercial cost optimization platform, and d) energy storage and automated DR.

Residential Intelligent Energy Management Solution: Advanced Intelligence to Enable Integration of Distributed Energy Resources. *Alternative Energy Systems Consulting, 2016-2020.*

This EPIC-funded project tests and validates an intelligent residential energy management system that communicates with a variety of DER such as solar PV, and energy storage in in 100 residences in San Diego, CA. The project integrates the use of pilot time-of-use utility rates in conjunction with simulated dynamic pricing signals to optimize cost savings. In addition, modeling and measuring the energy implications and costs without affecting occupant comfort is also being explored.

Synthetic Reserves from Aggregated Distributed Flexible Resources. *GE, LBNL, SCE, 2016-2019.*

General Electric Global Research along with its partners will develop a novel distributed flexibility resource technology that aggregates responsive flexible loads and DERs to provide synthetic reserve services to the grid while maintaining customer quality-of-service. Key innovations include a forecast tool, an optimization framework, and a scalable control and communication architecture will enable coordination and control of the resources.

Transactive Control Demand Response. *PNNL, 2017.*

This project developed a novel demand response system that is based on a bi-directional "transactive" response approach to control system demand peaks and create a stable and predictable load profile for the utility. This transactional-control demand response system was tested in PNNL's landmark Olympic Peninsula Smart Grid Demonstration Project that proved the ability and willingness of customers to respond to real-time price information.

Unified Control of Connected Loads. *ORNL, 2016-2018.*

Develop a retrofit system for coordinating the operation of multiple loads to reduce peak demand, reduce energy consumption, and provide transactive energy services to the electric grid.

VOLTTRON™ Controller for Economic Dispatch. *PNNL, 2016-2018.*

The primary goal of this project is to provide a general procedure for formulating an economic dispatch in a commercial building for optimal day-ahead scheduling and realizing optimal real-time operation. Secondary goal: performance monitoring, automated fault detection and diagnostics (AFDD) and automated continuous commissioning (ACCx)

Communications and Interoperability

Customer-controlled, Price-mediated, Automated Demand Response for Commercial Buildings. *CIEE, 2016-2019.*

The purpose of this EPIC-funded project is to improve small and large commercial customer participation in demand response programs by providing a cost-effective, open source and open architecture platform that can interface with multiple hardware devices from different vendors as well as include software applications from various vendors.

Distributed Energy Systems Integration and Demand Optimization for Autonomous Operations and Electric Grid Transactions. *LBNL, 2015.*

This paper presents a cost-effective solution to DER systems integration and communication challenges by exploring communication technologies and information models for DER system integration and interoperability, using open standards and optimization models.

Field Testing of Telemetry for Demand Response Control of Small Loads. *LBNL, 2015.*

The goal of this project was to evaluate methods of enabling fast demand response (DR) signaling to small loads for low-cost site enablement. It used OpenADR 2.0 to meet telemetry requirements for providing ancillary services, and we used a variety of low-cost devices coupled with open-source software to enable an end-to-end fast DR.

Integration of Responsive Residential Loads into Distribution Management Systems. *ORNL, 2017-2020.*

This objective of the project is to develop and demonstrate home energy management system (HEMS) as an interface to enable seamless aggregation and disaggregation of residential distributed energy resources (DERs) using open communication interfaces and advanced distributed controls to improve the economics and resilience of grid operations. This project will perform field evaluation to demonstrate advanced controls supporting distribution resiliency and end-to-end interoperability.

Interoperability of Demand Response Resources Demonstration in NY. *ConEdison, 2015.*

This project designed and implemented a central load curtailment controller with cybersecurity provisions enabling it to be used within the framework of a major national telecom network and provide interoperability between DR resources and an Electric Distribution Utility.

Market Aware High-Performance Buildings Participating in Fast Load Response Utility Programs with a Single Open Standard Methodology. *IPKeys Technologies, 2017.*

This project is demonstrating machine-to-machine communication between DoD facilities and energy providers, enabling secure participation in the new grid balancing and demand management programs. Demonstrations are taking place at Fort Irwin, Camp Pendleton, and Picatinny Arsenal.

Transactive Incentive Signals to Manage Electricity Consumption for Demand Response. *EPRI, 2016-2019*

EPIC will fund the design, development, implementation, testing, and operational deployment of transactive signals (proxy prices) that can be used to facilitate Demand Response (DR) provided by California utility customers and other recipients.

Using OpenADR with OCPP, *Greenlots, SCE, 2014.*

The project, which started in October 2014, is among the first large scale pilots to use open standards protocols OpenADR 2.0b and OCPP in combination for electric vehicle charging.

Grid Optimized Loads

GridOptimal Initiative. *New Buildings Institute, 2018-Present.*

NBI is creating a standardized metric that defines a building's contribution to the relevant utility grid scale—the building's operational performance as a grid asset.

Demand Response-Ready End-Use Technologies: Overcoming Barriers to Customer Adoption of DR-Ready Devices. *EPRI, 2015.*

The objectives of the project are twofold: 1) develop a methodology for identifying the customer rationale for adoption of connected devices and leveraging them to participate in DR programs; and 2) refine the functional criteria for DR-Ready end-use devices to support grid needs.

Demand Response Technology Readiness Levels for Energy Management in Blocks of Buildings. *The University of Manchester, 2018.*

This paper describes the "Demand Response in Blocks of Buildings" energy management solution and outlines demand response technology readiness levels (DRTRLs) for the implementation of such a solution in blocks of buildings.

Measures to improve energy demand flexibility in buildings for demand response (DR): A review, *Energy and Buildings, 2018.*

This paper summarizes the measures for improving the flexibility of commercial and residential buildings and develops a systematic methodology framework to evaluate energy demand flexibility in buildings.

Predictability and Persistence of Demand Response Load Shed in Buildings. *LBNL, 2015.*

This project analyzed data from 36 commercial and government buildings that participated in a Demand Response (DR) program in California, to investigate the extent to which DR load shed in each building depends on outdoor air temperature, and whether the load shed varies systematically from year to year.

Recommended Practice for Characterizing Devices' Ability to Provide Grid Services. *PNNL, 2017-Present.*

This document describes a Recommended Practice for characterizing the ability of various types of devices to provide a broad range of existing and emerging grid services and to characterize any potential impacts of doing so on other services that are their primary function.

Technology for Building Systems Integration and Optimization – Landscape Report, DOE Building Technologies Office, *Jan 2018*

This report will be characterizing the state of the art and other current R&D activities, evaluating the energy savings impact across a broad set of building and systems and then identifying integration capabilities and needs. This will enable DOE to characterize and prioritize the integration research, development and field study necessary to achieve optimized and efficient, ultra-low energy building.

Smart Inverters and Grid Edge Communications

Communications and Cybersecurity

Cybersecurity for Renewables, Distributed Energy Resources, and Smart Inverters, *ANL, 2016.*

The objective of this project is to develop a holistic attack-resilient architecture and layered cyber-physical solution portfolio to protect the critical power grid infrastructure and integrated distributed energy resources (DER) from malicious cyber attacks.

Information and Communications Technology and Security Architecture for DER Integration, *EPRI, 2017.*

The objectives of this supplemental project are to develop and demonstrate secure communication architectures that will enable coordinated control of DER.

Opportunistic Hybrid Communications Systems for Distributed PV Coordination, *NREL, 2018.*

Project intends to develop a novel communications network to better suit the needs of the monitoring and control of distributed PV generators, develop resilient decentralized state estimation, and conduct rigorous validation of communications systems. Make sure new architecture meets system response time goals in both normal and contingency event operational states.

Secure, Scalable, Stable Control and Communications for Distributed PV, *SNL, 2018.*

Goal of project is to develop a distributed control and communications architecture that refines the SunShot Systems Integration communications target metrics by clearly articulating the impact of each metric on the grid. Depending on the application, some metrics can be relaxed, resulting in cost savings. For others, stricter requirements may be necessary. Project underway; no publications yet.

Interoperability and Standardization

Communications Standards for Demand Response and DERs, *EPRI, 2014.*

Discusses communications protocols for DR, PEVs, and Smart Inverters. Useful background material but may be out of date at this point.

Expanding Standards and Developing Tools to Enable DNP3 support of energy storage use cases, *EPRI, 2016.*

This EPIC project will develop tools to make adoption of DNP3 for communication and controls of distributed energy resource (DER) systems simple and seamless. An ancillary benefit will be to improve communications with stand-alone energy storage systems and control of other inverter-based devices, including solar and plug-in electric vehicle fleets.

Smart Inverter Working Group Phase 3 DER Recommended Requirements,

Summarizes Smart Inverter Working Group recommendations to include 8 functions into Rule 21. These recommendations result from the additional SIWG 191 discussions held during February and March 2017.

Smart Inverter Interoperability Standards and Open Testing Framework to Support High-Penetration Distributed Photovoltaics and Storage, *Olivine, 2015.*

This project will deliver a smart inverter test framework and open source software tools to enable rapid product development and safety testing and will demonstrate the benefits to all stakeholders including ratepayers, utilities, manufacturers, investors and operators.

Standard Communication Interface and Certification Test Program for Smart Inverters, *EPRI, 2014- 2016.*

Funded by California Solar Initiative's RD&D Program, this project to assess the potential for solar inverter manufacturers to massproduce and certify products that could work in any communication system by way of a standard modular communication interface. The project also focused on developing a ready certification and compliance test framework that includes the functional and communication aspects of smart inverters

Advanced Functionality Research and Demonstration

Arizona Public Service Solar Partner Program Smart Inverter project, *APS, EPRI, 2017.*

This program sought to evaluate and improve the integration of “advanced” or “smart” inverters into the electric distribution system. The research questions answered in the report span multiple technical areas, including advanced inverter settings, PV system performance, hosting capacity, substation capacity deferral, and distribution operations.

Assessing the Benefit of Smart Inverters to Reliability (Distribution Modeling), *FERC, 2018.*

This study assesses whether smart inverters on the distribution system provide greater benefits than regular inverters used in some DER installations. This study examines the potential impacts of smart inverters providing volt-VAR control; it does not include frequency control.

Assessing the ability of smart inverters and smart consumer devices to enable more residential solar energy, *EPRI, 2015.*

This EPIC project will identify how Rule 21 functions can be used and configured so that multiple smart inverters work in harmony. This project will also identify how other common consumer devices, such as electric vehicle chargers and other smart loads, can serve to further enable high penetration levels of residential solar PV into the distribution system.

Demonstrate the Phase III functions of a PV Smart Inverter and a storage inverter with a communications gateway, *Advanced Microgrid Solutions, 2017-2020*

This EPIC project will test and validate the Phase III functions of a PV smart inverter and a storage inverter with a communications gateway to support higher penetrations of solar on the grid at the South Coast AQMD Headquarters in Diamond Bar, California.

Duke Energy Smart Inverter case study, *Duke Energy, NREL, 2016.*

The specific goal of the project was to compare the operational—specifically, voltage regulation—impacts of three methods of managing voltage variations resulting from such PV systems.

Enabling Smart Inverters for Distribution Grid Services White Paper, *Joint CA IOUs, 2018.*

This report is intended to inform electric utilities, regulators and DER industry stakeholders nationwide by consolidating results and learnings achieved in demonstration projects.

Grid Frequency Support from Distributed Inverter-Based Resources in Hawaii, *SNL, HECO, 2016-2017.*

The project will develop new control methods to improve inverter-based frequency response and new models to evaluate DER-based frequency support. The project will also test the frequency support functions of PV and battery storage in the field and in the lab.

HECO Voltage Regulation Operational Strategies (VROS) project, *HECO, NREL, 2017.*

This project evaluated different modes of voltage-regulation grid support functions (GSF) to better understand the trade-offs of the grid benefits and curtailment impacts from the activation of selected advanced inverter GSF.

Hawaiian Electric Advanced Inverter Grid Support Function Laboratory Validation and Analysis, *HECO, NREL, 2016*

The purpose of this project was to: 1) characterize how the tested grid supportive inverters performed the functions of interest, 2) evaluate the grid supportive inverters in an environment that emulates the dynamics of Oʻahu's electrical distribution system, and 3) gain insight into the benefits of the grid support functions on selected Oʻahu island distribution feeders.

Impact assessment & secure implementation of California Rule 21 Phase 3 Smart Inverter Functions to support high PV penetration, *EPRI, 2017-2020.*

This EPIC project will conduct a comprehensive assessment of the California Rule 21 Phase 3 functions, including computer modeling and laboratory and field testing. In addition, this agreement will assess cyber security and deploy the digital certificate infrastructure needed to support the Institute of Electrical and Electronic Engineers (IEEE) 2030.5 requirements identified in Phase 2.

Lab and Field Experience, *SCE, PG&E, 2018.*

A partnership to perform lab testing of smart inverter functions between SCE and PG&E.

Salt River Project Advanced Inverter study, *SRP, EPRI, 2017.*

The Advanced Inverter Project will help the utility to better understand advanced inverter functions, its communication and control capabilities, and how these functions can benefit both the customer and SRP now and into the future.

Smart Grid Ready PV Inverters with Utility Communication, *DTE, National Grid, EPRI, 2016.*

The objective of the project was to successfully implement and demonstrate effective utilization of inverters with grid support functionality to capture the full value of distributed photovoltaic (PV).

Smart Inverter Demo C, *SDG&E, 2015*

This project tested three autonomous Volt VAr/Volt-Watt curves, PV on/off effect on voltage, and fixed power factor.

Pilot Distributed Energy Management Systems (DERMS), *PG&E, 2015-2018.*

This EPIC project will demonstrate up to 8 use cases coordinating energy storage and PV-connected Smart Inverters, evaluate DERMS requirements (e.g., communication requirements for PG&E and 3rd party owned DERs), and define boundaries and integrations with other PG&E systems.

Test Capabilities of Customer-Sited Behind-the-Meter Smart Inverters, *PG&E, 2017.*

The project aims to demonstrate the functionality of customer-sited behind-the-meter (BTM) photovoltaic (PV) Smart Inverters (SI) and the grid impacts of their use. Demonstrations at "Location 1" have been completed, and demos at "Location 2" are still in progress.

Virtual Oscillator Controls, *NREL, 2018-Present.*

NREL researchers are working to analyze the limitations of conventional grid-following controllers and develop models of low-inertia systems with traditional controllers, leverage digital microcontrollers for next-generation inverter controllers, and assess the compatibility of novel grid-forming controllers on commercial off-the-shelf inverters.

Distribution Grid Communications

Advanced Functionality Demonstrations

Demonstration of integrated photovoltaic systems and smart inverter functionality utilizing advanced distribution sensors. *LBNL, 2015-2019.*

[EPIC-14-035] Demonstration of inverter controls of solar plus storage installation, including input from distribution synchrophasor units. A Micro Phasor Measurement unit (uPMU) was installed at building feeder in 2018 and scripts were written to identify grid-event triggers. At this point open loop control based on the uPMU.

Grid Communication Interface for Smart Electric Vehicle Services Research and Development. *Andromeda Power, 2016-2019.*

[EPIC-15-015] Project will develop advanced smart grid communications interface that allows utilities to send dispatch signals to EVSE in real-time to optimize the bidirectional power flow depending on local conditions. Two prototypes of L2 chargers capable of V1G managed charging. Also installing in microgrid to demonstrate the feasibility of mitigating renewable energy overgeneration.

Next Generation SmartMeter Telecom Network Functionalities. *PG&E, 2016.*

[EPIC-PGE-1.14] Project evaluated the ability of the SmartMeter Telecom Network to support a variety of smart grid use cases. Major categories were: baseline network performance, communications with grid devices, and SmartMeters for outage reporting.

Communications Protocols

Transactive Incentive Signals to Manage Electricity Consumption for Demand Response. *EPRI, 2016-2019.*

[EPIC-15-045] Project develops Transactive Load Management (TLM) signals, expressed in the form of proxy prices reflective of current and future grid conditions. Signals will be tested in projects awarded under GFO-15-311.

Expanding Standards and Developing Tools to Enable DNP3 Support of Energy Storage Use Cases. *EPRI, 2016-2019.*

[EPIC-15-089] Project supports open communication with energy storage systems by focusing on a Distributed Network Protocol (DNP3) for smart inverters. Current work is mostly regarding PV; intends to extend the smart inverter function set with energy storage in mind.

Unlocking Plug Load Energy Savings through Energy Reporting. *LBNL, 2016-2019.*

[EPIC-15-026] Project will develop an interoperable protocol that can be implemented in all plug-load devices to enable energy reporting such as operational state and power consumption. After a communications infrastructure is enabled for plug-load devices, this can be used to send control signals. List of devices published to Open Connectivity Forum (https://openconnectivity.org/)

Total Charge Management: Advanced Charge Management for Renewable Integration. *BMW of North America, 2016-2019.*

[EPIC-15-084] Portion of this project develops advanced vehicle telematics for utilities and grid operators to align vehicle battery status, driver mobility needs and grid conditions.

Communications and Interoperability: New Requirements for DERs. *EPRI, 2017.*

Three protocols available through IEEE 1547: IEEE 1815 (DNP3), IEEE 2030.5, and SunSpec Modbus. IEEE 1547 applies to local DER interface, while Rule 21 applies to protocols between DER managing entity and DER gateways.

Cybersecurity is expected to be address in the DER communications networks rather than at the local device interface (only one device is accessible in physical location). However, a compromised DER managing network would have the scale to be dangerous, and new standards and codes could be created.

The Value of Direct Access to Connected Devices. *EPRI, 2016.*

Paper qualitatively identifies the value of open, standard direct access to devices.

DER Cybersecurity R&D and Standards Development. *Sandia, 2018.*

SunSpec/Sandia DER Cybersecurity Workgroup is actively looking at:
DER Devices & Servers - standardized procedure for DER vulnerability assessments
Secure Network Architecture - create DER control network topology requirements and interface rules
Soon - Data-in-flight requirements - Define physical/logical DER boundaries and requirements; authentication and encryption requirements

Transactive Energy and Future Markets: Opportunities for OpenADR. *EPRI / OpenADR Alliance, 2018.*

Discusses the sub-projects of CEC GFO 15-311 (including BMW project listed above). Includes Load Management Systems as Supply Side, LMS as Demand Side, and Transactive Signals

Communications Standards for Demand Response and DERs. *EPRI, 2014.*

Discusses communications protocols for DR, PEVs, and Smart Inverters. Useful background material but may be out of date at this point.

Interoperability Strategic Vision. *GMLC, 2018.*

Provides high level qualitative assessment of the value of grid interoperability. Assesses interoperability categories as Technical, Informational, and Organizational in useful Figure 3. Also provides framework for interoperability roadmap in Figure 10.

Device Functionalities

Smart Inverter Working Group Phase 3 DER Recommended Requirements. *CPUC, 2017.*

Rule 21 Phase 2 - Communications requirements go into effect February 2019; Phase 3 expected to include additional advanced functionality

Grid Communications Requirements for DER. *UtilityDive / Nokia, 2017.*

Existing utility field area networks (FAN) were not designed for the extent of data produced by high-granularity edge devices. As a result, utilities may have multiple independent, purpose-built FANs that are difficult to coordinate.

New Long Term Evolution (LTE) converged FAN based on IP/Multi-protocol label switching (IP/MPLS) may be useful for DER integration. Advantages include high radio frequency transmit power and receive sensitivity, high non-line-of-site performance and wide ecosystem.
IP/MLPS allows utilities to converge all DA applications atop LTE.
Provides list of barriers.

NYISO DER Roadmap for Wholesale Markets. *NYISO, 2017.*
Focused on bulk power system impacts, but contains section of DER telemetry.
1. Real-time telemetry requirements (6-second) for DER coordinators at the scheduling point node level.
2. All coordinators required to have revenue-quality (minimum ANSI C12 hourly interval) for settlement and billing.
3. NYISO is permitting aggregations of less than 1 MW to use real-time telemetered data from a sample set (at least 30%) of DER under a coordinator's control. Purpose is providing a representative view while lowering the requirements for some of the small DERs. Details TBD.

Overview of DoE's Grid Modernization Initiative and Multi-year Program Plan. *GMLC, 2018.*
Sensing and Measurement Expected Outcomes:
- Advance and integrate novel, low-cost sensors
- Incorporate new data streams (e.g. weather, fire conditions)
- Develop real-time data management and exchange frameworks
- Develop next-generation sensors that are accurate through disturbances and enable closed-loop controls

Grid Sensing and Measurement Strategy. *GMLC, 2017.*
Draft Sensing and Measurement Roadmap submitted to DoE in 2017; awaiting public release. Graphic of subprojects on page 5.
List of Communications R&D Thrusts on page 22. Contains more detailed subprojects.
1) Distributed Communication Architecture Development
2) Low Latency, Robust, and Secure Communications Technologies Development
3) Networking Technologies to Tackle Challenges of Scalability, Diverse Quality of Service Requirements, Efficient Network Management and Reliablity
4) Input into Standardization Efforts for Interoperability

Secure, Scalable, Stable Control and Communications for Distributed PV. *GMLC, 2018.*
Goal of project is to develop a distributed control and communications architecture that refines the SunShot Systems Integration communications target metrics by clearly articularting the impact of each metric on the grid. Depending on the application, some metrics can be relaxed, resulting in cost savings. For others, stricter requirements may be necessary. Project underway; no publications yet.

Opportunistic Hybrid Communications Systems for Distributed PV Coordination. *GMLC, 2018.*
Project intends to:
1) Develop a novel publish-subscribe pattern-based communications network in order to better suit the needs of the monitoring and control of distributed PV generators.
2) Develop decentralized state estimation with dimensionality reduction algorithms that are resilient to measurement outliers.
3) Rigorous validation of communications systems developed through hardware-in-the-loop testing. Make sure new architecture meets system response time goals in both normal and contingency event operational states.

The Smart Grid: Status and Outlook. *Congressional Research Service, 2018.*
Department of Energy estimation of Smart Grid funding from 2008 to 2017. Predicts significantly reduced grid modernization efforts in the absence of additional intentional concentrated funding.

DER Technical Considerations for the Bulk Power System. *FERC, 2018.*
Primarily focused on bulk system impacts of DER but contains brief section on DER communications. Discusses IEEE 1547.2018 communications capabilities mandate but reiterates utility responsibility for communications network itself.

Cybersecurity

Cybersecurity for Renewables, Distributed Energy Resources, and Smart Inverters. *GMLC, 2018.*
Develop a holistic attack-resilient architecture including:
- DER cyber-security framework
- Cyber-physical models that incorporate cyber threats, control, communication, and physical properties of the power grid and dispersed DER
- DER attack prevention, detection, and response measures across the cyber, physical device, and utility layers of the power system

- Extensive validation and verification of the developed methods through realistic testbed evaluation

Information and Communications Technology and Security Architecture for DER Integration. *GMLC, 2017.*
Challenges:
- How to cost-effectively scale up and manage dynamic aggregations of diverse DER assets
- Establishing cyber-security responsibilities for different stakeholders
- Requirements to enable market integration
- Managing uncoordinated or partially coordinated DER impacts on grid operations

Cyber Security for DER Systems. *EPRI, 2013.*
Slightly dated but very comprehensive resource diagramming the layers of the system architecture with definitions of cybersecurity requirements for each of them.
Level 1: Autonomous DER Generation and Storage
Level 2: Facility DER Energy Management
Level 3: Utility / Retail Energy Provider Information and Communications Technology
Level 4: Distribution Utility DER Operational Analysis
Level 5: Transmission Operations

Distributed Grid Management

Advanced Management Systems

UniGen Smart System for Renewable Integration. *Onset, Inc., 2016 - 2019.*

EPIC project aimed at developing grid control software that disaggregates the large, problem of integrating renewables under centralized control into smaller, more manageable clusters that can be controlled at the generator level as opposed to the grid level. This is a possible version of a distribution system operator (DSO).

Coordinating Distributed Energy Resources for Grid Services: A Case Study of Pacific Gas and Electric. *NREL*

The PG&E DERMS demonstration is among the first field validations of DERMS core capabilities in the United States. Among several key outcomes, it showed that a DERMS can be used to coordinate DERs, leverage DERs to mitigate capacity constraints and voltage violations, and provide distribution grid services while potentially enabling DER resources to bid into wholesale markets. This case study analyzes the PG&E DERMS demonstration project to identify outcomes, lessons learned, challenges, and possible next steps. Specifically, DERMS performance is evaluated across seven use cases.

Developing a Distribution Substation Management System. *Siemens Corporation, 2016 - 2019.*

EPIC project aimed at developing an operational dashboard for electrical distribution substations. This dashboard display would show the current grid state, display warnings for detected problems, and automatically suggest potential solutions to reduce the duration of power outages. Siemens is providing $455,000 in match funds. This dashboard will allow operators to use an intuitive and real-time visualization of the current grid state and potential grid problems, and will permit further automation of routine and non-routine engineering and maintenance tasks performed on substations.

Distribution Management System Volt/VAR Evaluation. *National Labs (NREL), Ongoing.*

This project involves building a prototype distribution management system testbed that links a GE Grid Solutions distribution management system to power hardware-in-the-loop testing. This setup is being used to evaluate smart-inverter operations and distribution management system integration of a mock utility distribution feeder and to compare the utility value of alternative volt/VAR schemes.

Integrated Distributed Energy Resources Management System (iDERMS). *The Regents of the University of California (UC Riverside), 2016 - 2019.*

EPIC project aimed at developing an Integrated Distributed Energy Resources Management System (iDERMS) to accommodate increasing renewable resources on the distribution network while improving distribution system reliability, flexibility and resiliency. Three decentralized distribution system control algorithms are proposed within the three-state security control framework (iDERMS) to coordinate the operations of a large number of distributed energy resources. The operational coordination of distributed energy resources will be achieved through an innovative three-phase distributed optimal power flow (OPF) algorithm and a distribution electricity market.

Residential Intelligent Energy Management Solution: Advanced Intelligence to Enable Integration of Distributed Energy Resources. *Alternative Energy Systems Consulting, Inc., 2017.*

EPIC project to test and validate an intelligent software solution that continuously learns, adapts, and manages residential energy usage to provide a scalable solution that maximizes value to the utilities, solar providers, and end-users.

Substation Automation and Optimization of Distribution Circuit Operations. *Advanced Power and Energy Program (APEP) - University of California, Irvine, 2017.*

EPIC project aimed at designing enhanced substation controls to manage distributed energy assets as a single unit. A controller for utility substations will be developed that optimizes the dispatch and use of distributed energy resources and investigates the ability of these resources to participate in electricity markets.

ADMS Testbed Development. *National Labs (NREL), Ongoing.*

This project will establish a national, vendor-neutral advanced distribution management system testbed to accelerate industry development and adoption of advanced distribution management system capabilities. The testbed will enable utility partners, vendors, and researchers to evaluate existing and future advanced distribution management system use cases in a test setting that provides a realistic combination of multiple utility management systems and field equipment. The project team will work closely with an industry steering group to ensure that electric utility needs are met and use cases are realistic and valuable.

Development of an Open-Source Platform for Advanced Distribution Management Systems. *National Labs (NREL), Ongoing*.

This project will build an open-source advanced distribution management system platform that will accelerate the deployment of advanced distribution management system technologies to address the operational challenges faced by distribution utilities. The project will also examine the different architectures that advanced distribution management systems can be built on to meet the needs of utilities. By reducing the cost and complexity of deployment, and by quantifying the operational benefits, barriers to widespread deployment will be eliminated.

Electricity VERKKO Information System (ELVIS). *IBM Analytics, 2016.*

IBM (piloted in FinGrid) provides energy and utility organizations with operational and analytical capabilities to improve distribution and transmission network performance. This is accomplished by an integrated grid-management system that brings together key operational control systems for outage management, distribution management, geographic information, asset and workforce management, DER dispatch, and settlement services.

Connected Distributed Resources

Demonstration of integrated photovoltaic systems and smart inverter functionality utilizing advanced distribution sensors. *Advanced Microgrid Solutions, 2017 - 2020.*

EPIC project aimed at demonstrating the Phase III functions of a PV smart inverter identified by the Rule 21 Smart Inverter Working Group and a bi-directional storage inverter with an advanced communications gateway.

Integrated Community-Level Solutions for Resource Management for a Grid and Customer Benefits. *Electric Power Research Institute (EPRI), 2017.*

EPIC project aimed at demonstrating the use of a package of technologies with community-scale integrated solar and storage to reduce the energy and carbon footprint in a low income multifamily community within a disadvantaged community.

Community Control of Distributed Resources for Wide Area Reserve Provisions. *National Labs (NREL), Ongoing*.

The goal of this project is to develop and demonstrate an advanced distribution management system that allows distributed energy resources to improve distribution system operations and simultaneously contribute to transmission-level services. In short, the team envisions (1) elevating load buses to the level of generator buses with respect to the degree of control authority they present to system operators and (2) simultaneously optimizing distribution-level measures such as resistive losses and nodal voltage magnitudes. NREL will bring significant expertise in network optimization and distributed control of power systems to this project.

Smart Meter Evaluation. *EPRI, 2018*.

Evaluation of multiple smart inverters operating in parallel. With initial results in 2016 (3002008218), this work continues to investigate performance with different grid support functions, voltage and frequency ride thru, islanding detection, and regulation impacts with variable solar irradiance and grid conditions.

Communication Protocols

Certified Open-Source Software to Support the Interconnection Compliance of Distributed Energy Resources. *EPRI, 2016 - 2019.*

EPIC project aimed at developing and demonstrating open-source communication software for distributed energy resources, and to develop certification test procedures for interconnection compliance. California, through the revision process of Rule 21, has recently identified the IEEE 2030.5 protocol do address the need for all solar PV to incorporate a smart inverter. Without consistent communication software and established compliance test procedures, complex protocols like IEEE 2030.5 will not result in interoperability in the marketplace. Instead, subtle differences in interpretation of the standards and slight differences in implementation of the protocols will prevent systems from working together.

Expanding Standards and Developing Tools to Enable DNP3 Support of Energy Storage Use Cases. *EPRI, 2016 - 2019.*

EPIC project aimed at developing and expanding the communication standards to support large-scale energy storage systems and maximize benefits to ratepayers. Existing efforts are underway to update smart inverter functions and develop DNP application notes. However, the infrastructure to support certification and accelerate its adoption is not. This project will address these needs by creating an open forum to identify needs and carry these opportunities directly into standardization groups.

Enabling Technologies

Powernet - A Cloud Based Method for Managing Distribution Resources. *SLAC National Accelerator Laboratory, 2016 - 2019.*

EPIC project aimed at developing Powernet, a cloud based method to manage energy resources in homes and businesses. This project includes a pilot test of Powernet, to automatically control and coordinate distributed energy resources both behind the meter and at the distribution system for residential and commercial ratepayers.

Customer-centric Demand Management using Load Aggregation and Data Analytics. *EPRI, 2016 - 2019.*

EPIC project that will influence aggregated demand side resources and consumer behavior to provide grid stability, reliability, and greenhouse gas reductions. EPRI will develop, deploy and operate a software aggregation platform (tool) that combines the response from multiple residential and small commercial customers and loads in a manner that both stabilizes and verifies the response from individual loads while enhancing grid stability and reliability.

Communications Data Management and Energy Management Systems Evaluation. *National Labs (NREL), Ongoing.*

NREL is working with EPRI and Schneider Electric to advance intelligent control of connected devices. This work involves demonstrating an end-to-end framework of communication and control technologies and integrating operation of different domains within distribution systems through open-source software tools. The framework includes an enterprise integration test environment, commercial advanced distribution management system from Schneider Electric, open-software platforms, an open home energy management system platform, communication modules, and applications.

Modern Distribution Grid Report (Vol I, II, III). *DOE/FERC, 2017*.

The U.S. Department of Energy is working with state regulators, the utility industry, energy services companies and technology developers to determine the functional requirements for a modern distribution grid that are needed to enhance reliability and operational efficiency, and integrate and utilize distributed energy resources. The objective is to develop a consistent understanding of requirements to inform investments in grid modernization. The requirements include those needed to support grid planning, operations and markets.

Distribution Planning Modeling Tools. *National Labs, 2017*.

The national labs have developed a set of modelling tools that are valuable for grid management and planning. These tools include applications for forecasting, power flow analysis, power quality analysis, fault analysis, dynamic analysis, and advanced optimization.

Taming the Electrical Distribution Beast. *National Labs (PNNL), 2015*.

This paper outlines the emerging distribution grid control environment, defines the new distribution control problem, and provides a distribution control reference model. The reference model offers a schematic representation of the problem domain to inform development of system architecture and control solutions for the high-DER electric system.

The Future of the Electric Grid (Chapter 6). *MIT, 2011*.

In Chapter 6 of this report, the researchers focus on the potential for new technologies to enhance the performance of distribution systems. New sensors, communication equipment, management systems, and automation and information technologies promise to improve the efficiency, reliability, and power quality of distribution systems

DER Aggregation as Non-Wires Alternative

Multi-Use Case and Valuation

Definitions Standards and Test Procedures for Grid Services. *National Labs, 2017*. Develops device testing protocol to assess the ability of a device to provide any grid service and quantify the value of the grid service(s) provided by a DER device.

Grid Services and Technologies Valuation Framework. *National Labs, 2016-2018.*
Develops a valuation framework that will allow stakeholders to conduct, interpret, and compare valuation studies of existing/emerging grid technologies and services with high levels of consistency, transparency, repeatability, and extensibility.

The Value of Aggregators in the Electricity System. *MIT, 2016.*
This research paper highlights areas where aggregators may create system-wide economic value even as the power system transitions to an idealized future. Furthermore, it identifies a series of flawed regulations that encourage aggregations that have the potential to harm power system economic efficiency: rules related to the procurement of balancing services, rules allocation of balancing costs to agents, and inconsistent locational price signals and network charges.

Valuation Methodology of Distributed Energy Resources Portfolios Based on an Electric Grid Business Model Innovation Framework for Renewable Energy Integration. *Georgia Institute of Technology, 2018.*
Develops a valuation methodology to quantify the value of a DER portfolio located in a distribution circuit under different scenarios of DER forecast, location, and dispatch schedules.

Planning Tools

CyDER_A Cyber Physical Co-simulation Platform for Distributed Energy Resources in Smart Grids. *LBNL, 2018*
This project focuses on developing a modular, scalable, and interoperable tool for power system planning and operation that will seamlessly integrate with utilities' existing tools to enable analysis of high penetration of distributed energy resources.

DER Siting and Optimization Tool to Enable Large Scale Deployment of DER In California, *National Labs, 2017.*
Deliver to stakeholders an integrated distributed resource planning and optimization platform, hosted online, able to identify meaningful behind-the-meter DER adoption patterns, potential microgrid sites and demand-side resources, and evaluate the impacts of high renewable penetration feeders on the distribution and transmission grid. This project directly links to the Grid Modernization Multi-Year Plan Activity Area of Design and Planning Tools and addresses all three Major Technical Achievements identified by DOE.

Enabling High Penetration of Distributed Photovoltaics through the Optimization of Sub-Transmission Voltage Regulation. *PNNL, 2017.*
This project will develop a coordinated real-time sub-transmission volt-var control tool (CReST-VCT) to optimize the use of reactive power control devices for stabilizing voltage fluctuations caused by intermittent photovoltaic (PV) outputs. In order to capture the full value of the volt-var optimization, the project team will couple this tool with an optimal future sub-transmission volt-var planning tool (OFuST-VPT) for short- and long-term planning analyses. Together, these real-time control and planning tools will remove a major roadblock in the increased penetrations of utility scale and residential PV.

Enhanced Modeling Tools to Maximize Solar + Storage Benefits. *E3, 2017-2019*
This EPIC-funded project will build the Solar + Storage Tool and enhance the existing LNBA tool for the IOUs to create an integrated model that can simulate customer DER responses to various tariff and program designs, and compare the cost-effectiveness of these tariff and program designs. The IOUs plan to use a version of the model for Distribution Deferral Opportunity Reports (DDOR) filings due in September under the CPUC Distribution Resources Plans (DRP) proceeding. A public version of the full model is planned for release in March 2019.

Integrate demand side approaches into utility planning. *PG&E, 2017.*

This EPIC-funded project demonstrated an enhanced and integrated analytical process to help evaluate various Demand Side Management (DSM) and other DER solutions for integration into utility investment planning, which ultimately may enable deferral (or delay) of traditional investment upgrades. The ultimate goal was to build capability to annually refresh customer class load shapes and efficiently execute cost/benefit analysis for DER deployments/impacts on a circuit level, in an automated fashion.

Planning for a Distributed Disruption: Innovative Practices for Incorporating Distributed Solar into Utility Planning. *LBNL, 2016.*
Comparative analysis and evaluation of roughly 30 recent planning studies, identifying innovative practices, lessons learned, and state-of-the-art tools.

State-of-the-art of hosting capacity in modern power systems with distributed generation, *Engineering for the Petroleum and Process Industries, 2018.*
Systematic and extensive overview of the hosting capacity research, developments, assessment techniques and enhancement technologies.

Non-Wires Alternatives Demonstrations

Lessons Learned from Utility-led DER Aggregation. *NREL, 2018.*
Review of five aggregation efforts across the United States. Major recommendations included: utilities will need to develop DERMS and cost-effective pathways to integrate DERs; utilities should consider how DER aggregation will impact or align with existing DER incentive structures; utilities can proactively work with local authorities to resolve permitting issues, particularly around batteries; communications reliability will need to improve to secure grid services from DER aggregations; and utilities should evaluate resource mix, operation protocols, and consumer behavior may impact DER performance.

Brooklyn/Queens Demand Management (BQDM), *ConEdison, 2014-2018.*
This project aims to defer the construction of a proposed $1.2 billion substation in the Ridgewood, Crown Heights, Richmond Hill neighborhoods of Brooklyn and Queens in New York City in December 2014. The PSC authorized ConEd to meet the forecasted load with 17 MW of customer-sided solutions and 52 MW from non-traditional utility-sided solutions.

Boothbay Sub-Region Smart Grid Reliability Pilot Project. *Central Maine Power, GridSolar, 2016.*
Sought to demonstrate whether a portfolio of NWAs could reduce effective load under peak conditions on specific transmission assets in the Boothbay sub-region of Central Maine Power Company's (CMP) electric grid. In addition, the pilot sought to discover the availability and pricing under competitive procurement of a full range of NWAs in Maine, operational characteristics and limitations, and whether NWAs could be so used at scale in other regions of the CMP and Emera Maine grids in Maine.

Energy Efficiency as a T&D Resource: Lessons from Recent U.S. Efforts to Use Geographically Targeted Efficiency Programs to Defer T&D Investments. *Energy Futures Group, 2015.*
This report focuses on the role efficiency can play in deferring utility transmission and distribution (T&D) system investments. In particular, it addresses the role that intentional targeting of efficiency programs to specific constrained geographies – either by itself or in concert with demand response, distributed generation and/or other "non-wires alternatives" (NWAs) – can play in deferring such investments.

Preferred Resources Pilot. *SCE*, *2014-Present.*
The Preferred Resources Pilot (PRP) is a multiyear study designed to determine whether clean energy resources – including solar, wind, energy storage, energy efficiency and energy conservation – can be acquired and deployed to offset the increasing customer demand for electricity. Based on the pilot's results, the need for new gas-powered power plants in the region may be deferred or eliminated.

Sonnen-Mandalay Homes. *Sonnen, 2017-Present.*

Over the next few years, Sonnen plans to add storage to around 2,900 new houses in Prescott, Arizona. Once built, the companies will have a virtual power plant on their hands. With just the first fifth complete, the neighborhood will have 10 megawatts of dispatchable power at the ready, surpassing the size of most VPP pilots today.

Tiverton/Little Compton Project. *National Grid, 2012-2017.*
This pilot was designed by National Grid to test whether geographically-targeted energy efficiency and demand response could defer the need for a new substation feeder to serve 5200 customers (80 percent residential, the remainder small businesses) in the municipalities of Tiverton and Little Compton. The project is shown to be cost-effective.

Targeted Energy Efficiency to Defer Substation Upgrade. *Pacific Power, 2017-2019.*
This project aims to identify areas of its Oregon service area where targeted community focused efforts could potentially help improve system operation during specific locational peak hours and possibly defer traditional system investments. Another key objective of this work is to understand the time needed for deployment of existing program services can be deployed to a focused area and whether deployment could be accelerated.

Reliability and Resilience

Technological Capability

Bosch Direct Current Building Scale Microgrid. *Robert Bosch LLC, 2018.*

EPIC project aimed at demonstration a simpler way to achieve zero net energy requirements in commercial buildings with on-site solar photovoltaics and battery energy storage.

DOE Infrastructure Reliability FOA. *DOE/FERC, 2018 - Future.*

The U.S. the Department of Energy (DOE) released a $5.8 million funding opportunity announcement (FOA) to support the research and development (R&D) of advanced tools and controls that will improve the resilience and reliability of the nation's power grid. Under this FOA, DOE's Office of Electricity (OE) Transmission Reliability Program will seek applications that explore the use of big data, artificial intelligence (AI), and machine learning technology and tools to derive more value from the vast amounts of sensor data already being gathered and used to monitor the health of the grid and support system operations.

Electric Power System Flexibility: Challenges and Opportunities. *EPRI, 2016*.

This paper describes technologies and tools that EPRI and electricity sector stakeholders are developing and applying to address the challenge of power system flexibility.

Transforming the Nation's Electricity Sector: The Second Installment of the QER. *DOE/FERC, 2017*.

QER 1.2 analyzes trends and issues confronting the Nation's electricity sector out to 2040, examining the entire electricity system from generation to end use, and within the context of three overarching national goals: (1) enhance economic competitiveness; (2) promote environmental responsibility; and (3) provide for the Nation's security.

Resilience and Intelligence Platform (GRIP). *National Labs, 2017 - 2020*.

The objective of this project is to anticipate, absorb, and recover from grid events by demonstrating predictive analytics capabilities, combining state-of-the-art artificial intelligence and machine learning techniques, and controlling DERs.

Resilient Alaskan Distribution System Improvements using Automation, Network Analysis, Control, and Energy Storage (RADIANCE). *National Labs, 2017 - 2020.*

The objective of this project is to enhance the resilience methods for distribution grids under harsh weather, cyber-threats, and dynamic grid conditions using multiple networked microgrids, energy storage, and early-stage grid technologies.

Increasing Distribution Resiliency using Flexible DER and Microgrid Assets Enabled by OpenFMB. *National Labs, 2017 - 2020*.

The objective to this project is to accelerate the deployment of resilient and secure distribution concepts through the flexible operation of traditional assets, DERs, and micogrids using OpenFMB.

Integration of Responsive Residential Loads into Distribution Management Systems. *National Labs, 2017 - 2020.*

The objective of this project is to research and validate open-source home energy management systems (HEMS) to support distribution resiliency use cases and end-to-end interoperability.

CleanStart-DERMS. *National Labs, 2017 - 2020.*

The objective of this project is to validate and demonstrate at scale a DER-driven mitigation, blackstart and restoration strategy for distribution feeders with integration of applied robust control, communications and analytics layer, and coordinated hierarchical solution.

Resilient Distribution Systems. *National Labs, 2017 - 2020*.

This activity will focus on effective integrated resource planning and metrics, control systems, inverter-dominated islanding with storage and regional consortia

Value of Technology/Service

Valuing the Resilience Provided by Solar and Battery Energy Storage Systems. *National Labs (NREL), 2018.*

The study demonstrates that even though a PV and storage system might not appear to be economical under traditional cost-benefit calculations, placing a value on the losses incurred from grid disruptions can make a PV and storage system fiscally sound investment. In most cases, incorporating the value of resilience will increase the optimal sizing of both the PV and battery systems, but the added cost to make a system islandable must also be considered.

Quantifying and Monetizing Renewable Energy Resiliency. *National Labs (NREL), 2018.*

This article highlights the unique value renewable energy hybrid systems (REHS), comprised of solar, energy storage, and generators, provide in increasing resiliency. NREL present a methodology to quantify the amount and value of resiliency provided by REHS, and ways to monetize this resiliency value through insurance premium discounts.

Microgrid/Islanding for Resilience

Demonstrating a Community Microgrid at the Blue Lake Rancheria. *Humboldt State University Sponsored Programs Foundation, 2018.*

EPIC project demonstrating a renewable-based community microgrid at the Blue Lake Rancheria located in Humboldt County, California. This microgrid will incorporate an existing biomass gasifier/fuel cell with a new solar photovoltaic array and battery energy storage to provide uninterruptable power for a nationally designated American Red Cross emergency center

Berkeley Energy Assurance Transformation (BEAT) Project. *City of Berkeley, 2018.*

A project that designed, planned and facilitated the permitting of a Clean Energy Microgrid Community (CEMC) that incorporates advanced energy efficiency technologies and will be operated to aggregate and share clean energy resources across several facilities, including facilities whose function is critical in the event of a disaster. This project will develop a regulatory plan, technical plan, business & financial model, procurement plan, and cost/benefit analysis that will ultimately become a Master Community Design of a Downtown Berkeley CEMC Pilot Project.

Port of Long Beach Microgrid – Resilience for Critical Facilities. *City of Long Beach Harbor Department (Port of Long Beach), 2018 - 2023.*

EPIC project for a technology demonstration of a microgrid at the Port of Long Beach that will create an integrated system of distributed energy resources and microgrid controls to achieve long-term islanding at the Port's critical response facility, the Joint Command and Control Center.

Laguna Subregional Wastewater Treatment Plant Advanced Microgrid. *Trane U.S., Inc., 2018.*

EPIC project demonstrating a microgrid that utilizes renewable electricity and battery energy storage at a City of Santa Rosa wastewater treatment plant. This project will also show how microgrids enable participation in ancillary services energy markets.

Supporting Content: Reliability and Resiliency

The electrical grid is dealing with unprecedented harsh conditions, from high winds to wildfires to hurricanes to ice storms, depending on the service territory. This section reviews the ability of distributed resources to contributed to the reliability and resiliency of the electric grid.

Technology and Strategy Review

Characterization of Technology and Strategy

Defining the terms reliability and resilience is critical to the start of any discussion on response strategies to large, unpredictable, extreme weather events.

This roadmap will use the definitions from the national Grid Modernization Laboratory Council Metrics Analysis, with reliability being the "*uninterrupted delivery of electricity with acceptable power quality in the face of routine uncertainty in operation conditions"* and resiliency as "*the ability to prepare for and adapt to changing conditions and withstand and recover rapidly from disruptions, including deliberate attacks, accidents, or natural disasters."*

The National Infrastructure Advisory Council defines resilience as having four dimensions (Figure 55 below):

- **i.** **Robustness.** The ability to absorb shocks and continue operating;
- **ii.** **Resourcefulness.** *The ability to skillfully manage a crisis as it unfolds;*
- **iii.** **Rapid Recovery.** *The ability to get services back as quickly as possible; and*
- **iv.** **Adaptability.** *The ability to incorporate lessons learned from past events to* improve resilience

These four elements are also consistent with the *Presidential Policy Directive (PPD-21) on Critical Infrastructure Security and Resilience*. Figure 55 depicts the relationship of these elements of resilience to the incident and timeline for the event.

Figure 55. Essential Elements of Resilience

Even with this definition, it is complex to distinguish the various domains for reliability and resilience. It is best to compare the various grid components and establish specific domains as defined in Table 26 below:

Table 26. Device Domain Examples

Device/System	Domain	Comment
Recloser	Resilience	Operates to prevent a breaker lockout
FLISR	Reliability	Operates after a breaker lockout
Battery storage	Both	Provides capacity to adjust to stress conditions; can provide backup in sustained
Building thermal storage	Resilience	Can be resource for gen/load balance; does not aid electric service restoration
Partial mesh feeders	Both	Support load rebalance to adjust to stress; support FLISR after lockout
Backup generation	Reliability	Operates in the event of a sustained outage
Generation reserves	Resilience	Used to adjust to gen/load stress such as in frequency regulation
Demand response	Resilience	Used for stress avoidance and strain adjustment, such as system peak limiting
Asset health monitoring	Resilience	In terms of predictive maintenance, asset monitoring can be viewed as a means to assist in preventing reliability events form
Microgrids	Resilience	Grid-directed microgrid islanding can be used as a grid strain compensation measure, whereas self-directed islanding may be a resilience measure *for the microgrid itself*, in response to a
Contingency Planning	Resilience	Contingency planning deals with how to adapt to grid strains.

Source: Electric Grid Resilience and Reliability for Grid Architecture, Pacific Northwest National Laboratory, November 2017.

Once these domains are analyzed and defined for either resilience or reliability, standards or indices can be developed to measure and track performance of these components of the grid. However, it does delineate the expectation of resilience and reliability for grid architecture.

i. **DER Technology.**

a. DER adoption is growing in the United States, due in part to: state, local, and federal policies, customer desire for self-supply (resilience), environmental considerations, and declining acquisition costs of DER technologies. The growing DER will impact the power resilience and reliability of the grid particularly as we experience more extreme weather occurrences.

b. DER technologies, such as microgrid electric power grid (smart grid/microgrids), use analog or digital information and communications technology to gather and act on data to improve the efficiency, reliability, costs, and sustainability of producing and distributing electricity. A micro or smart grid can provide many diverse functions and benefits to investor-owned and public utilities, technology manufacturers and vendors, ratepayers in the residential, commercial, and industrial segments, and ultimately to California in meeting its energy policy objectives. Emerging smart grids/microgrids are spurring development and demonstrate advanced energy conversion, energy storage, and secure power delivery technologies. These systems increase energy resilience and deliver reliability benefits to the overall grid.

c. Energy storage integrated with other DER technologies has the potential to provide grid level services, such as regulation, reserves, and voltage support. However, the provision of these services from energy storage devices can affect voltage and power quality on the distribution system, and potentially on the transmission system as well.

d. Energy storage systems used to provide frequency regulation service can increase feeder peak demand if the charging of the energy storage system is coincident with the occurrence of the feeder peak load. If this happens, the increase in the peak load on the affected feeder may be larger than the installed storage capacity (in MW) due to the increase in feeder power losses. Probability of this scenario is high due to the volatility of the regulation signal. Energy storage is a unique technology in its ability to both consume and generate power, meaning that it may increase or decrease feeder loading.

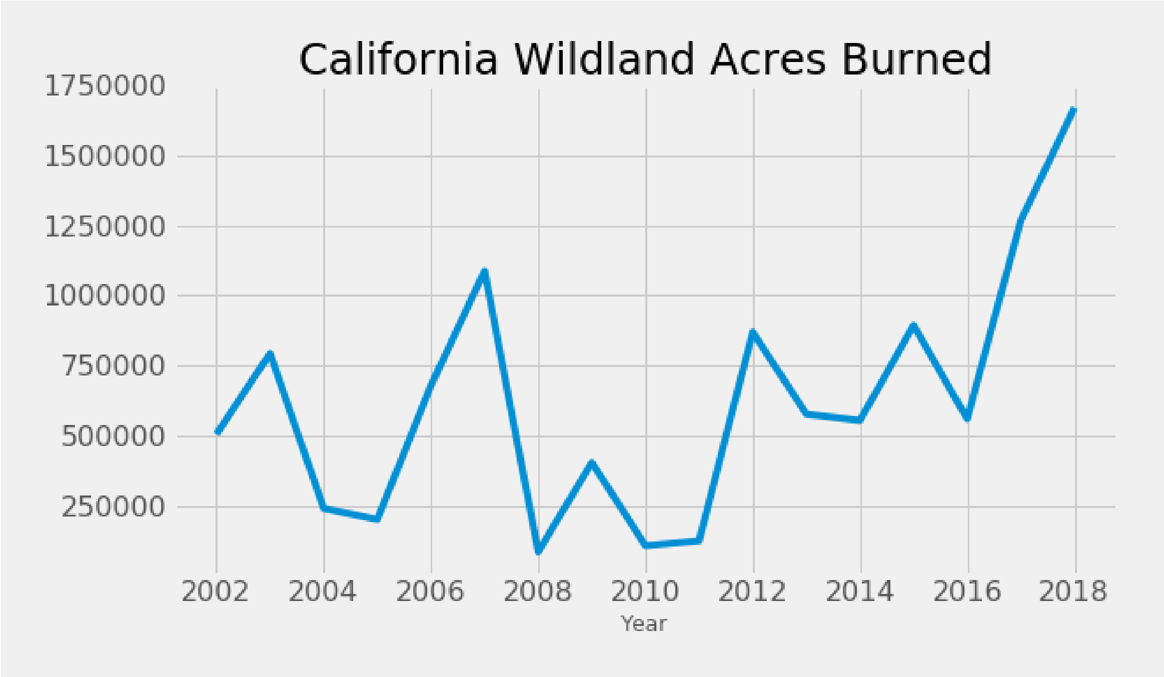
e. Wide distribution of energy generation and storage (thermal and electric) on the grid generally improves, reliability. Availability of numerous sources of electricity generation across a wide geographic area reduces the likelihood a weather event (or other emergency condition) will knock out all generation.

f. However, DER systems that rely on grid voltage may not result in improved reliability, since a grid outage may curtail its ability to operate. In addition, these DER devices are often not designed to supply an entire facility load, further limiting the reliability benefits to the full facility being served.

g. Microgrids enable continued power distribution within their system, thereby maintaining the reliability of service. demand high levels of reliability have been early implementers of microgrids. Microgrids not only improve reliability but can also help as hubs for community support during grid interruption events.

h. Reliability and resilience of the grid is fundamentally dependent on the threats and risks (see Table 27 below) associated with environmental and natural disasters. Many of the threats routinely encountered by the electricity system are natural in origin, such as weather, wildlife and vegetation that come in contact with system components. Weather is by far the most common and potentially severe naturally-occurring threat to grid power. Wildfires represent the biggest threat for major weather-related outages in California. Years of drought followed by abnormally high wind conditions and low humidity (Santa Ana conditions) combine to create a volatile threat to the State's electric grid. Figure 56 shows the historical trend for wildfires.

Figure 56. Historical Trend in California Wildfire Area (2002-2018)



Source: National Interagency Fire Center

Examples of California Microgrid Affecting Resiliency

California is home to three well known microgrid demonstration projects in the U.S.: SDG&E's Borrego Springs project, the Santa Rita Jail, and the University of California-San Diego microgrid. The state has successfully leveraged funding from the federal government, primarily the U.S. DOE, and invested its own funds through the California Energy Commission and other state-sponsored programs to support microgrid development. The CEC microgrid initial awards include a mix of military and university projects:

i. $1.7 million award to develop a set of intelligent microgrids that use community scale renewable resources within an existing utility grid - Marine Corps Base, Camp Pendleton.

ii. $2 million award to share costs in a U.S. DoD vehicle-to-grid demonstration project - Naval Air Weapons Station, China Lake.

iii. $1.6 million award on top of previous funding of $1.4 million for the UC San Diego's electric microgrid. Additional $200,000 funded to expand campus charging network for plug-in electric vehicles.

The CEC announced in January 2018 four additional microgrid awards that divided $22 million between the following entities: Pala Band of Mission Indians-$7 million, City of Long Beach Harbor Department-$5 million, Lawrence Berkeley National Labs-$5 Million, Regents of the University of California San Diego-$5 Million to be deployed at Marine Air Station Miramar. These awards are focused on addressing the business case for microgrids to enhance future deployment and replication of technology and markets.

On the resilience front, California joined the U.S. DOE in funding the California Local Energy Assurance Program (CaLEAP) in 2011. The program aims to help local governments develop strategic plans for energy assurance by offering education and technical assistance. While not solely focused on promoting DER, the program has led three educational sessions for local government officials focusing on microgrids and even included a trip to tour the UCSD microgrid installation. CaLEAP also encourages communities to collaborate with their local utilities to better understand their positions in regard to local energy assurance and resilience.[247]

Description of Technical Specifications and Requirements

i. **IEEE 1547.** New revisions to the IEEE 1547 Standard for Interconnecting Distributed Resources with Electric Power Systems are expected to mandate communication capability from all DERs and standardize the related communication interfaces, protocols, and information models. National Energy Regulatory Commission (NERC) has commented that the revisions to IEEE 1547, coupled with smart inverter technology, could have substantial benefits for operations of distribution and transmission grids.

Recent and Current RDD&D Activities

i. There has been some research regarding resilience completed through EPIC projects, EPRI, the National Labs, and the DOE. Primarily, the research has been seeking to learn more about the technological needs for resiliency, defining the value of resiliency, and the efficacy of islanding microgrids for resiliency.

    a. Technological Capability. Projects testing DER technologies, such as generation resources, load management resources, and sensors, that improve the electric system resilience/reliability

    b. Value of Technology/Service. Projects attempting to quantify the value of incremental increases in distributed grid resilience/reliability due to the implementation of DERs

    c. Microgrid/Islanding for Resilience. Projects testing a facility's capability to operate fully independently of the grid to sustain essential operation during significant disruption is electric service.

ii. The goals of this research are primarily to test the feasibility of DER-focused microgrid and islanding, develop standard metrics for the value of resiliency, and explore cutting edge technologies that may enhance current resiliency technologies.

Figure 57 shows some potential metrics that would be useful in defining the value and efficacy of resilience.

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[247] *Barriers, Opportunities, and Pathways Toward Energy Assurance*
, Microgrid Institute (2014)

Figure 57. Metrics for Reliability / Resiliency

Reliability Metrics	Unit
Granular value of load lost for different times, regions, customer types	$
DER downtime by technology compared to grid-tied counterparts	time
DER downtime by technology for scheduled and unscheduled maintenance	time
Estimated system restoration time following hypothetical significant disturbances	time
Amount of islandable load	MW/MWh
Percentage of clean backup generation as a fraction of all backup generation	%
Total backup generation emissions	Tons CO2

A selection of DER resiliency research and demonstration projects is included below; a full list of identified work is contained in the appendix.

i. **Schofield Barracks-Oahu, Hawaii.** A 50-megawatt (MW) peaking facility was constructed on eight acres at Schofield Barracks that the Army is leasing to Hawaiian Electric. It will be the only power plant on Oahu that is located inland, immune from the potential impacts of storms, tsunami and rising sea level. Sited on a secure Army base, the facility can be a key component of recovery in the event of an emergency that affects the power grid. The Schofield facility will run on a combination of biofuels and conventional fuels and will feed into the island's electric grid and serve all customers on Oahu. In the event of an emergency, it will be able to directly feed Army facilities in Central Oahu, if necessary, to provide reliable power to Schofield Barracks, Wheeler Army Airfield, and Field Station Kunia in the event of a major disruption to the grid. The 50-megawatt microgrid power plant could support recovery operations after a major weather event and provides black start capability to the island grid.

   Cost of the plant was born by the utility with the Army providing the no cost lease. The plant is owned and operated by the utility. The benefit to the Army is priority restoration by "islanding" the military bases in the event of a long-term grid outage.

ii. **Borrego Springs Microgrid Demonstration Project.** This project focused on the design, installation, and operation of a community scale "proof-of- concept" Microgrid. The Microgrid was an existing utility circuit that had a peak load of 4.6 MW serving 615 customers in Borrego Springs, California, a remote area of the San Diego Gas & Electric service territory. The key aspects of the project were integrating and operating the following types of equipment and systems:

   a. Distributed Generation
   b. Advanced Energy Storage
   c. Price Driven Load Management
   d. Fault Location, Isolation, Switching and Restoration

e. Integration with utility control systems and Microgrid Controls

This project was funded through a US Department of Energy and California Energy Commission grant, and cost share provided by San Diego Gas & Electric and other project team members. The Energy Commission portion of the project focused on the integration of resources on the customer-side of the meter and evaluated their contribution to Microgrid operations - primarily on the Price Driven Load Management aspects of the Microgrid.

This project demonstrated specific scenarios for operating Microgrid resources under real operating situations while serving actual utility customers. This work helps advance future deployment of Microgrids by both California utilities and electric customers. One of the highlights of the project was the ability to effectively island (isolate) the entire Microgrid supporting more than 600 customers. The islanding demonstrations transitioned in and out of the island mode without affecting the quality of customer service (seamless transitions). The island demonstrations evaluated the island operations with the Engine Generation (DG) units only, the DG units operating with the substation energy storage in both charge and discharge modes, and the DG units operating with the substation energy storage unit providing a majority of the reactive power requirements.[248]

As an example, on September 6, 2013 a weather-related outage demonstrated the value of the Borrego Springs microgrid in San Diego Gas & Electric's service territory. Power to Borrego Springs was interrupted, but "As soon as the storm passed, and utility patrols were able to determine the damage, the microgrid began to restore power to customers. In total, 1,060 customers (out of 2,780 in the town) had their power restored automatically within hours by the microgrid, using on-site power."[249]

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[248] *Borrego Springs Microgrid Demonstration Project*, SDG&E (2013)

[249] *Microgrid powers Borrego during emergency*, Union-Tribune San Diego (2013)

Table 27. Summary of Key Threats to the Electricity System

Threats	Threat Characteristics					
	Historical Trend		Projected Trend		Predictability	
					Near-Term	Long-Term
Natural/Environmental Threats						
Hurricanes	↑	Intensity, frequency, and duration of North Atlantic hurricanes have increased since the early 1980s[a]	?	Intensity is projected to increase due to climate change[a]	●	○
Drought	↑	Increasing in the Southwest; declining in other U.S. regions[a]	↑	Increasing due to higher temperatures and evaporation, particularly in the Southwest[a]	●	◐
Winter Storms/ Ice/Snow	↕	Storms have increased; total snowfall has declined; extreme snowfall has increased in the East and North[a]	?	Insufficient information and predictability to assess[a]	●	○
Extreme Heat/ Heat Wave	↑	Increases in heat waves have been observed, particularly in the West[a]	↑	Heat waves are projected t become more frequent, intense, and persistent[a]	●	◐
Flood	↕	Increasing in the Midwest and Northeast, declining in the Southwest[a]	↑	Flood risk is projected to increase due to increases in extreme rainfall events	●	○
Wildfire	↑	Numbers of large wildfires have increased in the western U.S. due to earlier and longer fire seasons.[a]	?	Projected to increase in the Arid West, Southeast, and Pacific coast[a,b]	◐	◐
Sea-level Rise	↑	Global sea level has risen by about 8 inches since reliable record keeping began in 1880[a]	↑	Projected to rise another 1 to 4 feet by 2100[a]	◐	◐
Earthquake	↑	Minor earthquakes have increased in Central and Eastern U.S. in association with underground disposal of waste water from oil and gas production[c]	?	Insufficient information and predictability to assess	○	○
Geomagnetic	↔	No trend has been observed	?	Insufficient information and predictability to assess	◐	◐
Wildlife/ Vegetation	↔	No trend has been observed	↔	No expectation of change in threat frequency	○	○
Human Threats						
Physical attack	↔	No trend has been observed in physical attacks	?	Insufficient information and predictability to assess	○	○
Cyber attack	↑	Attacks have increased markedly in recent years[d,e]	↑	Current trends are projected to continue or increase[d,e]	○	○
Electromagnetic	↔	Although a plausible threat, few events have occurred	?	Insufficient information and predictability to asses	○	○
Equipment failure	↔	No trend has been observed	↔	No expectation of change in threat frequency	○	○
Combined Threats	↔	No trend has been observed	?	Insufficient information and predictability to assess	○	○

Key to Symbols

<u>Assessment of Threat Predictability</u>

- ○ – Poor: Inability to predict general trends or discrete events
- ◐ – Moderate: Some predictability of trends, but not discrete events
- ● – Robust: Skillful predictions of discrete events and trends

<u>Assessment of Threat Trends</u>

- ↑ – Increasing
- ↔ – No change
- ↓ – Decreasing
- ↕ – Trends vary by geography
- ? – Insufficient information

Source: Resilience of the U.S. Electricity System, Department of Energy

Description of Commercial Readiness Level, Including Current Market Participation

i. Distributed Energy Resource systems have the potential to supply electricity during grid outages resulting from extreme weather or other emergency situations. As such, DER can significantly increase the resiliency of the electricity system. In order to take advantage of this capability, however, the DER systems must be designed with resiliency in mind and combined with other technologies, such as energy storage and auxiliary generation. Strengthening policy and regulatory support could encourage deployment of DER systems designed for resiliency and improve public access to power during emergencies.

ii. To date, the major barrier to the deployment of energy storage devices in conjunction with DER systems has been cost. But battery prices have declined notably in recent years. One study indicates that the incremental cost of adding batteries to a residential PV system in California declined at an average rate of 11% per year between 2007 and 2013, and costs are expected to continue dropping.[250]

iii. Based on analysis by Rocky Mountain Institute, PV systems with storage will be cost-competitive with grid power in some locations within this decade.[251] Lower battery prices, increased demand for backup power, and uncertainty in the future cost of grid power are all stimulating interest in distributed energy storage. Other possibilities receiving attention include using electric vehicles as multi-use storage units and reusing vehicle to grid (V2g) capable batteries for power applications.

Federal and/or State Policy Influences

i. Drivers

a. Self-Generation Incentive Program (SGIP). California is providing incentives for the development of advanced storage associated with distributed energy through the Self-Generation Incentive Program (SGIP).[252]

b. AB2514. Storage procurement targets have been set for load serving entities (AB2514), and the California Public Utility Commission (CPUC) has been directed to consider methods to place appropriate value on the services that storage provides.[253]

c. Decision 14-05-033. To remove interconnection barriers to storage, the CPUC issued clarification on the issue, specifying that customer side storage associated with generating systems that are eligible for net-metering should be treated as an "addition or enhancement" to the system, and are exempt from additional interconnection application fees, supplemental review fees, costs for distribution upgrades and standby charges.[254]

d. Rule 21. In a separate proceeding, the CPUC is making updates to Rule 21, which lays out interconnection procedures, in order to standardize the processes for projects involving storage.[255]

e. Public Safety Power Shutoff Criteria. Increasing risk of wildfires has California distribution operators pursuing all available options, one of which is a Public Safety Power Shutoff. When wind, humidity and other weather conditions exceed criteria deemed unsafe by the grid operator, transmission and distribution power lines may be de-energized until the dangerous conditions abate. Significant numbers of these power shutoffs may drive end consumers to pursue individual reliability and resiliency purchases in order to avoid outages. As shown in Figure 58, a significant portion of California is currently experiencing high or very high fire risk conditions.

ii. Barriers

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[250] *Residential Solar Energy Storage Analysis*, NYSERDA (2013)

[251] *The Economics of Grid Defection: When and Where Distributed Solar Generation plus Storage Competes with Traditional Utility Service*, Rocky Mountain Institute (RMI) (2014)

[252] *Self-Generation Incentive Program Handbook*, CPUC

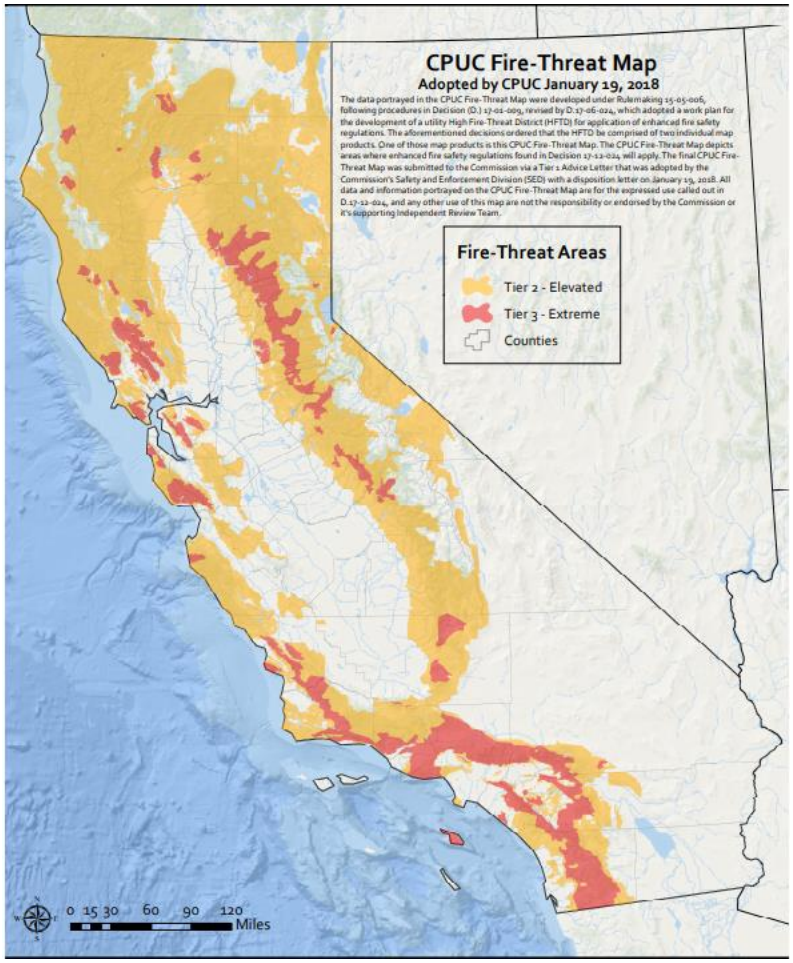
[253] *Assembly Bill 2514*, California Legislature (2010)

[254] Decision 14-05-033, CPUC (2014)

[255] *Issues, Priorities and Recommendations for Energy Storage Interconnection: Staff Proposal*, CPUC (2014)

a. Lack of Standardized Resiliency Metrics. Individual entities are able to make their own decisions on resiliency investments based on their own risk profile, but state or public agencies do not have a standardized value of resiliency or methodology for calculating the effects of low probability high impact events.

Figure 58. California 2018 Fire-Threat Map



Source: California Public Utility Commission

Assessment of Barriers to Further Adoption

i. **Conflicts with utilities.** Microgrids typically require the use of existing lines or the construction of new power lines within the defined zone, which may infringe on utility franchise rights. Microgrid operation may involve the exchange of power between parties or the transmission of power across streets or public areas, which could make operators subject to public utility regulation.

ii. **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.

Identified RDD&D Needs

Actions to Bring Key, High Impact Technologies and Strategies to Market

As demonstrated by the FERC technical assessment Docket No. AD18-10-000, February 2018, given the growing adoption of DERs in the United States, there are a number of key power system reliability topics to explore.

i. **<u>Near-Term</u>**

a. The impact of the current common industry modeling practice of netting DERs with load, which may mask the effects of DER operation.

b. DER capabilities for voltage and frequency ride through during contingencies.

c. The sensitivity of voltage or power needs to different types of DER applications (i.e., providing energy, capacity, or ancillary services).

d. The advantages and disadvantages of allowing DERs to participate directly in the organized wholesale electric markets.

e. Forecast impacts of increased numbers of public safety power shutoffs on SAIDI/SAIFI reliability metrics.

ii. **<u>Mid-Term</u>**

a. The potential for improved voltages due to the unloading of the bulk power system associated with the location of DERs at or near customer loads.

b. Potential effects upon system-wide transmission line flows and generation dispatch due to changing load patterns.

iii. **<u>Long-Term</u>**

a. Develop planning processes that capture more detailed models of DERs and allow for modeling of the interface between the transmission and distribution systems to enable information exchange and more accurate calculations of the DER impact on the power system. Further discussion also is needed on potential means to improve modeling practices with respect to DERs, including options for improving available data and the incorporation of detailed DER models into existing industry models.

b. Facilitate the deployment of new financing models for developers of microgrids would help overcome the barrier of high upfront costs and accelerate microgrid adoption.

Identification of Any Policy Influences

i. **<u>Federal Policy.</u>**

a. <u>Creating the Build America Investment Initiative</u>. The Federal Government has created this initiative – an interagency effort led by the Departments of Treasury and

Transportation – to promote increased investment in U.S. infrastructure, particularly through public-private partnerships.[256]

b. Enhancing grid resilience to geomagnetic storms. In June 2014, the North American Electric Reliability Corporation adopted a new reliability standard to mitigate the impacts of geomagnetic disturbances on the grid. In November 2014, the Administration established an interagency Space Weather Operations, Research, and Mitigation Task Force to develop a National Space Weather Strategy, to include mitigation of grid vulnerability.[257]

c. Department of Energy's Grid Modernization Initiative (GMI). Includes funding of $220 million per year for three years, for the Grid Modernization Laboratory Consortium (GMLC) – a collaborative R&D program across DOE's national laboratory system.[258]

d. Partnership for Energy Sector Climate Resilience. Under this Partnership, owners and operators of energy assets will develop and pursue strategies to reduce climate and weather- related vulnerabilities. Collectively, these Partners and the DOE will develop resources to facilitate risk-based decision making with cost-effective strategies for a climate-resilient U.S. power grid.

ii. State Policy.

a. No direct state policy influences identified.

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256 *Build America Investment Initiative*, Treasure Department (2015)

257 *Geomagnetic Task Force*, NERC (2015)

258 *Initiative Description*, Grid Modernization Laboratory Consortium