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FINAL PROJECT REPORT

Customer-Centric Demand Management Using Load Aggregation and Data Analytics

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PREFACE

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

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

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

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

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

ABSTRACT

This project developed and demonstrated the Open Demand Side Resources Integration Platform (OpenDSRIP) to allow the integration and coordination of distributed energy resources to maximize load flexibility in response to California's ambitious climate initiatives and greenhouse gas emission reduction mandates. The proliferation of behind-the-meter, distributed energy resources require careful and thoughtful management of grid resources given intermittent generation from wind and solar resources and increased electrification of buildings and transportation. The platform allowed the integration of diverse customer-distributed energy resources that are connected to the internet but managed through aggregation and coordinated responses driven primarily by dynamic rate signals and how these devices are managed in the industry today. The project was designed to help Californians better understand current mass-market technologies such as smart thermostats, internet-connected water heaters, and other connected devices that are part of an increasingly decentralized grid, and how these technologies can aggregate electric loads at community levels to provide aggregated-demand responses. This report describes the platform design, development, and demonstration of how connected technologies and distributed energy resources can be controlled separately or as an aggregated set of loads within a building or community, as well as what data can help improve understanding of occupant preferences or device performance in response to grid signals. The goal was to understand current opportunities and barriers related to aggregated mass-market end-use devices and technologies as part of a flexible energy system.

Keywords: demand side management, electrification, price signaling, smart buildings, behind-the-meter distributed energy resources, data analytics, connected communities, load aggregation

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Executive Summary

Introduction

The use of distributed energy resources has witnessed a remarkable surge in California over the past few years. Distributed energy resources are technologies used and possibly owned by energy consumers on their side of the utility meter and encompass small-scale energy resources such as rooftop solar panels or battery storage. This high level of intermittent power generation primarily associated with sources such as solar and wind has led to an increasingly unbalanced daily power demand curve, commonly referred to as "the duck curve," that shows deep declines of electricity use midday and steep upward ramps into the evening. The electric system uses natural gas generation plants to balance this inconsistency, creating a conflict with the goal of reducing greenhouse gas emissions set by regulatory bodies.

In 2018, California Governor Jerry Brown signed Senate Bill 100 (de León, Chapter 312, Statutes of 2018), requiring all retail electricity to be carbon-free by 2045. For California to reach this long-term goal while avoiding problems with demand curve imbalances, it will need a strategy around efficient electrification of its transportation and building sectors. The continued use of centralized and distributed renewable energy sources such as solar and wind may need to be accompanied by robust customer energy efficiency and demand-response programs that help manage the amount and timing of electricity consumption by customers in order to achieve ambitious environmental goals set by state regulators.

Today, demand-response programs receive a significant portion of their load from large commercial and industrial customers, so integrating residential and small commercial loads may be essential for achieving California's ambitious greenhouse gas reduction mandates. Current technology in the mass market segment, which primarily involves turning off air conditioners and pool pumps, has fallen short of its desired result due to its negative effect on comfort in residential communities. In the case of small businesses, it has also been cost prohibitive to incorporate sophisticated control systems that can balance facility needs (comfort, business operations) with electricity grid needs.

However, recent technological advances such as smart thermostats, connected electric vehicles, energy storage, and photovoltaic systems offer the opportunity to tune energy use and the needs of mass market customers in line with grid demands. These devices are purchased by consumers, can communicate with the internet, and have essential computing and control capabilities that provide energy savings and shifting features without compromising comfort. Their collective potential, however, cannot be harnessed toward either supporting grid reliability and stability or reducing greenhouse gas emissions without mechanisms to aggregate and manage them in a manner consistent with consumer preferences. Therefore, these technologies potentially represent a vastly underused grid asset as California looks at decarbonizing its energy system.

Project Purpose

The buildings sector represents a large portion of the greenhouse gas emissions throughout California. Many efficient, flexible technologies are installed in homes and businesses but may not be fully harnessed to their potential for grid benefit. This is partly due to the lack of ways stakeholders can communicate and share the ability to control their energy use across the grid through the grid edge and behind-the-meter devices. Grid edge refers to the point where the electricity grid intersects with the end user, such as homes, businesses, and other distributed energy resources. It is the location where grid operators and energy consumers interact, and it includes various devices and technologies that can monitor, control, and manage the flow of energy at the edge of the grid. Additionally, the industry lacks an understanding of how a more flexible grid with leveraged behind-the-meter technology will affect consumers, and it is important for the proliferation of such strategies that consumers remain satisfied customers. Therefore, to meet the carbon-free electricity mandate by the 2045 target date laid out in California SB 100, it is important to better recognize and manage these efficient electrification loads and to understand their impacts on customer bills and the energy system when scaled.

Part of this understanding lies in the changing landscape that is the electricity rate structure. As California requires a more flexible electricity system to meet decarbonization targets, a shift to more dynamic energy markets is planned to better reflect the actual costs of electricity. Through its work engaging energy stakeholders that include product manufacturers and service providers as well as builders and developers, the project team identified a group of stakeholders interested in offering its customers and tenants tools to help them shift to time-of-use and other real-time dynamic energy costs. This project tested price-signaling structures for mass-market end-use devices — establishing the feasibility of how these customer-owned technologies would respond to time-of-use rates through project demonstrations.

Project Approach

The project approach had three primary research objectives.

1. Developing a platform (Open Demand Side Resources Integration Platform [OpenDSRIP]) that would collect data and manage mass-market "Internet of Things" devices. This platform includes functional requirements development, platform development, and functional testing in laboratory environments to validate functional performance.
2. Developing a framework for how the integration of behind-the-meter distributed energy resources can be used as a grid resource, from a practitioner's perspective.
3. Assessing market-ready technologies in field demonstrations for their ability to leverage behind-the-meter data acquisition and control features on the OpenDSRIP platform to provide demand-response value to the grid while maintaining occupant comfort.

A framework was used to address the technical and non-technical barriers that hinder the adoption of behind-the-meter resources. This framework evaluates demand-side resources based on their ability to control the technology and their non-technical value, which may be influenced by customer preferences and market conditions.

Multiple challenges were encountered in establishing the feasibility of existing connected devices and services including:

- Lack of third-party (direct consumer) access to device data or controls.
- Software updates, which lacked persistent service discovery mechanisms crucial for maintaining the availability, performance, and usability of networked systems and devices.
- Differing requirements across resource types and manufacturers for installation, commissioning, and provisioning.
- Communication infrastructure failure, which resulted in lost connectivity leading to stranded assets.
- Customer participation and impacts such as navigating and managing the needs and expectations of different customer groups.

Technology performance and technical characteristics were evaluated by summarizing the control capabilities and data availability of each customer's distributed-energy resource type, based on today's market. These findings — along with results of OpenDSRIP field demonstrations — were used to develop recommendations for a demand-side resource design specification. This design specification outlines the state of data and control parameters made available by technology in the market today, as well as the ideal set of data parameters needed to fully harness the capabilities in California's transition to a decarbonized energy system.

Project Results

This project successfully defined, developed, and tested OpenDSRIP for demand-side resource aggregation and leveraged this platform to assess the scalability of behind-the-meter technologies in field demonstrations. Through conversations and development activities with behind-the-meter distributed energy resource product and service providers, the project team successfully evaluated data and controls availability. The project team assessed device controllability based on whether third-party control is possible, how controls are used, and relevant customer impacts. Data assessments were divided into types such as device ability and performance, customer preference, environmental data, customer data, and retrieval method.

The team concluded that, in the current market of available technologies, there is a lack of clarity in the value propositions that persistent grid resources offer to both the customers and the energy system as a whole; still absent is a fully vetted business case for a scalable solution that leverages mass-market end-use loads as persistent grid resources. Although there are pieces of technology infrastructure available in the market today, the market is still fragmented. Lack of standardization in device technical capabilities as well as both unclear financial mechanisms for generating value through grid services together present areas where future work is needed.

Work with manufacturers and service providers showed that the collection of operational data may be a way to start valuating behind-the-meter distributed energy resource systems as a grid resource in areas of rapid technology change. Technology policy and programmatic work are still needed to both valuate and enable the use of small end-use loads to achieve California's decarbonization goals and to be leveraged as tools to help customers manage California's shift to dynamic energy rates.

Technology/Knowledge Transfer/Market Adoption: Advancing the Research to Market

Several activities were used to disseminate the results provided by OpenDSRIP and the lessons learned from this project, including:

- OpenDSRIP's codebase and functional requirements are made open-source via the following repositories:
  - Codebase Repository: https://github.com/eprissankara73/openDSRIP
  - Functional Requirements Summary: https://aec.epri.com/OpenDSRIP
- Stakeholder workshops, industry publications, and technical advisory committee activities: several stakeholder workshops, published technical publications, engaged California stakeholders, and presented results and lessons learned at several events.
- Collaborative projects leveraging OpenDSRIP: The OpenDSRIP platform was leveraged and is being used in several California Energy Commission and other demonstration projects looking at aggregating mass market behind-the-meter technologies to provide load-management and data-collection capabilities.
- Framework and specification for smart-home readiness: The OpenDSRIP platform activities established a current state of how smart home and connected mass market end-use loads can be controlled to respond to grid signals, and what data can validate that control functions were actually acted upon.

Benefits to California

A 2019 Brattle Group Report estimated that load flexibility will be a sizeable and impacting grid resource for the United States by 2030. Through the aggregation of demand-side resources and using the lessons learned from the OpenDSRIP project, significant energy savings and demand reductions can be realized in California's small commercial and residential buildings. Energy savings will reduce the cost of procuring energy and therefore translate to lower costs for all California ratepayers. With potential reductions in demand during critical events, reliability in California will also increase, benefiting all California ratepayers.

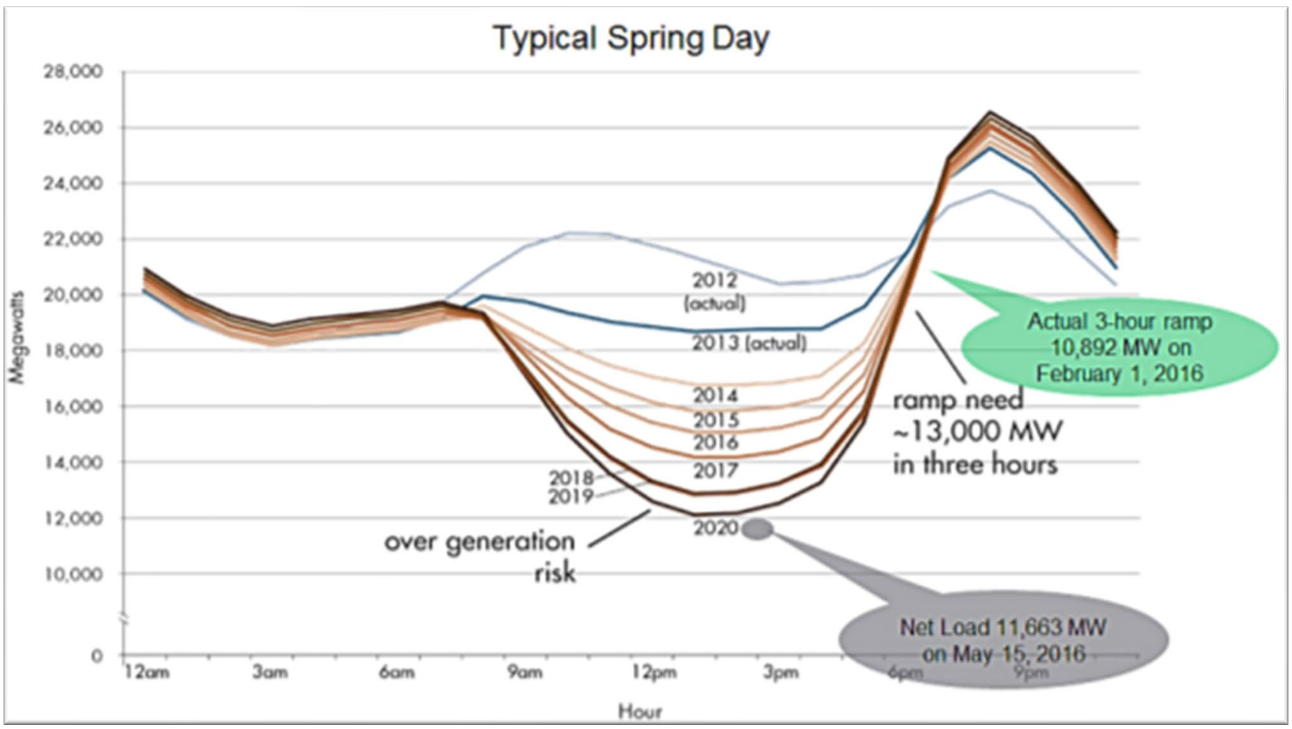
In addition, this project has and continues to explore developing tools for low-income customers to help manage California's investor-owned utility transition to time-of-use rates. Through work on this project, the team learned that the switch to a time-of-use rate structure could have a greater bill impact on lower-income customers with ostensibly limited access to technologies to enable better management of their bills in communities where connected technology is not as prevalent and broadband connectivity is tied to mobile applications as opposed to procured Wi-Fi. By using the results of the project about mobile application designs for time-of-use management in low-income and disadvantaged communities, the team expects to develop tools that can help mitigate energy burdens on low-income Californians.

Finally, the project provided technical specifications and functional requirements that help bridge current interoperability barriers to enabling mass market end-use loads to participate in a dynamic energy system. The result of this effort is lower costs to ratepayers that enable interoperability while potentially improving the efficiency and reliability of California's electric grid. For additional quantifiable results, please see Chapter 6.

CHAPTER 1: Introduction

In 2018, then-Governor Edmund G. Brown, Jr., signed Senate Bill (SB) 100 requiring all retail electricity to be carbon free by 2045 (de Leon, Chapter 547, Statutes of 2018). For California to reach this long-term goal, it will need a strategy around efficient electrification of both the transportation and building sectors alongside continued deployments of centralized and distributed renewable energy resources such as solar and wind. However, the intermittent nature of wind and solar generation in states with high renewable penetration (such as California) produces what is known as the "duck curve" (Figure 1) — a curve that reveals California's power production over a day, associated with its high penetration of renewable sources.

Figure 1: California Duck Curve Associated With Renewable Energy Penetration



Source: ISO 2016

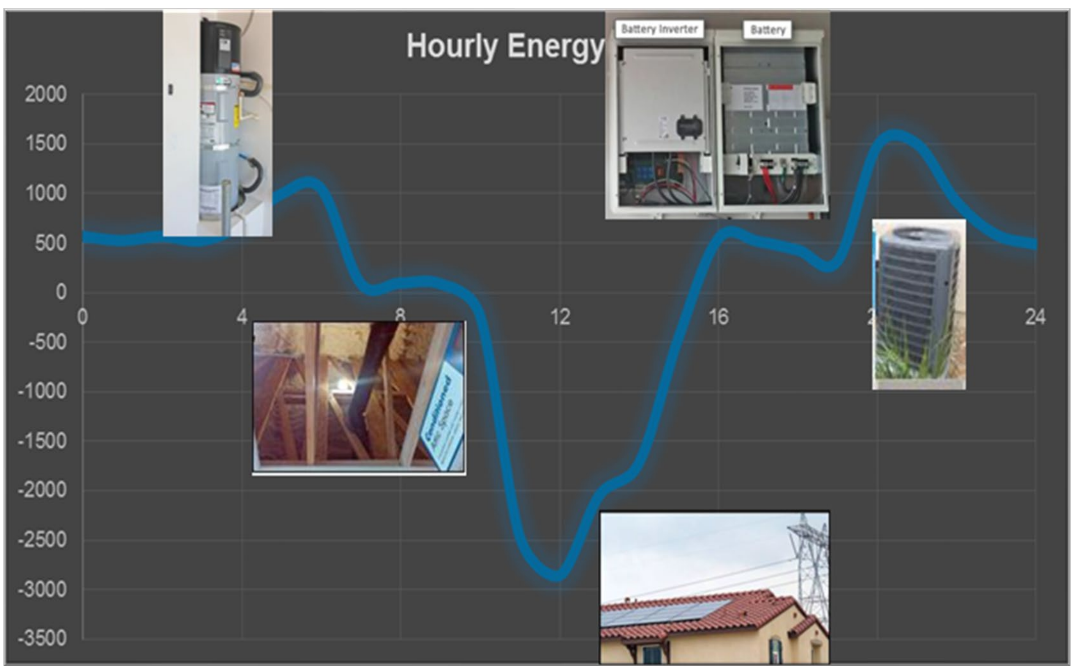
Natural gas generation plants have been used to balance variability. But future scenarios may eliminate fossil generation as a means to meet California's climate goals. This highlights the need to consider and implement efficient electrification and demand-side management (DSM) of behind-the-meter (BTM)[1] distributed energy resources (DERs) to help manage the supply-demand requirements of California's future decarbonized energy system.

[1] Behind-the-Meter in this project is defined as systems, devices and technologies are customer-sited and typically customer owned.

The grid impact of achieving these long-term goals is the heightened need for flexibility at all levels of grid operations, and through a distribution system (from substations and feeders to the edge of the grid) comprised of distribution transformers and "last mile" wiring. The energy system will need to address periods of both overgeneration and under-generation (Figure 2), as well as evolve distribution systems for two-way power flows, which is a substantial departure from historic distribution planning activities. Without the capability for active and reliable management of BTM DERs, which are typically customer owned, the cost of strengthening the infrastructure could be substantially higher. Larger transmission, substations, feeder lines, distribution transformers, and building wiring all need to be built to account for the possibility of a couple of hours a year of high generation combined with low loads.

The distribution and transmission grid are expected to resemble the duck curve shown in Figure 1, with a deep trough in the midmorning hours and a sharp ramp in the late evening. High reverse power flows can create high voltage rise at the end of distribution lines and create unforeseen impacts on feeders and substations. Demand management strategies may be needed to meet the capacity needs of both the transmission grid and distribution system by both reducing and increasing loads for several hours.

Figure 2: Springtime Energy Consumption of a Zero Net Energy Community



One-day load profile from a zero net energy (ZNE) residential building built in 2015 that illustrates the need for future load shape management.

Source: EPRI

Today, demand-response (DR) programs obtain a substantial portion of their load from large commercial and industrial customers. Integration of residential and small commercial loads may be essential to achieving California's ambitious greenhouse gas (GHG) reduction mandates. Current technology in the mass market segment, which primarily involves turning off air conditioners and pool pumps, may impact occupant comfort, and in the case of small businesses, it can also harm business growth. It has additionally been cost prohibitive to incorporate sophisticated control systems able to balance facility needs (comfort, business operations) with grid needs for these customers. However, recent technological advances such as smart thermostats, connected vehicles, storage, and photovoltaic (PV) solar systems offer the opportunity to tune energy use for mass market customers to grid demands. These devices are procured by consumers and possess the ability to communicate with the internet and have requisite computing and control abilities to provide energy-saving features without compromising comfort. Their collective potential, however, cannot be harnessed toward supporting the grid and greenhouse gas reduction goals without mechanisms to aggregate and manage them in a manner consistent with individual consumer device preferences. They therefore represent a vastly underutilized grid asset.

Project Drivers

In addition to addressing fundamental building and demand-side flexibility to help achieve California's overall decarbonization mandates, this project examines several other California objectives to meet its overall climate goals while still accounting for dynamic consumer market needs.

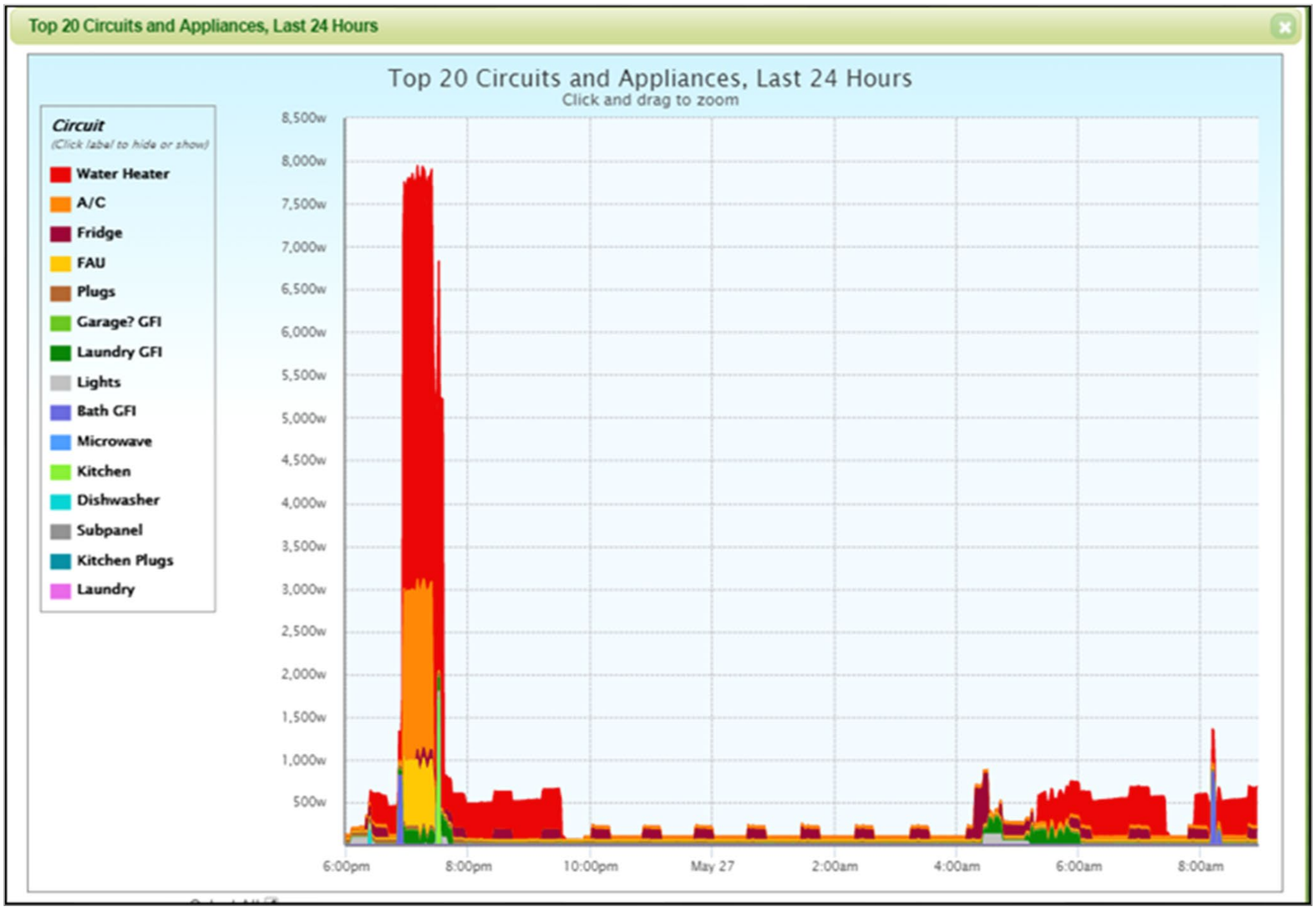
Electrification of the Transportation Sector

As part of California's SB 350, the state is required to deploy 1.5 million zero-emission vehicles (ZEVs) by 2025 (de Leon, Chapter 547, Statutes of 2015). This includes plug-in electric vehicles (PEVs), plug-in hybrid electric vehicles (PHEVs), and hydrogen fuel-cell electric vehicles. These goals will require a greater understanding of electric vehicle (EV) adoption trends, driving patterns, and associated adoption barriers. Finally, there is ongoing work on leveraging vehicles as a grid resource. These vehicle-to-grid (V2G) platforms are investigating vehicle-charge management strategies to better understand customer needs while harnessing the capability of batteries natively found in PEVs and PHEVs.

Electrification of Buildings Sector

To address climate targets requires efficient electrification of the building sector. This includes building new residential and mixed-use communities with emerging and efficient electric technologies such as efficient heating, ventilation, and air conditioning (HVAC) equipment and the use of heat pump water heaters (HPWHs). Although efficient, there is little empirical data showing how advancements in efficiency, combined with the electrification of space heating and water heating, will actually impact community energy profiles (see Figure 3).

Figure 3: 24-Hour Load Shape of Zero Net Energy Home in Southern California



Source: EPRI 2016

Figure 3 shows a 24-hour period in a ZNE home built to California Building Code (Title 24) standards in Fontana, California, in California Climate Zone (CZ) 10. Note that although individual consumer electricity demand on a summer day rarely reaches 500 watts (W), there is a considerable spike in electricity usage due to the coincident usage of air conditioning and water heating.[2] Moving forward, it is important to better understand and manage these efficient electrification loads to assess their impacts on customer bills and the energy system (when scaled).

Managing the Shift to More Dynamic Rates

Residential customers historically pay for electricity through a tiered system. A tiered rate system assumes a flat cost of electricity in the order of a cost per total kilowatt-hours (kWh) used per month. Once a threshold of monthly electricity is used, a customer is then charged a higher rate for electricity. Because California requires a more flexible electricity system to meet

[2] The large, 4-kilowatt (kW) water heater load is because although heat pump water heaters are efficient most of the time, conditions such as cold climates and frequent use of hot water may cause the heat pump to be insufficient for meeting a building's target temperature. As a result, an electric resistance element, typically found in conventional electric water heaters is used to maintain the desired temperature.

decarbonization targets, a shift to more dynamic energy markets is planned to better reflect the actual cost of electricity.

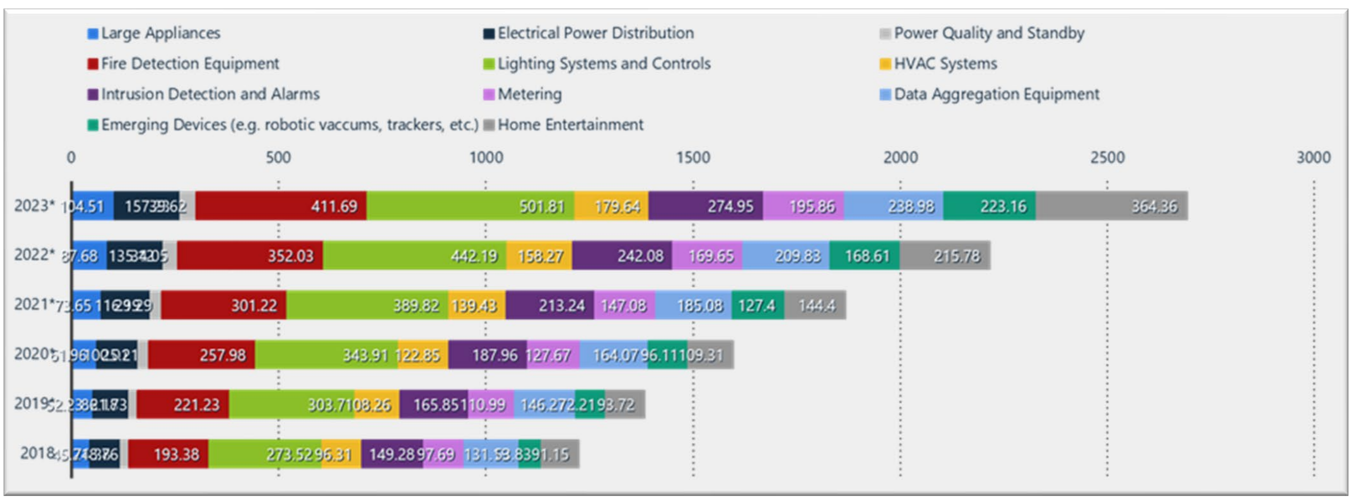
Mass Market Interest in Behind-the-Meter Distributed Energy Resources

Over the last few years, the marketplace has seen the proliferation of customer-side smart connected devices such as smart thermostats, connected heat pump water heaters, PV, PEVs, and battery storage. Several builders, developers, and managers of residential and small commercial communities are looking for ways to leverage these smart devices.

Figure 4 shows not only growth in the smart device industry but also in the variability in the applications that consumers are buying these devices.

However, in using these devices, whether a water heater, an HVAC system, or an EV in support of a more flexible grid, it is crucial not to overlook that the persistent use of these devices as a DER to fulfill contractual energy-impacting services is contingent on the ability of the devices or system to maintain the same quality of service or better for its users. This is important to understand as these systems serve a purpose other than energy generation and management. The project will approach project objectives with the understanding that the devices and systems discussed in this report provide a service to its users, and that any compromise of that service will result in a devaluation of that device to the customer, which needs to be either understood or compensated for.

Figure 4: Installed Smart-Home Devices in the United States, by Application



Source: Continental Automated Buildings Association 2019.

Project Objectives

The objective of this project was to demonstrate the effectiveness of transactive and dynamic pricing tariffs and the readiness of BTM DER technology today in the management of demand-side resources in residential and small commercial segments. The project intends to accomplish this by completing the following objectives:

- Design a flexible and Open Demand Side Resource Integration Platform (OpenDSRIP) enabling integration of residential and small commercial customers and their devices.

Understand technical and market barriers to scaling the integration of residential and small commercial technologies.

- Demonstrate a wide variety of BTM devices (smart thermostats, HPWHs, electric vehicles (EVs), PV systems, customer-sited energy storage) and other technologies found in smart homes and communities today. Establish the feasibility of how these emerging, connected technologies, designed to provide a better customer experience, can be leveraged to also provide aggregated load response. Load response will primarily be triggered through dynamic rate signaling (such as time-of-use [TOU] rates), with insights into enabling transactive energy signaling. To establish feasibility, the intent is to complete this using current infrastructure provided by BTM DER providers today and leveraging infrastructure provided by residential and small commercial providers as part of smart-home and smart-building offerings.
- Establish feasibility and evaluate operational strategies for load management using BTM resources, with a specific focus on coordinated load management in a concerted effort to help California ratepayers manage TOU and other dynamic energy rates. Establish feasibility in laboratory and field settings with varying levels of communication and controls infrastructure.
- Develop frameworks to better understand occupant preferences of residential and small business customers for load management, then measure using data from connected devices.
- Demonstrate advanced telemetry possible using circuit-level, smart-meter data, and data from other BTM DERs.
- Develop a framework to understand the scalability of technology solutions and approaches to aggregate and manage mass-market end-use technologies.
- Create a path to technology acceleration and commercialization of the resultant tools and benefits through open-source tools.

The remaining report summarizes the project's completion and the project team's plan going forward. Chapter 2 focuses on the project's approach and consists of OpenDSRIP platform development, functional requirements development, and testing. Chapter 2 also presents a framework for assessing both the feasibility and scalability of using BTM DERs as grid resources while providing consumers with rate management tools and strategies. Finally, the chapter lays out a few similar initiatives to better understand what parallel research is going on in the space. Chapter 3 focuses on presenting the results of working with BTM DERs, answering two fundamental questions:

1. What type of controls are mass market devices willing to receive and how do third parties provide these controls?
2. What type of data can you provide to third parties and how do you provide this data?

Chapter 3 then discusses the results of developing OpenDSRIP as a research platform for various field and laboratory demonstration projects. Chapter 4 summarizes knowledge transfer activities. Chapter 5 provides overall project conclusions and recommendations for future research. Finally, Chapter 6 summarizes how California's ratepayers will benefit from overall project outcomes and results.

Key Innovations

Key innovations that were developed as part of this project include:

- Creating an open, flexible software framework in the form of OpenDSRIP that is also broadly accessible through an open-source code base and an open application programming interface (API) that allows integration of diverse customer and end device segments to be managed through aggregation and coordinated responses driven primarily by dynamic rate signals.
- Developing a framework and infrastructure to collect data from BTM DERs with a focus on leveraging DERs as "sensors" to better understand customer usage and its effects on building and community load shapes.
- Developing interfaces to test the feasibility of various operational strategies that accomplish the customer preference-constrained optimization of grid demand and energy use in response to transactive pricing tariffs.
- Understanding nuances in addressing these challenges in low-income, disadvantaged communities since many lack reliable broadband connectivity and opportunities to use tools enabled by OpenDSRIP.
- Creating a framework to better understand the feasibility and scalability of leveraging BTM DERs to help customers manage dynamic energy rates as DERs enable overall grid flexibility.

Project Limitations

As a new pursuit, using BTM DERs as a grid resource is a broad and dynamic industry. The outcomes of this report are therefore limited by the overall project's objectives, timelines, and budget.

1. Industry is undergoing rapid and dynamic technology changes. As in most consumer-driven markets, BTM DERs are so diverse that it is likely some information is outdated when this report is read. As a result, the focus of this project was a combination of research platform development and a framework to evaluate the feasibility and scalability of approaches developed as part of this project.
2. This project was not a comprehensive account of BTM DERs. Although it would have been useful to identify all BTM DERs, the project focused on specific BTM DERs, including smart thermostats, connected HPWHs, voice assistants and smart speakers, smart hubs, and mobile applications (apps). The project team also investigated PEVs and battery energy-storage systems as part of residential energy management.
3. This project focused on feasibility versus enablement. This approach looks at a variety of connected technologies in a variety of residential use cases, most times chosen by specific site providers. The project team adopted a broad focus on market space

versus and in-depth focus on enabling a particular technology solution in the market. Although it is important to understand the "how," as in how a BTM DER can be controlled into a grid resource, this project takes a unique approach. The approach is not only to understand how a BTM DER can be controlled using the infrastructure available today, but also why users are using these BTM DERs and the technical and programmatic opportunities and barriers to scaling.

4. The project does not provide specifics about various communication protocols and standards. Although connectivity and interoperability are the main research questions associated with the BTM DER space, this project does not go into detail on communication protocols and standards available in the market today. Instead, the project focuses on two specific questions related to "What does the industry want these systems to do?" (in terms of functional requirements), as well as "How does the industry validate that these systems performed this function?" (in the form of data assessment).

CHAPTER 2:
Project Approach

This chapter consists of three main sections.

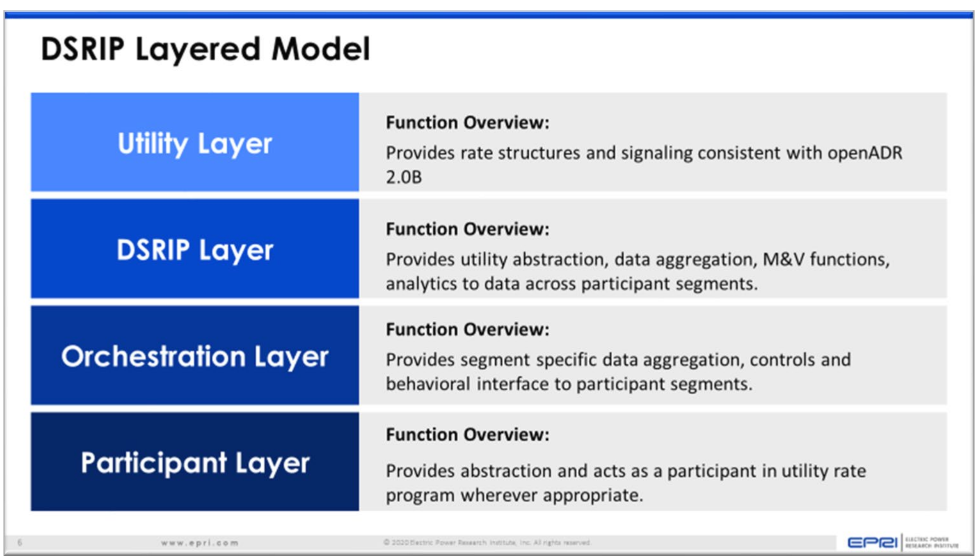
1. The first section describes the development of the OpenDSRIP platform including functional requirements development, platform development, and functional testing of OpenDSRIP in laboratory environments.
2. The second section focuses on the project's approach to developing a framework for how the integration of BTM DERs can be used as a grid resource, from a practitioner's perspective.
3. Finally, the chapter discusses similar initiatives and projects in the industry to gauge OpenDSRIP application to activities currently conducted by industry today.

Open Demand Side Resource Integration Platform Development

Platform Architectural Choices for the Open Demand Side Resource Integration Platform

OpenDSRIP development follows a conceptual framework that attempts to integrate utility/ distribution system operation (DSO)/Independent System Operator (ISO) side data with customer-sited (behind-the-meter) data from Internet of Things (IoT) devices representing various flexible loads, DER, and advanced metering infrastructure (AMI) data. The integration of these different sides of the utility-customer interaction uses a layered-function model. This model is shown in Figure 5.

Figure 5: Architectural Choice Summary for Open Demand Side Resource Integration Platform



Source: EPRI

Utility Layer

The utility layer provides an abstracted model of utility service requests in the form of rate-use cases and associated signaling mechanisms (for example, OpenADR2.0B). Architecturally, OpenADR2.0B was found to be a better protocol for signaling given the one-to-many virtual top node (VTN)-virtual end node (VEN) associations and extended signaling structures that account for different types of rate-structures (for example, critical peak pricing [CPP], TOU), and rate specifications (for example, raw value, multiplier on a baseline, difference from a baseline).

DSRIP Layer

The DSRIP layer supports cross-market, aggregated functions spanning multiple buildings, communities, IoTs, and DER technologies. This layer also supports other functions that are functionally invariant to changes in utility territories and DER technologies. This layer supports both normalized data interfaces and data warehousing functions for analytics and measurement and verification, using aggregated data. The normalized interface can additionally expose utility service requests in a technology-agnostic manner.

Orchestration Layer

The orchestration layer supports functions that are dependent on the specifics of the sites, including the ability to orchestrate across buildings within a market context, integrating specific IoT and DER technologies used in these buildings and communities, and establishing pipelines for data acquisition from the sites. Wherever appropriate, this layer also implements functions that allow customer-centric control of behind-the-meter DERs (flexible loads, energy storage, and California Rule 21 supported smart inverters) that satisfy utility-service requests.

Participant Layer

The participant layer supports data acquisition from customers so therefore establishes the built environment as an integral feature of the overall architecture. The participation layer functions include the ability to message customers of upcoming rate-change events, provide recommendations on how to conserve energy including the ability to automate energy conservation, and how to opt-out of automated control.

Functional Requirements

Solution Architecture

OpenDSRIP is being developed as a large-scale project combining both market-based hardware and software products integrated into a coherent solution. To this effect, OpenDSRIP was integrated with utility rate-signaling systems (for example, Electric Power Research Institution [EPRI] transactive load management[3] [TLM] commercial building energy management systems (BEMS), EV-aggregation platforms such as open vehicle to grid integration platform (OVGIP), and home energy management systems (HEMS) such as

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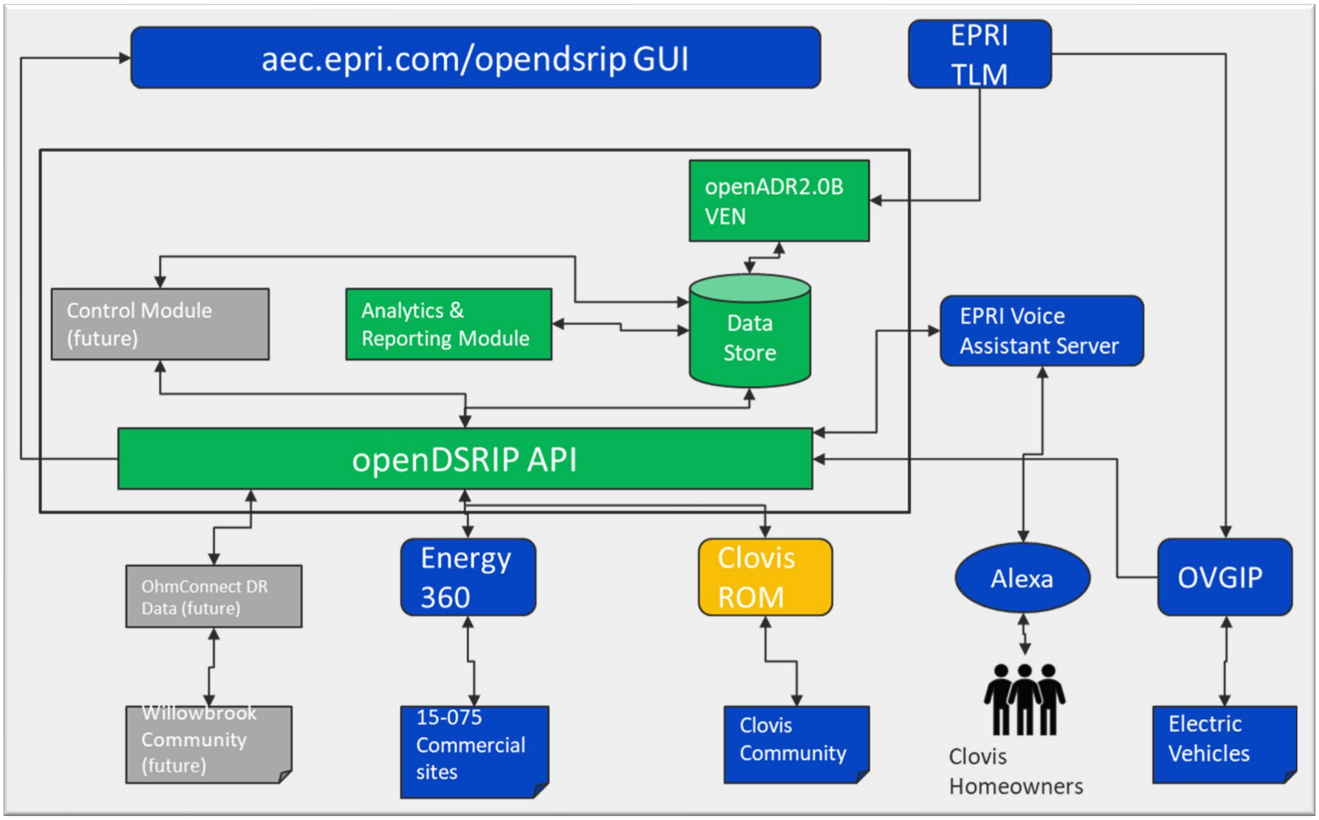
[3] Later in the project, the TLM rate signaling system was later renamed to the Transactive Incentive-Signals to Manage Energy-Consumption (TIME).

residential orchestration modules. The proposed OpenDSRIP solution approach is provided in Figure 6.

Figure 6: Solution Architecture Diagram for the Open Demand Side Resource Integration Platform



Source: EPRI

The solution develops two distinct systems: the core DSRIP platform component (shown in green with a thick black boundary) and an adjunct Residential Orchestration Module (ROM, shown in orange) for both control and aggregation of residential communities into the DSRIP platform. Customer messaging and feedback are enabled via a form of applications: mobile applications, web applications, and voice-assistant (Alexa-based).

Open Demand Side Resource Integration Platform Component Descriptions

1. OpenADR2.0B VEN: The platform integrates the EPRI-developed open-source OpenADR2.0B VEN. (EPRI's TLM system is used as an OpenADR2.0B VTN and provides proxy-utility rate signaling representative of price fluctuations in the wholesale energy market.)
2. Analytics and Reporting: Provides functionality to analyze aggregated data for deriving information that informs both customer- and aggregate-level (market level, market-segment level) information.

3. Control Module: (To be developed in the future) This module provides the functionality for implementing high-level (for example, supervisory) control algorithms based on aggregated data.
4. Data Store: A common data storage infrastructure, a Hadoop Distributed File System (HDFS)-based data store that houses the aggregated data and provides APIs to third parties to access the data subject to a set of rights-of-use and rights-of-access restrictions.
5. OpenDSRIP API: Provides a set of normalized data and control APIs that allow third-party applications that provide data to DSRIP (for example, BEMS systems that provide commercial-building-level data) and receive stimuli for control actions (for example, demand response (DR) signals based on a DR schedule and dynamic rate signaling such as TOU rate schemes). Data can be energy or load data or non-energy data such as operating data from DERs. The data collected and used would be application-dependent, but the architecture is developed to be agnostic to both specific DER/smart-home device technologies and vendors.
6. OpenDSRIP Graphical User Interface (GUI): The GUI is developed by EPRI to provide structured analytical results from the data collected. The analytical results are provided hierarchically.

Residential Orchestration Module

This is an adjunct module developed in parallel with other OpenDSRIP platform modules. This module provides an abstraction for data aggregation across customer homes from multiple end-user devices and is responsible for initiating and orchestrating control actions in response to utility-based stimulus events (in conjunction with customers' preference for automated control via mobile application or voice-assistant). By keeping the complexity of the variability in individual home devices and user preference-driven control actions outside the boundary of the core platform, DSRIP effectively becomes a database of record and a bridge between utility-related systems (for example, rate-signaling systems at Investor-Owned Utilities [IOU]/ ISO/regional transmission organization [RTO] levels) and customer-facing systems (for example, BEMS, EV gateways, HEMS, and residential-orchestration modules).

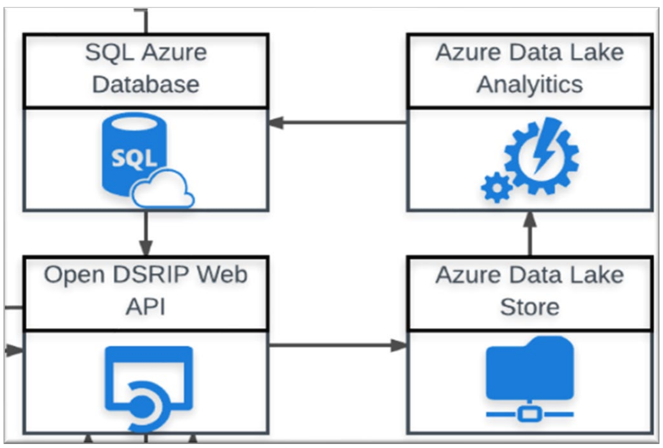
To allow for scalability while accounting for variations in customers' devices and configurations, ROM architecture allows for a hybrid (cloud + collocated EMS) approach. The co-located energy management system (EMS) is one-to-one for each residence though the ROM itself can be one-to-many residences (driven by performance considerations and the latency of individual vendor APIs for data acquisition and control action execution). The number of homes that are under the purview of a single ROM instance depends on performance considerations and was decided based on each demonstration site. However, it is essential to realize that this architecture allows for both single-family and multifamily buildings.

System Architecture

The system architecture for DSRIP is shown in Figure 7. To allow for flexibility in data models and to ensure long-term scalability for the number of customers, a variety of end-user devices, and associated data models, the system uses a Microsoft Azure Data Lake-based architecture. The highlights of this architecture follow.

- System architecture guided by the principle of leveraging best-of-breed technologies:
    - Configure commercial off-the-shelf (COTS) functionality.
    - Develop custom interface processors.
    - Define normalized and abstracted web API.
- Microsoft Azure Cloud platform for high reliability and scalability.
- High-performance HDFS (Azure Data Lake Store) for transactional data processing.
- Azure Data Lake Analytics provides robust analytics (reactive and predictive).
- SQL Azure database and Power BI for reporting and ad-hoc data queries.
- Authenticate, Authorization, and Accounting functions are provided through Azure Active Directory.

Figure 7: System Architecture for the Open Demand Side Resource Integration Platform



Source: EPRI

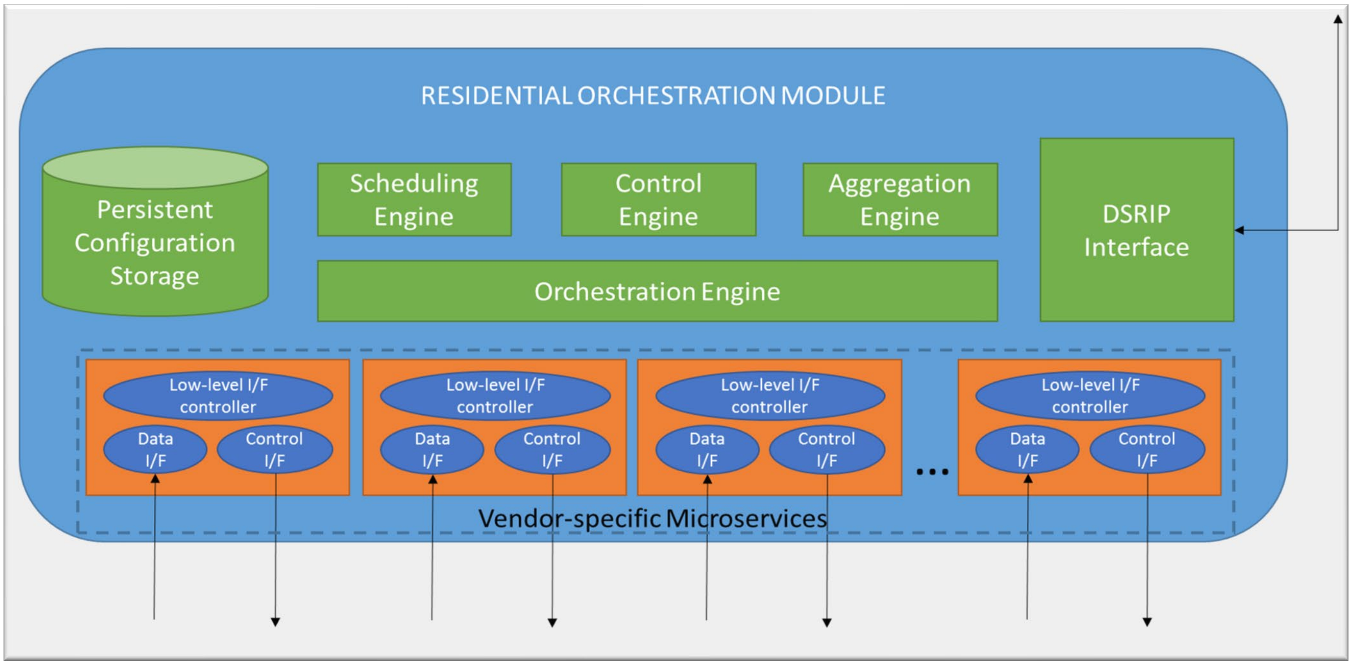
For more information on the functional requirements for OpenDSRIP, refer to Appendix A.

Residential Orchestration Module Architecture

The ROM[4] provides a scalable abstraction architecture for isolating low-level data acquisition and control tasks specific to a given customer's household and subject to the customer's preferences. The ROM by itself is developed as a containerized component with a collection of a few invariant functions and a few functions that are configuration driven. Figure 8 shows the ROM functional architecture. Functions in green are the invariant components of the ROM, and configuration-specific functions are shown in orange. Each of the configuration-specific functions was developed as micro-services with three internal functions that support vendor-specific data, control interfaces, and low-level interface controllers for implementing interface mediation rules. External interfaces are shown in thick dark lines crossing the boundary of the ROM.

[4] As the project progressed other Orchestration Modules (OM)s were developed in the residential, commercial and EV space. These OMs were based off of the same software architecture as described here in the ROM.

Figure 8: Residential Orchestration Module Functional Architecture Showing Invariant (Green) and Configuration-Dependent (Orange) Functions



Source: EPRI

For more information on ROM requirements, please see Appendix B.

OpenDSRIP Platform Configuration and Design

The OpenDSRIP platform configuration and design consists of three main components: (1) a normalized data mapping module, (2) interface design plan, and (3) a data visualization plan. See Appendix C for additional details on these three main components.

OpenDSRIP Interface Design

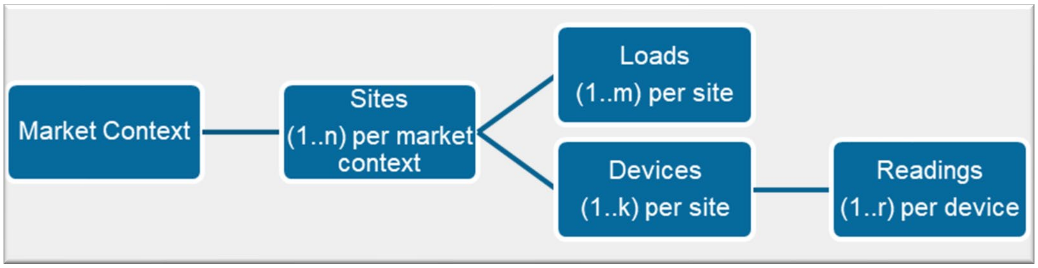
OpenDSRIP provides a single point of access for all data, including the ability for orchestration modules to post, receive, and modify data in the DSRIP data store using an authenticated and authorized access mechanism. OpenDSRIP provides a range of APIs that encompass both energy and non-energy operating data from IoT devices and DER.

The OpenDSRIP interface provides the ability to perform a variety of tasks dynamically. These include:

- Adding customer service locations (sites).
- Allowing customer service locations to opt-in and opt-out of providing services.
- Allowing customers to add DER (devices).
- Associating sites with load monitors (loads).
- Allowing monitoring systems to provide load power (power readings).
- Allowing DERs to provide operating data (device readings).
- Allowing utility systems to provide load management stimuli (for example, pricing). Allowing DER management functions to query for pricing-based events (pricing events).

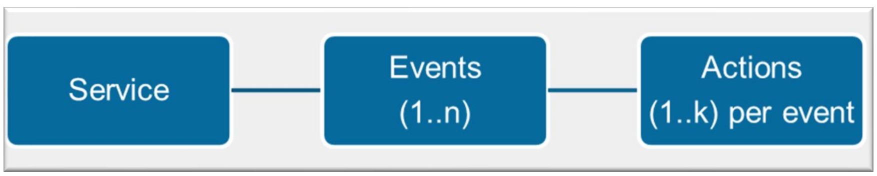
Figure 9 and Figure 10 show how the normalized data model and normalized service model that translates into a set of orchestrated actions, both inter- and intra-site).

Figure 9: Normalized Data Model in the Open Demand Side Resource Integration Platform



Source: EPRI

Figure 10: Normalized Service Model in the Open Demand Side Resource Integration Platform



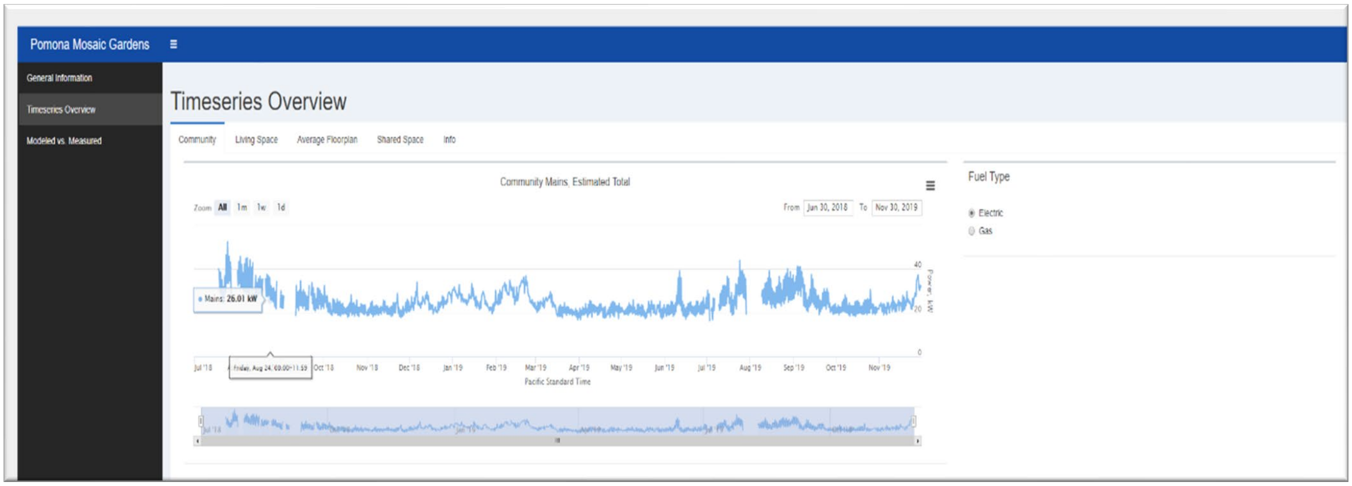
Source: EPRI

OpenDSRIP Data Visualization Configuration

Data visualization is configured with pre-processed data for a variety of research questions and use cases. Each use case allows the user to explore data in a guided, high-level manner in multiple contexts such as community level and appropriate sub-community levels (for example floor plan, residence, building), depending on the site.

The typical layout of the visualization dashboard follows as Figure 11. The top-left corner shows the name of the research site. Use-case tabs pertaining to that site are listed below the site's title. When the user clicks on a use-case tab, the data visualization section appears in the middle, and the data selection section appears on the right. This middle-data visualization section has several tabs breaking down the data visualization into community and sub-community level views. There is also a tab for additional information on this breakdown and use case, as well as links to other relevant EPRI research. The data selection section on the right allows the user to take a deep dive into the use case derived from a particular research question. On this site, the user can toggle between electricity and gas usage timelines to better understand the impacts of efficient electrification technologies such as load shapes and carbon. This is presented and updated on a monthly basis. Other sites have a monthly slider bar.

Figure 11: Open Demand Side Resource Integration Platform Visualization Layout



Source: EPRI

For additional set of use cases enabled by the OpenDSRIP visualization tool, please see Appendix C.

Energy Data Warehouse Specification

OpenDSRIP collects a variety of BTM IoT and DER data. Table 1 shows a typical dataset available from residential sites.

Table 1: Residential Energy Data Availability

Device	Data Parameters	Notes
AMI	kW/kWh	
Circuit Level Monitoring	kW/kWh at the circuit breaker level	Circuit-breaker level metering. It is important to note typical construction practices when analyzing grouped residential loads
Smart Thermostats	Temperature Setpoints, Indoor Temperature, HVAC runtime, etc.	Note that certain data parameters such as temperature setpoints and schedules can be used as proxies for customer preference/occupancy
Connected Water Heaters	Water Temp, Runtime, Set-points, Operating Modes, etc.	The primary focus of this project was electric heat pump water heaters.
Smart Appliances	Temperature settings (Fridge), DR event participation, etc.	
Solar/Storage Energy Management Systems	Frequency, Voltage, Main Power, Solar Power, Battery Energy, State of Charge, etc.	
Survey Data	Customer responses	Specific surveying techniques such as discrete choice experimentation can potentially be used to indicate customer preferences.

Device	Data Parameters	Notes
Battery Storage	Solar production, building energy usage, energy back-feed to the grid, battery state of charge, voltage, frequency	Note that operational data is in its nascent stages, especially in residential energy storage applications.
Electric Vehicles	Battery state of charge, location, energy back-feed to the grid.	Note that operational data w/ this DER for utility load management purposes, especially as part of connected residential ecosystems.

Source: EPRI

For detailed information on the Energy Data Warehouse and functional testing validating the performance of OpenDSRIP, please see Appendix D.

Project Evaluation Metrics

The second section of this chapter focuses on a general, high-level approach to evaluating how an integrated set of customer-sited DER can provide grid flexibility and how this can be done at scale. The project team will propose a framework to evaluate various combinations of mass-market BTM DERs and how they can be aggregated to provide grid or customer services, primarily driven by dynamic-rate signaling. The framework uses the following equation for evaluating building and system flexibility using BTM DERs:

$$F(x,t) = Obj(x,t)*\lambda(x,t):$$

- Where F(x,t) represents grid functions or energy services.
- Obj(x,t) represents objective functions and strategies to enable buildings, devices, and communities to become flexible grid resources.
- λ(x,t) are practical and market factors that represent opportunities and challenges for solution scalabilities.

Note that Equation 1 is a function of both time(t) and location(x). This assessment and framework recognizes the need to understand when and where buildings and communities need to be grid resources as California advances toward its decarbonization mandates.

Grid Signals or F(x,t)

In the simple equation, F(x,t) symbolizes the energy or grid service that is to be achieved. The objective of this project is primarily driven by the evaluation of dynamic and transactive rate signaling. As a result, this was the primary grid signaling used as part of this project. F(x,t) can also represent an energy service or an achievable use case that a third party provides its customer base.

Improving Behind-the-Meter Controllability, or Obj(x,t)

In the project's approach, Obj(x,t) symbolizes coordinated control based on grid signaling or specific customer energy services. This has been the primary focus in the industry today: to improve the controllability of DERs to prepare for the need for a more flexible energy system as California meets its decarbonization mandates.

This project takes a heuristic[5] approach based on the feasibility of controls to give a better understanding of what BTM DER controls baselines are, with specific emphasis on residential and small-commercial sectors. This sets a baseline for the flexibility of a particular system (in this case dynamic or transactive rate signaling).

This project will ask three primary questions to achieve the following objectives:

1. How can we define the control of an aggregate set of devices based on grid objectives?
2. What controls are available and how are those controls made available by BTM products and service providers?
3. Which data are available to validate that grid objectives have been achieved? And how can data improve and optimize control for these grid objectives?

For additional informational information enabling controllability, see Appendix E.

Assessing Scalability Through Understanding the Market, or λ(x,t).

While much of the research has focused on understanding and improving the technical feasibility of how to enable BTM DERs as flexible, grid resources, it is important to ask one fundamental question: What are and will be barriers to scaling this to a larger population than the project or pilot? Historically, in utility DSM programs, this was done through pilot design, specifically by defining baseline or control-group scenarios. In this case, scalability is assessed from a practitioner's point of view. It asks the fundamental question of "What and where are implementation barriers that could happen when scaling a particular solution?" Implementation barriers include:

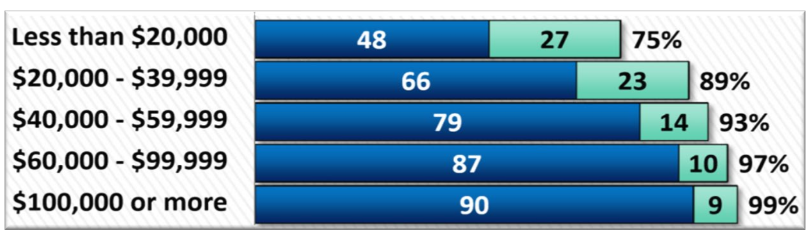
- Lack of Third-Party Data or Controls: Many of these systems assume the controllability of a system is available to third parties. However, due to concerns with customer security and privacy, there is a lack of available infrastructure for a manufacturer or service provider and/or protection of data and/or controls due to intellectual property (IP) protections. Corporate mergers, acquisitions and other consumer market-influenced decisions that happen dynamically may affect corporate policy on third-party data and control of a particular device or system.
- Updates to Third-Party Application Programming Interfaces (APIs): With any consumer-facing product, one can expect product changes that are responsive to a targeted market. As a result, one can also expect manufacturer and service provider-level APIs to adapt as well. It is important to have hand-offs, standardization mechanisms, and exchange protocols (either technical or programmatic) to understand when updates happen and what effects those updates will have on achieving the necessary grid function in this framework F(x,t). The project team has been part of other projects

[5] A set of practical methods learned through previous projects. The project took a heuristic-based approach as there are no universally adopted standards in enabling coordinated control of residential technologies.

where this transaction was not standardized, resulting in unachieved grid functions and customer issues.

- Commissioning of Particular DERs: Proper installation and commissioning of BTM DERs are important for proper operation. Improper commissioning can potentially lead to a lack of connectivity, minimizing potential grid flexibility and, most importantly, a device or system that was not installed that meets customer needs. For example, in residential water heating, improper commissioning may lead to a lack of connectivity to the internet, minimal flexibility (some systems will only increase or decrease water heater setpoints based on what the original setpoint the plumber sets it, and improper installation of an emerging technology leading to poor performance and customer dissatisfaction.
- Infrastructure Failure Resulting in Stranded Assets: Most of these devices and systems are perceivably "smart" when they provide two-way communication. However, when those communication links fail, it is important to understand what local intelligence (in this project's case, energy intelligence) is left. This is more important in areas of society where a "digital divide"[6] is present. For example, low-income communities are more susceptible to lacking reliable personal broadband connectivity. See Figure 8 (EPRI 2021) and Figure 12 (Berkely GIS 2017) for more detail.

Figure 12: Gaps in Broadband Access Based on Household Income



Source: University of California, Berkeley Institute of Governmental Studies 2017

In Figure 12, the dark blue bars represent California survey responses that show a computing device in the house (a potential proxy for internet access). The added dark blue and light blue bars represent responses indicating that he or she has either a computing device or a mobile phone. Note that infrastructure differences based on metrics such as income affect persistent availability of current BTM DERs due to technology infrastructure requirements such as Wi-Fi connectivity.

As previously discussed, company mergers, spinning off companies, closures, and acquisitions will also affect the support of particular smart functions. In the consumer market, it is not guaranteed that grid-facing functions are and will be supported through this change. As a result, one could envision a scenario where assets could be deemed as stranded in the eyes of the grid as its grid-related functions would no longer be supported.

[6] Digital divide can be defined as a division of society as a result of one group's lack of access to communication or connectivity attributed to infrastructure deficiencies (for example lack of reliable internet access).

- Customer and Consumer Participation: Finally, and probably most importantly, is that customer willingness to provide devices as DERs will influence the market scalability of any technology solution. As previously discussed in Chapter 1, many of these BTM DERs are procured and installed for reasons other than enabling grid service. As a result, one can hypothesize that if the economic incentive is not high enough, or if control causes a BTM DER to perform at a substandard level, it can be assumed that customer participation will be low and short-lived (EPRI 2019a).

Assessing scalability through a lambda function $\lambda(x,t)$ was accomplished in this project by detailed monitoring of system and device installation processes and understanding challenges associated with trades, installers and other necessary support infrastructure are needed to successfully install, commission, and onboard BTM DERs.

Table 2 provides additional considerations for classifying data.

Table 2: Data Classification Summary Table

Data Classification	Description	Example	Application
Availability	Data to better understand if DER can be used at that time	Connectivity status	Understanding what resources are available or are still participating.
Performance	Data to better understand operational characteristics of a DER	HVAC runtime collected from a smart thermostat	Understanding actual system performance to intended system performance
Preference	Data to proxy customer desired operational state of a DER	Setpoints (HVAC and HPWH)	Understanding customer's comfort conditions or perceived modes of operation
Environmental	Data to understand indoor conditions caused by a system or outdoor conditions in which a system is responding to	Outdoor and Indoor Air Temperature. Humidity	Understanding conditions in which the customer is comfortable. Understanding how a system responds to weather.
Energy	Data to understand electricity or gas usage	Energy or Power data from circuit meters	Can associate energy with customer cost/bill.
Customer	Data to uniquely identify a system to its user	Usernames, Serial Numbers, Unique Identifiers	Connects device information to other historically siloed pieces of information.

Source: EPRI

For additional details on these approaches, please see Appendix E.

Industry Tracking: Similar Demonstration Projects to OpenDSRIP

During this project's period of performance, there were several initiatives tracked by this project team looking to integrate solar, storage, and loads for residential load management. See Appendix F for more detail. Brief summaries follow.

- Lesson 1: Technology Capabilities Are There: Several initiatives show the technical feasibility of using BTM DERs today to minimize the overall cost of electricity. The use of novel integration methods, as well as consumer-enabling tools (such as voice assistants), all help provide new methods to engage consumers and provide actionable approaches that can achieve reduced energy consumption. There is quite a bit of work both at the academic and industry levels on enabling building flexibility or the Obj(x,t) component of the framework that this project team presents in this chapter. It is important to understand various approaches to enabling building flexibility, developing metrics to help valuate performance and understanding their applicability and extensibility.
- Lesson 2: Scalability is a challenge. Although aggregation of single-device systems for DSM programs has been around for quite some time, it is important to note that many of these initiatives examining multi-device orchestration and optimization within a spatial boundary (typically a home or community) are either demonstrations or pilots. There are only a few examples of scaled field placements of integration of BTM DERs in homes or communities that have scaled. This is possibly due to many of the reasons discussed in addressing the scalability of λ(x,t) function of the framework.

Chapter Summary

This chapter summarizes the creation of DSRIP — from functional requirements to platform development to overall testing of the TIME signal server — to provide coordinated control of BTM in a laboratory setting. In addition, the project team presented a framework: $F(x,t) = Obj(x,t)*\lambda(x,t)$ to describe how the project team will assess the demonstration leveraging DSRIP for both its ability to enable building flexibility and to scale the approach using dynamic rate signaling. In the next chapter, the results of the project are presented, including the assessment of data and controls enabled by BTM DERs today, as well as a set of demonstration project results leveraging OpenDSRIP.

CHAPTER 3: Project Results

This chapter details the background work with BTM DER providers to better understand how these resources can be managed using the current device infrastructure. In addition, this chapter addresses the results of the application of OpenDSRIP for conducting field trials and laboratory assessments for several use cases. The overarching objectives of these field trials were establishing the feasibility of demand-side resource aggregation, defining scenarios for spatial and temporal orchestration and optimization of BTM DERs, and understanding the conditions of the orchestration and optimization of behind-the-meter resources scales.

Most field trials follow high-level architectural guidelines laid out in the previous chapter with the DSRIP layer and orchestration layer coordinating with behind-the-meter DERs. While the specific research questions addressed in each of these field trials are different, the high-level narrative for the field trials involved:

- Aggregation of energy and operating data from one or more behind-the-meter resources.
- Orchestration of one or more individual DER technologies within a laboratory setup, home, premise, or community.
- One or many orchestration modules that perform low-level data and control of behind-the-meter DER, wherever applicable.
- Use of DSRIP API as an integration point between DERs (proxied by orchestration modules) and DSRIP API to provide stimuli for control actions.

As Chapter 2 developed a framework to assess data availability from BTM DERs, this section of Chapter 3 focuses on the lessons learned from development activities with several BTM DER products and service providers throughout the project's period of performance.

A summary of control feasibility and data availability of various BTM DERs collected through the development of OpenDSRIP and associated demonstration projects appears in the next section. For specifics of the various BTM DERs, see Appendix G.

Controls and Data Made Available From Behind the Meter Distributed Energy Resources

The project team assessed BTM DER controllability from the implementation perspective of coordinated control. In addition, data availability was investigated to both validate the results of the control objective and build sets of information to develop more advanced algorithms, optimized for user preferences. For the discussion in this section, we define controllability as the ability of a device or system to be accessed and controlled either by a web interface or portal or by some type of schedule, a third party through an API or a similar mechanism, or through some form of standardized utility-signaling mechanism. Each could provide a certain form of orchestration capabilities, especially when driven by rate signaling. The API does not have to be web or cloud-based and it may be a local API accessible only within a local area network (LAN) or via colocation with the DER. Given this definition, unlike data gathering and aggregation, the options and assessment of controllability are restricted activities. Controllability is defined by both what is possible (such as shifts in the operational state), as well as how these actions are enabled. Table 3 summarizes the controllability of BTM DERs. Customer impacts will also be assessed to better understand how the controllability of this device could adversely affect the original intended purpose of that particular BTM DER.

Similarly, data made available by BTM DERs were also investigated by the project team. Data availability was based on the framework established in Chapter 2 and describes what is feasible and how it is made available to third parties. See Table 4. For specific information on available parameters see Appendix G.

Table 3: Capability Summary – Controlling Behind-the-Meter Distributed Energy Resources

BTM Distributed Energy Resource	3rd Party Controls Possible	How Controls are Possible to Third Parties	Customer Impacts
Circuit Level Metering and Smart Panels	Historically, unavailable as previous technologies have focused on data monitoring, recent interest in smart panels and controllable circuit breakers offer future potential for a controllable resource to third parties. These resources enable/ disable current to flow through a circuit similar to Direct Load Control (DLC) switches.	Smart panels can potentially respond to a command or expose an API to third parties to enable controls. Controls capabilities are new.	Customer impacts are dependent on what breaker or panels are connected to it.
Smart Thermostats	The smart thermostat manufacturers who do provide controllability provide it in the form of setpoint and mode changes based on hold and/or schedule preferences by its user.	Many models provide utility-scale DR functionality and/or platforms for the management of multiple thermostats for orchestrated control or grid services	Customer comfort will potentially be impacted as well as the HVAC lifecycle will potentially be impacted if smart thermostats are not operated correctly. In addition, it is important to understand is participation in utility-facing aggregation programs will forfeit a customer from participating in any other energy-related services (for example HVAC diagnostics program provided by HVAC trades).
Variable-Speed HVAC Systems	In residential applications, variable speed HVAC systems historically have proprietary controls for capacity adjustment and thermostat controllability by third parties. When these systems do provide third party controllability, it is similar to smart thermostats as it is in the form of hold and/or schedule preferences by its user.	Manufacturers and service providers can potentially provide aggregate-scale controllability. This work is fairly nascent.	Similar to smart thermostats, customer comfort will potentially be impacted as well as the HVAC lifecycle if these systems are not operated correctly. In addition, it is important to understand participation in utility-facing aggregation programs will forfeit a customer from participating in any other energy-related services (for example HVAC diagnostics program provided by HVAC trades).

BTM Distributed Energy Resource	3rd Party Controls Possible	How Controls are Possible to Third Parties	Customer Impacts
Heat Pump Water Heaters (Unitary)	Models of water heaters allow for: (1) setpoint or mode changes, (2) relay-type switching on-off through the installation of additional hardware, or (3) specific utility commands via open standards.	Controls provided through either vendor-published APIs or via open Standards (for example CTA-2045). Some models allow aggregation through utility aggregation platforms (sometimes requiring additional hardware).	Availability of hot water could be impacted. The lifetime of the water heater may be impacted through the installation of additional mechanical equipment to enable additional thermal storage functionality. Additional complexity and plumbing can add additional points of failure and corrosion can be a risk without proper maintenance.
Residential Energy Storage	Storage charge and discharge commands based on rate, utility and/or user signaling.	Fairly nascent space w/ much work being completed in the standards (OpenADR, IEEE2030.5) as well as providing OpenAPIs or proprietary aggregation services (for example a Virtual Power Plant-type service)	Battery storage may not have availability for customer-related purposes (for example backup power). Impacts on battery lifecycle from continuous charge and discharge of devices.
Electric Vehicles	Charge deferral based on rate signaling. Discharging as a grid resource is of interest to some.	Provided by OEMs or aggregation platforms that receive fleet-level signaling.	Lack of EV battery availability resulting in range anxiety[7] is one of the main customer barriers to EV adoption
Voice Assistants	Platform to enable skills/routines-based development to control other BTM DERs	Provided by manufacturers who have integrated with these systems to provide specific approved actions by the manufacturers.	Customer impacts are dependent on the device(s) that are controlled.
Smart Hubs	Platform to enable coordinated control-based development to control other BTM DERs.	Provided by manufacturers who have integrated with these systems to provide specific approved actions by manufacturers.	Customer impacts are dependent on the device(s) that are controlled.

Source: EPRI

[7] Range anxiety can be defined as a customer's concern that a vehicle does not have enough energy to reach a driver's desired destination.

Table 4: Data Availability Summary – Behind-the-Meter Distributed Energy Resources

Customer DER	Availability Data	Device Performance	Customer Preference	Environmental Data	Energy Data	Customer Data	How Data is Made Available
Circuit-Level Metering and Smart Panels	Proxied through data presence	None	None	None	Yes	Possible	Through APIs, downloadable reports and secure file transfer protocol (SFTP) sites
Smart Thermostats	Sometimes available. Sometimes proxied	Through runtime analysis	Through customer setpoints and modes	Indoor tempera-ture via sensors. Outdoor conditions through third-party partnerships	Proxied through runtimes.	Possible	Through APIs, downloadable reports and SFTP sites.
Variable Speed HVAC Systems	Sometimes available. Sometimes proxied	Yes	Through modes and setpoints	Indoor tempera-ture via sensors. Outdoor tempera-ture through third party partnerships	Possible. But difficult w/the data currently available.	Possible	Through APIs and downloadable reports.
HPWHs (Unitary)	Sometimes available. Sometimes proxied.	Tank temperatures	Mode of operation	None	Calculated through the mode of operation and runtime	Possible	Through downloadable reports or APIs
Residential Energy Storage	Yes	Yes	Possible through SoC reserve for backup power or TOU preferences.	Possible. Through third parties.	Yes	Possible.	Through downloadable reports, SFTP sites and APIs
Electric Vehicles	Yes	Yes	Possible through preference input or TOU preferences	None	Proxied through charge profiles	Possible	Through downloadable reports and SFTP sites

Source: EPRI

Open Demand Side Resource Integration Platform Demonstration Summaries

Leveraging the OpenDSRIP platform, the project team identified several field-ready and laboratory environments. For most site assessments, the project team noted the following:

1. DERs installed in the residential sites were not, in general, selected by the project team. As previously stated, the project team attempted to minimize the amount of trade and business intervention with potential site providers to get a sense of existing market conditions and avoid self-bias or self-select technologies based on existing business agreements or opportunities, thereby achieving maximum grid flexibility and control through exhaustive data collection (or both). As a result, the team received a considerable amount of variability in both the data and controls collected from specific DERs, achieving a broad perspective of what can be achieved. This is to get a broader range of the challenges of scalability.

2. The project team worked with the existing infrastructure of the BTM DER providers. Although this was previously referred to, this is important to note. The intention was to simulate current market conditions data pertaining to:

    a. What controls are made available by BTM DER providers.
    b. What data are made available by these DER providers.
    c. How both are made available by DER providers today.
    d. What variability is there between various DER providers in the same end-use space?

    One criticism of this approach is the lack of standardization of parameters collected and controls provided. The rationale for the lack of standardization is based on not only simulating market conditions but also testing and vetting the implementation of various standards in the market and vetting them for the varying use cases show-casing flexibility using control of DERs (both behavioral and control-logic wise).

    The philosophy of the project was guided by standards and specifications in the customer space but was also to understand how current manufacturers and service providers are implementing these standards. This, in turn, leads to a representative baseline of not only how standards are being implemented but also the technical, market, and implementation gaps of standards as they address various controls and rate-driven flexibility use cases pertaining to BTM DERs. In addition, in the absence of a governing standard for the project, the project team did stage-gate DER by implementing the next consideration.

3. The project team eliminated certain DER providers. As much as the project team attempted to not meddle in the existing business relationships of site providers, there were instances where certain DER providers were eliminated. These DER providers were eliminated when a third party presented itself as an entity unwilling to share information in the form of data to the project, indicating an unwillingness to share with third parties (a proxy for understanding on levels of orchestration that can be enabled). However, it was usually the final say of the site provider.

See Table 5 and Table 6 for a summary of field and laboratory evaluations completed as part of this project.

Table 5: Open Demand Side Resource Integration Platform Demonstration Summaries (1 of 2)

Demonstration	City	Climate	Building Type	Sites/Units/ Buildings	Technologies	Progress
Laboratory Testing	N/A	N/A	Simulated Residential	N/A	Energy storage, HPWH, thermostat and circuit-level metering	Completed
Clovis Model Home	Clovis	13	Single Family Residential (Model Homes)	3 total homes, but treated as 1 test home	Energy storage, HPWH, thermostat, circuit level metering, smart hubs and voice assistants	Completed/ Continuing work
Clovis ZNE Community	Clovis	13	Single-Family Detached Homes	36 total homes.	HPWH, circuit level metering, solar, energy storage (in some homes) smart thermostat (attempted) voice assistants, smart hubs and variable speed HVAC systems (attempting)	Continuing work
San Diego Voice Orchestration	San Diego	7	Single-Family Detached Homes	5 single-family homes	Voice assistants, smart thermostats and connected heat pump water heaters and building submetering.	Continuing work
Jackson Small to Medium Businesses	Jackson	12	Schools	3 schools	Building Energy Management Systems for small to medium businesses	Completed
Thermostats for Multifamily DACs	Firebaugh	13	Multifamily/DAC	64 units in a 16-building complex	Aggregated smart thermostats	Continuing work
Optimization of electric vehicles to TOU	N/A	N/A	N/A	1 EV	Electric Vehicle	Completed
Vehicle to Grid Integration work	N/A	N/A	N/A	N/A	Electric Vehicles	Continuing Work

Demonstration	City	Climate	Building Type	Sites/Units/ Buildings	Technologies	Progress
TOU applications for disadvantaged communities	N/A	N/A	N/A	N/A	Mobile Applications	Completed

Source: EPRI

Table 6: Open Demand Side Resource Integration Platform Demonstration Summaries (2 of 2)

Demonstration	Demonstration Summary
Laboratory Testing	Functional testing to validate the operational performance of DSRIP. Consisted of two main activities: (1) integration with utility rate engines and (2) Enablement of coordinated control of BTM DERs
Clovis Model Home	Model homes of a larger residential community were used for this project. Used to do functional testing and proof of concept testing of any potential residential orchestration/optimization test before deploying to a larger population. Done at the request of the homebuilder.
Clovis ZNE Community	36-home ZNE community with efficient electrification technologies as well as smart home technologies. Looking to show energy system impacts of larger community built to 2020 ZNE code w/ efficient electrification technologies + tools to help manage TOU rates. Understand opportunities and test opportunities for flexibility and collect operational data.
San Diego Voice Orchestration	5 homes selected in the San Diego area looking at how voice assistants (for example Amazon Echo and Google Home) can be used as tools to help customers manage TOU rates. Various orchestration routines have been created and used to collect operational data.
Thermostats for Multifamily DACs	64 units were equipped with smart thermostats. Property managers are interested in demand-charge management because of high space conditioning electricity use in the summer. Interested in batteries but wants to see what can be done w/ smart thermostats aggregated and controlled together.
Optimization of electric vehicles to TOU	Use of electric vehicle applications alongside its charge and TOU optimization algorithm.
OVGIP	Aggregation of electric vehicles for dynamic rate-based charge management.
TOU Applications for Disadvantaged Communities	Development of functional specifications of a mobile application intended to help low-income community tenants and homeowners manage TOU rates. Done as consumer WI-FI ownership, usually needed for many of these smart devices, is necessary for smart home operation.

Source: EPRI

A summary of results detailing lessons learned from not only the collection of operational data, but also from overall commissioning, installation, and integration work needed to enable coordinated load management using dynamic energy rates (at scales) are detailed below. For additional information, see Appendix H.

Single-Family Residential Demonstrations

The project evaluated two residential sites during the project's period of performance. The results of providing tools to help customers manage dynamic energy signaling and evaluation for both the feasibility and scalability of those two sites follow. The report will summarize the results using the framework discussed in Chapter 2. The goal is to evaluate both feasibility and scalability.

Clovis Zero Net Energy Community

The project team worked closely with a local homebuilder that developed a community of zero-net-energy homes in Clovis, California (Figure 13). The community is comprised of 36 high-efficiency (HERS 57) single-family homes with a combination of efficient electrification technologies (connected HPWHs and high-efficiency heat pumps), smart home devices (voice assistants, smart hubs, and circuit level metering), and distributed generation (solar PV arrays and the option to purchase battery storage).

Figure 13: Street View of Clovis Zero-Net-Energy Community

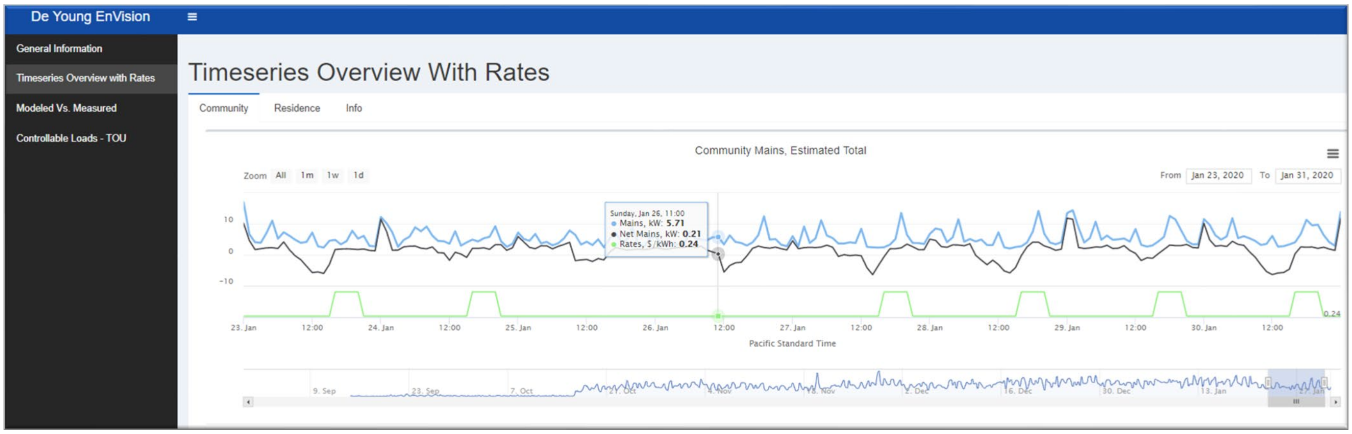
Source: EPRI

The overall goal of this demonstration and its associated site was to address two questions: (1) What is the feasibility of aggregation of tiered coordinated control strategies of BTM DERs using an open-sourced residential orchestration of devices today for load management, using rate signaling?, and (2) What are the opportunities and barriers to scaling orchestration for providing utility-grade grid and energy services in a fairly fragmented DER market?

Current Project Results

The project team has conducted several tests of residential orchestration using rate signaling, using the community's model home as a tool to show feasibility. However, the project team has experienced several lessons learned when considering the scalability of a technology solution. In addition, by using community-level data visualization of the total power consumed on an hourly basis (alongside energy rates in the community), the team can better understand the impact of just rates and how community members are using that connected technology to help them manage rates – without coordinated control. Figure 14 shows a visualization of community-level rates and power consumption at the aggregate level on a Sunday in January.

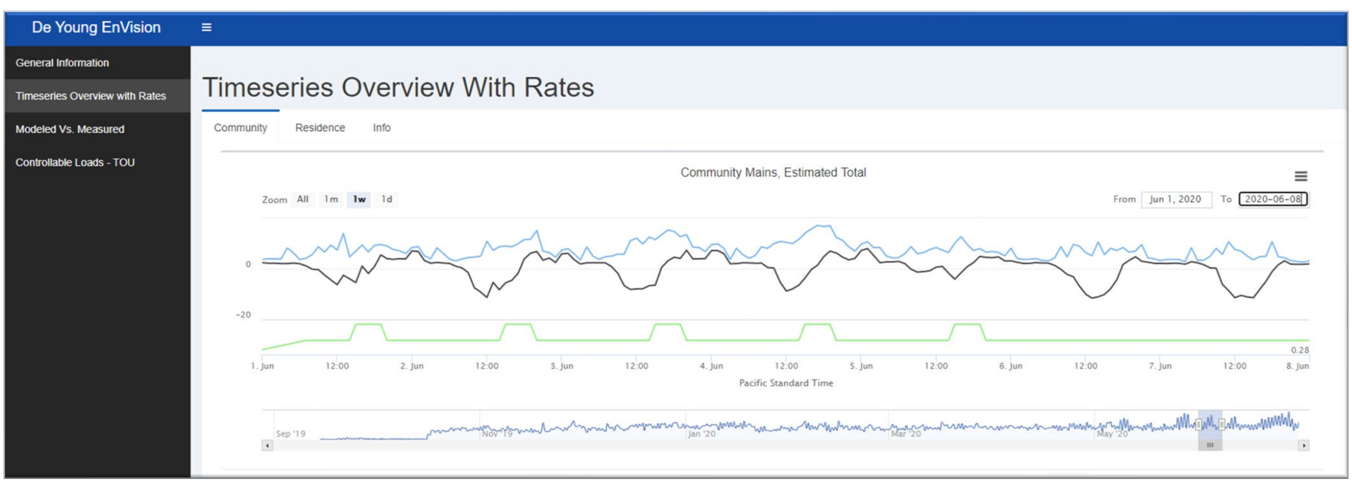
Figure 14: Community-Level Total Power Consumption Juxtaposed Against Rates



Source: EPRI

Figure 15 depicts community-level total power consumption. Notably, there is an induced "Duck Curve" by solar over-production, especially evident during the weekday. There is a significant ramp-up in total power consumed during the period of high TOU prices, with large coincident peaks in the 5 p.m. to 9 p.m. period.

Figure 15: Weekly Community-Level Total Power

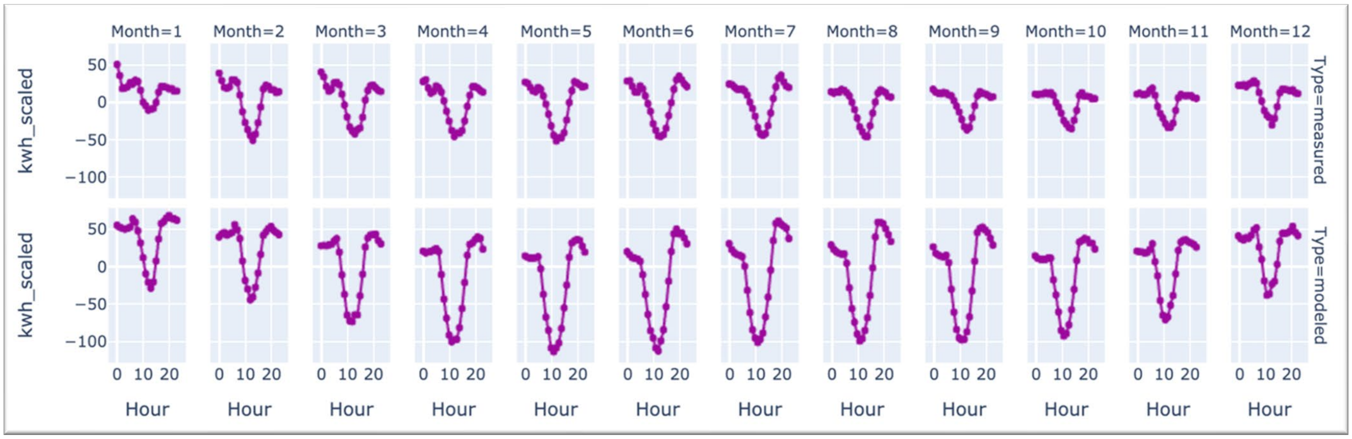


Source: EPRI

Figure 16 depicts more preliminary community-level results, showing a significant ramp-up in total power consumed during periods of high TOU prices. In general, the community's net load shapes show mixed consumption patterns attributed to behavioral or occupancy differences compared to the code-based energy simulation for the climate zone.

Differences exist in the depth of the duck curve "belly" due to lower than predicted solar output and higher electricity consumption during the hours of 9 a.m. to 5 p.m.[8] From a grid perspective, this is more manageable with less dramatic ramp rates and lower levels of reverse-power flow around noon. Part of the lower solar production than expected can be attributed to customers who did not immediately interconnect their solar.

Figure 16: Monthly Average Community-Level Load Shapes (bottom graphs) Versus Actual Community Load Shapes (top graphs) in 2020



Source: EPRI

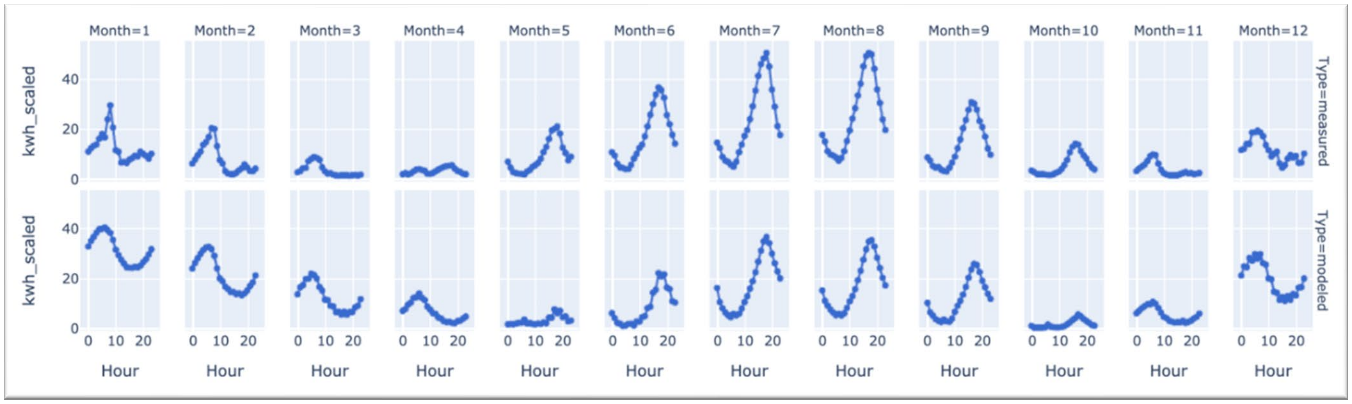
The midnight 50-kW spike in consumption in January, and to a lesser extent February and March, can be attributed to EV charging. In early 2020, the dual-EV home would routinely charge every night beginning at midnight. By April, and for the remainder of 2020, this EV charging load disappears, it can be hypothesized this is due to COVID-19-induced behavioral shifts. The dual EV home represents two EVs per six homes. If EV owners were to use similar charging schedules, the coincident load has the potential to overshadow the evening peak demand. Notably, neither the evening nor EV charging peaks match the magnitude of the "belly" of the duck curve. From a grid perspective, if all homes in the community are designed with large enough solar PV systems, distribution systems will need to size-up infrastructure according to these penetration levels.

The models represent non-controllable loads (Figure 17). These non-controllable loads include appliances, plugs, and lighting. They are, for this project, less important since they represent inflexible end-uses that customers are not likely to compromise in service.

Measured HVAC consumption (Figure 18) is similar in shape and magnitude to building models. However, there is a slight over-prediction of HVAC consumption in the winter and under-prediction in the summer.

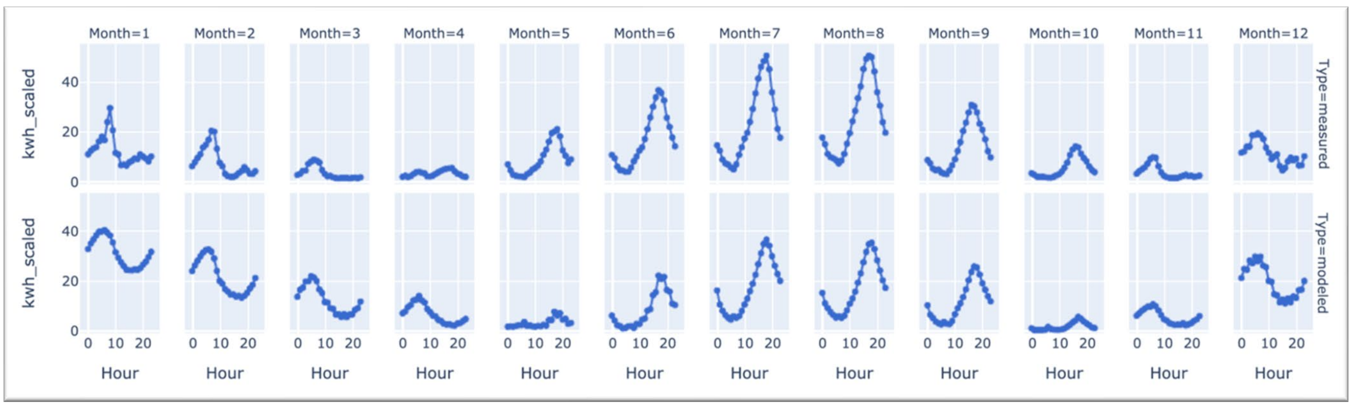
[8] Higher occupancy (and higher energy consumption) during the daytime can potentially be attributed to COVID-19, where many people stayed home due to shelter-in-place and other mandates.

Figure 17: The Evening Peak Energy Usage Is Driven by Non-Controllable Loads Year-Round and HVAC for the Summer Months



Source: EPRI

Figure 18: Community-Level Comparison of Modeled (bottom graphs) and Measured HVAC (top graphs) Load in 2020



Source: EPRI

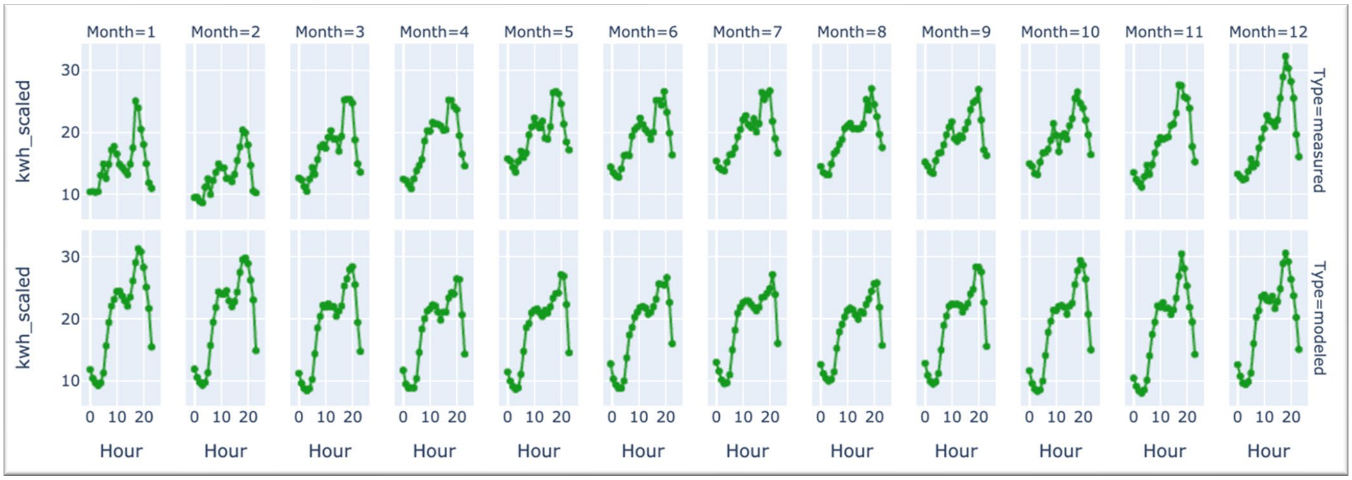
Water heater load shapes were defined as individual behaviors such as reliance on the resistive element versus a heat pump to heat water in a home. For example, an occupant who programs his or her water heater to "high demand" mode[9] may consistently use resistive water heating at the same time of day. For example, this report will look at the analysis of the heat pump water heater in three homes in the community that have widely varying water heating usage patterns, and the impact this water heater usage has at the individual home level.

The heat pump water heaters deployed in the Clovis community can run on either the efficient heat pump mode (running on the order of 100's of watts), or in the resistive heating mode, which draws 1000's of watts. Since a typical single-family home will have multiple loads on the order of kilowatts, maximizing the efficient usage of the heat pump can diminish the water

[9] In this community, High Demand mode for the water heater maximized reliance of the water heater's electric resistance element for water heating versus the heat pump. Result is higher electricity consumption.

heating loads' impact on the grid. Figure 19 shows monthly graphs of modeled vs. measured loads.

Figure 19: 2020 Community-Level Comparison of Modeled (bottom graphs) and Measured (top graphs) Non-Controllable Load

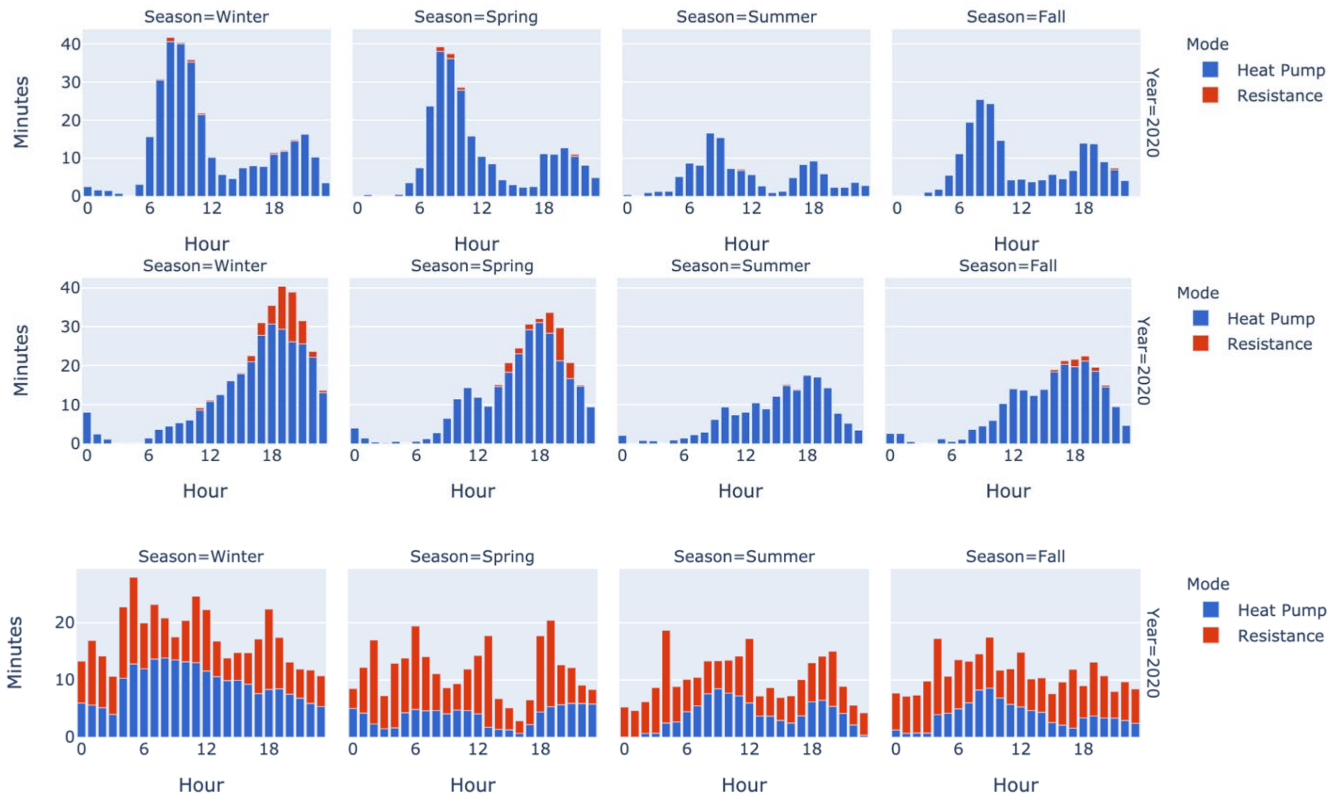


Source: EPRI

Figure 20 shows the average hourly duty cycles for three different homes in the Clovis community. These homes were referred to as the "efficient heat pump" user (top), the "mid-level" user (middle), and the "high demand" user (bottom). The y-axis can be interpreted as the average number of minutes per hour when each water heating mode is utilized. Observations from the three users follow.

- Efficient heat pump user (top): The efficient heat pump user has set their water heater to the "heat pump only" user-defined operating mode. This mode prioritizes efficient usage of the heat pump to maintain hot water.
- Mid-level user (middle): The mid-level user uses the efficient heat pump but at certain times of day when hot water demand is high and seasons when the ambient temperature is cooler — when the heat pump runs at a lower coefficient of performance — they must resort to some resistive heating.
- High-demand user (bottom): The high-demand user has the highest usage of resistive water heating in the community. This user has set their water heater to operate in the "high demand" mode, which prioritizes comfort and maintaining the temperature setpoint over minimizing electricity consumption.

Figure 20: Hourly Water Heater Duty Cycle Usage Patterns From Three Clovis Homes in 2020



Units: average minutes per hour

Source: EPRI

In Figure 21, corresponding to these duty cycles shows the corresponding home-level load shapes (split by load group) for the "efficient heat pump" user (top), the "mid-level" user (middle), and the "high demand" user (bottom). Note that solar and battery data were not available on the high-demand user during the fall and part of winter, 2020.

Figure 21: Home-Level Load Shapes Split by Load Group From Three Clovis Homes in 2020

Source: EPRI

Water heater impacts on home-level loads from the three users follow.

- Efficient Heat Pump User (top): The water heater usage characterized by heat pump and resistance duty cycles are apparent in the water heater contributions to the homes' overall load shapes. The "efficient heat pump" user has little water heater load contributing to the overall energy usage of the home. Typical usage is highest in spring during the 8 a.m. and 9 a.m. hours, at which point the water heater runs at an average of 345 W. This is in line with the expected power draw of the water heater running in heat pump mode.
- Mid-Level User (middle): The mid-level water heater usage is highest in winter during the hour beginning at 8 p.m. (at 1,250 W). This is in alignment with the increased reliance on resistive water heating observed in the duty cycle patterns for this home.

- High-Demand User (bottom): The high-demand user averages water heater consumption of over 1,400 W during multiple periods through the year including winter at 6 a.m., spring at 1 p.m. and 7 p.m., and summer at 4 a.m.

With respect to opportunities for reduced grid impacts from flexible loads, the following was observed, based on measured data.

- HVAC: Pre-cooling in summer afternoons while solar is producing could reduce evening peaks and ramp rates.
- Solar PV: If unmanaged and adopted broadly, reverse power flows due to overgeneration present potentially greater impacts on the grid than consumption-driven peak loads.
- Water Heater: Maximizing the usage of the efficient heat pump operating mode of water heaters can minimize impacts on the grid.
- EV: EV charging behaviors for the dual EV home were consistently scheduled for charging at midnight. It is unclear how flexible the timing of this charging demand is, or how diversity would impact these community-level trends under higher EV adoption levels.

See Appendix H for additional results on this demonstration site.

Voice Assistants as Tools to Enable Load Management in San Diego

The widespread market adoption and platform capabilities that are potentially available with mature voice-assistant technologies like Amazon Echo and Google Home provide a unique opportunity for the integration of platforms with OpenDSRIP. The intent is to use existing voice assistant infrastructure as orchestration modules, enabling messaging and possibly coordinated control of smart home systems. Voice assistants, being both novel and ubiquitous, have the potential for presence-driven messaging, better customer engagement, and automation that is pre-built via IoT integration of smart home products.

These sites test the ability of voice assistants to engage homeowners and reduce energy consumption during peak periods using behavioral intervention, with the potential for automated load shed.

Five homes in San Diego (CA CZ 7) were retrofitted with a variety of BTM DERs including voice assistants, smart thermostats, heat pump water heaters, and circuit/AMI reading devices. See Table 7, which details the technologies installed within each home.

Table 7: Technologies Installed in San Diego Homes

	Voice Assistant	Circuit Meter Reader	Heat Pump Water Heater	Smart Thermostat
Home 1	x	x	x	x
Home 2	x	x		x (no access)
Home 3	x	x		x

	Voice Assistant	Circuit Meter Reader	Heat Pump Water Heater	Smart Thermostat
Home 4	x	x		x
Home 5	x	x		x

Source: EPRI

Current Results

In 2019, the number of smart home devices compatible with Alexa rose to around 60,000 devices. The number of Alexa-compatible smart home devices increased exponentially since 2017 when it was at four thousand (Tankovska 2020). This trend is highly indicative of the creation of de-facto standards in the smart-home IoT segment, which centers around voice-assistant compatibility. The global market for smart-home devices is expected to reach 45-million homes up from 17-million homes in 2017; the revenue potential for smart-home devices is expected to quadruple from $1 billion in 2017 to $4 billion in 2024 (Statista 2020a). This indicates potential for a high degree of scalability.

Single Family Residential Demonstrations Summary

Through conducting single-family residential demonstrations, the project team identified these opportunities and challenges. The project team plans to use the framework discussed in Equation 1 in Chapter 2 to better understand how certain implementation, installation, demonstration, and operational components would affect enabling small loads and devices as grid resources. Note that opportunities are indicated by a "↑" arrow and challenges are indicated by a "↓" arrow.

Impacts on Building Flexibility

- ↑ Technology infrastructure using APIs potentially allows coordinated control.
- ↑ Data parameters collected from BTM DERs potentially help understand customer preference and system operation.
- ↓ Siloed systems potentially minimize orchestration capabilities.
- ↓ Pricing signals are not in line with objectives.

Impacts to Scalability

- ↑ Leveraging market-accepted products like voice assistants could enable orchestration at scale.
- ↓ Lack of trade ally buy-in potentially results in improper commissioning, installation, and permitting BTM DERs.
- ↓ Limited operational data result where understanding of behavioral preferences is not persistent.
- ↓ Value proposition of priced-based load management (for example bill savings) is not high enough to change overall behavior.

The Open Demand Side Resource Integration Platform in Small Commercial Demonstrations

To assess tools to help customers manage energy bills in small commercial facilities, the project team recruited three schools in Amador County, California (CA CZ 12). Each of these facilities had circuit-level metering with software tools and potentially controllable HVAC and lighting loads.[10] A BEMS, which was used to recruit customer participation, interfaced with OpenDSRIP to obtain and provide energy and DER operational data that could potentially enable system-level controls within the building. The main research questions were:

- Can small and medium commercial buildings use cloud-based BEMS to identify opportunities for energy efficiency?
- Can COTS cloud-based commercial BEMS feasibly provide mechanisms for facility managers to set up energy-efficient configurations across multiple behind-the-meter DERs without compromising occupant comfort?
- Can COTS cloud-based commercial BEMS scale to provide appropriate load management and control functions in a fragmented DER market?

Additional information is provided in Appendix H.

Results

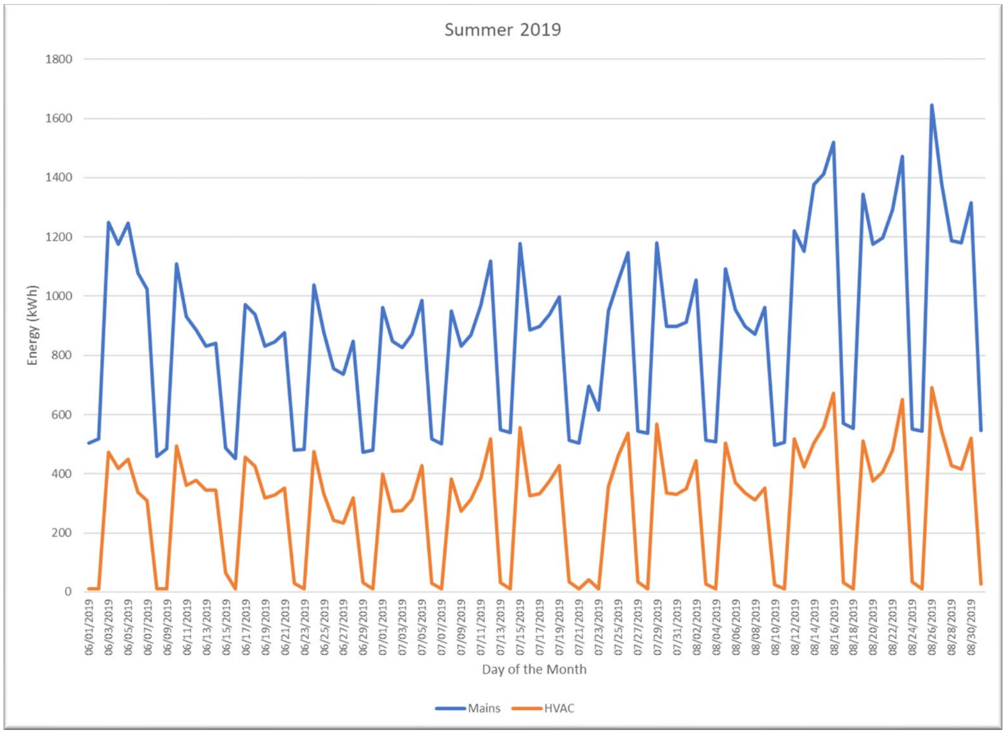
The project team experienced recruitment challenges for small commercial sites. Although over 100 sites were recruited as part of this and other parallel projects conducted by the project team (EPRI 2019b), many sites declined to participate for reasons that included a lack of concern for energy bills, administrative approval requirements and responsibility for equipment during (they were leasing the building) and after the project was completed. Building space and infrastructure challenges made it challenging to conduct the demonstration project without additional cost.

Controls implementation results for bill management were inconclusive since the project team experienced several challenges with the implementation of building controls in these three schools. The project team investigated operational data from the three sites to identify opportunities for rate management in these buildings.

Building-level load shapes are primarily driven by HVAC loads (Figure 22), although there is a considerable component of non-HVAC loads, a potential opportunity for efficiency measures to reduce energy consumption, showing HVAC and mains consumption as a function of average ambient temperature (Figure 23). There are two interpretations: that there are two distinct clusters pertaining to weekdays and weekends (the cyclical short periods of low consumption indicate the same), or the positive correlation of HVAC consumption with respect to the average ambient temperature.

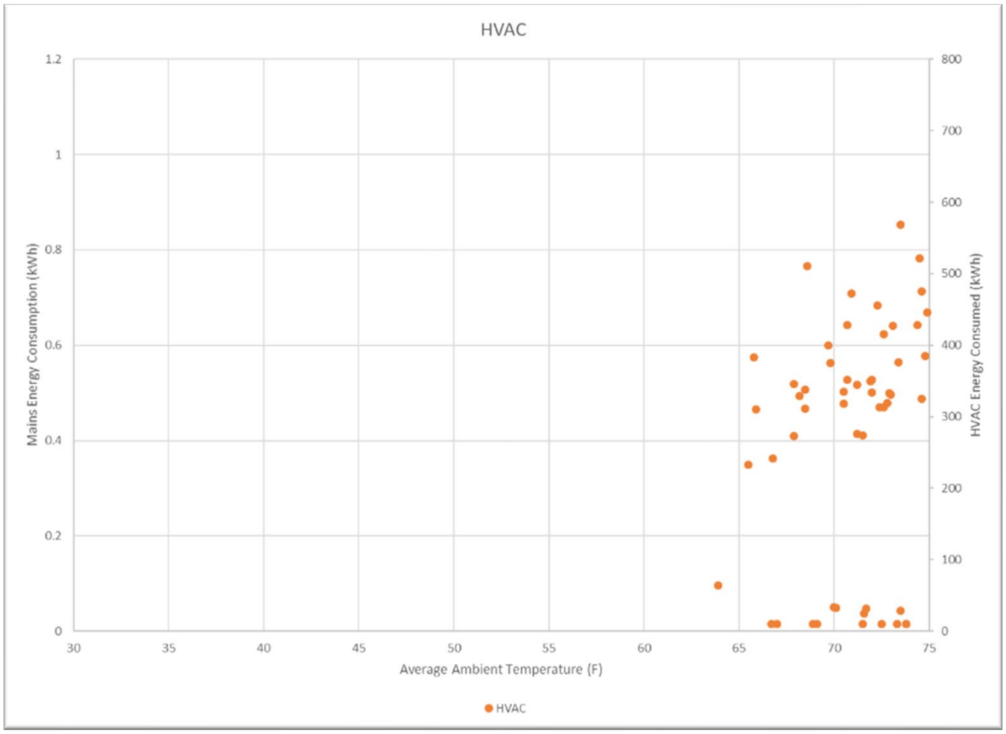
[10] Project team evaluated possibility of load management through automated control of several other commercial end-uses. However, these devices were deemed potentially feasible based on the BEMS selected.

Figure 22: Summer Mains and Heating, Ventilation, and Air Conditioning at School



Source: EPRI

Figure 23: Dependency of Heating, Ventilation, and Air Conditioning Loads on Average Ambient Temperature

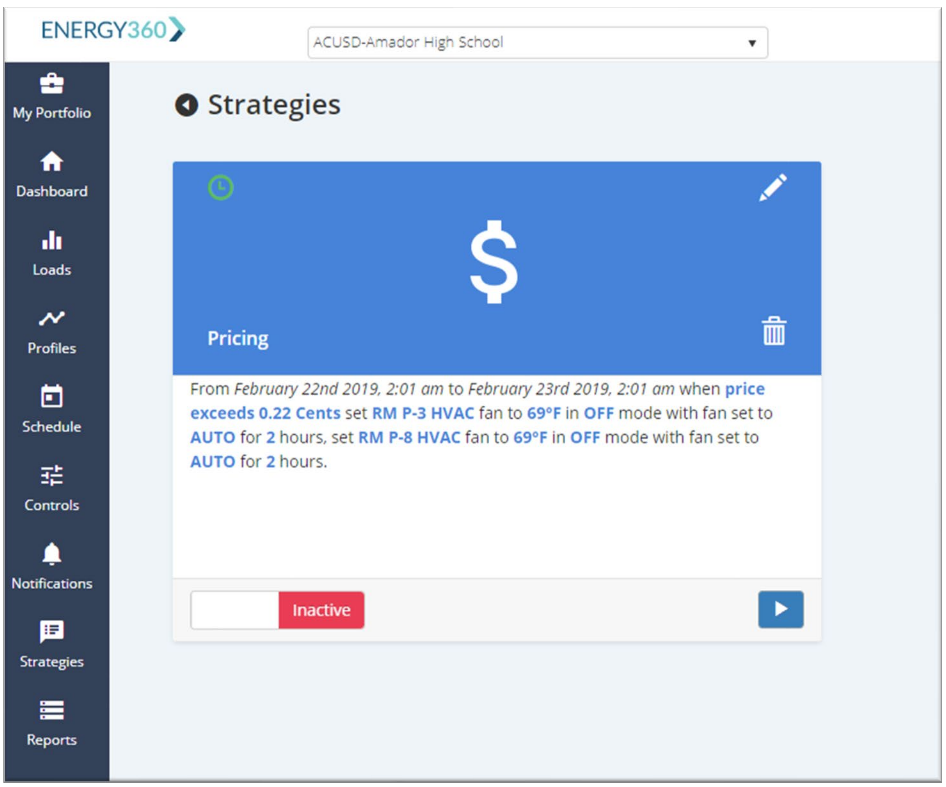


Source: EPRI

With this in mind, the project team looked at potential rate-based load management scenarios and current technology and market gaps.

To automate load-management contingent upon a set of conditions, the BEMS provides a rules engine ("Strategies") that allows facility managers to set up triggers for action, along with a specific set of actions showing a pricing-based energy management strategy set up by the facility manager (Figure 24). The project team identified that the Strategies engine was only commissioned for a short period of time (less than one week) and the interface with OpenDSRIP to enable Strategies was never accomplished during the project period of performance for small commercial buildings. However, this software module potentially provides rate-based coordinated control and load management in the residential space discussed in Chapter 2.

Figure 24: Pricing Strategies Made Available from Commercial Building Energy Management Systems



Source: EPRI

Small Commercial Demonstration Summary

Scalability considerations for commercial-building energy management are heavily dependent upon identifying critical loads and controlling non-critical loads through appropriate party integrations, subject to occupant-comfort constraints. These constraints must additionally not affect the core operations of the building. In general, scalability is addressed through vendor-proprietary point-to-point integrations between BEMS vendors (for example, Schneider Electric, Siemens, others) and commercial HVAC systems and thermostats (for example, Pelican, Honeywell, others). Emerging paradigms in commercial buildings such as Solar +

Storage + Load Management require specialized controller development and more industry fragmentation to handle different types of PV inverters, batteries, and associated battery energy-management and building automation systems. Feasibility and scalability summaries follow.

Impacts on Building Flexibility

- ↑ Technology tools are available to enable load management based on cost (price) and behavioral (schedule) factors.
- ↑ More pricing mechanisms are available when compared with residential spaces.
- ↓ Coordinated control technologies are like residential spaces. However, integration with commercial BEMS is not as mature as with residential home automation systems (for example, voice assistants).

Impacts to Scalability

- ↓ Split incentives make it challenging to obtain approvals.
- ↓ Limited value propositions create challenges in persistent operations.

For additional information on the small-commercial demonstrations, see Appendix H.

The Open Demand Side Resource Integration Platform in Electric Vehicle Demonstrations

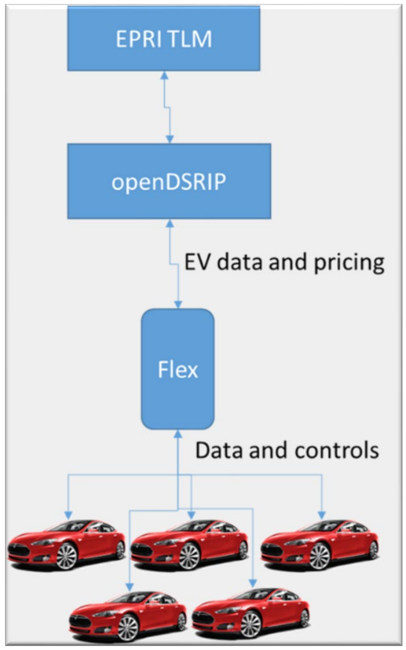
The project team evaluated two main demonstrations to investigate how electric vehicles can be part of residential solutions and tools to help California ratepayers manage dynamic energy rates.

Electric Vehicle Charge Optimization Based on Time-of-Use Rates

One of the use cases for DSRIP is the ability to understand how EVs can be integrated alongside other demand-side resources. The use case for EVs is distinctive because the impact of EVs (unlike other DERs) has a distinctive spatial-temporal signature. EVs can charge at different times and places during the day depending on whether workplace charging is available, and any charge optimization algorithm must be able to distinguish home-based charging and workplace or third-party charging.

The project team recruited EV drivers who were provided a mobile application. The mobile application is a commercially available EV charge optimization platform that currently works for two EV OEMs. Figure 25 shows the integration architecture for EVs using this EV charge-optimization platform.

Figure 25: Electric Vehicle Mobile Application Integration With the Open Demand Side Resource Integration Platform



Source: EPRI

The platform was extended to:

a. Obtain retail TOU prices for California's three large IOUs through DSRIP.

b. Change the optimization algorithm to use TOU rates to shape charging behaviors.

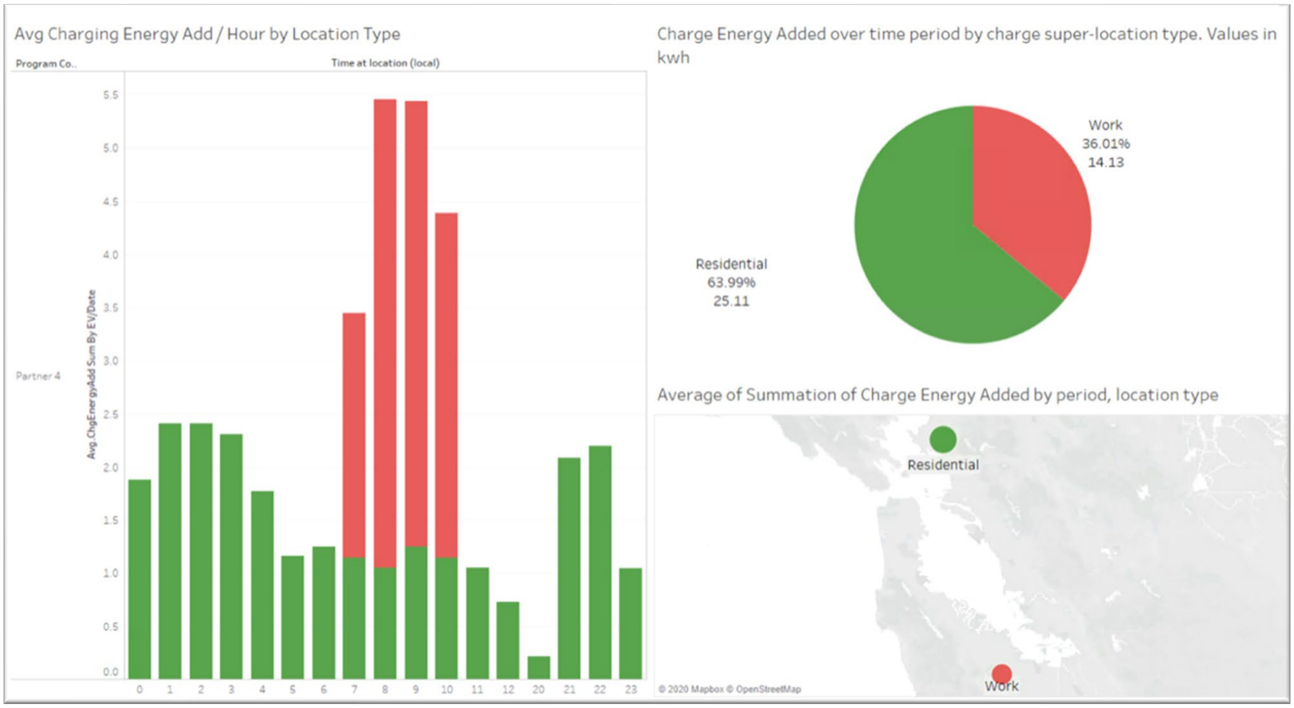
c. Extend the embedded messaging in the application to include information about upcoming and past high/low price events.

d. Send EV operating data as it relates to charging performance before, during, and after charging events.

The project team also established algorithms for the computation of baselines using 10/30/90 day periods for comparison of optimization performance to pre-optimization performance.

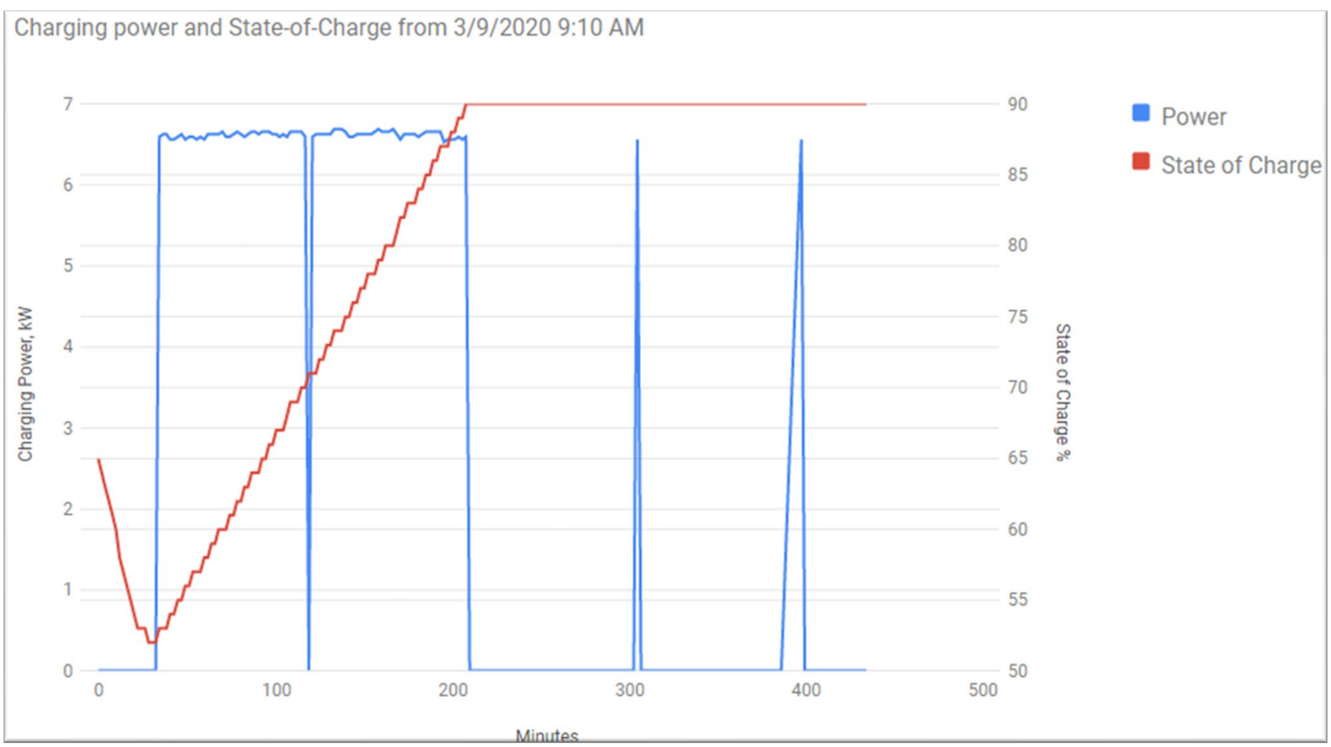
The team also obtained some initial data as a baselining period while the platform was tested and prepared for optimization changes. As shown in Figure 26, the platform can distinguish between residential and workplace charging and between Level 1 (home-based) and Level 2 (workplace charging). Additionally, the platform also provides per-event charging profiles (Figure 27). These can be useful to compare a charge profile under optimization with a non-optimized charge profile to estimate grid service potential.

Figure 26: Visualization of Data from Mobile Application on the Charging Behavior and Charge Profile of a Recruited Electric Vehicle



Source: EPRI

Figure 27: Charge Profile for Electric Vehicle Charging a Level 2 Charger (workplace charging)



Source: EPRI

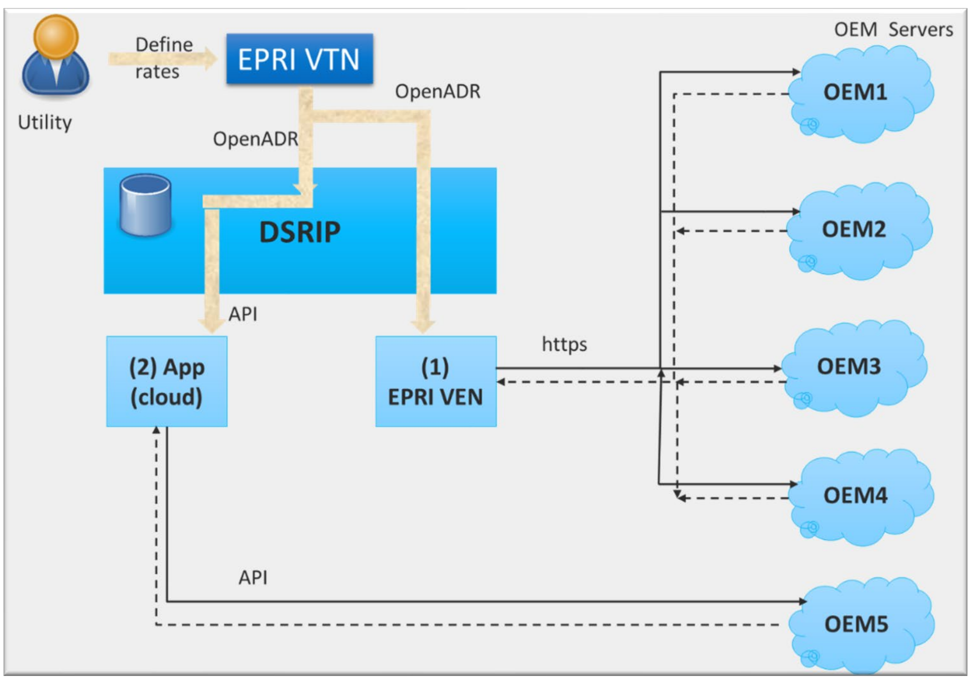
Qualitative data from the demonstration participant shows challenges with the current application such as nowhere to set a potential charge schedule. As a result, the participant has uninstalled the mobile application. This indicates additional information is needed in both EV driver behavior and segmentation and clustering activities to develop charge optimization strategies targeted towards certain types of EV adopters as well as additional operational data on EV performance as it pertains to grid-resource use.

Electric Vehicle Load Management Using an Open Vehicle-to-Grid Integration Platform

The OVGIP can manage the interactions of PEVs or PHEVs and the grid for charging, based on dynamic energy pricing and user behavior. This allows greater control of the resources (when EVs are available) to provide grid services and is likely to become more important with the sale of EVs and hybrids increasing over the next few years. For additional information, see Appendix H.

The project team successfully integrated the OVGIP into DSRIP based on the architecture described in Figure 28. At the time this report, demonstrations of price-based charging behavior modifications were ongoing or had been completed with Detroit Edison (DTE),

Figure 28: Architecture Diagram of Open Vehicle to Grid Integration Platform to the Open Demand Side Resource Integration Platform



Source: EPRI

Southern California Edison (SCE), Xcel Energy, ConEdison, Hawaiian Electric and Southern Company. All are in different stages of implementation and testing. As an example, DTE completed a pilot and is working on analyzing the data gathered during the pilot phase. Xcel Energy is similarly at the beginning of the pilot phase to evaluate price strategies and their effects on charging-control behaviors.

Electric Vehicle Demonstration Summary

Emerging research leverages electric vehicles as a grid resource. Results from the two demonstrations conducted by OpenDSRIP follow.

Effects on Building Flexibility

- ↑ EVs provide a potential grid resource through V2G-type platforms.
- ↑ Data is made available to enable intelligent charge management that considers customer preference.
- ↓ Limitations in standardized commands that enable electric vehicles as grid resources

Effects on Scalability

- ↑ State and federal mandates on EV adoption is potentially enabling tools for greater EV adoption.
- ↓ Range anxiety and other issues concern EV owners.
- ↓ Current cost/benefit analysis results in an indeterminate value proposition.

Tools to Help Disadvantaged Communities Manage Time-of-Use Rates

The previous demonstration relied on technologies that are usually adopted by those with the financial means to afford them. Adopters of smart devices like smart thermostats and electric vehicles are those in higher annual income brackets. As this project focuses on tools and technologies from a breadth perspective, addressing a wide range of residential and small commercial applications, it is important to understand how tools and technologies can enable utility bill savings in California's low-income communities.

Time-of-Use Rate Management for Residents of Disadvantaged Communities Using Mobile Applications

Energy programs across the country are interested in providing tools to help low-income customers manage their energy bills. For example, Consolidated Edison in New York has developed a mobile application with the intent of providing technology solutions that can be leveraged by low-income communities (EPRI 2019c). Inspired by this effort, the project team investigated and commenced the development of a mobile application to evaluate the effects of behavioral intervention for ratepayers in California (especially those living in low-income communities) through mobile app-driven messaging and education mechanisms by addressing the following questions:

- Can customers who are subject to TOU rates benefit from messaging and education on how to reduce their energy use during the day, consistent with TOU rates?
- What types of mobile app designs help promote energy-efficient behaviors and improved adoption in low-income communities?

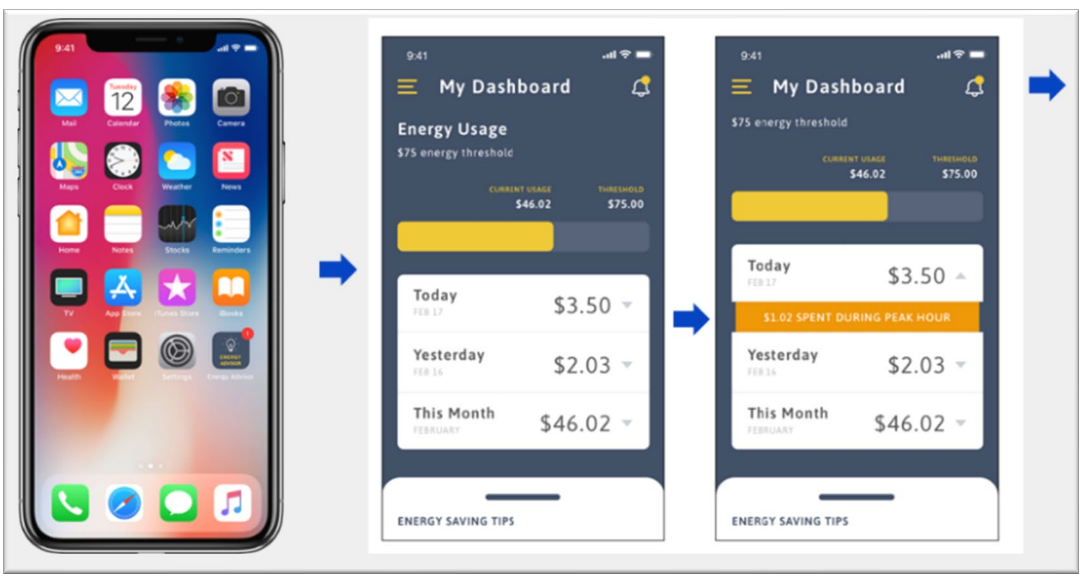
The project team contracted a California-based mobile app development team to produce a reference design for a mobile app that enables energy-efficient behaviors in customers with a

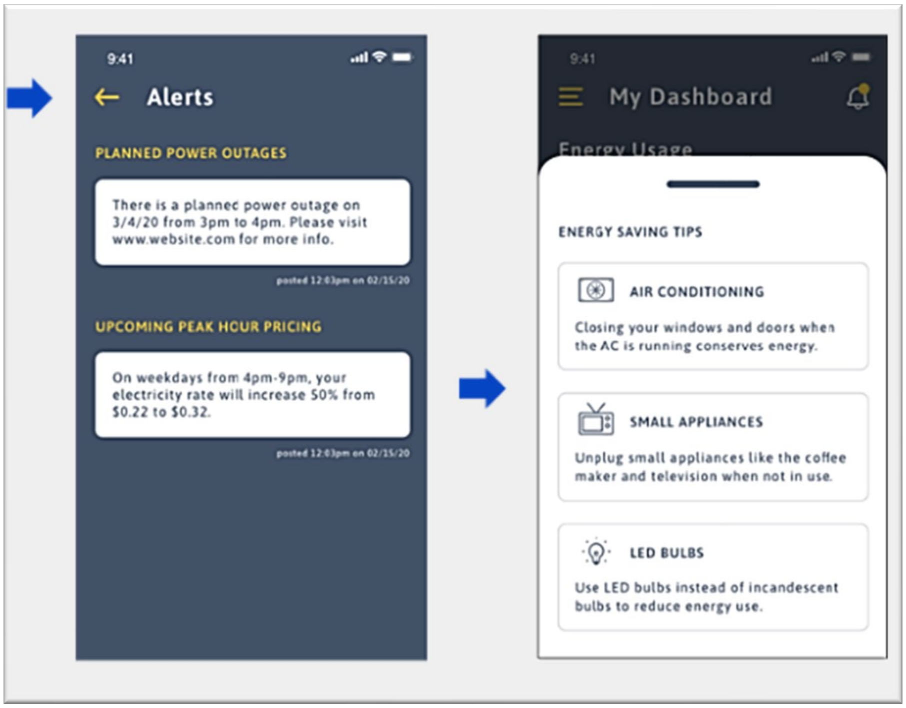
TOU rate plan. In particular, the app team was asked to develop designs with a set of functional requirements. These functional requirements follow.

1. Customer registration: TOU app shall obtain customer information (such as name and address) to register the customer as part of the app.
2. Customer configuration data: TOU app shall allow customers to configure their homes' energy consumption using information such as appliances (for example, room-based air-conditioner, swamp-cooler, water heater, refrigerator, gas or electric range, gas or electric oven). In addition, a customer can also provide a threshold for how much that customer is willing to spend on electricity each month.
3. Messaging: TOU app shall provide customers with notifications on upcoming high-price events based on pricing data received from OpenDSRIP on a day-ahead basis. The TOU app shall also provide periodic energy-saving tips (based on a customer's configuration data).
4. Customer's electricity usage tracking: TOU app shall provide the customer with a set of easy-to-understand information about their energy usage.

The project team developed a set of reference designs that are platform (iOS and Android) agnostic and focused on simple and intuitive customer experiences. The app designs may be tested with a set of residents to better understand the usability of the design before the mobile app is fully developed. Figure 29 shows a customer experience through the mobile app.

Figure 29: Proposed Customer Journey Through Time-of-Use Energy Management App





Source: EPRI

Load Management in Multifamily Residential Communities

The project team installed smart thermostats and is collecting data on 64 two- and three-bedroom units in Firebaugh, California (CA CZ 13). See Figure 30 and Figure 31.

Figure 30: One Building in Firebaugh Community and 16 Buildings in Firebaugh Community (Aerial View)

Source: EPRI

Figure 31: Installation of Smart Thermostats for Demand-Charge Management in Firebaugh, California

Source: EPRI

The community houses primarily migrant farm workers in the summer on its 16-building, master-metered campus, while it remains mostly unoccupied in the winter. Driven by a need for better cooling systems, the site's evaporative coolers were upgraded to electric heat pumps in 2019. Conversations with the property management, maintenance, and HVAC contractors identified that in the summer, occupants of the community would often decrease their setpoint down to 50 degrees Fahrenheit (10 degrees Celsius). This resulted in increased HVAC consumption and larger electricity costs for the property manager, primarily due to a considerable demand charge, peak energy use and peak-day pricing. The project team leveraged existing COTS tools to enable demand charge management strategies for this community (Ecobee 2020).

Disadvantaged Community Demonstration Summaries

Lessons learned from these sets of demonstrations follow.

Impacts on Building Flexibility

- ↑ Device providers such as thermostats have recently developed projects that target disadvantaged communities.
- ↑ Energy impacts could also lead to additional non-energy benefits (for example improved indoor-air quality).
- ↓ Limitations in connectivity and communications infrastructure, such as Wi-Fi.
- ↓ Limited technology choices were available in these disadvantaged communities.

Impacts to Scalability

- ↑ Partnerships with device manufacturers and community-based organizations enable adoption and buy-in.
- ↓ Lack of upfront capital to procure devices
- ↓ Building infrastructure not able or not compatible with some BTM DERs
- ↓ Limited knowledge or lack of trust in third parties on emerging technologies

Summary

This chapter showed the current state of controllability of BTM DERs, from a practitioner’s standpoint, to show technology opportunities but also to lay out implementation challenges of integrating BTM DERs (both emerging and currently available) to dynamic rate signals. As the value proposition to the customer and the energy system is still not yet well defined, understanding the need to comply and how to comply with specific data and grid management specifications and standards is not yet well understood by the market.

Work with both manufacturers and service providers shows that the collection of operational data may be a way to start valuating BTM DER systems as grid resources in areas of rapid technology change. However, data specifications and necessary analysis tools are still new to the market and currently being evaluated.

Finally, a set of demonstration projects leveraging the OpenDSRIP infrastructure was used to understand implementation challenges such as customer appetite, trade-ally capability and other areas that need to be addressed to scale building flexibility. Results of this work show that although there are pieces of technology infrastructure available in the market today, the market is still quite fragmented and new, with an ill-defined value proposition to both enable buildings as grid resources and also understand opportunities and barriers to scalability. Technology, policy and programmatic work are still needed to valuate and enable the use of small end-use loads as a means to achieve California’s overall decarbonization goals, but also be leveraged as tools to help customers manage California’s shift to dynamic energy rates.

CHAPTER 4: Technology/Knowledge/Market Transfer Activities

The project team conducted several activities to disseminate project objectives and results. Although the development of OpenDSRIP and its associated laboratory and field demonstrations were compulsory components of this project, the team worked through and identified other opportunities to understand the market and technology landscape throughout the project and presented results of all aspects of the project. These activities are divided into the following groups of activities:

- Open-Source Materials: Details on where OpenDSRIP codebase or other materials can be found and used.
- Stakeholder Workshops, Industry Publications, and Technical Advisory Committee Activities: These activities constitute work done by the project either to present results to energy stakeholders or receive feedback from energy stakeholders on the project and project-related activities.
- Collaborative Projects Leveraging OpenDSRIP: Described activities, projects, and points of coordination enabled by OpenDSRIP during the project's period of performance.
- Advanced and Connected Community Demonstration Projects Leveraging OpenDSRIP: Demonstration projects leveraging OpenDSRIP and OpenDSRIP concepts to better understand how mass-market end-use loads can respond to grid signals.
- TOU Rate Management Tool Assessment for Disadvantaged Communities: Activities identifying methods to assess and develop tools for California's disadvantaged communities to manage a shift to TOU rates.
- Aligning Future OpenDSRIP Activities With United States Department of Energy (U.S. DOE) Initiatives: Intends to leverage OpenDSRIP to address research questions posed by the United States Department of Energy (U.S. DOE) grid-interactive efficient buildings activities.
- Assessment Tool for Emerging Building Electrification Technologies: Methods in which OpenDSRIP can potentially be used as an assessment tool for building electrification technologies.
- Framework and Specification for Smart-Home Readiness: Discusses how OpenDSRIP activities have established the current state of how smart home and connected mass market end-use loads can be controlled to respond to grid signals, and what data validate that control functions were actually acted upon.

OpenDSRIP Codebase and Functional Requirements

The openness of OpenDSRIP manifests in both the OpenDSRIP platform codebase and functional requirements, which are publicly available and require no prior authorization. Additionally, the codebase and functional requirements are maintained as more features are added to the platform. Links in which OpenDSRIP's codebase and functional requirements include:

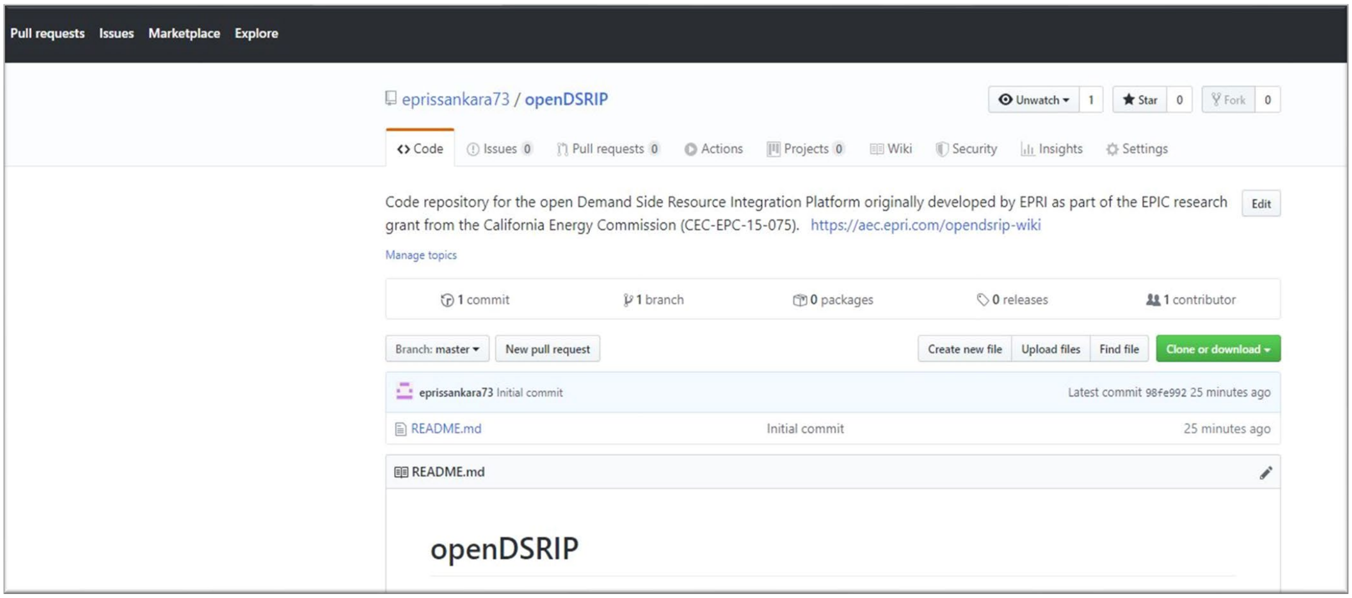
- Codebase Repository: https://github.com/eprissankara73/openDSRIP.
- Functional Requirements Summary: https://aec.epri.com/OpenDSRIP.

The OpenDSRIP codebase repository is housed in EPRI's GitHub account as a public project Figure 32 and Figure 33). The standard practice for open-source code includes:

- Definition of Licensing Terms: Constructed like the Creative Commons noncommercial application, which can be used and modified with attribution.
- Roles: For Who Can Develop and Contribute to the Code Base: A registration process for enrolling as a developer is defined (though currently limited to GitHub users with established user profiles).
- Process for Issue Tracking: An issue-tracking form was added to track issues along with priority. Higher priority issues were tested and accepted in a shorter time period (< 72 hours) compared to lower-priority issues (< 168 hours). Issues that were tested and found to be non-issues were rejected.
- Process for Patching: An enrolled developer may contribute a patch to an identified issue. Patches were tested for coding style compliance, patch efficacy, and regression testing before the patch is accepted to a specific forked dev branch. After the patch was found useful through developer community interest, the patch was merged into the master branch.
- Process for the Addition of Features: An enrolled developer may contribute a new feature with (a) justification for that feature, (b) tested code for the feature, and (c) a test plan to show both what was tested and the test results. After the feature has been found useful through developer community interest, the feature was accepted to a specific forked dev branch and eventually into the master branch.

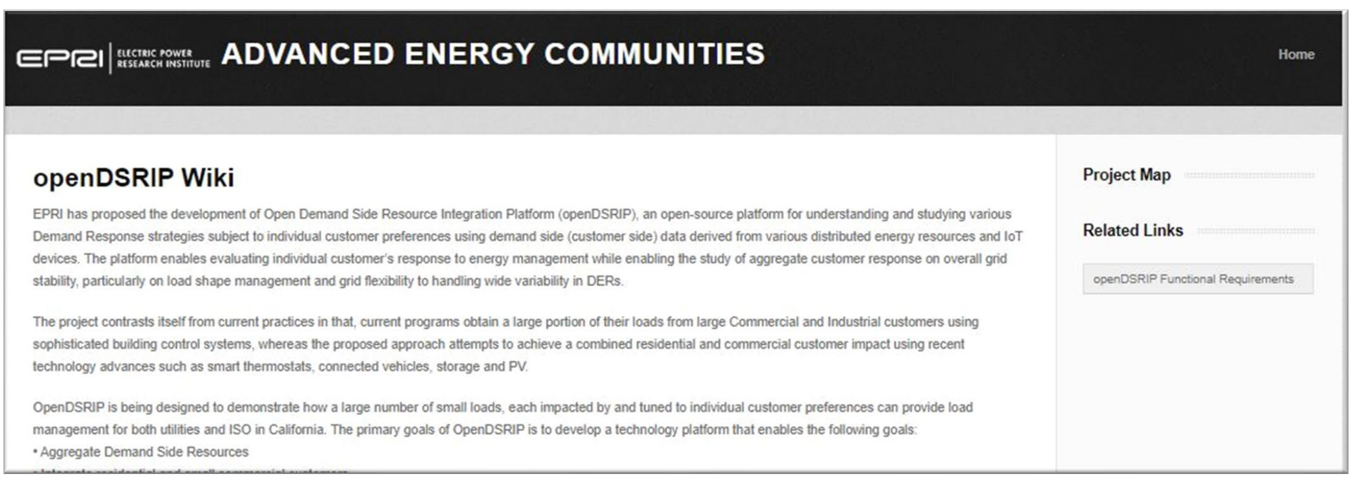
The functional requirements are being hosted on EPRI's aec.epri.com/OpenDSRIP-wiki site. In addition to the document download, the OpenDSRIP wiki site also provides additional information about the OpenDSRIP platform including information on how to request access to the OpenDSRIP platform, how to use OpenDSRIP for various feasibility study exercises, and how to request access to OpenDSRIP data.

Figure 32: Codebase of the Open Demand Side Resource Integration Platform on GitHub



Source: EPRI

Figure 33: Open Demand Side Resource Integration Platform Wiki on EPRI Advanced Energy Communities Website



Source: EPRI Stakeholder Activities, Industry Publications and Technical Advisory Committee Activities

The project team conducted several activities to disseminate results and solicit feedback on the project's direction. The project team assembled a technical advisory committee (TAC) consisting of various stakeholders. The project team worked with the TAC, meeting throughout the project to better direct the overall OpenDSRIP platform and project design and guide the project throughout its period of performance. See Appendix I for the list of TAC members. In addition to TAC meetings and webcasts, the project team identified other opportunities during the period of performance to discuss the current results of the project.

- EPRI Advisory Meetings: EPRI members in the energy efficiency/demand response research and advanced buildings research programs are deeply interested in learning more about OpenDSRIP and its applicability to technology evaluation activities focused on energy efficiency and connected technologies for customer programs. The project has spurred interest in leveraging the OpenDSRIP research platform for specific use cases.
  - A benchmarking/sandbox tool before procurement of commercially available platforms. OpenDSRIP is being considered as a tool to baseline or benchmark the feasibility of BTM DER integration.
  - Developing a framework for valuing the scalability of building and community flexibility.
  - Data collection and analysis strategies of BTM DERs to better understand energy system planning and operation strategies as a result of building electrification.

The project team continues to work with TAC members on valuation metrics to understand how buildings and built environments can enable energy-system flexibility.

- Industry Publications: EPRI is working closely with energy industry publications to disseminate lessons learned from this project. This is done through channels such as the American Council for an Energy Efficient Economy (ACEEE), through project TAC members, and California IOUs including SCE, which has developed a compendium of CEC-funded projects championed by EPRI for wider dissemination of research results within SCE's emerging markets and technology areas. Finally, publications have been made available through traditional EPRI membership channels. A sample list of publications follows.
  - An ACEEE paper and presentation to better understand how customer-sited solar, storage, and load management enable customer and grid services entitled "Integrating Connected Loads to Provide Grid Balancing and Distribution Support" (Pabi et al. 2018).
  - A report to SCE on CEC EPIC-related work discussing next-generation projects on demand response entitled "Technology Assessment and Delivery (TA&D): Assessing the Potential of CEC's EPIC Projects in Demand Response" (EPRI 2020a).
  - A review of the current state of flexible loads, distributed solar, energy storage and EVs called "Assessment of Integrated Energy Technologies Research: Flexible Loads, Distributed Solar, Energy Storage and Electric Vehicles" (EPRI 2018b).
- Market Engagement: The project has enabled the project team to engage market stakeholders such as smart technology providers and other BTM DER market players to

help understand how to develop technology that meets customer needs first and understand the need for energy-system flexibility in decarbonized communities. Through technology task forces and other engagements, the project team has presented both the project itself and lessons learned from the project in many forums throughout the project's period of performance.

Collaborative Projects Leveraging the Open Demand Side Resource Integration Platform

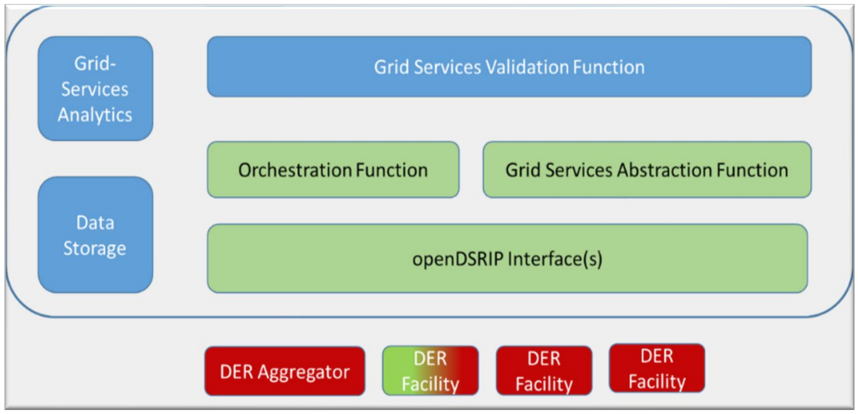
Information and codebase of OpenDSRIP have been widely distributed and leveraged via collaborative projects and industry activities. A subset of these projects follows.

Service Discovery for Smart Home Readiness

The team actively participated and collaborated with Pacific Northwest National Labs and Lawrence Berkeley National Labs in grid modernization activities focused on interoperability between DERs and the grid to enable flexible grid services. EPRI teamed with DER vendors to demonstrate how the OpenDSRIP API can be used for enabling easier customer registration and signaling for grid services without the need for pervasive standardization of communication interfaces. The project team extended the original conceptual design of OpenDSRIP to include a few key features with smart-home/TOU rate management readiness in mind. As shown in Figure 34, the concept is called "Plug and Play DER" and this extension was proposed as a solution to the U.S. DOE-sponsored Grid Modernization Laboratory Consortium (GMLC) efforts (SEPA 2019) to enable DSRIP to complete the following main requirements:

- The ability for customers to register their site as a "grid-service" provider with their utility's OpenDSRIP instance. – Step 1.
- The ability for customers to register their smart home devices as part of a "grid-services" provisioning through their utility's OpenDSRIP instance. – Step 2.
- The ability for customers to be assessed for "service readiness" through a service discovery protocol that uses the information collected on the smart home device against a database of grid-services ready implementations. – Step 3.
- Upon successful service readiness verification, the customer is enrolled in providing grid services and a residential orchestration module is provisioned for the customer.
- The residential orchestration module coordinates with OpenDSRIP to receive grid-service triggers, for example, pricing signals to control behind-the-meter smart-home devices and collect data on service fulfillment to help with payments and settlements.

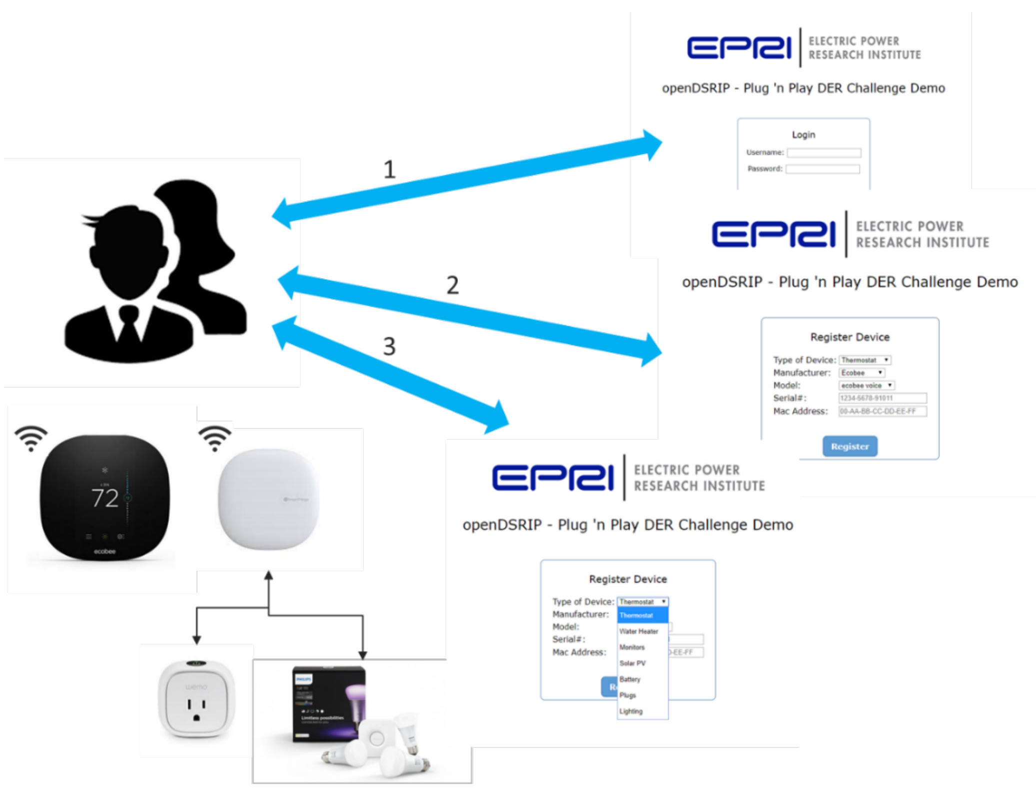
Figure 34: Extending the Open Demand Side Management Platform to Provide Plug-and-Play Functionality



Source: EPRI

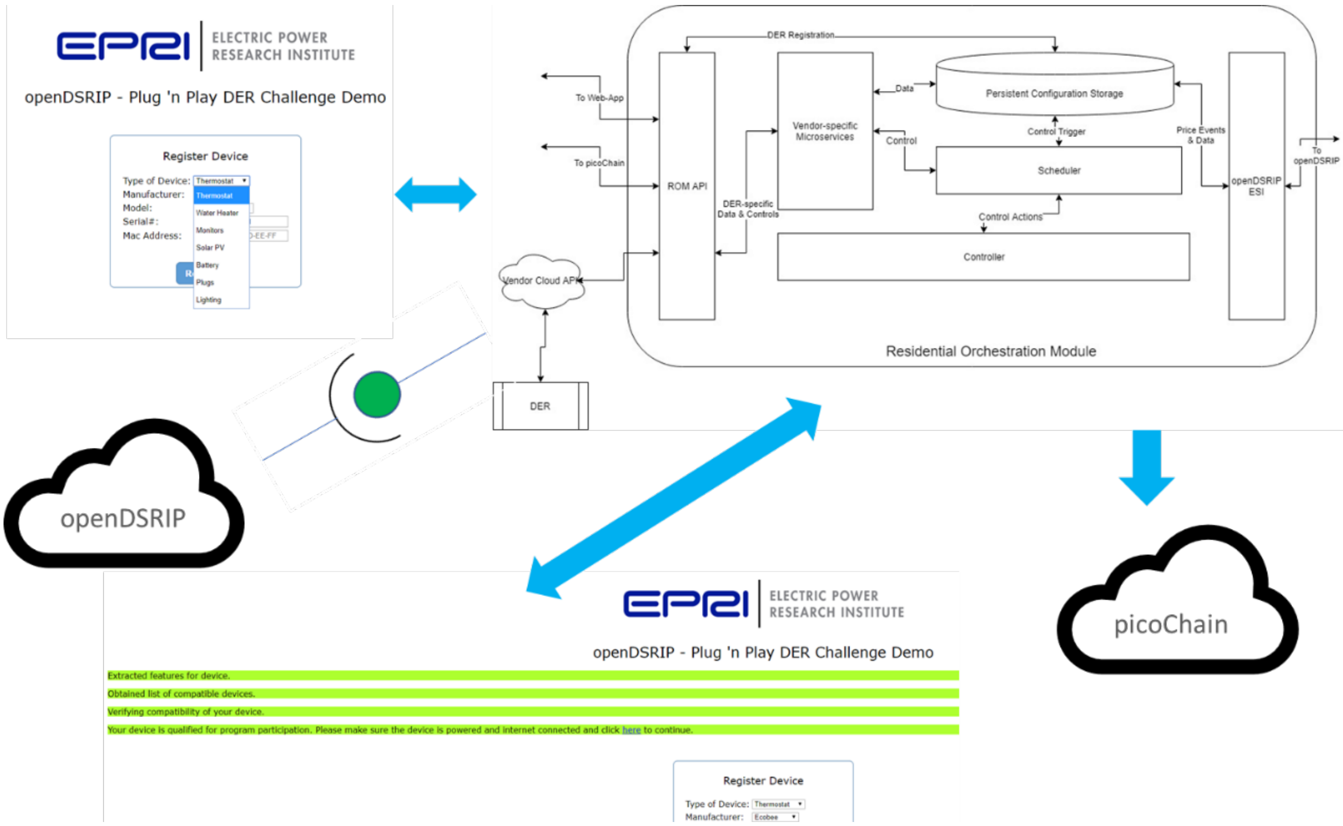
The project team was a finalist for the Plug and Play DER challenge that solicited visionary solutions for promoting interoperability and ease of adoption of behind-the-meter DERs to provide grid services. The project team demonstrated this concept of site and device registration plus service fulfillment through a live demonstration at the North American Smart Energy Week in September 2019. The demonstration script for the registration and service discovery and verification is shown in Figure 35 and Figure 36.

Figure 35: Demonstration Script for Open Demand Side Resource Integration Platform Plug and Play Functionality



Source: EPRI

Figure 36: Successful Service Discovery and Smart-Home Readiness Verification



Source: EPRI

Southern California Edison Technology Assessment and Delivery Project

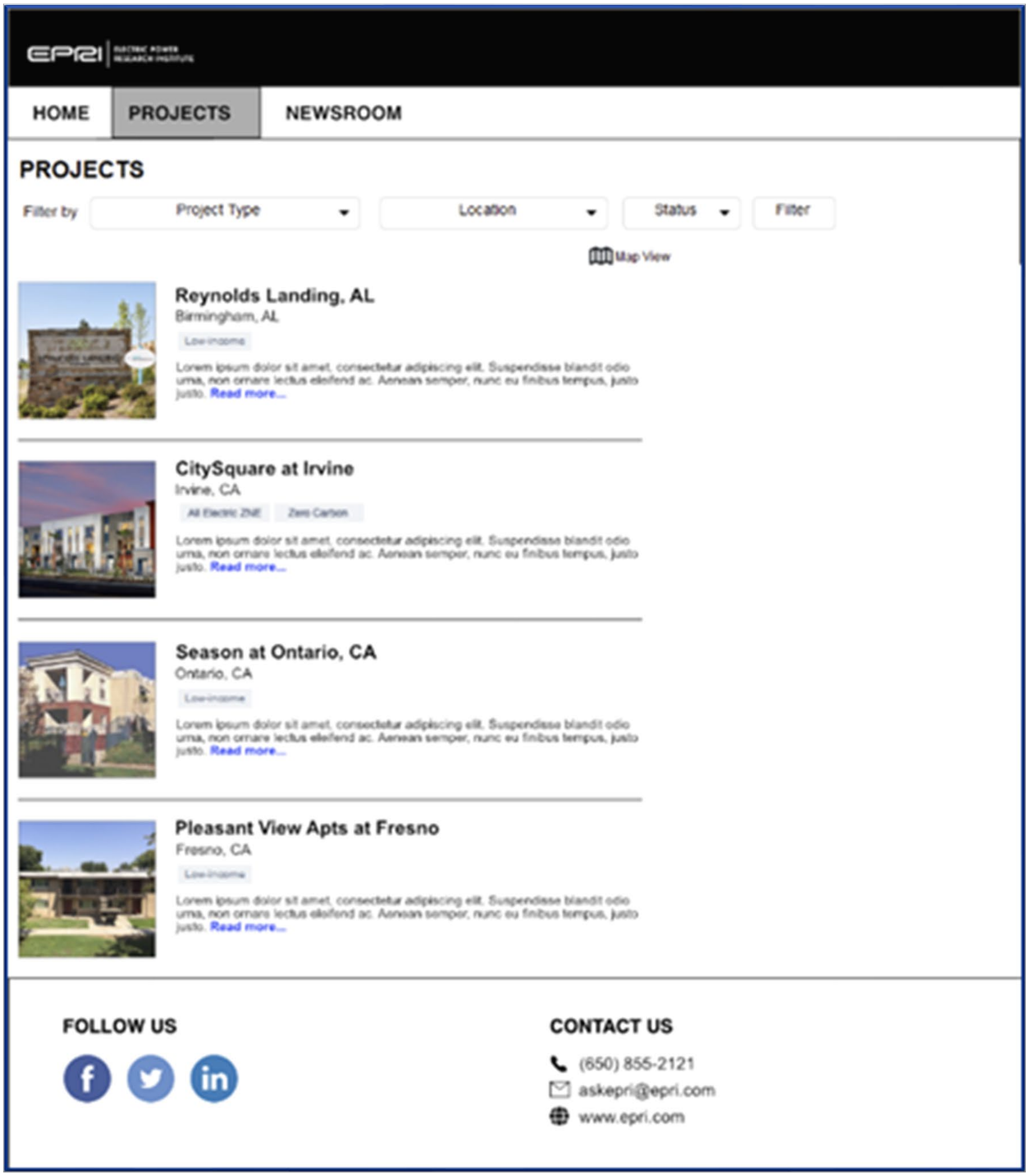
EPRI is working closely with SCE in developing a portfolio of CEC-funded projects that are championed by EPRI for wider dissemination of research results within SCE's emerging markets and technology area. As part of this initiative, periodic presentations of OpenDSRIP and its research results are discussed with SCE.

EPRI Advanced Energy Communities Collaborative

EPRI's Advanced Energy Communities collaborative is actively pursuing projects ranging from retrofits in disadvantaged communities in San Diego County to the use of OpenDSRIP for residential DR programs in Hawaii. OpenDSRIP plays the role of platform enabler in these projects to support the data from these field demonstrations, visualization through in-time data dashboards, and ex post-facto analysis of data for understanding performance results.

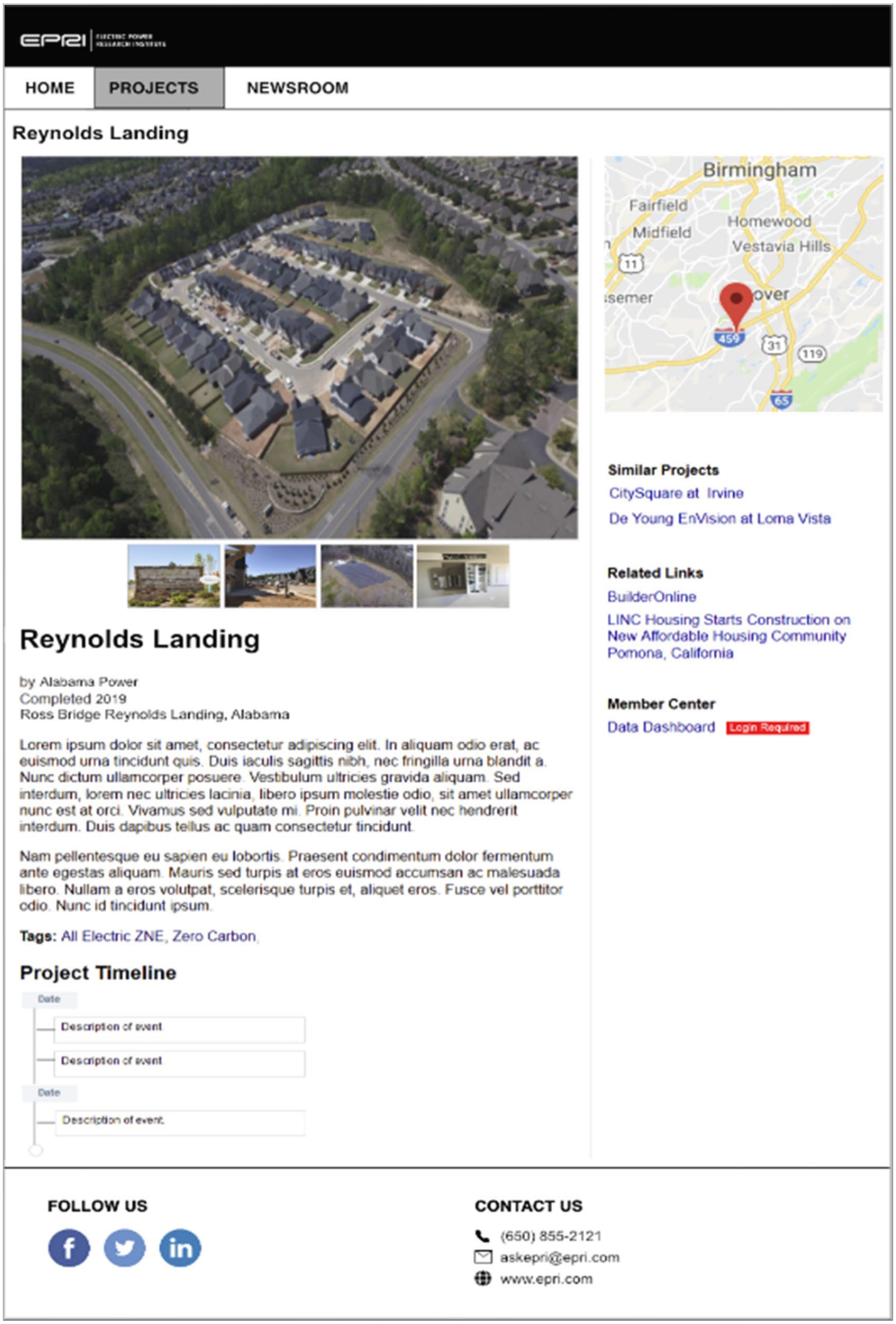
EPRI conducts these residential field demonstration projects involving the integration of emerging efficient electrification technologies to better understand how these communities can be built at scale; what perceived value or risk these communities face to potential home-buyers, community occupants, and managers; and to better understand how an energy system needs to be planned, operated, and managed in these electrified communities. This initiative is called EPRI's Advanced Energy Communities (EPRI 2017b) and consists of demonstrations both in California and throughout the United States that examine the integration of BTM DERs in demonstration and deployment settings. The OpenDSRIP platform is a tool that visualizes the results of the overall initiative through the creation of normalized data acquisition and visualization tools from these demonstration projects, but also as a tool for technology and knowledge transfer to a greater audience through the development of a knowledge transfer portal. The portal contains all demonstration projects and associated case studies for each pilot project, lessons learned and best practices, and normalized analyses and analysis tools. See Figure 37, Figure 38, and Figure 39 for screenshots of the launched website (EPRI 2016b).

Figure 37: EPRI Advanced Energy Communities Portal



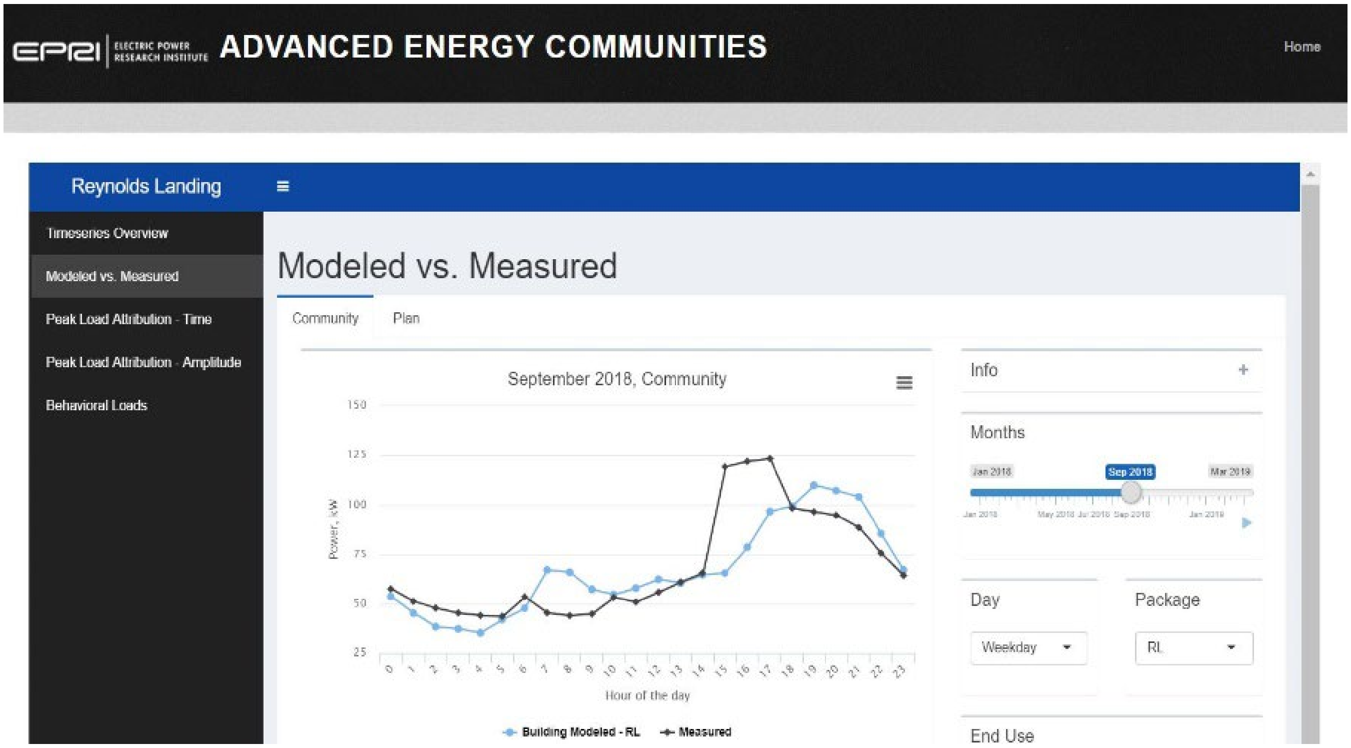
Source: EPRI

Figure 38: Structure of Specific Project Pages in EPRI Advanced Energy Communities Portal



Source: EPRI

Figure 39: Data Dashboard for Specific Projects in EPRI Advanced Energy Communities Portal

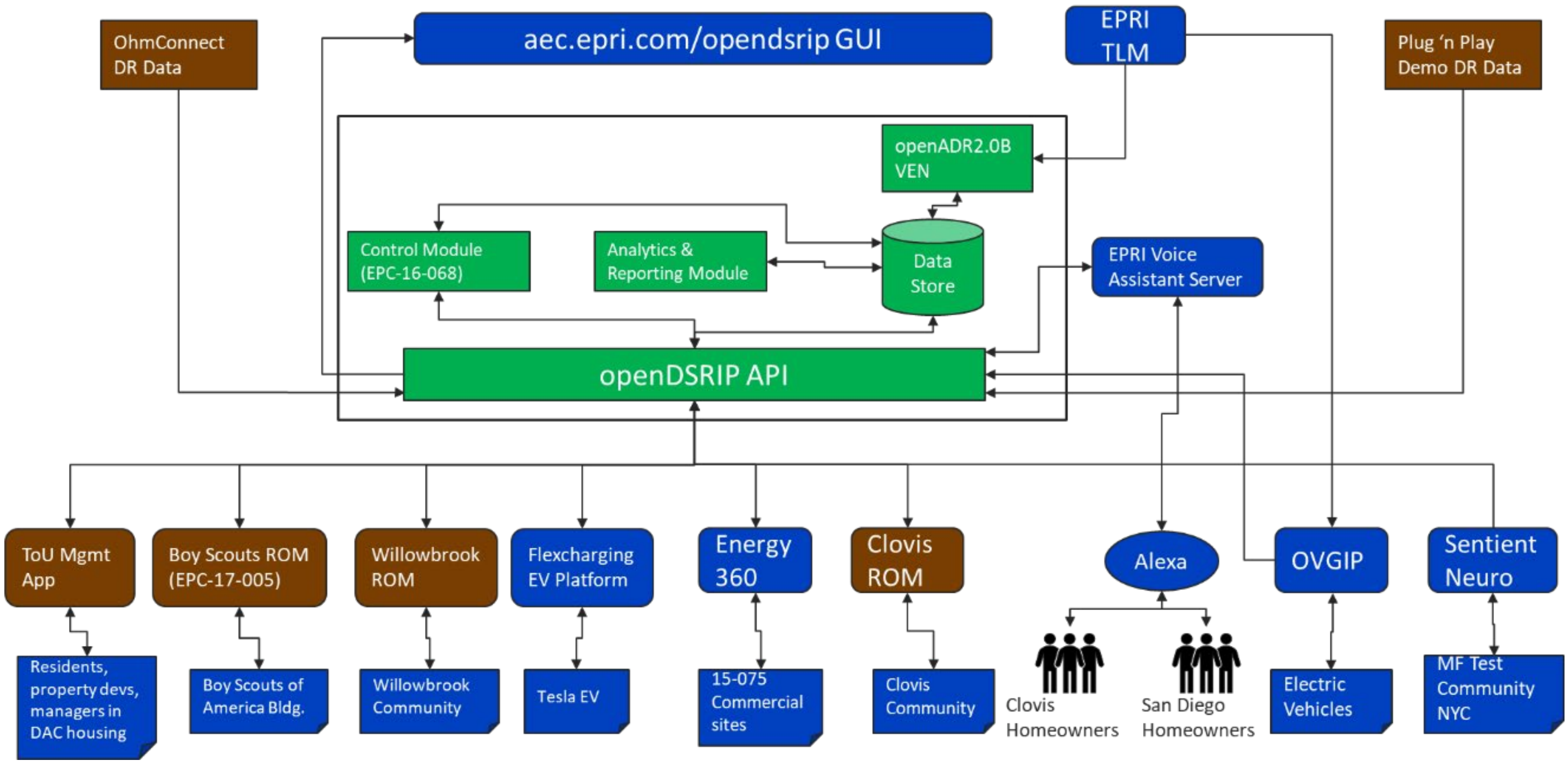


Source: EPRI

Continued Work With the Open Demand Side Resource Integration Platform Field Demonstration Sites

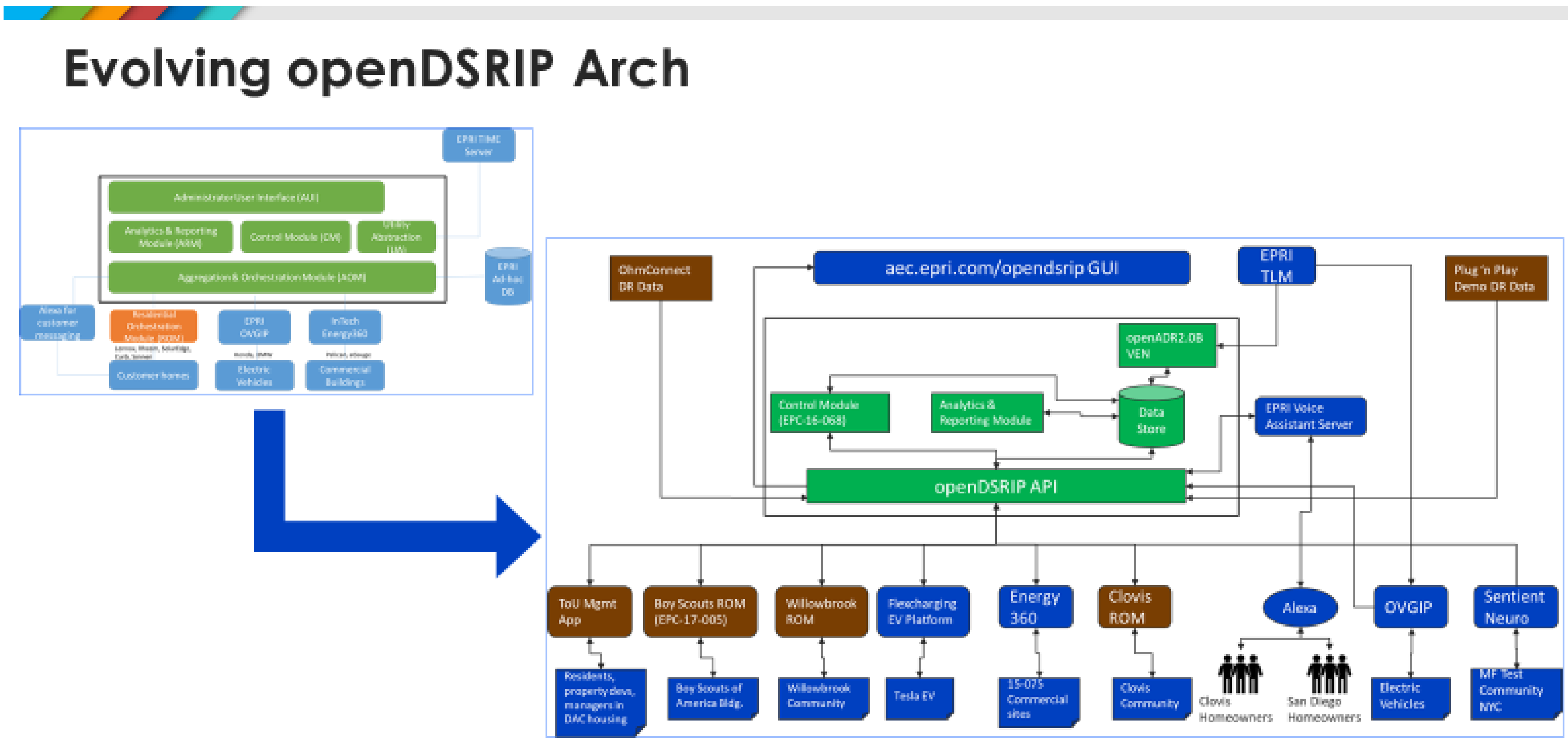
Originally intended to be orchestration and demonstration on a single residential community, a few small commercial buildings, and a proof-of-concept on PHEVs and BEVs, the project has developed an extended set of field demonstration sites with the capability to both manage BTM DERs and the collection of operational data. This data helps the project team better understand the persistence of any efficient electrification measures and associated orchestration modules moving forward. This additionally helps the team better understand how California's ratepayers can use BTMs today to help them manage shifts to dynamic energy rates (for example, TOU). The final state architecture for OpenDSRIP after extension and application to other field demonstrations is shown in Figure 40, and the comparison of the initial to the final state is shown in Figure 41.

Figure 40: Final State Architecture of the Open Demand Side Resource Integration Platform After Enhancements Driven by Field Demonstration Projects



Source: EPRI

Figure 41: Evolution of the Open Demand Side Resource Integration Platform Architecture from Project Start to Completion



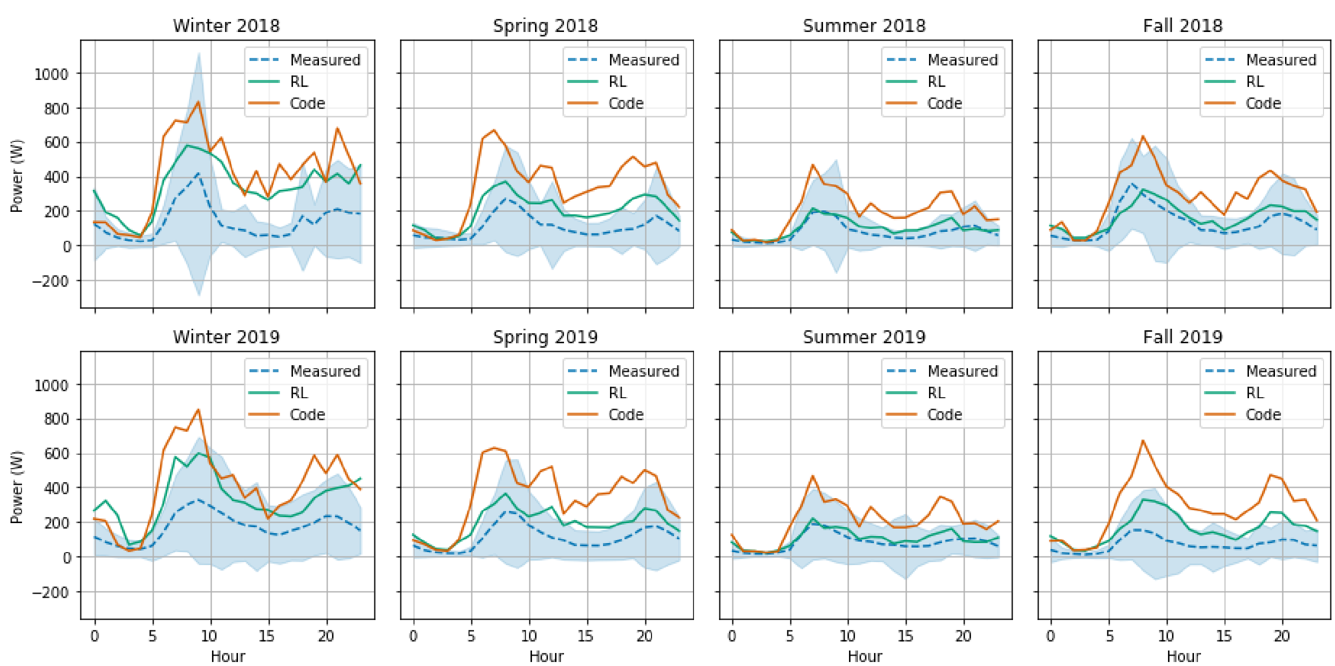
Source: EPRI

Moving forward, the project continues to work on several of the field demonstration sites completed as part of this project with the overall goal of continuing to better understand the feasibility and scalability of how smart homes and communities can provide intelligent rate management tools for its owners and occupants. Specific demonstration projects of interest to the project team are discussed in the next sections.

Alabama Power Smart Neighborhood

The project team continues to work with Alabama Power, Southern Company, and the U.S. DOE on understanding how a microgrid combined with a community built with advanced, energy-efficient technologies impacts the energy system. The project team has collected over two years of operational data in this community on a combination of use cases that includes impacts of price optimization to efficient electrification technologies (such as HPWHs) and variable capacity HVAC equipment. See Figure 42 for two years' worth of seasonal heat-pump water heater load shapes in this 62-home community (EPRI 2020b).

Figure 42: Alabama Power Smart Neighborhood Heat Pump Water Heater Seasonal Load Shapes



Source: EPRI and Southern Company

Zero Net Energy Communities in Clovis, California

The project team will continue to collect data and test how the technologies are being used in this ZNE community in Clovis, California. This provides a good understanding of both electrification of space and water heating from a load shape perspective, but also from achievable flexibility of these emerging efficient electrification technologies in a decarbonized, ZNE community.

Disadvantaged Community in Firebaugh, California

The project team will continue to work with the low-income, migrant farming community in Firebaugh, California to better understand how BTM DERs, aggregated together in a multi-family community, can provide demand-charge management for this low-income, master-metered community. As previously mentioned in Chapter 1, California low-income community developers and managers are interested in tools and financial to help these communities shift to more dynamic energy rates as the state meets its decarbonization targets. The project team has installed smart thermostats and begun to collect information on this community and plans to better understand how smart thermostats can be used to reduce energy bills.

All-Electric, Zero Net Energy homes in Irvine, California

The project team is working with SCE and Meritage homes in the design, construction, and collection of occupant data in an all-electric, zero-net-energy community in Irvine, California (CA CZ 6). OpenDSRIP is being used as a tool to collect operational data from these communities, and its visualization tools were used to present how a combination of efficient electrification technologies and California's shift to TOU rates are impacting community energy-load shapes.

Use of Voice Assistants as a Tool to Help Customers Manage Time of Use Rates in San Diego, California

The project team has developed a set of demonstration sites in the SDG&E service territory looking at how voice assistance can be used as an orchestration tool to help customers manage TOU rates. The project team has developed an infrastructure of energy tips and plans to develop a combination of coordinated control tools and behavioral messaging.

Application and Extension of the Open Demand Side Resource Integration Platform for Solar+Storage+Load Management Demonstrations for Commercial Buildings in Disadvantaged Communities (CEC EPC 17-005)

Open building autonomous tuning system (OpenBATS, CEC EPC 17-005, Zhao 2020) is an open-source supervisory control application that enhances the native control capabilities of building energy management systems by providing added intelligence based on learning building occupancy and built environment characteristics. The OpenDSRIP architecture was enhanced to provide an orchestration module, the Boy Scouts Orchestration Module (BSOM), which implements an optimized control algorithm for estimation of solar output, short-term load estimation, and joint optimization of load and battery charge/discharge profiles. OpenDSRIP provides the rate stimuli via OpenDSRIP API and the BSOM is optimized to reduce demand peaks (through optimal battery discharge), based on the predicted load. The controls are applied continuously throughout the day, adjusting HVAC loads (through setpoint temperature and mode manipulation) and battery charge/discharge profiles to provide optimal control.

Application and Extension of the Open Demand Side Resource Integration Platform for Solar+Storage+Load Management Demonstrations for Multifamily Residential Buildings in Disadvantaged Communities

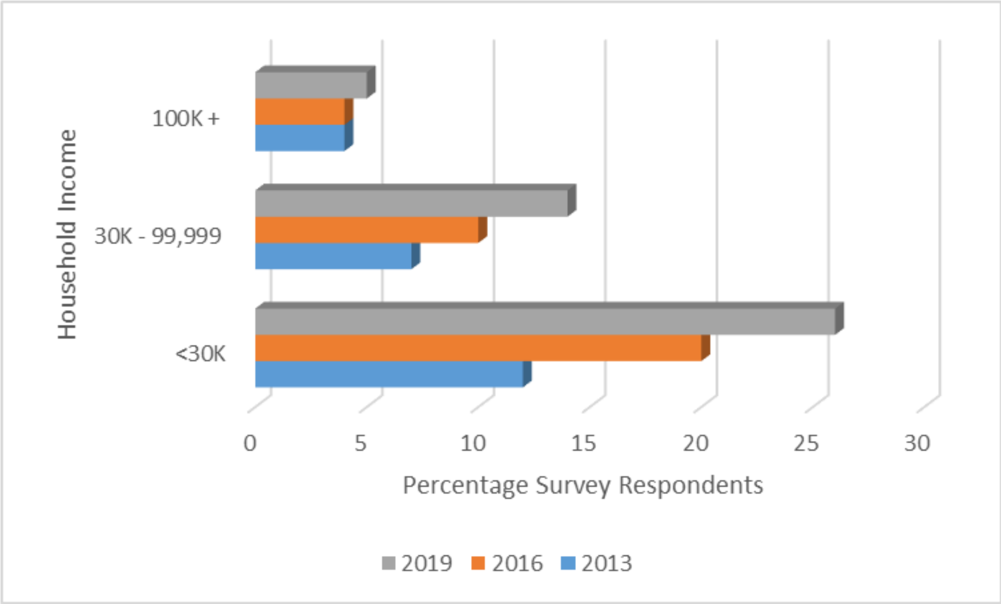
CEC EPC 16-068 (Narayanamurthy 2020) or the "Willowbrook Project" is a demonstration of solar + storage + load management in a multi-family residential setting, employing best-in-class solar technology coupled with residential energy storage for enhanced resiliency and customer-centric load management. OpenDSRIP architecture was enhanced to provide an orchestration module (Willowbrook Orchestration Module) specifically to address the use case of load management, including residential variable speed HVAC (mini-split systems) along with water-heater and plug-load controls (for use during California's Demand Response Auction Mechanism [DRAM]-enrolled DR events). Additionally, given the addition of solar+storage in the site, the coordinated control of solar+storage along with load management was demonstrated as an example of the extensibility of OpenDSRIP platform capabilities. Unlike the BSOM, the control in the Willowbrook case is based on DR events; studying the effects of a tiered control strategy that starts with messaging then adds on layers of customer preferences and automated load management.

Tools to Help Low-Income Customers, Property Developers, and Managers Shift to Time-of-Use Rates

OpenDSRIP can serve the role of providing information for TOU rate management applications and systems to help customers, building developers, and building managers in disadvantaged communities. Through the TAC, the project team identified various low-income property developers and managers interested in tools to help management staff and tenants manage California's shift to TOU rates. Activities that DSRIP conducted and will continue to conduct in this space include:

- Demand-Charge Management Using Intelligent HVAC Controls. In addition to centralized HVAC controls, master metered property managers have indicated a desire to investigate how to leverage smart thermostats in a community to enable demand charge management. The project team will continue to work with demonstration activities like the Firebaugh community to understand the impacts of a centralized thermostat control using technology.
- Mobile Application-Based Bill Management. National research shows an increase in reliance on mobile/smartphones as the primary method for internet access in low-income households with a household income of less than $30,000 US dollars (USD)/year (Pew Research Center 2021). See Figure 43.

Figure 43: Households With Primary Access to Internet via Mobile Phone



Source: Pew Research Center 2021

Note that there is a 12-percent increase in households that rely on mobile phones for access to the internet, but Figure 43 also shows that the number of households doubled in the less than $30k USD income bracket between 2013 and 2019. As many smart devices rely on Wi-Fi connectivity, there is a need for technical solutions to address a digital divide based on household income.

By combining data from the California ISO (ISO) and DSOs signaling systems, data from AMI smart meters and submetering data (wherever available) and through its interface with appropriate customer-facing mechanisms such as mobile apps, OpenDSRIP provides valuable information including:

a. Timely notification of rate change events.

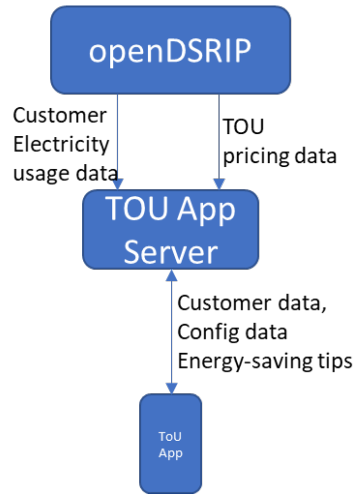
b. Information on energy use in conjunction with rate information.

c. Gamification of energy use to elicit energy-efficient behaviors.

d. Specific recommendations based on the availability of controllable, flexible loads.

Figure 44 shows the expanded architecture for how OpenDSRIP works together with a TOU rate-management mobile application.

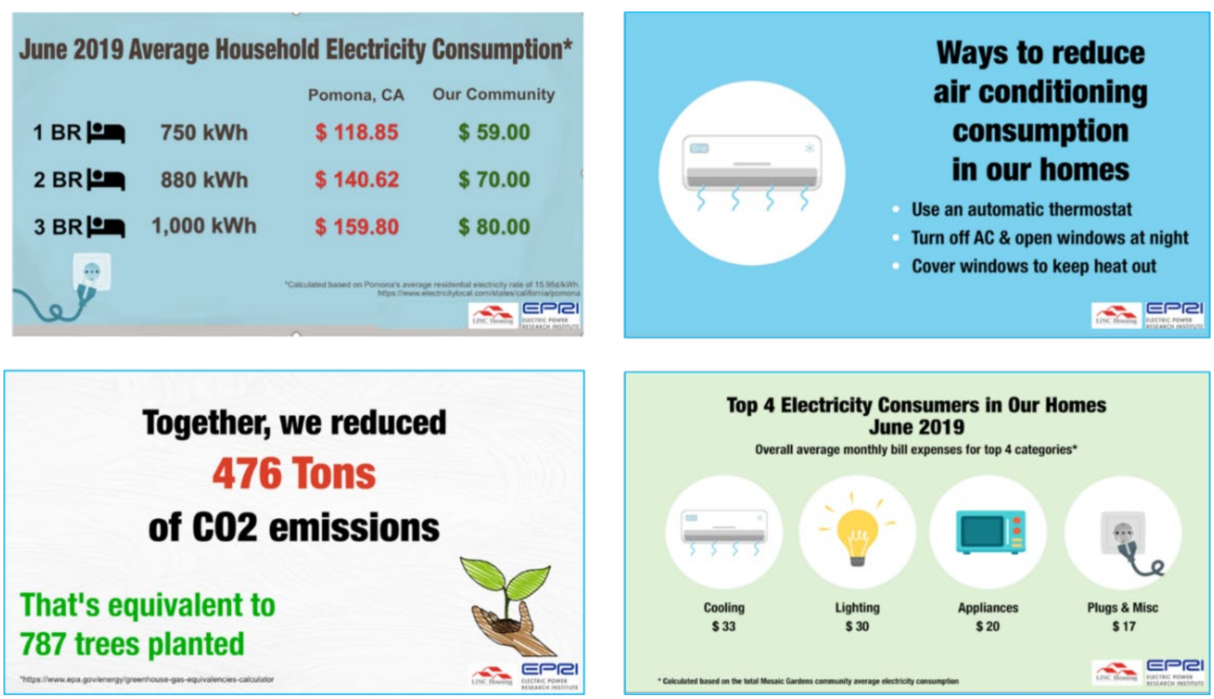
Figure 44: High-Level Solution Architecture for Time-of-Use Rate Management Mobile Application



Source: EPRI

The project team is working with a low-income community in Southern California with a similar interface at the community level, as seen in Figure 45.[11]

Figure 45: Community Energy Information Dashboard for Low-Income Multifamily Community in Southern California



Note: Energy, cost, and carbon values are for illustration only.

Source: EPRI

[11] Note that energy, cost and carbon values depicted in Figure 45 are not accurate. Actual community dashboard will have accurate values based on community sub metered and AMI data.

The project team leveraged the OpenDSRIP project in crafting a framework to develop tools to help low-income community managers and tenants manage California's shift to more dynamic rates while addressing the digital divide challenge.

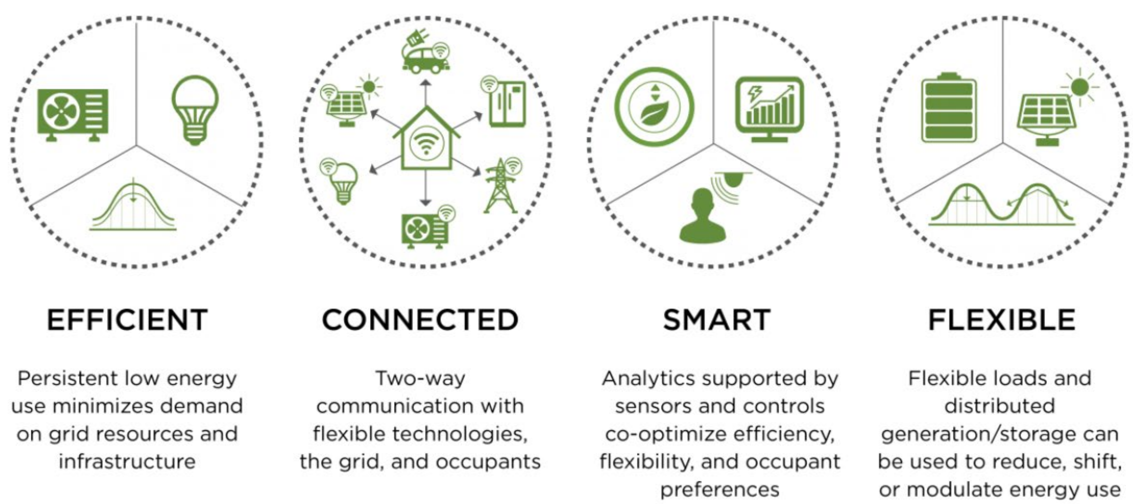
Connections With Disadvantaged Communities on Energy Working Groups

The project team has connected with low-income community energy task forces on conducting a quick lesson learned and workshop from previous, current, and future work conducted by the project team to help low-income communities manage TOU rates. This working group seems very interested in the lessons learned as property managers and billpayers are also looking at smart thermostats as alternatives (or complements) to battery storage to enable demand-charge management in master-metered communities in California.

Aligning the Open Demand Side Resource Integration Project with U.S. DOE-sponsored initiatives.

The U.S. DOE has launched a focused research initiative on grid interactive and efficient buildings (GEB) to make buildings smarter about the amount and timing of energy use. In particular, the focus of the research is on adding intelligence to equipment through next-generation sensors, controls, connectivity, and communication. Figure 46 shows the framework for GEB (U.S. DOE 2019).

Figure 46: Grid Interactive and Efficient Buildings Framework Used by United States Department of Energy Building Technologies Office

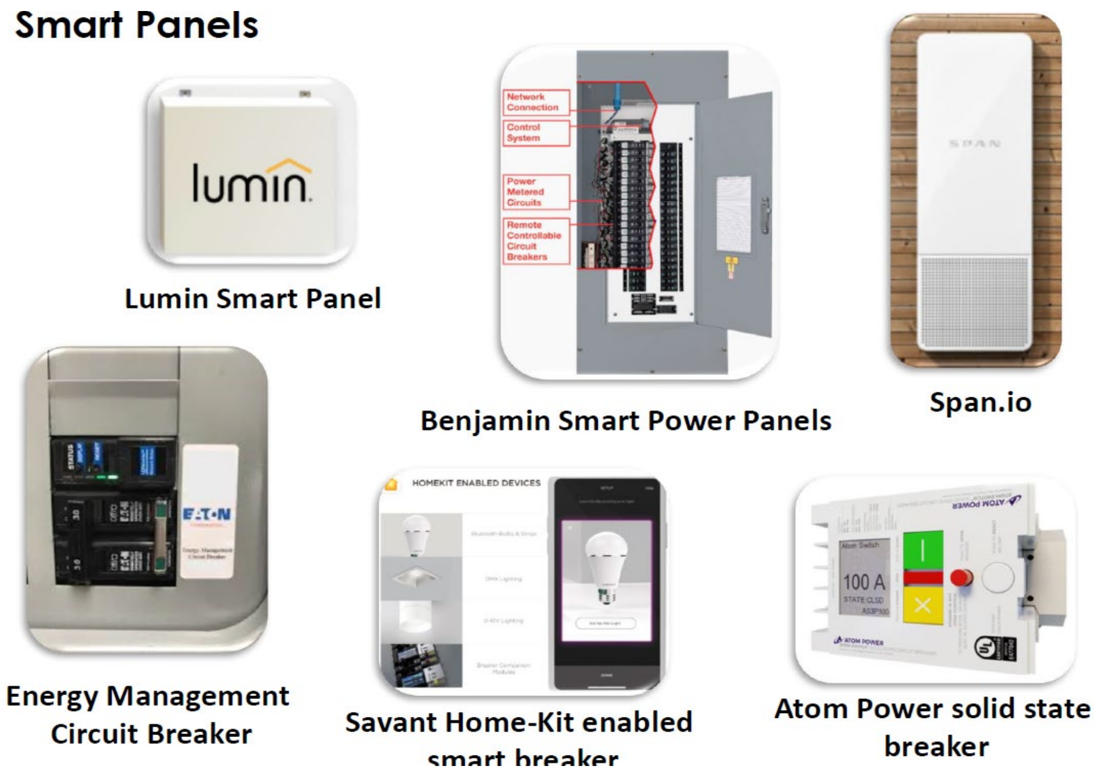


Source: United States Department of Energy Buildings Technology Office

Tool in Assessing Emerging Technologies to Enable Building Electrification

Through the work of the project both developing an infrastructure to provide coordinated control and collection of data from mass market BTM DERs, the project team has identified several product providers to leverage California's need for more flexible BTM resources that enable building electrification. As discussed in Chapter 2, advancements in circuit-level metering technology are now providing intelligent methods to control and manage loads for rate management. Several different approaches can embed both metrology and controllability into current technologies such as electrical panels and circuit breakers. See Figure 47 (EPRI 2020c).

Figure 47: Examples of Smart Panels that Integrate Telemetry and Programmable On/Off Control



Source: EPRI

With advancements in smart panel and smart breaker technology, one could envision a scenario where the intelligence of these tools can help property managers defer building-panel upgrades as well as provide property owners and managers intelligent tools to help manage electricity bills. The project team plans to evaluate the aggregated controllability of smart panels and breakers for energy management and building electrification.

Tool in Assessing California Codes and Standards Using Operational Data

California Title 24 Joint Appendix (JA) allows the use of emerging technologies such as customer-sited battery energy storage and connected heat pump water heaters.

California Title 24 JA 12 gives credits for the installation of customer-sited battery energy storage systems that maximize solar utilization, grid management, and bill management. JA12 requires battery energy storage systems to provide DR responsiveness and/or TOU management. OpenDSRIP has worked with several battery energy storage providers to collect operational data on battery energy storage systems installed as part of this project.

California Title 24 JA 13 gives credits for the installation of HPWHs demand management system. The primary function of the system is to interface with the HPWH to serve the users' domestic hot water needs and provide daily load shifting, as applicable, for the purpose of user bill reductions, maximized solar self-utilization, and grid harmonization. Through this project, the team has collected operational data on load shapes of HPWH deployments at not only the home but at the community level to better understand aggregate impacts on energy systems. In addition, the project has established feasibility on how connected heat pump water heater systems can be controlled and the data they provide, the goal of which is to better understand how HPWHs can be leveraged as a grid resource, and how connected HPWHs and their adoption will affect energy system planning, operation, and management. This is done using operational data. During this project, the team coordinated with CEC representatives and other subject matter experts involved in the development of these joint appendices and provided insights based on platform development and community demonstration activities associated with this project.

Development of a Framework on Enabling Smart Communities as a Grid Resource

The project team has developed a novel framework (Equation 1 in Chapter 2) in the form of a practitioner's way of understanding and begin to start evaluating not only buildings and BTM DERs can be made as grid resources (Obj(x,t)), but opportunities and barriers to a solution's scalability (λ(x,t)). The proposed framework was used at a high level to get a better baseline understanding of two main questions in the residential BTM DER space: (1) how BTM DERs can be controlled today using dynamic rate/control signaling, and (2) what data BTM DERs provide to help understand how users/systems are responding to dynamic rate signaling. Finally, the project team used the proposed framework in assessing both how flexible and how scalable various laboratory and field orchestration modules/demonstrations are throughout this project. The collection of this information helps get a better baseline understanding of where the current technology sits, helps identify technology and market gaps, and presents a practitioner's viewpoint in understanding barriers to scalability.

Summary

In addition to OpenDSRIP platform creation, the project team set up technology transfer mechanisms of both platform creation/valuation framework development and field demonstration activities enabled by the OpenDSRIP project. These include:

- Applications to other CEC EPIC projects, as well as other field demonstration sites within California and the nation.
- Knowledge transfer opportunities with low-income property developers and managers in California interested in tools to help their property managers and tenants manage their electricity bills.
- Application and alignment with national initiatives laid forth by the U.S. DOE.
- Insights and feedback to California Title 24 Building Codes and Standards with specific emphasis on JA 12 (battery storage) and JA 13 (HPWHs).

- Platform and benchmarking tool to test emerging residential building electrification and DER technologies and associated service platforms.
- Presentations and publications to various stakeholders including energy industry experts, manufacturers and service providers, and California builders and developers.

The project team understood the importance of not only transferring the results of emerging technology development and demonstration but also gauging the industry and the market to understand the appropriateness of the project objectives. This information is included in the conclusions and recommendations section.

CHAPTER 5: Conclusions and Recommendations

The previous chapters discussed OpenDSRIP platform development and evaluation metrics to include barriers to scalability as well as the work demonstrating the platform and transferring the results gained through project completion. This chapter summarizes the results of the project as well as providing recommendations for extending the work of DSRIP and addressing technology and market gaps. As California reaches its overall decarbonization targets, there is a need for a more flexible electricity system. It is important to understand how customer-sited, behind-the-meter resources can play a role in that flexible energy system and how dynamic rate signaling can enable them.

Key Findings From Open Demand Side Resource Integration Platform Development and Functional Testing

Key findings from OpenDSRIP functional testing focus on the lessons learned from platform development and associated activities follow.

- Customer DER Management Systems Need at Least Two Generic Layers. Original depictions of OpenDSRIP represented it as a single platform, layer architecture. Lessons learned when developing functional requirements using demonstration test cases found that to accommodate wide variations in the availability and capabilities of BTM DER technologies, infrastructures, and deployment scenarios, OpenDSRIP was split into two layers: the grid-supporting functions layer and the orchestration layer. The top layer, referred to as the DSRIP layer, is comprised of components that implement a set of grid-supporting functions. The bottom layer, referred to as the Orchestration layer, is comprised of DER management systems, DER aggregation systems, energy management systems, fleet charging control systems, and optionally custom-developed open-source orchestration modules (for example, ROM). This layer provides a pipeline for the acquisition of energy and operating data from behind-the-meter IoT and DER and supports control functions.
- Security and Privacy Are Important. Personally identifiable information (PII) needs to be handled appropriately. Given that most of the data collected in DSRIP come from behind-the-meter IoT and DER, the potential for this data to contain customer PII is high. To prevent any exposure of PII, all customer identifiers were scrambled using Globally Unique Identifiers (GUID)/Universally Unique Identifiers (UUID) v4.

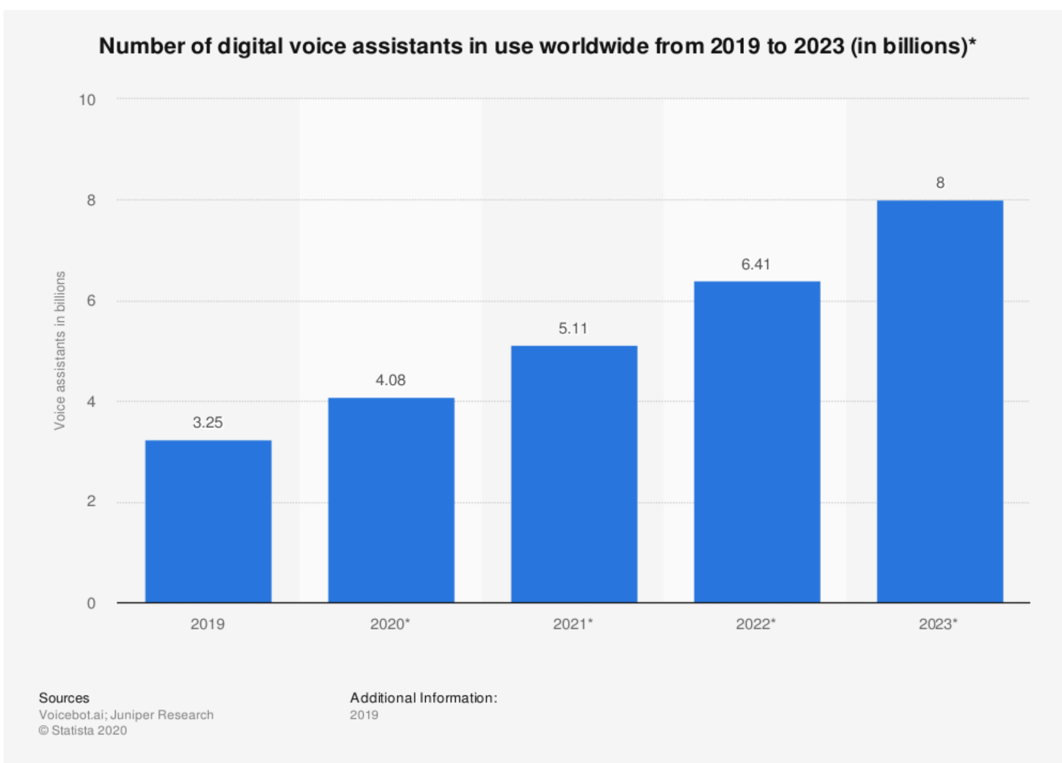
Results From Open Demand Side Resource Integration Platform Implementation

The following results are associated with the implementation of OpenDSRIP.

- Availability of Open Third-Party Energy-Focused Control Mechanisms is Limited: Few BTM DERs provide mechanisms that enable third-party coordinated energy management functions. Most IoT devices expose this information to HEMS or BEMS providers in agreements for home automation or other energy-related services. Aggregators also play a role in coordinated control, with various assessments ongoing both in California and across the country. This is important to note as control infrastructure development is different for each case when considering the security and privacy requirements discussed here. It is important to understand how automation leads to energy management when thinking about how rate-based energy management solutions scale.

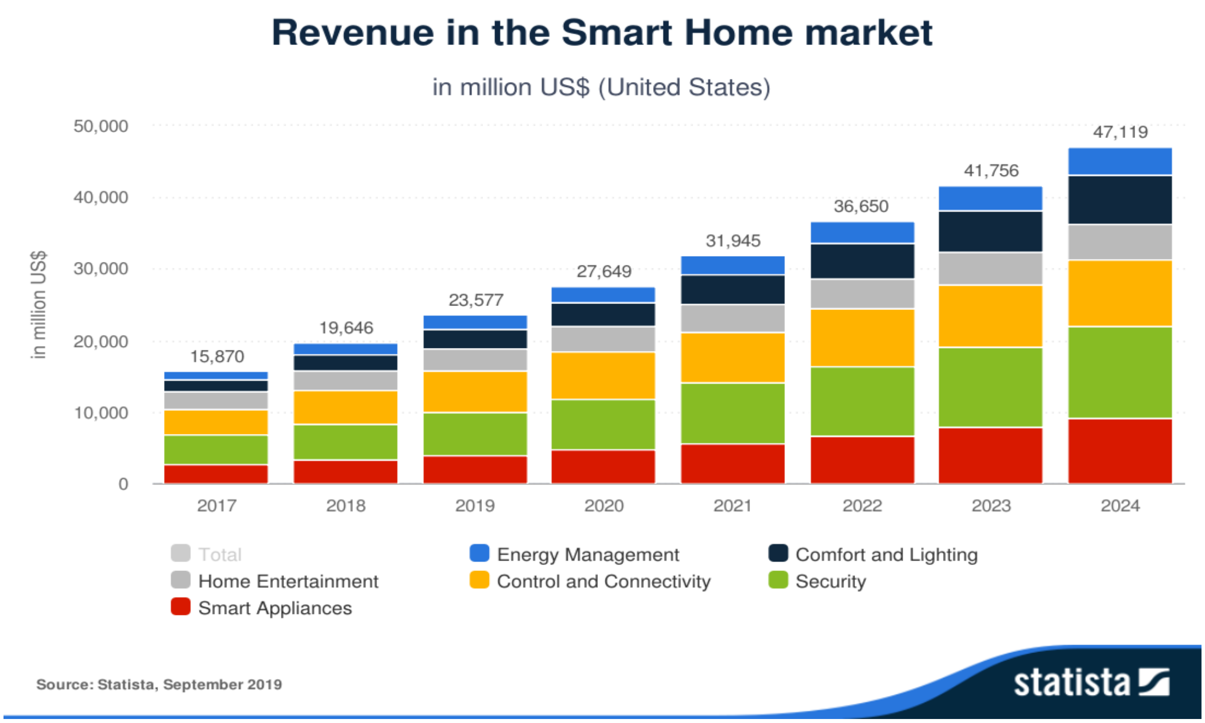
- Understanding the Evolution of Energy-Related Standards: While there are many standards in the market today, it is important to understand how these standards and how their flexibility is keeping up with rapid technology change. As BTM IoT is a rapidly evolving market that is primarily customer-facing, it is important to minimize the cost and complexity of customer participation.
- Leveraging De Facto Standards Based on Market Adoption, Offer Interesting Opportunities for IoT and DER Aggregation: Through the use of smart speakers (Figure 48) and home automation platforms such as Amazon Alexa and Google Home, the potential for integration of multiple IoT devices on a common platform is high. These platforms effectively form a de facto standard for integration and aggregation of mass-market IoT devices and provide opportunities for customization through skills and applications. See Figure 49 for projected growth in smart-home products.

Figure 48: Smart Speaker Adoption Worldwide



Source: Statista 2020b.

Figure 49: Projected Growth for Smart Home Products in the United States



Source: Statista 2019.

Results From Laboratory and Field Demonstration of the Open Demand Side Resource Integration Platform

Results from lessons learned from laboratory and field demonstration follow.

- Technology Solutions Are Needed to Address Disadvantaged Communities: Many of the BTM IoT solutions available today require technology and building infrastructure such as advanced HVAC systems or reliable Wi-Fi connectivity that are less available in disadvantaged communities. It is important to test and evaluate strategies that enable, develop, and assess technology solutions that provide low-income property managers and tenants with tools to manage California's shift to TOU rates.
- Customers Prefer Notification Mechanisms for Information on Dynamic Rate Events: Customer Appetite for third-party automated control is still low: In general, home builders and tenants expressed interest in informing homeowners of dynamic rate events based on homeowners' rate plans. However, these same demonstrations identified that rate-management technologies do not appear to be high on the priority list for homeowners.
- Price Differentiation Between Periods of High and Low Rates May Stimulate Customer Action: Beyond automated responses of BTM DERs through optimized load management, effective messaging of actual $/kWh rates and price differentiation multipliers or percentage-difference over/under a baseline could potentially spur customers into action. Energy companies in Arizona have found success in changing the

behaviors of customers through TOU rate signaling where customers have become bill-conscious enough to change their behavior (for example, by pre-cooling homes using programmable thermostats). However, this requires additional research and investigation to understand how these solutions scale.

- Device Specification Based on Feasibility Is a Pathway to Standardization and Interoperability: The project proposes that device specification based on a current state of technology capability today is a pathway to begin normalizing understanding of the value of standardization of mass market end-use loads for demand response or other grid functions.

Recommendations

The design, development, and demonstration of OpenDSRIP was the main objective of this project and its lessons learned from these demonstrations are described throughout this report. However, it is important to provide additional research recommendations to achieve California's decarbonization mandates:

- **Understand the Value Of Demand Flexibility In Decarbonized Communities.** The project team has demonstrated the technical feasibility of coordinated load management of BTM DERs through rate signaling based on technology infrastructure. However, there are still questions as they pertain to the scalability of particular DERs to larger markets as well as the value of residential and small commercial load flexibility in a decarbonized energy system. It is important to understand the value of serving the grid - not only the bulk transmission system but also the electricity distribution system that depends upon it.
- **Understand Building Load Flexibility and Its Implications for Building Electrification.** The state of California is looking at dynamic rates and other mechanisms that enable the system flexibility needed to meet California's decarbonization targets. However, efficient electrification of both California's new and existing residential and small commercial communities is needed to meet the state's environmental mandates. It is important to understand how efficient electrification and building flexibility enable and impact one another. In addition, understanding and developing rate-management tools that enable building electrification are important in meeting overall decarbonization targets.
- **Continued Operational Data Collection of BTM DERs:** A continued collection of operational data of emerging BTM DERs provide several values to the energy industry. Data organically collected from BTM DERs helps better connect value to specific energy-impacting decisions on how customers are leveraging BTM DERs and enabling technologies to help them manage dynamic energy rates. Operational data collection can also help better understand and validate adoption models with operational data collected through device and building-level load shapes. The collection of data also provides persistent information since many of these solutions are new. In addition, operational data collection and transfer can also enable additional training data used to

enable customer-centric optimization models to better provide technology solutions that balance energy costs and comfort in a variety of consumer options.

- **Enable Demand Flexibility in Hard-to-Reach Market Segments:** While policy-level directives on decarbonization are leading to market shifts in California's generation mix and its marginal carbon contribution from buildings, the built environment tends to change slowly; this is particularly true in disadvantaged communities where socio-economic factors impede adoption of technology solutions that provide energy efficiency retrofits. In those cases, flexibility may play a critical role in helping reduce their carbon footprints through the carefully sequenced adoption and development of market-ready energy-efficiency practices and technologies.
- **Workforce Engagement and Training Materials to Enable Proper Installation, Commissioning, and Operation of BTM DERs**: While technology solutions are currently available in the market, the project identified barriers in their implementation with improper installation, commissioning, and operation of BTM DERs. It will be important to provide necessary code compliance levers and workforce training and engagement materials to capitalize on the flexibility opportunities of residential and small commercial BTM DER.

These recommendations, as well as the material and lessons learned presented as part of this report, help answer the overall general question of how typical customer-owned connected technologies and resources can help California consumers manage dynamic energy rates, and how an energy system needs to be planned, operated, and managed to meet California's overall decarbonization mandates.

CHAPTER 6: Benefits to Ratepayers

A flexible energy system is needed to meet the state's decarbonization targets, and to accomplish that we must collectively better understand how behind-the-meter, customer-owned distributed energy resources can be leveraged to help California manage its dynamic energy rates, one of the main objectives of this project. Due to the private nature of these technologies with their end users, it is important to anticipate and acknowledge how ratepayers will be affected. Some national estimates predict that "…load flexibility is much more powerful and could become a 200-GW grid resource for the U.S. by 2030" (Hledik 2019). Through the aggregation of demand-side resources using the lessons learned from the OpenDSRIP project, significant energy savings and demand reductions can be realized in California by small commercial and residential buildings. Energy savings will reduce the cost of procuring energy and therefore will translate to lower costs for all ratepayers in California. With a potential reduction in demand during critical events, reliability in California is increased, also to the benefit of all California ratepayers. The project takes a consumer-market approach to this problem by focusing on technologies available in the market today. It is critical to better understand their feasibility to support future baseline studies with both current technology and infrastructure gaps to scaling. The result is actionable approaches that minimize capital investment risks in the development of programs with either minimal market uptake (sometimes a challenge in historic DSM program delivery) or unforeseen product-development costs. The goal is to develop actionable approaches that drive standardized methods in the commissioning, installation, and operation of demand-side technologies as potential grid resources, as well as the development of programmatic metrics to understand practical and consumer barriers to scalability. Additional ratepayer benefits follow.

- Dynamic energy pricing requires additional messaging and communication to California ratepayers, as well as the tools and technologies to manage their energy bills. During the demonstration stage, the project team did not self-select technologies to provide proxies for consumer-enabling conditioning. By not limiting customer choice, the demonstration reproduced realistic adoption scenarios of emerging technologies. This reinforces the feasibility of widespread adoption, followed by enablement of the technology. This also gives a better idea of market readiness and how consumer-adopted technologies can be leveraged as grid resources while minimizing capital investment in technologies with no scalable consumer market. Enabling engagement through market-available technologies and platforms (such as voice assistants) with real-time information on price incentives therefore increases the possibility of reaching end users and shows a higher probability of widespread adoption.
- Results of the project and continued efforts by the project team strive to encourage utility service planners, program designers, and manufacturers to tailor their services and programs for their customers through their operational data. The project looks at communicating specific systems and technologies that both provide building flexibility and device data to better understand the current feasibility and technology

opportunities (and gaps) that can achieve both program scalability and development of customer-centric algorithms. The result is both a more responsive technology service and lower operational costs for California's energy system.

- This project explored developing tools for low-income customers to help manage California IOU's transition to time-of-use rates. It is important to note that work on this project coordinated with both technology providers and disadvantaged community property developers and managers to identify the needs of these communities where: connected technology is not as prevalent, and where broadband connectivity is tied to mobile applications (as opposed to procured Wi-Fi). It is important to understand how and what tools are available to various customer segments in California.
- Since the conception of this project, the team has looked at building decarbonization through various efficient-electrification technologies. As the state meets these goals through improvements in the electricity generation mix (for example, utility-scale renewable generation), the need for flexibility on the distribution and utilization sides of the energy value chain becomes especially important. This project provided a realistic understanding of the potential for flexibility as a pathway to decarbonization by developing frameworks and open-source tools for evaluating flexibility in buildings and the built environment.

Quantifiable benefits of enabling buildings as a grid resource could include statewide residential electricity savings of 1036.9 GWh per year and small commercial of 52.5 GWh per year for a total of 1089.4 GWh per year, which translates to a statewide CO2 annual reduction of 397,631 tons per year. The total commercial bill reduction is $8.21 M per year based on energy savings, while the total residential bill reduction is $185 M. Among small commercial office buildings and single-family residential homes, a savings of 10 percent of the total building electricity load is expected through coordinated demand management. The 10 percent of electricity load is based on adopting a conservative approach to previous electric utility assessments involving efficient end-uses enabled by an open platform such as DSRIP. Residential space conditioning energy savings are estimated at around 5 percent when smart thermostats are implemented based on a PG&E study completed in 2016 (PG&E 2016). It is estimated that the impacts of smart plugs have energy savings ranging from 1 percent to 4.5 percent (NEEP 2015). Previous research shows that providing energy portals and load monitors is typically in the range of 4 percent to 7 percent (Karlin 2015). The project developed tools to refine these ranges because it is important to understand both interactive effects when deploying multiple efficient end uses to prevent "value stacking" calculations, and additionally to understand the effects on customer comfort, behavior, and preferences associated with deployment of integrated end uses. Specific secondary resources on potential load impacts follow:

- Implementation and control of connected thermostats can result in anywhere from 0.7 kW to 1.5 kW of demand reductions per home, per event (Narayanamurthy 2016).
- Implementation of water heater demand response is 0.5 kW per premise per event (Hledik 2016). However, it is important to understand and update load flexibility opportunities based on California's movement towards efficient electrification

technologies such as HPWHs and HVAC HPs. This may lead to actual decreased load shifting capabilities, but similar results can also be due to improvements in efficiency and distribution factors of water heating and HVAC usage.

- Advanced control of smart thermostats through strategies such as pre-cooling or pre-warming has shown approximately 0.8 kW of demand reductions in residential-scaled field assessments (EPRI 2017c).
- Thermal (water heaters) and batteries (electrical) storage mechanisms to balance renewable generation are possible, but evaluation of controls is still needed. The research project looked at the feasibility of systems today and the barriers to scalability.
- Electric vehicles, miscellaneous electric loads, residential energy storage, and lighting could also be used for peak shaving, but few field studies are available to calculate its impacts on both peak demand reduction and moving loads to times when renewable generation exceeds grids needs, sometimes called "valley filling."
- The emergence of voice assistants as methods for demand reductions or valley filling also needs additional investigation. However, this technology is in its nascent stages of development, with few empirical studies quantifying the energy impacts of these technologies.

GLOSSARY AND LIST OF ACRONYMS

Term	Definition
ACEEE	American Council for an Energy Efficient Economy
AMI	advanced metering infrastructure
AOM	Aggregation and Orchestration Module
API	application programming interface
APS	Arizona Public Service
ARM	Analytics and Reporting Module
BEMS	building energy management systems
BSOM	Boy Scouts Orchestration Module
BTM	behind-the-meter: a term commonly used to describe a technology installed at a residential, commercial or industrial premise – typically customer-owned.
ISO	California Independent Systems Operator
CCA	Community Choice Aggregators
CDD	cooling day degree
CEC	California Energy Commission
CDD	cooling degree days
CEE	Consortium of Energy Efficiency
CM	control module
ConEd	Consolidated Edison
COTS	commercial off the shelf
CPP	critical peak pricing
CZ	climate zone
DER	distributed energy resources: this report defines a DER to include customer-owned solar, storage, electric vehicles as well as connected devices and appliances.
DERMS	Distributed Energy Resource Management System
DLC	direct load control
DOE	Department of Energy
DR	demand response
DRAM	demand response auction mechanism
DRMS	demand response management system
DSM	demand side management
DSO	distribution systems operator
DSRIP	demand-side research integration platform
DTE	Detroit Edison

Term	Definition
EMS	energy management system
EPIC	Electric Program Investment Charge
EPRI	Electric Power Research Institute
EV	electric vehicles
GEB	grid-efficient and interactive buildings
GHG	greenhouse gas
GMLC	grid modernization laboratory consortium
GUI	graphical user interface
GUID	globally unique identifiers
HDD	heating degree days
HDFS	Hadoop Distributed File System
HECO	Hawaiian Electric Company
HEMS	home energy management system
HPWH	heat pump water heaters
HVAC	heating, ventilation and air-conditioning
IFTTT	If This Then That
IoT	Internet of Things
IOU	investor-owned utility
JA	joint appendix
kWh	kilowatt hour
LAN	local area network
LAP	load aggregation points
LMP	locational marginal pricing
MUD	multi-unit dwellings
NEM	net energy metering
NILM	non-intrusive load monitoring
OM	orchestration module
OpenBATS	Open Building Autonomous Tuning System
OpenDSRIP	open demand-side research integration platform
ORNL	Oak Ridge National Laboratory
OVGIP	open vehicle-grid integration platform
PEV	plug-in electric vehicle
PHEV	plug-in hybrid electric vehicle
PII	personally identifiable information
PV	photovoltaic

Term	Definition
ROM	Residential Orchestrating Module
RTO	regional transmission organization
SB	Senate Bill
SCE	Southern California Edison
SDG&E	San Diego Gas and Electric
SEPA	Smart Electric Power Alliance
SQL	structured query language
SFTP	secure file transfer protocol
STAT	Smart Thermostat Analytics Toolkit
SUD	single unit dwellings
TAC	technical advisory committee
Title 24	California Building Efficiency Codes
TLM	transactive load management
TOU	time of use
UAM	Utility Abstraction Module
UI	user interface
UM	user management
USD	US dollar
U.S. DOE	United States Department of Energy
U.S. EPA	United States Environmental Protection Agency
UUID	Universally Unique Identifiers
V2G	vehicle-2-grid: A term commonly used for initiatives investigating looking at how vehicles can be used as energy system resources.
VEIC	Vermont Energy Investment Cooperative
VEN	virtual end node
VTN	virtual top node
W	watts
ZEV	zero emission vehicle
ZNE	zero net energy

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