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ENERGY COMMISSION

Energy Research and Development Division

FINAL PROJECT REPORT

Residential Intelligent Energy Management Solution: Advanced Intelligence to Enable Integration of Distributed Energy Resources

Gavin Newsom, Governor

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PREPARED BY:

Primary Authors:

John Clint, AESC
Hunter Richards, AESC
Stephan Barsun, Itron
Jean Shelton, Itron
Kristin Larson, CSE
Jonathan Hart, CSE
James Tamerius, CSE
Christopher Vogel, CSE
Stephen Gunther, CSE
Chun Zhu, CSE
Steve Davis, KnGrid
Tyler Sybert, SDG&E

Alternative Energy Systems Consulting, Inc.
5927 Balfour Ct. suite 213
Carlsbad, CA 92008
Phone: (760) 931-2641
http://www.aesc-inc.com

Itron
12348 High Bluff Drive, #210
San Diego, CA 92130
Phone (858) 481-0081
http://www.itron.org

Center for Sustainable Energy
3980 Sherman Street, Suite 170
San Diego, CA 92110
Phone (858) 244-1177
http://www.energycenter.org

KnGrid (dba Oxygen Initiative)
26602 Dapple Grey Drive
Laguna Hills, CA 392653
Phone (949) 338-9908
https://oxygeninitiative.com

Contract Number: EPC-15-048

PREPARED FOR:
California Energy Commission

Dustin Davis
Project Manager

Virginia Lew
Office Manager
ENERGY EFFICIENCY RESEARCH OFFICE

Laurie ten Hope
Deputy Director
ENERGY RESEARCH AND DEVELOPMENT DIVISION

Drew Bohan
Executive Director

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PREFACE

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

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

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

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

Residential Intelligent Energy Management Solution to Enable Integration of Distributed Energy Resources is the final report for Contract Number EPC-15-048 conducted by Alternative Energy Systems Consulting, Inc. The information from this project contributes to the Energy Research and Development Division's EPIC Program.

For more information about the Energy Research and Development Division, please visit the CEC's research website (www.energy.ca.gov/research/) or contact the CEC at 916-327-1551.

ABSTRACT

Load volatility and grid reliability challenges are growing in California, in part due to the amount of renewable resource generation, photovoltaic solar roofs, electric vehicles, and other distributed energy resources. Managing this volatility requires innovation and practical applications of emerging technologies.

The vision for management of tomorrow's dynamic electric grid is already on the horizon and will include several key components:

1. Individual homes with distributed intelligence to manage smart loads, in concert with on-site renewable power production and on-site battery storage systems
2. Load forecasts from millions of homes aggregated and provided to electric grid operators
3. Dynamic price signals that prompt load profiles and price signals to quickly achieve balance between electricity supply and demand

With Alternative Energy Systems Consulting, Inc., as the project lead, the technical team applied a residential distributed energy resource management system, developed by Itron, lead technologist on this project. The system was deployed to a 100 -home, real-world laboratory equipped with distributed energy resources and smart loads to study practical applications of technology and dynamic price strategies.

This system leverages continuously updated information to allow smart, efficient, energy use. Its web-connected hub analyzes price and weather data to communicate with end-use devices and regulate electricity consumption to deliver low consumer energy costs. The system consolidates day-ahead loads and facilitates dynamic price signals by transmitting forecasts to a demand clearing house that is ultimately connected to grid operators.

Project results and data collection support this technology's potential to dynamically adjust the electric grid by functioning as a missing link between rapid load fluctuations and the grid. This dynamic technology could potentially and dramatically flatten the duck curve and balance renewable resources, including generation, with the existing electric grid through innovative energy management practices.

Keywords: distributed energy resources, DER, RDERMS, overgeneration, real-time pricing, transactive energy, electric vehicle, solar, dynamic pricing, demand clearinghouse

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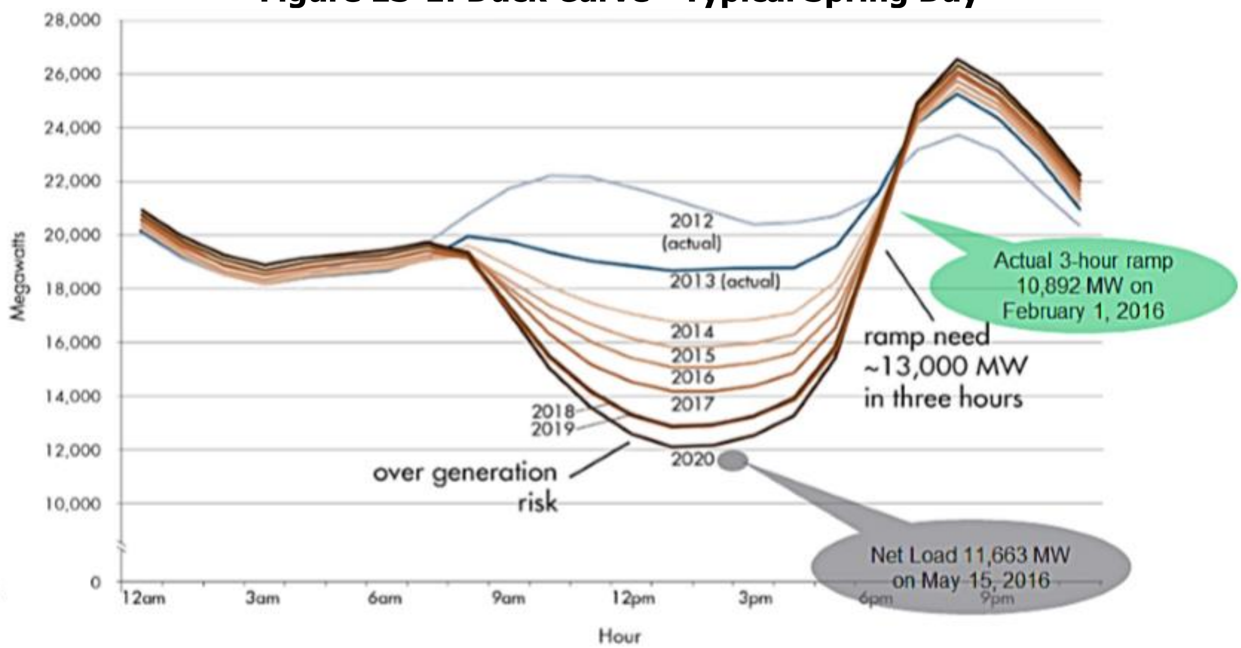
EXECUTIVE SUMMARY

Introduction

California's ambitious long-term energy plan mandates that 100 percent of the state's electricity come from renewable resources, primarily wind and solar, by 2045. The California Energy Commission reports that the state is on track to meet that goal, which will reduce the greenhouse gas emissions from fossil-fueled power plants that contribute to climate change. Challenges persist, however, on how to most efficiently and economically incorporate relatively small sources of renewable resource generation into the existing electric grid, which has traditionally delivered electricity generated by large baseload power plants. The state's electric grid also faces growing pressure for greater flexibility as more Californians opt for rooftop solar, electric cars, and other technologies that either add to or reduce distribution and grid electric loads. A key issue resides in the "duck curve," coined by the California Independent System Operator (Figure ES-1). A duck curve graphically illustrates the imbalance between electricity demand and available renewable resources, current and projected, through the supply and demand peaks and valleys of a single day. On a hypothetical warm spring day with low electricity demand, for example, the grid may not be able to accommodate all available renewable generation. This project addresses this imbalance and offers solutions to minimize or eliminate it.

Figure ES-1: Duck Curve - Typical Spring Day



Source: CAISO, 2016

Project Purpose

In addition to California's fast-growing renewable resource energy production, this heightened load volatility and other potentially costly risks are also growing in severity from the number of roof-top photovoltaic panels, electric vehicles, and other trends that require adaptation. The duck curve renewable energy/grid imbalance could be alleviated in millions of homes with new capabilities offered by distributed intelligence and dynamic management and scheduling of resources. Applied research, focusing on new technology, will be a key component of the broader solution to these challenges as California increases production of renewable resource energy to meet mandated statewide clean-air targets.

This project specifically advances objectives to identify, inform, and develop strategies for overcoming technical, institutional, and regulatory barriers to expanding demand-response participation in California. Given the growing proliferation of photovoltaic solar roofs and electric vehicles in the state, this project aspires to flatten the demand-curve imbalance, or duck curve, through new technology that enables alleviation of heightened electric load volatility and grid costs. In the real-world laboratory of 100 homes in various climate zones within San Diego Gas & Electric (SDG&E) service territory, this project assessed and tested a new distributed intelligence technology. Observations and data collection support this technology's potential to dynamically adjust the electric grid by functioning as a missing link between rapid load fluctuations and the grid. This dynamic technology could potentially and dramatically flatten the duck curve and balance renewable resources, including generation, with the existing electric grid through innovative energy management practices.

Project Approach

The project team created the real-world lab to advance understanding of innovative distributed energy management opportunities made possible by advanced intelligent controls. The prime contractor selected three major subcontractors to provide expertise in distributed energy resource control, vehicle to grid integration, and tariff assessment. A technical advisory committee provided guidance on topics related to project direction such as scope, methods, timing, project deliverables, and coordination. Committee members were selected based on traits including technical expertise, market knowledge, or familiarity with related projects.

To participate, each residence was required to have broadband internet access and a utility smart meter. To calculate benefits of the technology, the project team evaluated the baseline period data before installation and surveyed existing end-use appliances. Lab configurations and scenarios were developed and studied under current block tariffs, time-of-use (TOU) tariffs, and future dynamic price-signal tariffs. Under various scenarios, data were collected on an ongoing basis; collected data included smart meter interval data, end-device data (whole home and disaggregated), and interval data. Analysis of the collected data allowed the project team to conduct a full assessment and develop conclusions. Final consolidated information includes observed consumer impacts, grid-level impacts, and key conclusions.

Project Results

The project successfully recruited 100 participants and installed thermostats, electric vehicle chargers, and battery energy storage systems at those test homes. The primary intent with these devices was to shift load from high-cost and high-carbon periods to periods with lower energy costs (and likely lower carbon content). During the recruitment and installation processes, the project team identified three specific issues that may hinder broader implementation or adoption of some intelligent distributed energy resources:

- Available space to install new equipment and electrical capacities in customer electrical panels
- Physical space in an appropriate location for the equipment (such as, a garage)

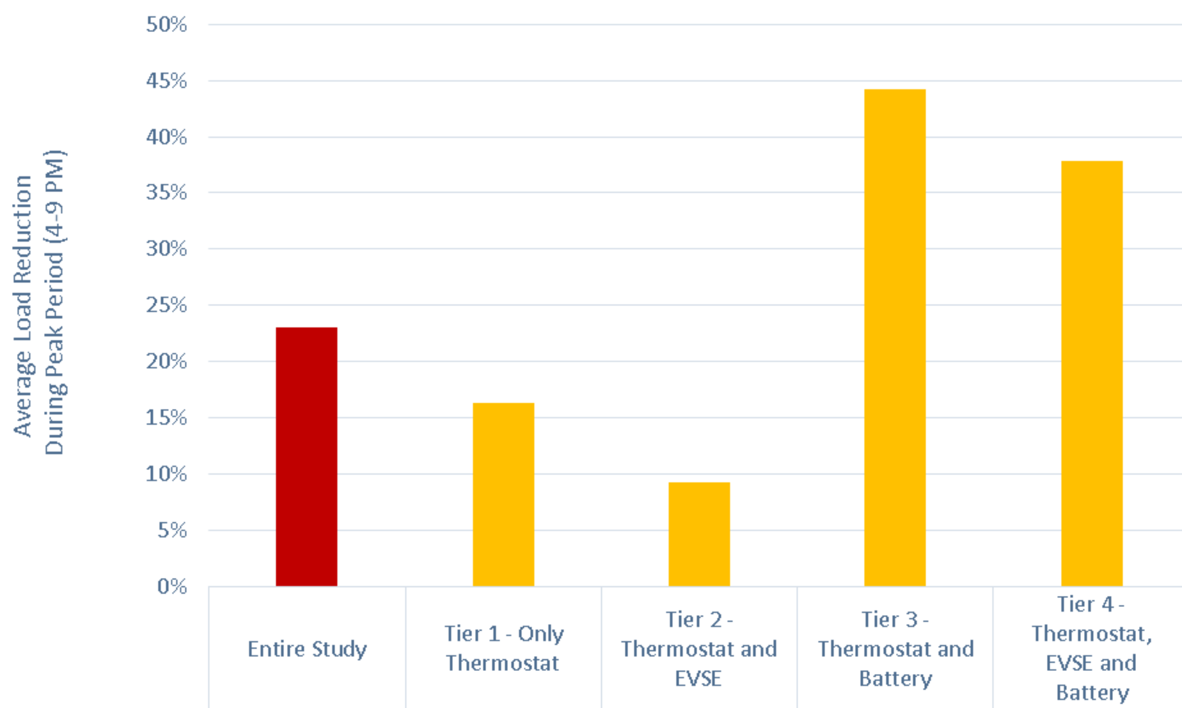
- Existing utility rates and tariff rules

After recruitment and installation, tariff modeling results confirmed that current time-of-use rate structures offered by SDG&E benefit customers and the grid through planned electric vehicle charging and energy storage dispatch. This indicates that current rate structures offered by the utility reward customers who use distributed energy resources that provide grid benefits. However, greater grid benefits can likely be achieved by further aligning distributed energy resource operations with dynamic (real-time) price signaling.

Additionally, two types of price signals that encourage residential customers to shift electric demand to periods of high renewable resource generation were investigated: retail rates and a wholesale market mechanism. Rewarding customers who shift loads to these periods through price signals could increase consumption of renewable energy generation without increasing utility costs. Although this research showed that compensation from negative prices in the wholesale market alone does not offer a strong economic incentive for behind-the-meter customers to participate in the California Independent System Operator's proposed load shift resource product, relatively minor adjustments to existing time-of-use rates in SDG&E service territory could reduce emissions by increasing load during these hours.

During the field demonstration periods, the project team successfully showed that control of electric vehicle charging, batteries, and thermostats contribute to dynamic pricing that better reflects cost and carbon content. The project team also successfully demonstrated a reduction in demand during peak hours, as shown in Figure ES-2.

Figure ES-2: Average Reduction During Peak Hours



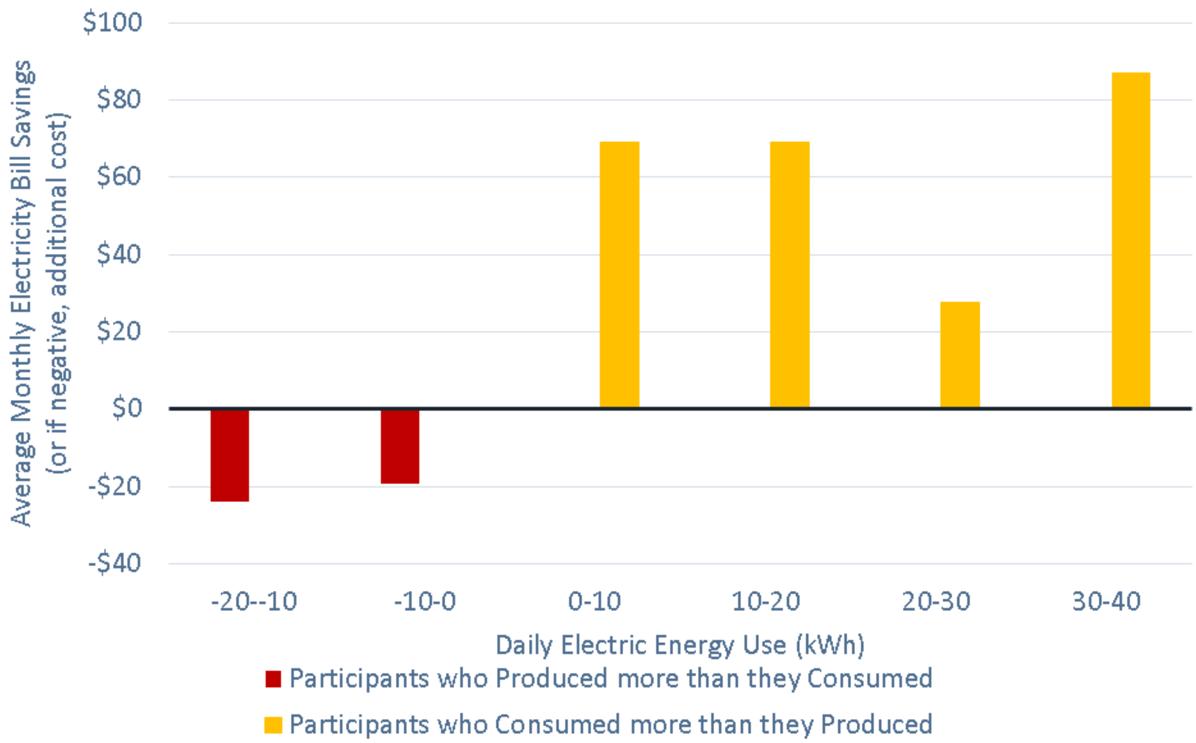
	Entire Study	Tier 1 - Only Thermostat	Tier 2 - Thermostat and EVSE	Tier 3 - Thermostat and Battery	Tier 4 - Thermostat, EVSE and Battery
Percent Reduction	23%	16%	9%	44%	38%

Source: Itron

These reductions helped drive customer energy bill reductions by moving energy demand away from high-cost, high-demand periods. Participants given only thermostats saw minimal change but participants in equipment tiers that received EV chargers and/or batteries displayed, on average, increase in consumption as many participants began either charging their electric vehicles at home or charging their vehicles more frequently at home. The battery energy storage system participant sites also increased their daily electricity consumption because of inherent energy losses as electricity is charged and then discharged from the battery.

The study showed dramatically different impacts on different household DER configurations. Ninety percent of participants in this study had existing solar PV. These households where the solar generation more often exceeded electrical demand, especially during the peak afternoon hours, offered the greatest potential to reduce energy bills and shift load to minimize peak demand. Figure ES-3 shows the relationship between monthly electricity bill savings during the study and monthly electricity consumption before the study.

Figure ES-3: Monthly Bill Savings Versus Monthly Electricity Bill Before Study



Source: Itron

Participants with higher energy use showed, on average, higher monthly savings during the study and switching to a time-of-use (TOU) rate. These are the households that are most likely to benefit from this technology and switching to TOU rates. Conversely, participants who produced more energy per month than they consumed, on average, lost money. These are participants with a large solar system that produces more energy than their home consumes. This is an important consideration for policymakers since participants with large PV systems on a grandfathered volumetric tiered rate will likely lose financially by actively shifting their loads. These are the very customers that may be the more environmentally minded early adopters who would otherwise be more receptive to innovative load shifting technologies and rates that would benefit society.

The study demonstrated energy reductions during the 4 to 9 PM peak hours (the "head" of the duck curve). The study did not show substantial reductions in midday energy export (during the "belly" of the duck) since current time-of-use rates and net-energy metering policies do not provide the financial motivations to do so. As a result, the existing operation is financially optimized by charging the battery energy system at night during super off-peak rather than during the daylight hours when the batteries could have been used to help mitigate grid overgeneration.

In summary, two types of price signals that encourage residential customers to shift demand to periods of high renewable generation in SDG&E service territory were investigated: retail rates and a wholesale market mechanism. Incentivizing customers to shift loads to these periods through price signals could increase the consumption of renewable energy without increasing utility costs. Although this research showed that compensation from negative prices in the wholesale market by themselves currently do not offer a strong enough economic signal for behind-the-meter customers to participate in the California ISO's proposed Load Shifting Resource product, relatively minor adjustments to existing TOU rates in the SDG&E territory could build load during these hours and also reduce emissions.

Advancing the Research to Market

The Residential Distributed Energy Resource Management System (RDERMS) is part of a suite of products consisting of a commercially available platform that integrates and controls readily available demand response and distributed energy resources equipment. These products, such as battery energy storage systems, intelligent thermostats, and advanced electric vehicle controllers, allow fast deployment and scale-up of any new load-shaping scenarios (advanced dynamic tariff or transactive real-time price mechanism).

The project team performed technology/knowledge transfer efforts throughout the study in three main areas:

- Home-Owner Recruitment and Engagement: The team interacted with over 200 potential participants and several industry organizations through its homeowner recruitment and engagement efforts. These activities provided the perfect platform to describe and promote the study. The team spoke at several seminars and provided material/website links that were distributed to members.
- Speaking Engagement: Industry leaders, stakeholders and other interested parties were targeted and informed by way of seven conference speaking engagements, a webinar, blog posts, a fact sheet-, reports (such as found here: https://energycenter.org/thought-leadership/blog/smart-home-energy-technologies-can-provide-greater-control-consumption-and) and the TAC.
- Regulatory Engagement: In June 2019, the project's tariff assessment results help to inform data and visuals used in providing comments to California Public Utilities Commission (CPUC) Proposed Decision Approving Greenhouse Gas (GHG) Emission Reduction Requirements for the Self-Generation Incentive Program (SGIP) Storage Budget or Rulemaking (R.)12-11-005. Comments highlighted average hourly marginal emissions rates by month and California Independent System Operator (CAISO) price signals in SDG&E's service territory in 2018 to show residential energy storage projects

will accomplish greater GHG emissions reductions and facilitate more renewable energy integration by charging during solar generation hours and discharging during evening peaks, and as such, planned TOU rates could be improved to encourage this specific type of behavior. Additionally, in January 2020, the project's tariff results, and report were used in providing comments to Re: Docket No. 19-OIR-01 regarding the 2020 Load Management Rulemaking Draft Scoping Memo. Comments noted that study modeling results indicated that dynamic real-time pricing can result in more grid and customer benefits when compared to block TOU rates. In addition, strong price differentials are needed within all seasons to ensure desired load shifting behaviors occur year-round. Comments suggested that the Energy Commission should consider the impacts of negative pricing events on load management strategies. In particular, the research showed that while compensation from negative prices in the wholesale market by themselves do not offer a strong economic signal for behind-the-meter customers to participate in the CAISO's proposed proxy demand, supportive utility rates could build load during these hours and reduce emissions.

Benefits to California

The RDERMS has shown its potential to provide California system operators, regulators, and utilities with the ability to promote electric consumption that reduces peak demand through automation, intelligent control, and price signals. Based on this study's results and conclusions, a fully developed and broadly applied system should provide the following benefits:

- Lower customer electricity costs: The RDERMS optimizes customer electricity use flexibility to minimize customer cost and reduce peak demand based on time-of-use or other dynamic electricity rates. This system incorporates predictive algorithms to forecast customer consumption and electric vehicle charging requirements while accounting for customer comfort levels. In turn, it allows the system to transparently control distributed energy resources and intelligent loads within predetermined customer constraints.
- Greater reliability and resiliency: Wide-scale adoption of this residential distributed energy resources management system in California will increase grid reliability by efficiently managing electricity usage in millions of homes. This will improve reliability on multiple feeders and reduce the risks associated with a single point of failure at a large battery-energy-storage farm. It also provides the opportunity to preserve and effectively manage energy use, storage, and load during public safety power shutoff events and other disaster-related outages.
- Environmental benefits: This RDERMS will contribute to California's state-mandated goal of 50 percent renewable resource energy by 2030 by intelligently using the residential electricity market to help balance energy supply and demand. Benefits of 50 percent renewable energy production will reduce greenhouse gas emissions and other pollutants that contribute to climate change.

Technology Transfer

At the end of the study, the thermostats, chargers, and batteries were left in place at participants' homes for use by the participants. The RDERMS was shut down when the project ended. During the study, participants were provided monthly summaries of their energy use, highlighting energy use during more expensive times. Project results were presented at the Association of Energy Services Professionals and the Electric Power Research Institute Forum in late 2019. A white paper was also submitted for publishing by the American Council for an Energy Efficient Economy.

CHAPTER 1: Introduction

Overview

California's single-family residences have become the front line in a market transformation that includes the proliferation of photovoltaic (PV) solar roofs, the advent of smart thermostats as a de facto standard, the early stages of an inexorable shift to electric vehicles (EV) and the recognition of advanced energy storage (AES) as a major part of California's future.

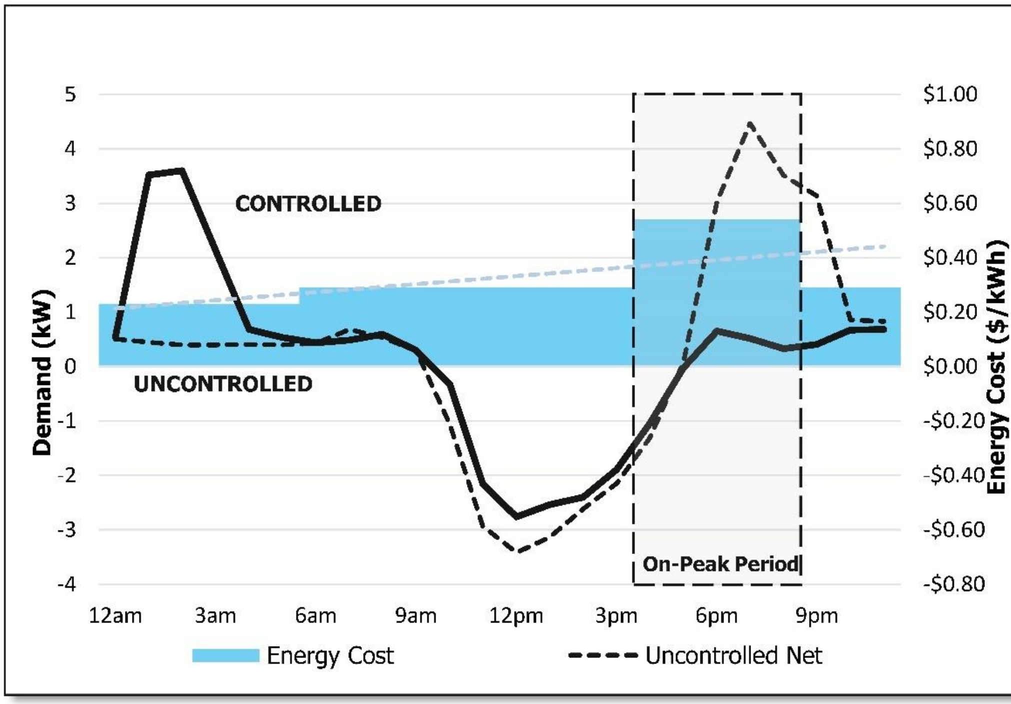
The vision of a smart grid is well established, where central and distributed energy resources (DER) dynamically interact with smart homes, and smart loads respond to price signals to effectively balance energy supply and demand. The technology in this vision of the future is here today, but the potential to optimize the smart grid and smart homes in concert has yet to be realized due to the lack of an enabling technology that will work with potential new utility rates and business models.

California Energy Commission Grant Funding Opportunity (GFO) 15-311 established the objective to identify, inform and develop strategies for overcoming technical, institutional and regulatory barriers to expanding demand response participation in California. A primary source of motivation was recognition of the requirement for smaller resources to play larger roles in distribution and transmission grid management. As California moves further toward distributed generation and intermittent renewable energy generation, this requirement is expected to grow. To encourage the development of strategies and technologies to address this gap, GFO-15-311 offered to fund applied research and development projects that assess how distributed energy resources respond to current, planned, and potential price signals.

California's Duck Curve

Distributed energy resources are creating two-way power flows, adding to increasing load volatility, as well as creating problematic load shapes like the duck curve in California. Distributed energy resources give customers more control over their energy use, but those resources can also dramatically change customers' impacts on the state's transmission electricity grid. By helping customers understand and control their energy use, it is possible to minimize the negative aspects of DER, such as overgeneration, and reap the benefits of these transformative technologies. Figure 1, which depicts a typical study participant, illustrates how DER contribute to spikes and ramps and how control of customer loads and DER together can redistribute customer electricity loads, allowing them to realize the benefits of these technologies.

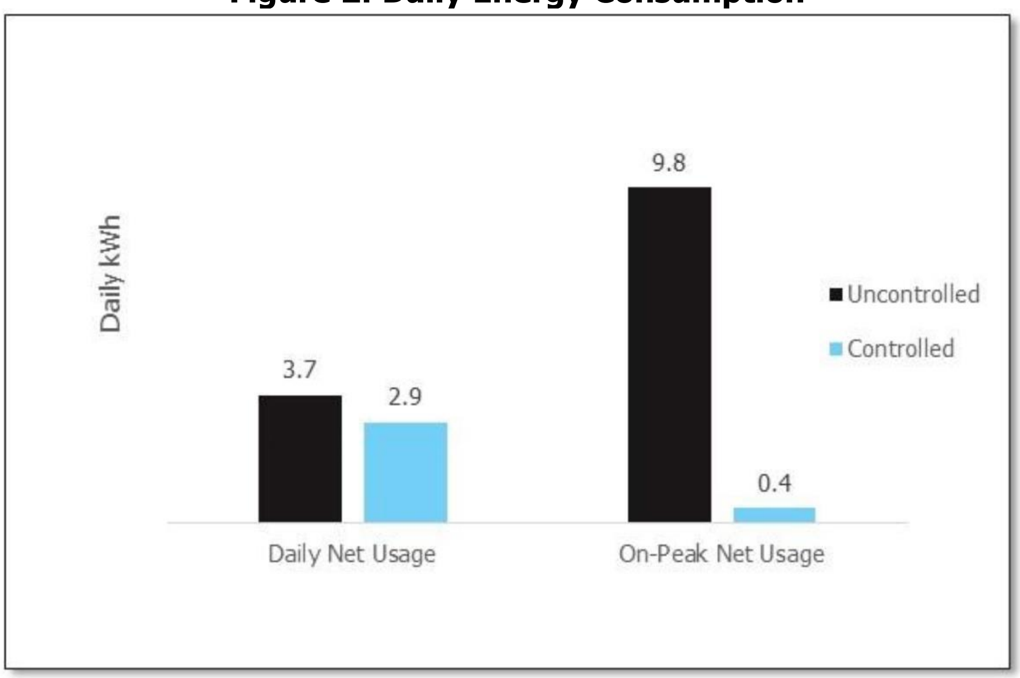
Figure 1: Uncontrolled and Controlled Load Shape



Source: Itron

Figure 2 displays the daily net and on-peak energy usage differentials between controlled and uncontrolled scenarios.

Figure 2: Daily Energy Consumption



Source: Itron

Figure 3 shows the daily net and on-peak energy cost differentials and savings between controlled and uncontrolled scenarios.

Figure 3: Daily Cost

Source: Itron

Role of Distributed Energy Resources in California's Future

The Residential Distributed Energy Resource Management System (RDERMS) studied in this report is an energy management solution for users, utilities, regulators, and renewable energy providers. This project documents the benefits of this system, including energy savings to users without impacting comfort and convenience. It also demonstrates the ability to stabilize aggregate demand on the grid by allowing load to react to dynamic pricing and eliminating the negative effects of integrating more renewable energy sources into the electric grid.

Smart Home Study

This project, known by its simplified name, Smart Home Study (SHS), shifted load shapes and minimized customer utility costs for 100 homeowners who were also San Diego Gas & Electric (SDG&E) residential electric customers. As part of the program, all participants with central air conditioning received a Honeywell Wi-Fi web-programmable thermostat, 30 participants received Webasto Level 2 EV charging stations, and 30 received Sonnen battery energy storage systems (BESS). Also, RDERMS were installed to communicate with these Distributed Energy Resources (DERs). The project used RDERMS to shift electric loads and minimize customer costs while maintaining customer comfort. The project used time-of-use (TOU) utility rates and, later, simulated dynamic pricing signals to support load shifting models that were intended to minimize customer costs.

Project Team

A project team was assembled to meet the diverse objectives of the program. The following summarizes individual responsibilities of subtask teams.

- Alternative Energy Systems Consulting – Prime contractor, project administrative lead, technical advisory committee (TAC) chair
- Itron – Lead technologist and developer of the RDERMS, IntelliSOURCE, and Riva meter
- San Diego Gas & Electric – Dynamic tariff, price signal and investor-owned utilities subject matter expertise
- KnGrid (dba Oxygen Initiative) – Demand clearing house technology and electric vehicle subject matter expertise
- Center for Sustainable Energy – Sample design, tariff analysis and modeling, and knowledge transfer

Technical Advisory Committee

As part of the project, the project administrators engaged, assembled, and convened a group of diverse professionals to serve as a TAC. The TAC members were selected based on willingness to participate, technical area expertise, knowledge of market applications, or potential synergy with other projects. Participation was completely voluntary.

Purpose

The purpose of the TAC was to provide expert guidance to help steer the project to maximum tangible benefits. Members were asked to help identify project elements, conditions, characteristics, and paths that enhanced the overall project and its ultimate results. They were asked to provide evaluations on current project design and suggest adjustments or alternate paths to improve project outcomes and value. Guidance addressed topics such as scope and methodologies, timing, and coordination with other projects. More specifically, the TAC:

- Reviewed products and provided recommendations for product adjustments, refinements, or enhancements.
- Evaluated the tangible benefits of the project to the State of California and provided recommendations to enhance project benefits.
- Provided recommendations regarding information dissemination, market pathways, and commercialization strategies relevant to project products.

Technical Advisory Committee Kickoff

After establishing the TAC, the project administrators provided members with abstracts and other documents that described the proposed project plan. TAC members were provided with the preliminary meeting schedule and relevant contact information, along with outlines of expected update procedures. Members had the opportunity to ask questions, request more information, and provide feedback.

Meetings

Meetings, including scheduled teleconferences, were the primary method for collecting strategic input from TAC members. Each teleconference began with a short presentation by project administrators, including a brief review of pertinent milestone documents. A directed open discussion was then held for all participating TAC members. Actionable project feedback was developed and, if possible, consensus was reached. Meeting notes captured substantive aspects of discussions and follow-up items were established.

Ad hoc meetings—on both individual and group occasions—captured additional input. Unlike the regularly scheduled teleconferences, these meetings were held as needs arose and focused on specific questions and issues. Ad hoc meetings were more closely tailored to individual TAC members who possessed specific knowledge required for the questions at hand. These meetings were generally short and detailed within a particular topic. The purpose of ad hoc meetings was to gather especially actionable and timely feedback. Meetings were also held over the phone, online, and in person.

Technology of Interest

The project installed Itron's RDERMS (IntelliSOURCE platform) control equipment in 100 homes to communicate with a spectrum of DER over different climate zones and behavioral patterns to determine the feasibility of the pre-commercial technology. The project modeled and measured the potential energy and cost impacts of RDERMS in homes where residents' comfort was not compromised. The project also integrated actual SDG&E TOU utility rates with simulated dynamic pricing signals to evaluate customer cost impacts.

System Architecture

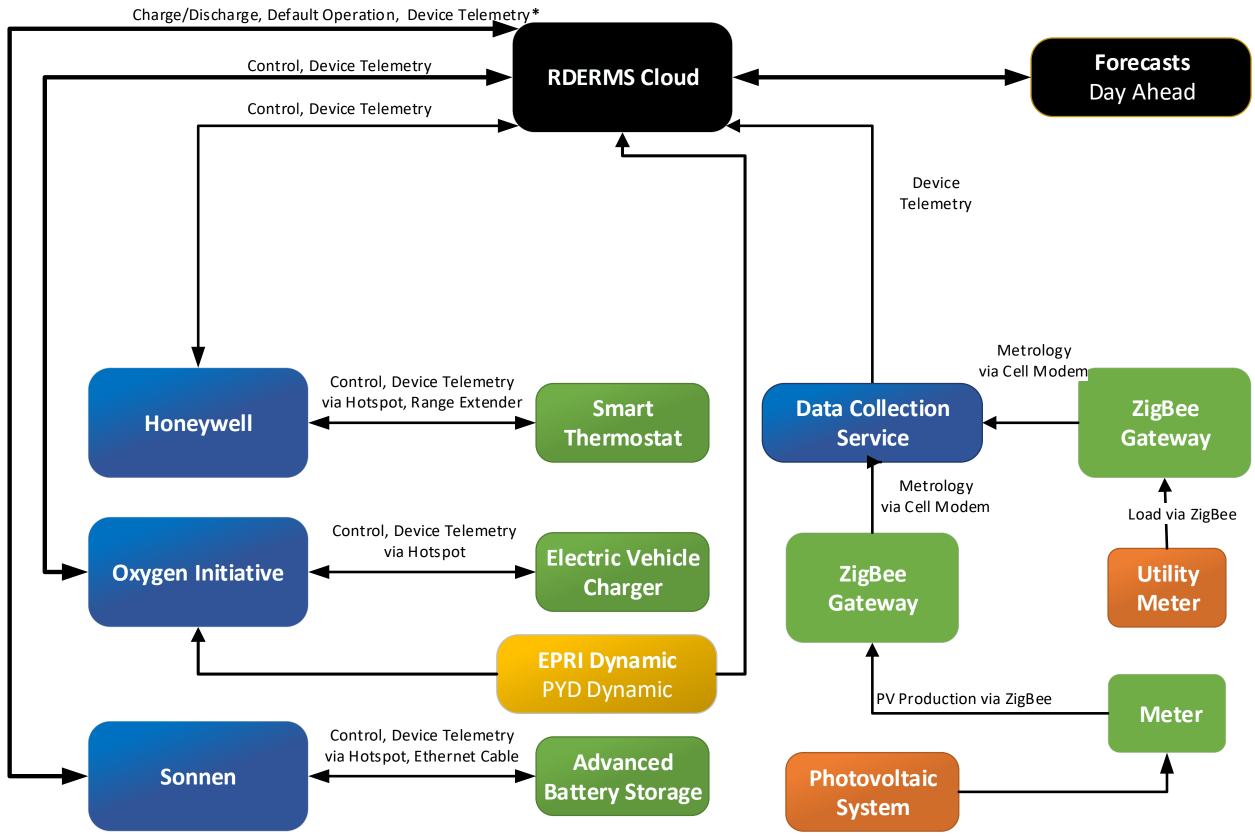
The IntelliSOURCE RDERMS system is a cloud-based system built on proven demand-response software and infrastructure. The project team had originally planned to use SolarGate to provide distributed intelligence and local control, but Itron's acquisition of Comverge in 2017 provided the IntelliSOURCE platform that already had connections to multiple thermostats and Sonnen batteries. This shift also eliminated the requirement for Itron to manufacturer any devices and leveraged established manufacturers' product lines.

The IntelliSOURCE RDERMS communicated with, monitored, and controlled up to four different DER systems at each project site. Those components included:

- Honeywell Lyric smart thermostats.
- Rainforest gateways to meter PV generation and net load.
- Sonnen advanced BESS.
- Oxygen Initiative-networked Webasto Level 2 charging stations.

The DERs and the component architecture of IntelliSOURCE are shown in Figure 4.

Figure 4: RDERMS System Architecture

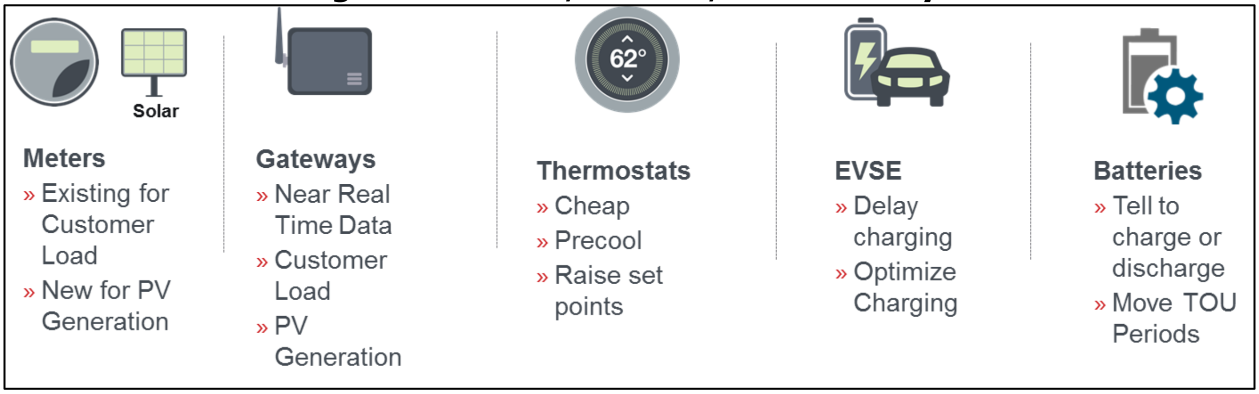


Source: Itron

Third-party devices are shown as green boxes and third-party cloud services are shown as blue boxes. The RDERMS cloud (based on IntelliSOURCE Enterprise) uses application programming interfaces to communicate with each third-party cloud service to receives data from devices and send commands to each device.

RDERMS was built into Itron's IntelliSOURCE platform. RDERMS leveraged IntelliSOURCE's platform for direct communication with, and control of, certain site DERs, and coordinated with partner internet portals (Honeywell, Oxygen Initiative, and Sonnen) to control and receive telemetry from site DERs including smart thermostats, electric vehicle charging stations, and BESS (Figure 5). IntelliSOURCE has a built-in analytical engine that uses SDG&E's existing residential TOU tariffs, site monitoring data, and day-ahead forecasts for whole-house electricity usage and solar PV power production, to most effectively use each site's combination of DERs.

Figure 5: Meters, Devices, and Gateways



Source: Itron

Demand Clearinghouse

The Oxygen Initiative demand clearinghouse can accept multiple inputs through its application programming interfaces to create grid-friendly charging profiles for vehicles:

- Local power limits for individual stations and station clusters
- Energy prices
- Building energy management systems (for this project, Itron's IntelliSOURCE)

In support of this study, Oxygen Initiative used OpenADR 2.0b virtual end node to connect to the Group 3 awardee's transactive signal server: The Electric Power Research Institute's (EPRI) OpenADR virtual terminal node. OpenADR 2.0b supports smart charging by providing a means for sending out a curtailment signal that requests all contracted resources to reduce load. Additionally, when the signal is published by the virtual terminal node and received by the virtual end node. In addition, grid operators can use OpenADR to publish location-specific prices for electricity. Typically, utilities use their default load aggregation point (DLAP) to set local prices system wide.

The demand clearinghouse connects to EPRI's OpenADR virtual terminal node. Node prices are combined with forecasts of building load and building/equipment parameters to balance thermostat and BESS operations over the next day.

This study created equipment operation profiles for electric vehicle charging, thermostats, and BESS that resulted in the following.

- Caused vehicles to charge on schedules aligned with low prices published by the utility (and avoided charging during high prices), thereby assisting the utility in reducing congestion on its transmission and distribution network.
- Caused thermostats and BESS systems to consume power when prices were low by either pre-cooling houses with enough mass on hot days or charging the BESS. It also saved energy during periods when prices were high through BESS discharge and pre-cooling the house ahead of high price periods or raising the thermostat setpoints within customer preference. The customer was always able to adjust the thermostat setpoints through the thermostat or a smartphone app.

Both the Oxygen Initiative and Itron's IntelliSOURCE have successfully connected their respective virtual end node to EPRI's virtual terminal node Transactive Signal Server. Tests show that the virtual end nodes were successfully accepting all published data from the virtual terminal node.

Further, the project team identified the pricing payload and can now create price-optimized vehicle charging profiles that turn off charging during high energy price intervals.

The project team successfully created electric vehicle charging profiles that align with pricing intervals by setting TOU vehicle charging profiles.

Intelligent Devices

The RDERMS platform uses several intelligent devices to either sense and communicate or sense and control load at the device. This section describes each of those devices.

Meters

The project used existing SDG&E utility meters to provide net load to feed house forecasts and provide ongoing data. Where possible, the project team also installed additional meters to monitor PV generation. These meters provided near real-time load and generation data to the IntelliSOURCE platform. Figure 6 shows an installed meter at an SHS house.

Figure 6: Installed Meter

Source: Itron

Gateways

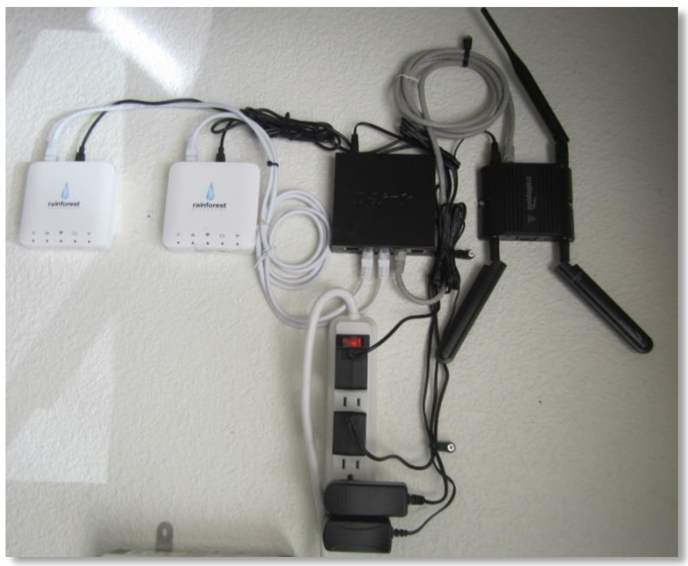
Each house had at least one Rainforest ZigBee gateway installed to provide near real-time data on customer load and, for some sites, PV generation. The gateways connected to the meters using Zigbee, read load and generation data every 15 minutes. This enabled data collection by the RainForest web service that Itron's IntelliSOURCE RDERMS system connects to through Rainforest's application programming interface. Rainforest also provides a user interface that allows the customer to access real-time data.

Wireless Hotspot

Based on prior experience with DR programs around the nation, the technology project team decided to use industrial-grade wireless hotspots instead of relying on customer broadband for connectivity. Customer broadband, while lower cost, is less reliable for device connections. The Cradlepoint wireless hotspots include a cellular modem and provided both a wireless network and a wired ethernet jack. These wireless hotspots provided connectivity for the gateways and the electric vehicle chargers and batteries. The project team installed most equipment in close proximity to the hotspot for better connectivity. The thermostats use the participant's Wi-Fi since they are inside the house.

A completed installation with two gateways (one for the SDG&E meter and one for the solar meter), an ethernet hub, and a Cradlepoint hotspot is shown in Figure 7.

Figure 7: Installed Gateways, Hotspot, and Ethernet Hub



Source: Itron

Control Devices

Each DER device (thermostats, electric vehicle chargers, and batteries) is connected to the DER device manufacturer's cloud either through the customer's internet or a cellular gateway. RDERMS connects to each of these clouds to collect data and provide control signals.

Smart Thermostat

Honeywell Lyric Wi-Fi thermostats, shown in Figure 8, were installed in nearly every house.[1] If the home had multiple central heating and cooling air conditioning systems, the project installed a thermostat to control each system. During the SHS, the project team requested that the participant use a Honeywell Lyric Wi-Fi thermostat time-based scheduling model. The thermostat included a location-based temperature-control (geofence technology) mode that

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[1] One house installed a new, higher-end HVAC system in between site visit and installation that is not compatible with a third-party thermostat. Another home only had mini-split air conditioning that is not compatible with the Honeywell Lyric.

the customer may still use upon completion of the study. During the study, the IntelliSOURCE platform communicated with the thermostat to pre-cool the home during periods with lower rates and increase the home's temperature during periods with higher rates.

Figure 8: Installed Smart Thermostat

Source: Itron

Electric Vehicle Charger

The project team installed a Level 2 electric vehicle charging station, also referred to as electric vehicle supply equipment, in standard SAE J1772, at 30 project participant sites (Figure 9). The specific charging component is Webasto's home charging dock, Model EVSE-RS, and the IntelliSOURCE platform communicated with the component through Oxygen Initiative's internet-based control system.

Figure 9: Installed Electric Vehicle Charger

Source: Itron

The project team created electric vehicle charging profiles that aligned with pricing intervals by setting TOU electric vehicle charging profiles in Phase 1 and charging profiles based on the EPRI virtual terminal node price signal in Phase 2.

Each time the customer connects the vehicle:

1. The vehicle's charging goes into "Suspended Mode" if connected during on-peak pricing.

    - The Oxygen Initiative ChargeCloud server automatically sends a text message to the driver's smart phone with the following message:

      Your vehicle is NOT charging. It will begin charging at 12:00 a.m.

      Tap the link below to start charging.

      https://webapp.oxygeninitiative.com/itron/charge/609aab157360be08ca25d3e775dc96cd

- If the customer does not click on the text message, the Oxygen ChargeCloud publishes the charging profile to Itron’s IntelliSOURCE. From this point, IntelliSOURCE can adapt the charging profile to reflect other known conditions to optimize charging. A potential use case for this is to charge the vehicle at midday when solar is forecasted to export to the grid and prices are near zero or even negative.

2. If the customer connects during a super off-peak rate period, the vehicle begins charging immediately and will charge until full, unless a higher rate begins before the vehicle is full.
    - If the vehicle is not yet full, the Oxygen Initiative ChargeCloud server automatically sends a text message to the driver’s smart phone with the “charge now” override link. The user will need to estimate needed charge since currently available communication protocols do not allow the charger to know the state of charge of the vehicle. This lack of communication is one of the major challenges highlighted by this study.
    - If the customer clicks on the link, the vehicle overrides smart charging and begins charging immediately. This enables a simple method of override and a user interface that “reaches out” to the customer for a convenient experience.

Energy Storage

Thirty Sonnen energy storage systems were installed at participant homes. These were all installed indoors, usually in the garage near the PV inverter (Figure 10). The BESS was sized based on the house loads and its PV system.

Figure 10: Installed Battery Energy Storage System

Source: Itron

The Sonnen BESS requires a connection to access the internet. The connection enables communications with the Sonnen server and connects with its intelligent charge management system.

In TOU mode, the application programming interface connection allows IntelliSOURCE to set the beginning of the off-peak period and the start and stop of the peak period. The BESS will start charging at the start of the off-peak period and then discharge during the peak period, but only to offset household load and not to discharge to the grid. For Phase 1 in summer, this would usually be set with the off-peak period starting at midnight and the peak period from 4:00 to 9:00 p.m. Note that in winter, the price differentials are small enough that cycling the BESS is likely to cost the participant money (except for EV-TOU-5) since batteries lose some of the energy used in charging due to inefficiencies.

CHAPTER 2: Project Approach

The project team created a real-world residential lab to advance understanding of innovative distributed energy management opportunities made possible by advanced intelligent controls. Alternative Energy Systems Consulting led this effort. Itron Inc., lead technologist and developer of a RDERMS, handled integration planning and readiness assessments. SDG&E provided subject matter expertise over the course of the project including analysis of dynamic tariffs, price signals, and demand response (DR) programs. KnGrid was responsible for managing its demand clearinghouse technology and providing other subject matter expertise. The Center for Sustainable Energy conducted sample design, tariff analysis and modeling, and knowledge transfer.

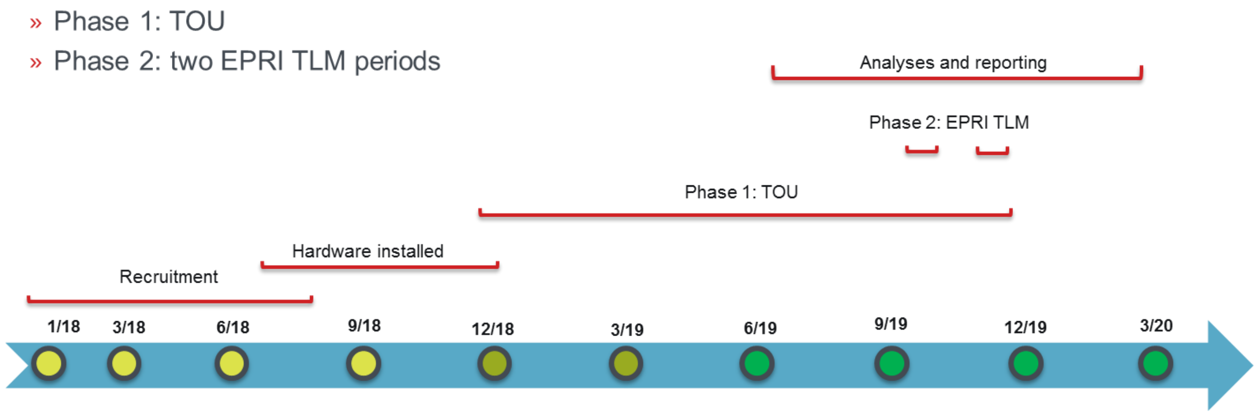
Demonstrations

To test and understand the impact of RDERMS control under two different scenarios—traditional TOU tariff rate and advanced price-signal optimization—the demonstration was broken into two phases:

- Phase 1: Optimization and response to existing SDG&E TOU rates. So that optimization and behavior would have direct impacts on customer utility bills, participants were asked to switch to one of three TOU rates: DR-SES, EV-TOU-2, or EV-TOU-5.
- Phase 2: Optimization and response to the EPRI transactive signal server to receive and respond to a transactive load management (TLM) signal. This consisted of two, two-week periods when the project team optimized thermostats, batteries, and electric vehicle charging based on the EPRI price signal. Note that these rates and signals do not directly impact customer utility bills.

The schedule for these phases is shown in Figure 11, with Phase 1 starting in December 2018 and the field demonstration lasting one year. Phase 2 experiments were performed in September and November 2019 with the hopes of catching variable weather and Southern California's hot Santa Ana winds conditions.

Figure 11: Demonstration Phase Schedule



Source: Itron

Phase 2 thermostat and EV charger controls could not be completed as planned. The project team attempted to initiate controls in response to dynamic signals across all devices but was unable to fully control thermostats and EV chargers in response to the TLM signal. However, EV charger control was demonstrated in a test case on one charger. The lack of a common communication standard across vehicle manufacturers proved to be a significant barrier in this study. Without the current state of charge and the planned leave time (information from the vehicle), it is very difficult to develop an optimized charging strategy in a dynamic pricing scenario. It was less impactful to the TOU demonstration because the vehicle could start charging the moment the EV tariff super off-peak rate initiated and the vehicle was generally assured to be fully charged. The Energy Commission and the CPUC are currently considering common EV communication standards which, if adopted, could be integrated into future DER studies.

Phase 1 (TOU Rate) Demonstration and Implementation

TOU demonstrations in Phase 1 formed the bulk of the one-year field data collection period. This provided the opportunity to test and refine communications and controls and develop a baseline for comparison with Phase 2 operations. Response to an energy based TOU rate is simpler than the response required in Phase 2 because the rates are static and change on an established schedule rather than receiving a new rate schedule daily. Figure 12 shows the energy rates for the two TOU rates selected for the study: EV-TOU-2 and DR-SES TOU.[2] Summer is June through October and winter is November through May.

[2] During the study, SDG&E introduced another EV-only rate, EV-TOU-5. This rate lowers the super off-peak rate to $0.09/kWh in exchange for a $16/month fixed fee. For many EV customers, this provided a more cost-effective rate, so the project team decided to recommend this rate to EV drivers.

Figure 12: SDG&E EV-TOU-2 and DR-SES TOU Rates

Source: SDG&E

Some key aspects of this rate are listed below.

- No tiers. All energy consumed or produced is credited[3] at the same rate schedule, regardless of kilowatt-hours (kWh) used.
- No demand charges. The electricity bill is dependent on the amount of electricity consumed by a participant in each period during a billing month.
- Rates differ greatly from summer to winter; winter rates are relatively flat for all times of the day.

Winter Phase 1 (Time-of-Use) Operation

The winter rates in Figure 12 have less than a 10 percent difference from super off-peak to on-peak. This small differential between super off-peak and on-peak rates means that shifting loads using BESS or thermostats could increase customer costs. So, during winter Phase 1 (TOU) operation, only electric vehicle charging was actively shifted for participants for most rates. Additionally, a handful of participants with both electric vehicles and BESS switched to EV-TOU-5 during 2019 and BESS was cycled in November, which was the first winter month when most of these customers were on this rate.

During Phase 1, optimal EV charging begins at midnight, when demand is low. The vehicle continues to charge until the battery is full. It is recognized that vehicle use varies according to the driver's specific travel needs at any one point in time. To allow specialized charging, the control strategy incorporated a feature that gave the participant the ability to override the next

[3] Because of NEM agreements in SDG&E territory, energy sold back to the utility is sold at essentially the retail rate.

scheduled charge session via text message reply. In this mode the charging strategy defaults to the vehicle charging schedule.

Summer Phase 1 Time-of-Use Operation

The summer rates do provide substantial incentives for participants to shift loads away from on-peak to either super off-peak or off-peak time periods. Shifting these loads varied by device, as further described.

Battery Energy Storage System Phase 1 Summer

During Phase 1, the optimal control of BESS charging and discharging is dependent on the utility billing season and TOU rate period. Interconnection rules do not allow batteries to discharge to the grid, so the Rainforest ZigBee gateway was used to verify that the discharge from the BESS did not exceed a test household's net consumption of electricity.

The following describes how BESS charging and discharging is implemented to minimize a customer's bill during the summer rate period.

- Charge the BESS off the grid starting at midnight.
- Discharge the BESS between 4-9 p.m.

There is no participant incentive to moderate charging or discharging during the TOU period. Participants were unaffected when their BESS discharged during the 4-9 p.m. summer peak if their BESS discharged to cover their utility electricity consumption during the peak period (or as close as possible without discharging to the grid). That could mean a 4 kW/8kWh BESS discharging at an average of 4kW from 4 to 6 p.m. Conditional to optimizing BESS usage for a participant's energy cost, it is unlikely that a rapid charge or discharge of the BESS is most beneficial for either the grid or a utility. Is a rapid discharge of the BESS early during the peak period the best discharge time for the utility? Or is there an alternative time during the 4-9 p.m. peak period when discharging the BESS would be equally beneficial to both the residential participant and the utility? During Phase 2 of BESS implementation, the batteries were charged and discharged based on a dynamic rate that may more accurately represent co-optimization for both the participant and the grid.

During the winter rate period customers on the DR-SES TOU rate should not use their batteries to reduce their bills. There is not enough of a price difference for residents to use BESS to their benefit. Since BESS does not have a round-trip efficiency of 100 percent, a larger differential between on-peak and off-peak is required to operate the BESS cost-effectively in the winter. In general, around an 80 percent round-trip efficiency is assumed for these systems.[4]

Electric Vehicles Phase 1

During Phase 1, the optimal control of electric vehicle charging, given currently available rate designs, is to begin charging at midnight. The vehicle continues to charge until the car battery

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[4] If the battery participant also had an electric vehicle and was on SDG&E's EV-TOU-5 rate, the rate differential in winter was sufficient to financially justify cycling the battery.

is full. The participant maintains the ability to override the RDERMS charging at the charger or with a text message reply.

Thermostat Phase 1 Summer

During Phase 1, a test home's thermostat was used to implement pre-cooling followed by a drift up in the home's temperature during peak (higher cost) hours. Given the SDG&E rates, pre-cooling was planned from noon to 4 p.m. After 4 p.m., a home's temperature was allowed to increase, or "set back." The relatively long period of pre-cooling cooled the air and the home's thermal mass.

To best apply and control thermostats during Phase 1, the project team first established if the thermostat was in cooling mode, then determined the thermostat temperature settings and the participant's minimum and maximum temperature preferences. The forecast for the next day's weather was also considered. If the home's thermostat was in cooling mode and a preferred temperature setting was inputted into the thermostat, the first step in the precooling algorithm compared the thermostat's setting in the late afternoon to the outdoor high temperature forecast for the next day.

San Diego has a relatively temperate climate. During the summer months it is not uncommon for air conditioners to be turned off, or for them to be left in the on or cooling mode, and the home's windows to be left open. In San Diego, the home may not be air conditioned until the hottest part of the summer (August through October), so the team had to determine whether the homeowner had set up his or her home for air conditioning. The study did not attempt to precool a participant's home when the windows were open. Comparing the home's thermostat setting with the forecast of outdoor temperature, the precooling algorithm was implemented if the forecast of the next day's high temperature was 10 degrees hotter than the home's late afternoon thermostat setting. Initially, this algorithm was relatively simple because it lowered the set point from noon to 4 p.m. by 2 degrees and raised the setpoint by 1 degree during peak hours (4 to 9 p.m.).[5] This algorithm was replaced during Phase 2 by a linear program that optimized for minimal cooling costs during hot days.

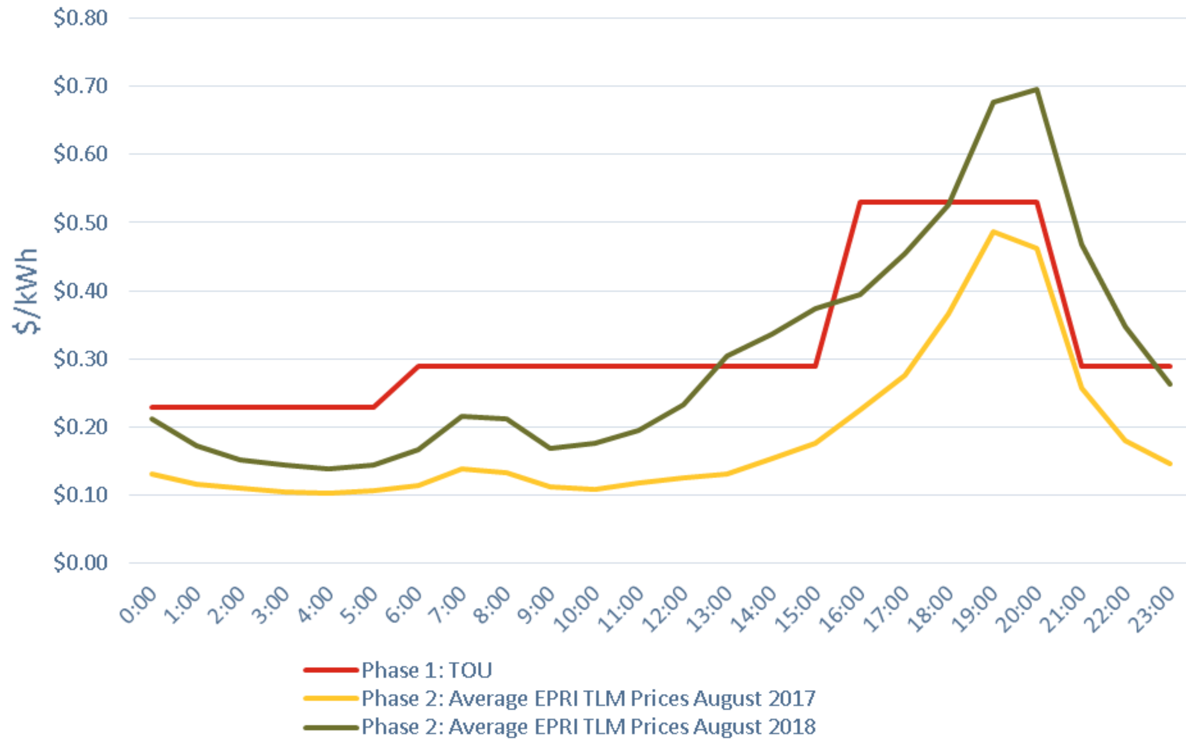
The project team decided early in the study to use the hourly setpoint function within the thermostat application programming interface to provide the ability to change each thermostat's setpoint every hour over the next 24-hour period. This provided more granular control than the 'hold' function. The hold function raises or lowers the thermostat setpoint by a set number of degrees for a set timeframe (such as the 2-degree pre-cooling for four hours just described). Unfortunately, the majority of hourly setpoint adjustments sent to thermostats did not result in thermostat temperature setpoint changes. Using the hold functionality would likely have delivered more reliable control since that functionality is broadly used for demand response programs throughout the country.

[5] Based on "SMUD's 2012 Residential Precooling Study–Load Impact Evaluation" by Herter Energy Research Solutions.

Phase 2 (Dynamic Rate) Demonstration and Implementation

Phase 2 of the SHS automated technology to the EPRI TLM tested a day-ahead dynamic rate. This rate aligns utility and customer costs, benefitting both the customer and the grid. The dynamic EPRI TLM varies in price for each hour of the next day and differs from TOU rates used in Phase 1. Figure 13 shows the average EPRI TLM summer prices for 2017 and 2018, and Figure 14 shows those prices for winter.

Figure 13: Phase 1 vs. Phase 2 Energy Prices in Summer

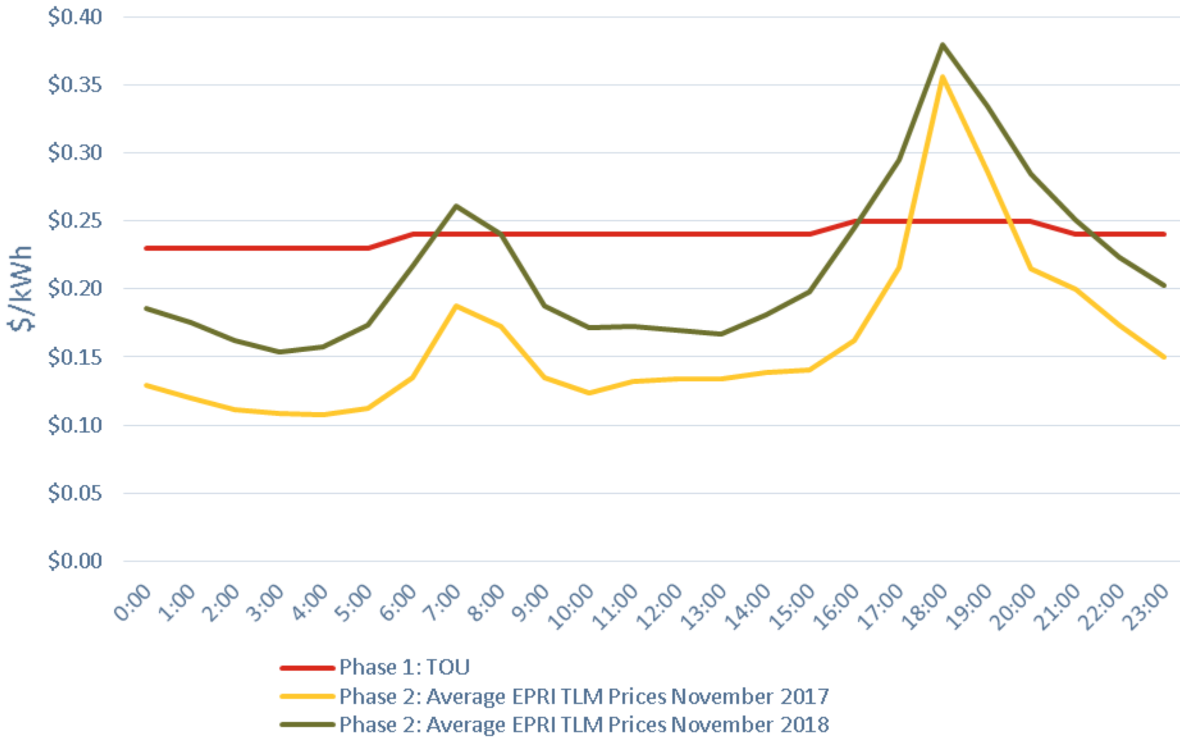


Source: Itron

In the summer, a small morning peak appeared in Phase 2 that is not reflected in Phase 1 TOU pricing. Additionally, peak prices rise in the later part of the TOU on-peak period. Also evident in Figure 13 and Figure 14 is that, year over year, dynamic prices can vary substantially between years, with 2018 showing much higher prices, likely caused by a hot, dry year.

Summer in San Diego is different from many other parts of the state. The early summer marine layer (known as the "June gloom" to residents) tends to drive temperatures and energy consumption down in the early part of summer. Higher temperatures are more likely in late summer. Largely for this reason, the project team chose the first test period to be in September to catch part of the hot spell when the Santa Ana winds drive up temperatures and demand, and therefore energy prices.

Figure 14: Phase 1 vs. Phase 2 Energy Prices in Winter



Source: Itron

Winter prices show a more substantial difference between phases 1 and 2. Phase 1 TOU prices are nearly flat, whereas Phase 2 dynamic prices show both morning and afternoon peaks. To allow comparison between these rates, the project team performed the final experiment late in the month of November

The control strategies for Phase 2 were more complex than the relatively simple strategies required to minimize cost in Phase 1. However, similar to Phase 1, the Phase 2 logic behind shifting loads varied by device.

Energy Storage Phase 2

Phase 2 of the SHS required a different control strategy for the energy storage systems. As previously discussed, while Phase 1 implementation aimed to benefit the participant, it did not necessarily benefit the electric grid. Phase 2 implementation required the following elements.

- Forecast of site net load – based on historical usage and forecasted weather
- EPRI dynamic price – This metric provides an estimate of day-ahead utility costs.
- BESS status – Current state of charge

These data were then used to schedule BESS charge and discharge for the following 24 hours. The charging of the BESS in Phase 1 was scheduled in two steps.

1. Estimate the charging time required (based on current state of charge and total BESS size).
2. Find the lowest consecutive prices for hours required, based on the EPRI dynamic price rate. Consecutive hours were required due to limitations imposed using this

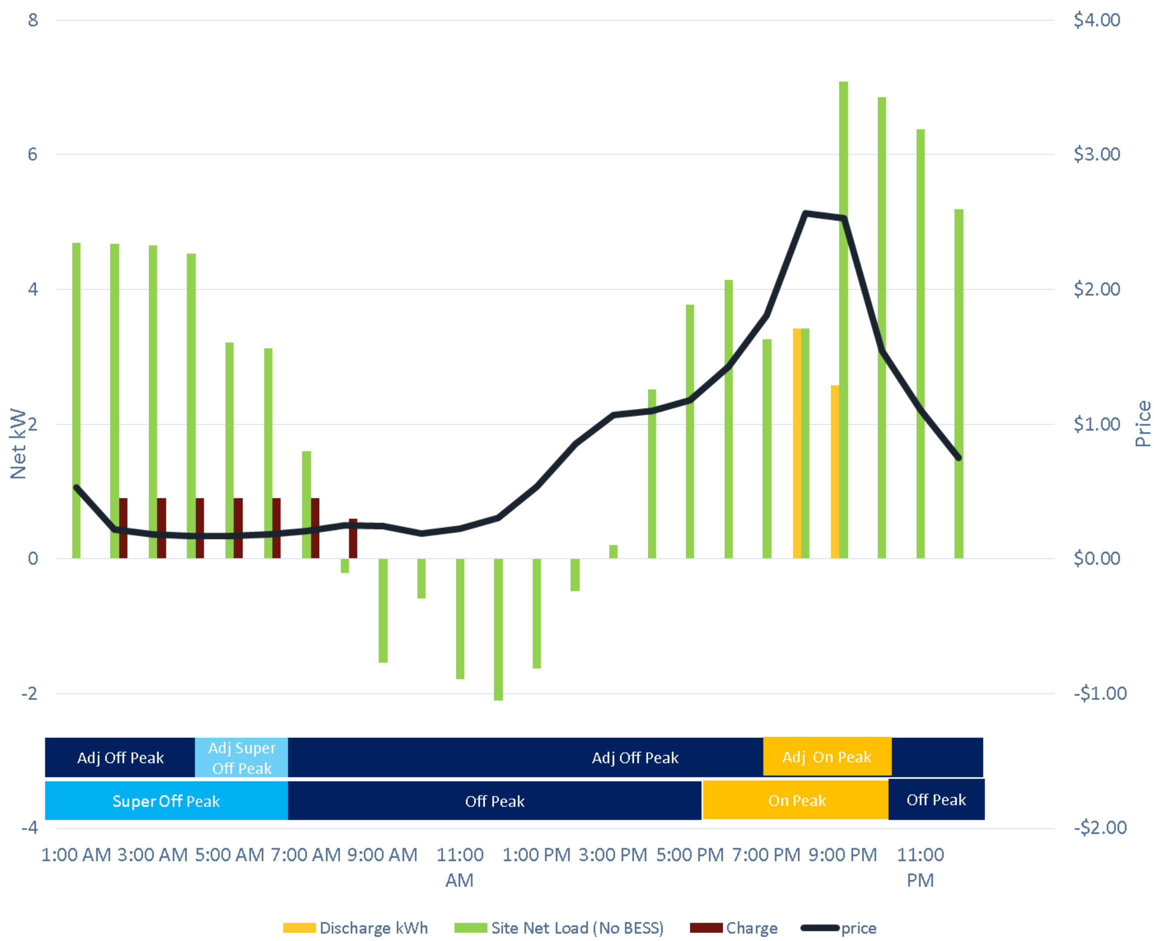
manufacturer's BESS TOU operating mode for control and this mode only allows one low price charging period per day. Other battery modes such as 'manual' could have enabled different charge and discharge rates by hour but in manual mode the discharge of the battery is not limited by net load. That lack of net load feedback to the battery means that the battery would likely export to the grid in many conditions, therefore violating customer interconnection agreements.

The discharging of the BESS in Phase 2 is scheduled in three steps.

1. Find highest price hour (based on EPRI dynamic prices) and subtract forecasted load from the BESS's total capacity.
2. Find the next highest consecutive price hour and subtract forecasted load from the BESS's remaining capacity.
3. Continue until BESS is expected to be empty if the price is over 1.2 times the charging price (to account for round-trip efficiency losses).

Figure 15 illustrates how charging and discharging were implemented in a sample SHS participant's home. On this day, PV generation was sufficient to exceed onsite consumption midday, therefore exporting to the grid, as evidenced by the negative site net load bars in green.

Figure 15: BESS Charging and Discharging Cycles



Source: Itron

The BESS begins charging at 2 a.m. since that is when the EPRI dynamic price is lowest. The BESS then discharges between 7 p.m. and 8 p.m. because that is when the price of energy spikes. Since this household is on a TOU rate, the household still would be expected to see a reduction in its electricity bills. The high EPRI dynamic price indicates that the grid tries to reduce customer demand during the 7 p.m. to 8 p.m. time period; therefore, this BESS implementation also benefits the grid.

Electric Vehicles Phase 2

The Phase 2 electric vehicle charging implementation was built on Phase 1 control and incorporated additional information for scheduling optimal car charging.

- EPRI dynamic price – This metric provides an estimate for utility costs, it is provided on a day-ahead basis.
- Expected unplug time based on historical data for that participant.
- Expected hours of charge based on historical data for that participant.

These data were then used to schedule charging for the next 24 hours. The charging of the car battery in Phase 1 was scheduled in three steps.

- Estimate the charging time required (based on historical charging behavior) for each site.
- Estimate the earliest expected departure time (based on historical charging behavior) for each site.
- Find the lowest consecutive prices for the hours of charge required after plugging in and before expected departure.

Unfortunately, only limited field testing was completed for EV charging in Phase 2. One site completed dynamic testing assuming a 4-hour charge time with a 7 a.m. departure time.

Thermostat Phase 2

As previously discussed, while a thermostat is the least expensive DER installed in this study, its control is the most complicated. The overall objective is to minimize electricity costs driven by air conditioning on a single day. Phase 2 estimated a thermodynamic model for each home to determine how quickly a home heated up as the outside temperature changed. Results from the thermodynamic model were intended as inputs to a linear programming equation used to minimize the cost of a participant running his or her air conditioner while still maintaining comfort levels. Unfortunately, due to the technological issues mentioned here and relatively mild weather in 2019, this control was only implemented on a handful of houses and days.

Sample Design and Recruitment

A sample design for 100 participants who could reasonably represent SDG&E residential, single-family homeowners was established, and a detailed sampling plan was developed. The plan identified the objective for diverse participant profiles, how to maximize research value while accounting for specified limitations, potential recruitment pools and data sources, and outreach methods. An outreach plan was then developed and implemented. Due to significant recruitment challenges, outreach efforts were adapted and revised until the desired sample size was achieved.

Sampling Limitations

The predetermined sample size of 100 single-family residences had some risk of bias and limited potential for statistical inference. This could not be avoided, only addressed, due to project budget constraints and the willingness of single-family homeowners to enroll in the study. The project team found access to all SDG&E customers was cost-prohibitive and had the inability to develop a true statistical sampling plan. Thus, it was not possible to develop weights to expand the findings from study participants to the entire utility territory population. The study's sample may therefore not represent the average single-family homeowner in SDG&E's service territory. Additionally, participants were instead selected from recruitment pools identified by the project team and likely include participants who are more aware of and interested in their energy usage than many other utility customers. Nevertheless, results from the project still provide valuable information about the future feasibility of RDERMS technology in both the study region and in California as a whole. Findings from this study were presented with these limitations.

Initial Recruitment Pools and Data Sources

The ability to manage and analyze many different residential energy loads using either DR or dynamic TOU utility rates during the study was key to understanding how the RDERMS technology can have a much broader reach throughout California. Differences in climate zones, participant electrical and mechanical mixes, load shapes, and other characteristics have significant energy consumption impacts. . To accomplish this objective, frequently encountered flexible, and high-energy-consuming end uses along with PV in a residential setting were identified as loads and in the case of PV, excess energy, that could be shifted to different times of day using RDERMS and BESS, and four different use cases or candidate profiles were initially developed using different mixes of end uses and PV (Table 1).

Table 1: Pre-and Post-Participant Enrollment Considerations

Eligible Candidate Profiles					Post-Enrollment Considerations		
Profile	**AC Load**	**EV Owner**	**PV Owner**	**Mid-day Load**	**Receives Honey-well T-stat & Enrolls in DR Tariff**	**Potential Load to Shift**	**Technology Installation Considerations**
1	X	X		X	X	AC, L2 EVCS and mid-day loads; discharge storage during peak	L2 EVCS or Storage (Arbitrage)
2	X	X	X		X	AC and L2 EVCS loads; discharge storage during peak	L2 EVCS or Storage
3	X		X		X	AC loads; discharge storage during peak	Storage
4	X		X	X	X	AC and mid-day loads; discharge storage during peak	Storage

Source: CSE

Candidate profile criteria included the presence and use of air conditioning (AC) throughout the day because this is typically a substantial portion of a homeowner's utility bill and can be efficiently controlled through a smart thermostat. Other criteria included the presence of an electric vehicle, which allowed for charging to be shifted to off-peak hours. In addition, presence of PV was considered since excess renewable energy can be stored and shifted for use during on-peak periods with a BESS. Households with high mid-day loads were also considered, with loads during peak times such as pool pumps or energy use associated with occupying a home, since more load can be shifted from peak periods to off-peak periods with a BESS.

Along with identifying residential participants who met those defined use cases, the project team decided that participants would be selected from different climate zones and areas designated as disadvantaged communities. Originally, the team considered including participants from all four of SDG&E's climate zones: coastal, inland, mountain, and desert (SDG&E, n.d.). However, because of the small sample size and strict eligibility criteria, the project team restricted participation from only two climate zones: coastal and inland. These climate zones are often used in new construction project evaluations since mountain and desert areas are sparsely populated and do not offer enough data points. Also, using the California Environmental Protection Agency's California Communities Environmental Health Screening Tool (CalEnviroScreen 3.0, n.d.), recruitment outreach was to target single-family homeowners residing in disadvantaged communities within SDG&E's coastal and inland zones.

The primary initial recruitment method to reach a sample size of 100 was to use identified recruitment pools. All known datasets or recruitment pools that were initially explored for the study are listed in Table 2.

Table 2: Study Participant Recruitment Pools

Known Data Set	Description of Data Set or Recruitment Pools
SDG&E customers & employees (coastal and inland)	Residential customer street and email addresses and eligible employees
Oxygen Initiative	400 University of San Diego electric vehicle owners addresses and emails
Net energy metering (NEM) participants	A map of residential customers with a renewable energy source
Itron employees	Eligible employees
Center for Sustainable Energy employees	Eligible employees
City of San Diego Development Services Department "OpenDSD"	A public permit database with available residential solar installation permit records with homeowner addresses
Other local government online permitting portals	Available public permit databases containing residential solar permits with homeowner addresses
Energy Commission's New Solar Homes Partnership	A database of residential new construction that includes solar PV

Source: CSE

Additionally, study recruitment was initially planned at sustainability and clean tech-related events and workshops, electric vehicle dealerships, websites, social media pages of partner representatives, solar installers, local jurisdictions, SDG&E, and San Diego–area clean energy and tech organizations. Solar installer outreach planned to target new residential solar PV owners (those who installed solar after June 2016 and are on NEM 2.0 but would be forced onto an SDG&E TOU rate in the near future).[6]

Outreach Methods

The project team developed a recruitment and application website to facilitate enrollment in the study (https://smarthomestudy.com/). Individuals with the required technologies (AC and electric vehicle and or PV) were encouraged to fill out the website survey to determine their

[6] TOU Period Grandfathering for NEM Customers. https://www.sdge.com/residential/savings-center/solar-power-renewable-energy/net-energy-metering/time-use-period-grandfathering

first-level eligibility for the study. The website collected information on the following eligibility criteria.

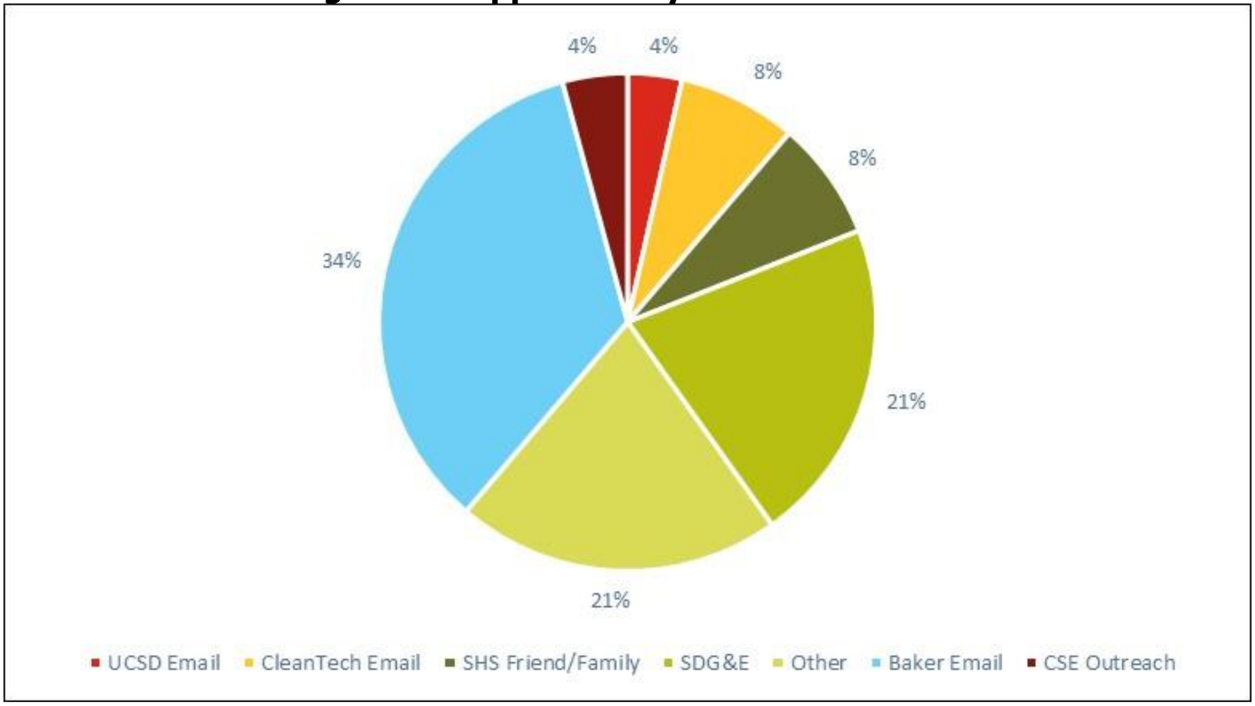
- The homeowner is an SDG&E residential electric service customer.
- The home is an owner-occupied, single-family, or multifamily household.
- The home has AC.
- The home has Wi-Fi internet service.
- The home has solar panels or an electric vehicle that are currently registered in California.
- The home does not already participate in an SDG&E demand-response program.

The project team recruited 100 participants between April and November 2018 within SDG&E territory based on the guidelines from the sampling plan. To reach 100 participants, a variety of additional outreach efforts were implemented, and all efforts were adjusted based on response. Applicants were asked where they first learned about the study. Based on this survey, the following are the primary outreach efforts that informed customers about the Smart Home Study.

- Smart Home Study Friends and Family: Provide SHS consortium representatives an initial recruitment email offering participation to employees and encouraging them to reach out to family and friends.
- CleanTech Email: CleanTech San Diego is a nonprofit trade organization that supports the clean-tech industry. CleanTech sent an email to its members with some background information on the study as well as directions on how to apply online.
- UCSD Electric Vehicle Email: University of California San Diego has an electric vehicle charging program. This program generated an email to its members with information on the study and directions on how to apply online.
- San Diego Gas & Electric: SDG&E sent both an email and paper mailer to customers who have dropped out of a demand response program.
- Baker Email: Baker Electric sent information on the program and directions on how to apply to its San Diego customers.
- Center for Sustainable Energy Outreach: The Center for Sustainable Energy undertook multiple outreach efforts including advertisements through Facebook, Twitter, and LinkedIn; an email campaign through Grid Alternatives targeting low-income communities in San Diego; and presentations at various community meetings throughout San Diego County.
- Other: Some applicants to the program did not recall where they heard about the Smart Home Study and are represented in this grouping.

The distribution of sources where applicants stated where they learned about the study is illustrated in Figure 16: Applicants by Outreach Source. The largest source of applicants was Baker Electric customers (34 percent). The next largest sources were SDG&E customers who had dropped out of earlier demand response programs, and the grouping of those who could not recall how they heard about the study, both at 21 percent. An example of an outreach email used in the study to encourage individuals to apply is in Appendix A.

Figure 16: Applicants by Outreach Source



Source: Itron

Recruitment Challenges and Solutions

Recruiting 100 participants brought about many challenges. Despite the recruitment challenges, the SHS only had one participant drop out during the pilot phase.

Green Button Data

Homes that passed the website eligibility process were asked to submit their Green Button energy usage data to help determine if their load profiles were a good fit for the study. While clear instructions were provided on how to obtain Green Button data via the customer's SDG&E portal, the requirement for customers to download their own usage data presented some recruitment challenges. The SHS call center helped many customers access their Green Button data, however there were some applicants who did not upload their data and could therefore not be considered for participation in the study.

Energy Usage Assessment

The Green Button hourly electricity usage data was analyzed for each applicant to determine the likely impact of the study on both the household and the grid. The first analysis looked at the potential bill impact of moving the household from SDG&E's tiered rate to the TOU rate applicable to the study. The second assessment reviewed the household's load shape and paid close attention to the average hourly summer shape to determine if the study's controls and technologies would likely result in changes to the household's load shape that would improve reliability of the grid.

Using 12 months of Green Button electricity usage data, the study team calculated the home's electric bill under a tiered DR rate and under SDG&E's SES TOU rate. This calculation is an estimate of the impact of the rate change and does not consider the potential load shift associated with study participation. In some cases, the study did not receive 12 months of usage data because an applicant's' existing SDG&E accounts were fewer than 12 months old. These applicants were sometimes difficult to fully review. In many cases, if summer data were available, a manual review of summer-usage patterns was sufficient to determine study eligibility.

Homes passed the first energy usage assessment if their utility bills were estimated to decline, or only increase by $150 or less, following a rate change from the tiered DR to the SES TOU rate. The assessment of the first-order bill impact of moving from the tiered DR to the SES TOU rate was implemented to ensure that the study had a high probability of saving money for participants. During the study, participants had bill protection for increases in their electricity bill associated with moving from the tiered to the TOU rate (see Chapter 2 Onsite Recruitment - Bill Protection Section below). Following completion of the study, however, participants forfeited that bill protection and will not be allowed to return to the tiered rate. The first usage data assessment minimized the number of participants whose bills are likely to increase following study participation.

Time-of-Use Rate

During recruitment, the project team found it exceptionally difficult to persuade customers to move from a tiered rate to a TOU rate. Even in cases where the customer would save money, many participants were unwilling to risk their tiered rate. Many SDG&E customers with solar were grandfathered into tier-based rate schedules that are no longer available; therefore, if a utility customer opted to switch to a TOU rate for the Smart Home Study, they could not return to their grandfathered rate. This was a major barrier for many applicants. To mitigate this challenge, the project team allowed study participants to remain on a tiered rate if they understood that this choice forfeited their access to bill protection. While the program could still apply and study technologies based on the suggested TOU rate, allowing customers to remain on their grandfathered tiered rates increased the desire of many applicants to participate in the study.

Participant Load Shape

Reviewing a customer's load shape and paying close attention to the time of a customer's electricity production and usage together helped ensure that the study's participant loads represented the types of loads contributing to grid insecurity. This step focused on customer energy usage during SDG&E's peak periods. To ensure that the customer had a large evening load, average hourly summer electricity usage between 7 p.m. and 9 p.m. was calculated for each home. Homes with large average evening electricity consumption were maintained for additional assessments. Homes with lower evening electricity consumption have less evening load to shift to other periods of the day.[7]

Customers with electric vehicles often charge their cars as soon as they arrive home from work in the evening when demand on the grid is greatest but solar PV production rapidly declines to zero. For homes with electric vehicles, the study encouraged vehicle charging from midnight to

[7] SDG&E's TOU SES rate has a peak period from 4-9 p.m. The summer evening load analyzed the 7-9 p.m. load to eliminate hours where PV systems are likely to be producing in the summer.

6 a.m., which is SDG&E's super off-peak period. Limited opportunities existed to improve the load shape of customers who were already charging their vehicles during this period. To focus study participation on homes with charging patterns that contribute to grid instability, the study team calculated the ratio of the average electricity usage from the utility at midnight relative to their 7 p.m. to 9 p.m. utility electricity usage. The larger the ratio, the more likely the homeowner was charging his or her electric vehicle at midnight. The study team reviewed the load data for sites with larger ratios to determine if there was potential to shift additional evening load from the SDG&E on-peak period. Homes with a large midnight to evening ratio were usually excluded from the study because their load shapes were not contributing to the head of the duck curve to the same degree as homes with a smaller midnight-to-evening ratio. Another unforeseen challenge with this metric was the load shape from multiple electric vehicles in a single home. There were some cases when the program found homes charging multiple electric vehicles using a single charger by moving the charger from one vehicle to another when the first had charged. Dual (or in one case, triple) electric vehicle homes make it very difficult to shift electric vehicle charging load because the vehicles may require being plugged in over both the evening (6 p.m.to 12 a.m.) and the early morning (12 a.m. to 6 a.m.) time periods.

Onsite Recruitment

Homes passing the website eligibility criteria and the Green Button data analysis were referred to on-site data collection. During on-site data collection, a project team engineer visited the homes and further reviewed their eligibility for the study, identifying the types of equipment that could potentially be installed. Equipment installed at all homes included a Honeywell Lyric T6 Wi-Fi thermostat to control the AC and a gateway to record the home's utility energy consumption. Homes with PV were also inspected to receive an OpenWay meter to record the PV's energy production. Thirty homes with electric vehicles received a Webasto EVSE-RS Level 2 charging station and 30 homes received a Sonnen batterie eco energy storage system. Initially, the study planned to install an OpenWay meter to record PV generation at all homes with solar; however, the installation of these meters could invalidate existing warranties. Therefore, only participants who had no warranty or were under a Baker Electric warranty received the OpenWay meters to measure their solar production.

Study participants were grouped into four tiers. A tier 1 participant received a smart thermostat. A tier 2 participant received a smart thermostat and an electric vehicle charger. In some cases, this replaced a level 1 (120v) wall socket charger, in others it replaced a level 2 (240V) charger. A tier 3 participant received a smart thermostat and a BESS system. And, a tier 4 participant received a smart thermostat, electric vehicle charger, and BESS. Table 3 shows the distribution of equipment for the 100 homes chosen to participate in the Smart Home Study.

Table 3: Smart Home Study Tier Distribution

Tier	Number of Participants	Equipment Received
Tier 1	50	Smart thermostat
Tier 2	20	Smart thermostat and electric vehicle charger
Tier 3	20	Smart thermostat and BESS
Tier 4	10	Smart thermostat, electric vehicle charger, and BESS

Source: Itron

During the on-site data collection, the field engineer inspected and scored the site's existing technologies (PV, AC and thermostat, electric vehicle), while also scoring both the site and smart home technologies, based also on ease of installation. A score of 10 meant that the engineer believed that the installation of a specific technology would go smoothly while a score of 0 indicated that the home and technology were incompatible. Thresholds for scoring, in combination with the sample design for the distribution of technologies and climate zones, were used to determine a home's priority to receive technologies.

Additional electrical information was collected for customers who either owned electric vehicles or looked to be a good match with a BESS. The electrical information was used in load calculation forms that provided electricians with enough information to determine if a permit application would be successful. The preliminary site visit form included a grading scale for all customer smart equipment. Customers who received the highest scores for the installation of smart equipment were offered the opportunity to participate in one of the tiers.

After the electrician's review, the acceptance of designated equipment by the potential participant, and approval from the customer's county jurisdiction holding authority, installation of the electric vehicle charger and/or BESS was scheduled with the customer. The study discovered that the length of time required to get these permits from the different jurisdiction holding authorities throughout SDG&E's territory varied substantially. As the study approached equipment installation deadlines, recruitment was targeted in areas with quicker permit turnaround times.

Table 4 shows the number of customers who proceeded through each step of the site selection process.

Table 4: Smart Home Study Selection Process

AC	PV	Electric Vehicle	Target Number	Applicants	Preliminary Sites	Installed Sites
Yes	Yes	Yes	20	133	68	45
Yes	Yes	No	68	176	78	46
Yes	No	Yes	12	44	19	9
Total			100	353	165	100

Source: Itron

Note that "yes" in columns AC, PV, and Electric Vehicle show that a customer had those technologies before the preliminary site visit. Due to the over application of electric vehicle customers, some of the customers with electric vehicles did not receive Level 2 electric vehicle chargers. The selection process is further described starting with the "Applicants" column and moving right to the "Installed Sites" column.

Every participant was considered for the installation of the BESS. However, during the recruitment phase of the study, it became apparent that there were multiple hurdles to installing a BESS.

Preliminary inspections found that a home's main electric-panel capacity often limited its ability to accept a BESS. Installing advanced energy storage in a customer's home requires approximately 20 percent of the main electrical panel amperage capacity, meaning that all the electrical equipment in the house cannot be rated to use more than 80 percent of the capacity the utility is providing. Many older homes without panel upgrades or major reconstructions or additions have main service panels with between 100-125 amperages. Typical residential appliances, including air conditioners, washing and drying machines, dishwashers, and ovens limit the ability of these older panels to add a BESS. Homes with main service panel amperages of 200 or more were often good candidates for a BESS, however, each home's existing electrical equipment had to be examined and recorded to confirm that additional electric loads could be installed.

There were multiple BESS sizes available as part of the program. Once it was determined that a household could safely handle the extra amperage from advanced energy storage, additional review was required to determine which size system the participant should receive. While these systems are traditionally sized to match the PV rating, the SHS sought to size batteries based on peak grid consumption, which effectively provided larger BESS households with higher energy usage from 4-9 p.m. The resulting distribution of participants can be found in Table 5.

Table 5: Smart Home Study Distribution of Technologies

AC	PV	Electric Vehicle[1]	Storage	Installed Sites
Yes	Yes	Yes	Yes	11
Yes	Yes	Yes	No	34
Yes	Yes	No	Yes	18
Yes	Yes	No	No	28
Yes	No	Yes	Yes	1
Yes	No	Yes	No	8
Totals				100

[1] **Some participants had existing EV chargers and are marked as yes under the EV column; only 30 chargers were installed as part of the study.**

Source: Itron

Bill Protection

Given that the study manipulates a homeowner's electricity usage, the impact on customer bills must be considered. Bill protection was an incentive offered to participants of the Smart Home Study. If the participant switched to the requested TOU rate they were guaranteed to pay less than or equal to the amount associated with their former rate and their current electricity usage during the length of the study. Participants were asked to enroll in the DR-SES TOU electric billing rate; however, participants were not required to change their rate.[8] Participants who did not change to a TOU rate did not receive bill protection during the study.[9]

The study assumed that all customers were on a TOU rate (as illustrated in Figure 17). Many customers were able to reduce their electric bills by switching to a TOU rate and shifting the timing of electricity consumption. Additionally, during Phase 2 of the study, household load was optimized for a simulated dynamic rate. Customers who had switched to the DR-SES TOU rate were able to receive protection for any increase in their electric bills during these dynamic rate experiments.

Figure 17: SES TOU Electric Billing Rate

Source: SDG&E, 2019

At the conclusion of the study, participants were able to choose from available SDG&E rates. However, net energy metering (NEM) rate holders, who were grandfathered into a tiered or

[8] During the initial part of customer implementation, SDG&E implemented a new EV rate, EV-TOU-5. Customers with an EV were referred to this rate if it was estimated to provide bill savings relative to the TOU DR-SES rate. The DR-SES and EV-TOU-5 have the same summertime periods, just different rates and fixed charges.

[9] Use of a BESS on a tiered rate (DR rate) will lead to an increase in the customer's electricity bills.

older rate, were advised that if they enroll in a TOU rate they would be ineligible for their previous tiered-based NEM rates once the study was over.

Field Operations Summary

This section summarizes field work undertaken to recruit, install, and maintain equipment for the 100 participants in the Smart Home Study. The official one-year pilot ran from December 1, 2018, to November 30, 2019. Supplemental information on installation and field service appear in Appendix B.

Field Work

The field work can be grouped into three sections, preliminary site visits, installation visits, and field service visits. On-site forms were used to record information for the preliminary and installation site visits, and the IntelliSOURCE system was used to record equipment status and customer communication during installation and field service visits.

Preliminary Visits

Preliminary site visits were completed for 151 recruits for the study. The purpose of the preliminary visits was to determine which customers would fit best with the goals of the program. These visits collected general information about each customer’s house including electrical information, square footage, and the number of occupants. Specific information about each type of equipment proposed for installation was also collected. Some examples of the information gathered for each equipment type follow.

Cradlepoint hotspots served as independent, secure Wi-Fi connections for the installed equipment. For the Cradlepoint hotspots, the on-site engineer would confirm which provider (Verizon/AT&T) had better service at each home. For homes where neither provider had good service, a Wi-Fi range extender was selected to extend the customer's Wi-Fi and provide an internet connection. The on-site engineers also checked in the garage if there was an outlet that wasn’t controlled by a switch where they could install the hotspots and gateways to confirm that they were continuously powered.

The project required separate Rainforest Eagle-200 gateways, one to connect to the house utility meter and one to connect to project team-installed PV meters. These gateways connected to the meters via Zigbee and communicated household energy usage and PV production. The preliminary site visit collected existing utility meter information and confirmed that the PV meter installation area complied with code requirements. The on-site engineer would also collect customer PV system information including make, model, size, and orientation.

The preliminary site visit collected the customer’s heating, ventilation, and air conditioning (HVAC) system information for the Honeywell Lyric T6 thermostat installation. They determined whether the wiring configuration was compatible with the new thermostat by confirming that the existing thermostats were powered by a common or C wire and not BESS powered. The preliminary visit also required that the HVAC system could complete a 10°F (5.6°C) rise and drop successfully, by adjusting the thermostat and recording the difference in temperature at the supply vent with a temperature gun in order to receive a smart thermostat.

Each preliminary site visit evaluated a customer's home and its electrical panel for a BESS. The preliminary visit determined if the customer's home met physical space requirements for the batteries. The batteries were required to be indoors on a flat concrete surface with 3 feet of space to the left and sufficient room in front to open the cabinet doors. They also had to be within 8 feet of the main service panel to connect the current transducers. The customer's home also had to meet certain electrical requirements to be permitted for advanced energy storage. The preliminary visit recorded the customer's main panel amperage and completed load calculation forms. These forms inventoried current electrical equipment and were used in calculations to determine whether there was sufficient amperage to install advanced energy storage.

For customers with an electric vehicle, the preliminary visit collected information pertaining to installation of the Webasto Level 2 electric vehicle charger. The preliminary visit confirmed whether a home was prewired for a Level 2 charger; some customers already had Level 2 outlets. Like the batteries, the visit would confirm that spatial requirements for the charger were met, both physically for installation and for the cord to run between the charger and the vehicle. The chargers came with 15-foot or 25-foot charging cables. The preliminary visit also confirmed the electrical requirements for the charger, including the main panel amperage and electrical inventory through the load calculation form.

During preliminary site visits, the project team considered installing demand-control units on the customer's pool pumps. The demand-control units are only effective on single-stage pool pumps since their control is only on or off. Demand-control units for the pool pumps were not installed because most customers with pool pumps already had variable-speed drive controls. The preliminary site visit recorded pool pump horsepower, control type, and schedule.

Like the pool pump demand-control units, the project team originally planned to install demand-control units on electric water heaters. The team found that most of the participants did not have electric water heaters, so no water heater demand-control units were installed. In the cases where electric water heaters were found, the preliminary site form collected heater maker, model, set point, and rated wattage and amperage.

The preliminary visit also collected general information about each home to help better understand its energy consumption. This general information included building age, square footage, number of floors, number of occupants, and general household schedules.

Installation Visits

Based on information collected during the preliminary site visits, 100 participants were selected to receive equipment. The equipment installed included Cradlepoint hotspots, house and solar gateways, solar meters, thermostats, batteries, and electric vehicle chargers. For hotspots, gateways, thermostats, and some electric vehicle chargers, a project team field technician installed the equipment; collected information; and set the equipment up to be monitored in IntelliSOURCE. For solar meters, batteries, and some electric-vehicle chargers an electrician was required to perform the installation work. The equipment installed and information collected for each equipment type are described below.

The hotspots and house and solar gateways were associated with the customer's site ID and paired with the meters before the site visit. The field technician installed the equipment (gateways and, if included, EV charger and BESS) in the garage. Gateways were connected to the hotspot via ethernet cable to provide the most secure connection. Due to warranty issues, the solar meters could only be installed on PV systems that had been installed by the partner electrical company or on PV systems out of warranty.

Field Operations Challenges and Solutions

During recruitment and installation, the project team encountered some unforeseen challenges. This section summarizes those challenges and the solutions adopted for thermostats, electric vehicle chargers, and batteries. They can be categorized in two groups: physical restraints and permitting challenges.

Physical Constraints

The preliminary site visits found multiple physical constraints in installing the equipment.

Thermostats

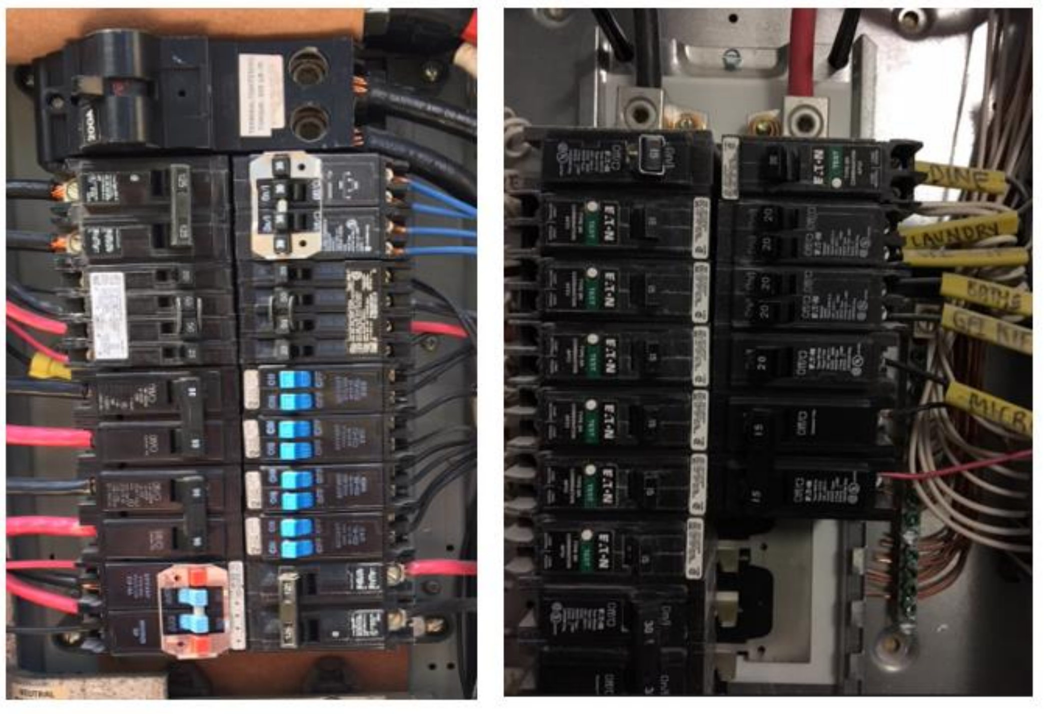
Physical challenges for thermostats were largely related to how the existing HVAC system and thermostat operated. Existing multi-zone HVAC systems are systems with one HVAC unit but more than one thermostat. These systems required additional testing. For multi-zone systems, both thermostats were tested individually and then together to confirm that both areas of the home were served properly by the HVAC system before installing the new thermostat equipment. Some wiring challenges were encountered in homes with heat pumps. These systems required the thermostats to be wired differently. Lastly, if the existing thermostat was not powered by a common wire (C wire) but instead powered by batteries, an add-a-wire kit was installed. These kits optimize the existing wire configuration to create an additional wire to power the C terminal, a necessity for smart thermostats.

Advanced Energy Storage and Level 2 Electric Vehicle Chargers

The largest physical constraint associated with installing an advanced energy storage or Level 2 electric vehicle charger in a home was the required physical space in the electric panel. Both pieces of technology require breakers to the panel to accommodate the equipment. In many homes, there were limited breaker slots, further restricting the number of houses that were eligible for installing these technologies without subpanel additions or panel upgrades, an additional expense not covered in the study's budget.

Figure 18 shows photos of two breaker panels, the left has insufficient room and the right has room for additional breakers. All available breaker slots on the bus bar for the left panel are occupied. A panel such as this necessitates installation of a subpanel to move load to free up space for the additional 40-amp breakers. On the right is a panel with empty breaker slots where additional breakers can be easily inserted at minimal additional cost.

Figure 18: Breaker Panels Without and With Room for an Additional Breaker



Source: Itron

Adding subpanels or upgrading the main panel can increase the cost of electrical upgrades and additions by over $3,000 per home. Another key issue was that many residences in San Diego are multi-unit, apartment, townhome, or condo communities. These homes face additional electrical challenges, including main service upgrades that require additional planning, permits, and coordination with the utility. In some cases, the power might be shut off to the house or to the entire building so the service can be upgraded to provide more power.

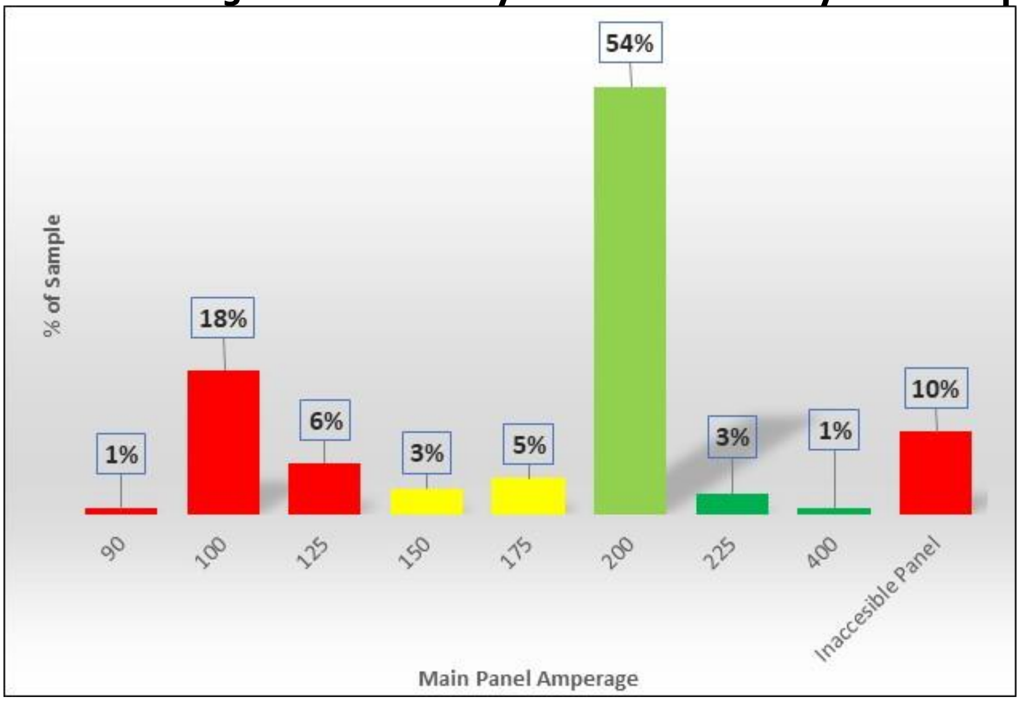
Another common issue for installation of electric vehicle chargers or a BESS was the distance from the breaker panel to the garage. Long distances from the breaker panel to the installation location require additional wire run, conduit, and occasionally trenching or wiring through walls or rooms. Since the garage is typically where advanced energy storage and electric vehicle chargers are installed, these issues can increase cost and prevent installation and are common in apartment, townhome, or condo residences, as well as in homes with detached garages.

Permitting

Preliminary inspections found that many sites were unable to accept advanced energy storage or electric vehicle chargers solely because of their main electrical panel capacity. Without enough electrical capacity, a customer's home would not pass the permitting process.

Figure 19 highlights in red the main-panel capacities that generally make a customer ineligible to add either a Level 2 electric vehicle charger or advanced energy storage because of safety and code-compliance concerns. Yellow highlights indicate that the customer may be eligible, and green highlights customers who would likely be eligible.

Figure 19: Percentages of Preliminary Sites Main Panel by Rated Amperage



Source: Itron

A BESS or Level 2 electric vehicle charger requires an additional 40-amperage breaker to the breaker panel. Generally, houses with main panel amperages under 150 amps would not be approved for permitting without a main panel service upgrade. The column listed N/A represents sites where the main panel could not be accessed, usually due to locked rooms in condo or townhome residences. These types of multi-unit residences typically had lower-than-required main panel amperages unless they were new construction.

The columns highlighted in yellow show panels that could potentially add an electric vehicle charger or BESS but were highly dependent on other electrical equipment at the house and were therefore unlikely to be capable of receiving both technologies. Houses with already-large electrical loads such as multiple air conditioners, pools, washing machines or electric drying machines, and ovens, may not be able to handle the additional amperage required for the project equipment.

The light and dark green columns show the homes with main service panels with higher amperage capacities. Generally, these were more likely to be approved for permits and selected for advanced technology installation because of their larger capacities.

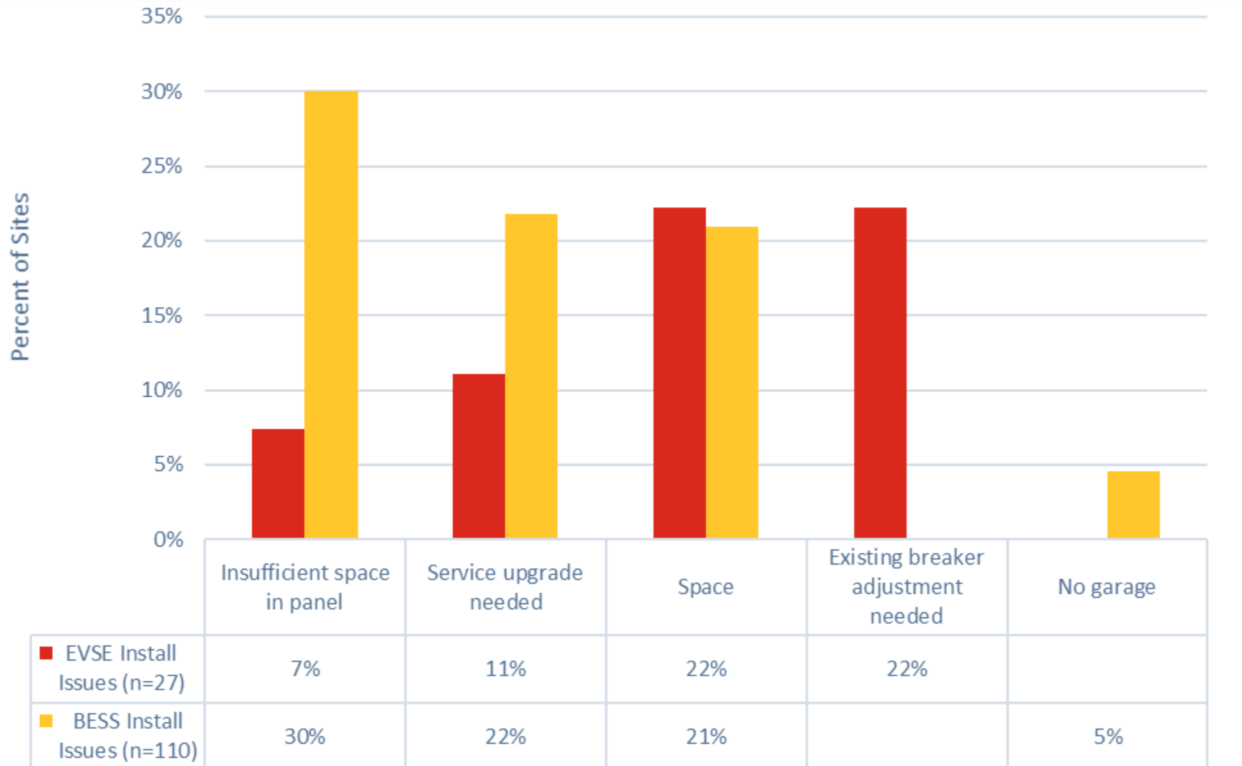
Many homes with higher main-panel amperages also had more square footage and larger pre-existing electrical loads. These homes could require more air conditioning or include other large electrical loads such as pool pumps or spas. Load calculations were required for all applicable homes after the initial electrical capacity audit.

Findings

As part of the preliminary on-site survey, field technicians were instructed to keep notes and supply a 1-10 grading score for each potential type of equipment. These notes provided information on common situations and potential issues encountered at customer houses.

Figure 20 illustrates the percentage of homes with comments, noting potential issues for Level 2 electric vehicle charger installations. The chart categorizes these issues into five bins.

Figure 20: Electric Vehicle Supply Equipment and BESS Issues



Source: Itron

Figure 20 shows the general categories of comments from on-site engineers regarding potential installation issues with Level 2 electric vehicle chargers or BESS. There were 87 preliminary sites where surveys were completed for customers who owned an electric vehicle. From these site visits, there were 27 comments regarding potential issues to installation at 27 of the 87 homes visited. A home could have more than one issue, but for the most part, the biggest issue was recorded.

Some of these issues would not necessarily eliminate a customer from installation but are shown to provide context to potential hurdles for residential Level 2 electric vehicle charger installation.

- The most common issue encountered was that the main panel was too far from the garage, which occurred in townhomes or condos.
- The next most prevalent issue was a breaker upgrade. For these customers, the home had an existing 30-amp breaker; however, the Level 2 charger requires a 40-amp breaker. In some cases, if the 30-amp breaker wire gauge was large enough, the upgrade was an easy switch. For others, if the existing wire gauge was too small, it required a complete rewiring of the circuit.
- A third issue was a lack of space to install the charger, usually the result of shelving or clutter in the area where the Level 2 charger would be installed.

- The fourth most prevalent issue was that the main service amperages were too low to accommodate Level 2 electric vehicle charger installation without a main service upgrade.
- The final issue frequently encountered was a lack of physical space in the main panel.

Similar to the issues noted for electric vehicle chargers, the on-site engineers also noted issues associated with the installation of a BESS.

Data Collection and Analysis

The SHS required data from many different sources to identify, inform, and develop strategies that expand the use of residential DERs. This section illustrates many various data sources.

Initial Recruitment Data: Online Applications

The initial recruitment was done with an online application form on the SHS website (form removed following the recruitment stage). This initial application included a request for applicants to upload their SDG&E Green Button data (along with instructions for how to download the data from their online SDG&E account). Once received, the project team was able to take the following actions.

- Analyze the number of applicants by inland or coastal region, technology mix, and energy-usage patterns.
- Compare how energy usage varies by technologies already in an applicant's home. Examine overall energy-usage statistics from applicants (only available for those who supplied Green Button data).

On-Site Survey Data

Once a self-reported online application had passed the initial review by the project team, an engineer visited the applicant's home. Engineers verified that the information provided by the applicant was accurate and collected additional site-specific information and measurements of electric load and capacity to determine which technologies would be best suited for the home. The data on the home was recorded on a form and later entered a database to store, compile, and analyze. These on-site measurements provided critical information:

- Panel amperage as compared to building vintage; it is very difficult to install batteries and electric vehicle chargers in households with lower amperage.
- Existing technology in the home compared with building vintage
- Pre-study average household energy usage for homes given technologies already installed in an applicant's home
- Energy-usage patterns and how these patterns differed for participants who passed the on-site inspection and those who did not

Technology Data (Installation)

Following the recruitment phase of the project, the new technologies were installed based upon the participation tier of each household. To determine the home participation tier, the project team analyzed pre-installation energy-usage patterns. This information was also used to determine BESS sizing for homes receiving a BESS.

Usage Data

The SHS installed various methods of measuring and studying energy usage within a participant's home. This energy usage was used both to install smart controls in the household and to analyze energy-usage patterns and the success of RDERMS in shifting load to lower-cost time periods. The following comparisons were undertaken with the energy-usage data.

- Baseline versus study period usage and billing data (by installed technologies to determine which had the greatest impact on energy usage, cost, and changes in energy-usage patterns)
- Usage patterns and changes in electricity costs for households that changed to TOU rates and those that did not
- Load shapes by technology to learn about how given end use impacts overall customer load shape

Weather Data

While no analysis was done on weather data alone, weather data was used to generate forecasts for the RDERMS control technology. This data came from DarkSky.net and provided site-specific hourly data.

Pricing Data

To study both actual and simulated bill impacts, a good understanding of pricing schedules was required. Both actual rates available at the time of the study from SDG&E and simulated day-ahead dynamic-pricing rates from EPRI were included in the rate analysis. The project team also performed a rigorous rate analysis using these rates to study bill impacts and their costs to customers under various billing scenarios.

Final Survey Results

Following the study, a final survey was administered to obtain feedback from participants. These results were used to both understand the customer experience and how their energy usage might change in the future as a result of the study. Given the small sample size of the study, survey results were limited to qualitative information, which can be used to better understand the overall impacts and customer satisfaction with these smart technologies.

CHAPTER 3: Project Results

The project team used three methods to analyze project results:

- Rata Analysis and Tariff Assessment: an analysis of the potential impact on customer energy use and bills based on responses to price signals
- Benefits Questionnaires: Surveys completed at the end of the study evaluated participant views of the study and its technology benefits
- Energy Costs and Impacts: observed changes in participant energy usage and costs

Rate Analysis and Tariff Assessment

This section describes the analysis and modeling that the project team used with observed data from study participants prior to demonstrations, to better understand the effects of different rate structures on customer costs, with or without ideal operational patterns for DERs. The project team further investigated the correspondence between time-varying utility costs and greenhouse gas emissions and developed an innovative rate structure based on market signals that could result in reduced greenhouse gas emissions without affecting utility costs.

List of Considered Rate Structures

Five SDG&E rate structures were evaluated to understand their effects on customer electric bills. The five structures were the Domestic Residential, Domestic Residential-Low Income, EV (electric vehicle) Time-of-Use 2 (EV-TOU-2), EV Time-of-Use 5 (EV-TOU-5) and Power Your Drive (PYD). Table 6 and Table 7 list the details of the Domestic Residential, Domestic Residential -Low Income, EV-TOU-2 and EV-TOU-5 rates. The TOU rates and rate periods vary seasonally and by weekday/weekend.

Table 6: SDG&E Tiered Rates

Billing Component	Domestic Residential	Domestic Residential -Low Income
Summer energy charges ($/kWh) – Tier 1	$0.26454	$0.16368
Summer energy charges ($/kWh) – Tier 2	$0.46375	$0.29396
Summer energy charges ($/kWh) – Tier 3	$0.54033	$0.34405
Winter energy charges ($/kWh) – Tier 1	$0.22379	$0.13703
Winter energy charges ($/kWh) – Tier 2	$0.39232	$0.24725
Winter energy charges ($/kWh) – Tier 3	$0.45711	$0.28962
Minimum bill ($/day)	$0.329	$0.164

Source: CSE

Table 7: SDG&E TOU Rates

Billing Component	EV-TOU-2	EV-TOU-5
Summer energy charges ($/kWh) – Peak	$0.52698	$0.51892
Summer energy charges ($/kWh) – Off-peak	$0.28888	$0.28082
Summer energy charges ($/kWh) – Super off-peak	$0.23393	$0.09302
Winter energy charges ($/kWh) – Peak	$0.25285	$0.24479
Winter energy charges ($/kWh) – Off-peak	$0.24427	$0.23621
Winter energy charges ($/kWh) – Super off-peak	$0.23475	$0.09384
Minimum bill ($/day)	$0.329	
Basic fee ($/month)		$16

Source: CSE

In addition to the Domestic Residential and TOU rates, the effect of the PYD rate, also known as the Electric Vehicle Grid Integration rate[10]—a non-residential hourly dynamic rate designed for vehicle charging, was assessed to examine its impacts on customers since a residential SDG&E dynamic rate was not currently available.[11] PYD rates are typically lower than EV-TOU-2 and EV-TOU-5 rates. However, during the time of day when the grid is constrained (such as in the late afternoon and early evening) PYD rates can be greater than TOU rates.

The annual customer bill was calculated for each customer and rate structure. The analysis showed that PYD is typically the most economical rate structure for large energy consumers, but the least economical for lower energy users. By contrast, the Domestic Residential structure is typically the most economical for households with lower consumption. This is because minimum bills and monthly fees contribute to a greater proportion of the final bill for households with low and, particularly, negative energy consumption. Another factor affecting bills for households with low energy consumption is that it is common for these households to have periods of excess generation and rate structures with lower rates that will receive generation credits at a lower rate than those with higher rates. All said, these general patterns are not consistent across all households showing that complexities, such as the period energy is consumed, can affect which rate is the most economical for an individual homeowner.

Ideal DER Dispatch for Each Rate Considering Customer and Grid Impacts

The project team then evaluated the potential impacts of RDERMS on customers and the grid.[12] In particular, the research project team estimated the cost impacts of optimized DER operations by comparing household consumption and bills with electric vehicle smart charging

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[10] SDG&E. 2017. *Schedule VGI.* https://www.sdge.com/sites/default/files/elec_elec-scheds_vgi.pdf

[11] Butler, Sabrina. 2016. Smart Pricing Program: Customer Outreach and Education Quarterly Briefing. https://www.sdge.com/sites/default/files/Q2%25202016%2520SDG%2526E%2520Interested%2520Parties%2520Briefing.pdf

[12] Day-ahead locational marginal prices for the SDG&E sub-load aggregation point for 2018 were used as proxies for grid costs.

and energy storage operations that were aimed at minimizing costs to scenarios with no storage and electric vehicle charging during the peak period (such as after-work charging). This was accomplished superimposing simulated electric vehicle and energy storage loads on observed customer load profiles. The optimized loads were determined using linear optimization techniques and applied to EV-TOU-2, EV-TOU-5 and PYD rate structures. The project team then repeated the analysis but tailored DER operations to minimize grid costs and, finally, another model that minimized the combination of grid costs and customer costs (the "dual-optimized" model).

The analyses showed that customer and grid costs were substantially reduced by managing electric vehicle and energy storage loads. However, these benefits varied dramatically by rate structure, commute distance (i.e., vehicle mileage), energy storage capacity and the electric vehicle model. By far, the rate structure that generates the greatest incentive for customers to shift loads was the EV-TOU-5 due to its low super off-peak prices with savings of over $1,000 per year for customers with 30-mile commutes and 8-kWh energy storage. By comparison, EV-TOU-2 and PYD customers with 30-mile commutes and 8-kWh energy storage would only average savings of approximately $500 and $300 per year, respectively. Due to differences in efficiencies, vehicle type also affected customer savings, but these differences were generally less than $50 a year. Shifting electric vehicle and energy storage loads to minimize grid costs resulted in grid costs savings of approximately $50–$300 per customer, primarily dependent upon the length of the commute (i.e., vehicle mileage), and energy storage.

These analyses demonstrated that managed operations of electric vehicle charging and energy storage can simultaneously provide considerable benefits to the customer and grid using existing SDG&E rate structures. Indeed, operational schedules for DERs were similar whether optimized for the customer or the grid in each analysis and, for every participant evaluated, customer bills and grid costs decreased when test operations took effect. This indicates that current TOU rate structures paired with dynamic grid cost signals can be used to construct price signals consistent with variable grid costs. The EV-TOU-5 rate, for households with longer electric vehicle commutes and larger energy storage capacity, provided the greatest savings when smart load-shifting technologies were installed. Table 8shows the scenarios with the most extreme customer-grid score for the dual-optimized model. Specifically, it shows that DERs can substantially reduce customer and grid costs, especially when the rate structure is EV-TOU-5 and there is relatively large DER load.

Table 8: Scenarios with Greatest and Least Savings for Dual-optimized Model

Savings	Rate Structure	Commute Length (miles)	BESS Size (kWh)	Vehicle Type	Annual Energy Consumption Difference (kWh)	Average Customer Cost Difference	Average Grid Impacts Difference	Average Customer-Grid Score Difference (10^2)
Greatest Savings	TOU-5	30	8	Model S	644	–$1224	–$282	–169
	TOU-5	30	8	LEAF	644	–$1141	–$245	–154
	TOU-5	30	8	Mi Electric vehicle	644	–$1118	–$240	–151
	TOU-5	30	4	Model S	379	–$1061	–$253	–148
	TOU-2	30	8	Model S	642	–$446	–$283	–133
Least Savings	TOU-2	5	0	LEAF	0	–$96	–$40	–21
	TOU-2	5	0	Mi Electric vehicle	0	–$93	–$39	–21
	PYD	5	0	Model S	0	–$59	–$45	–15
	PYD	5	0	LEAF	0	–$54	–$41	–13
	PYD	5	0	Mi Electric vehicle	0	–$52	–$39	–13

Source: CSE

Overall, the modeling results indicate that current SDG&E TOU rate structures provide considerable benefits to both utility customers and the grid through managed electric vehicle charging and energy storage dispatch. This indicates that current rate structures offered by SDG&E do encourage customers to use DERs in a manner that also provides grid benefits. However, greater grid benefits can likely be achieved by further aligning DER operations to forecasted or dynamic price signaling.

Other High Value Rate Structures

In addition to modeling existing SDG&E rates, the project team analyzed hypothetical rates designed to reduce both utility costs[13] and greenhouse gas emissions. Specifically, the research project team investigated the potential of two types of price signals to encourage residential customers to shift demand to periods of high renewable generation in SDG&E's service territory: retail rates and a wholesale market mechanism.

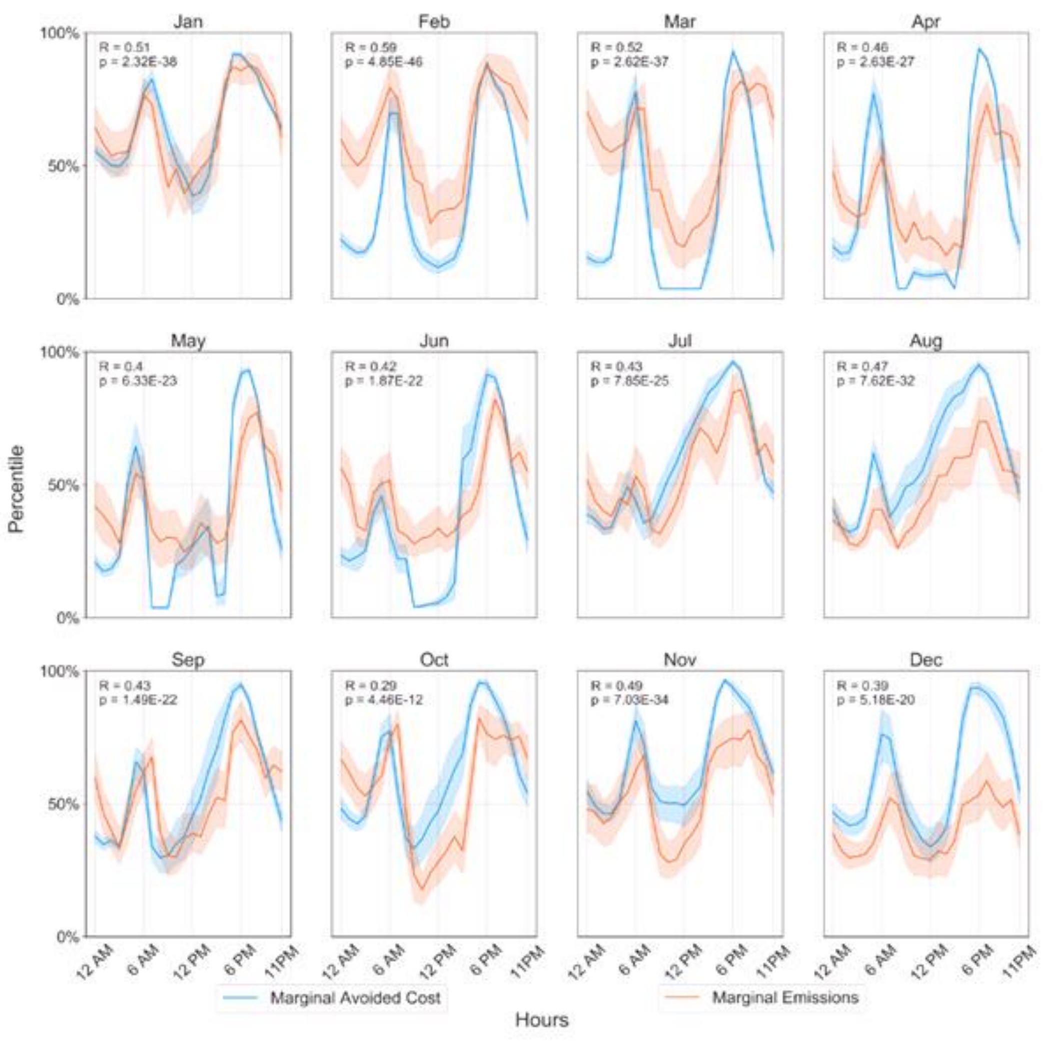
Retail Rate Analysis

In the retail rate analysis, the research project team assessed the degree to which utility costs and greenhouse gas emissions were aligned and examined opportunities to modify SDG&E's EV-TOU-5 to better align it with reducing emissions. The marginal avoided costs data were collected from the CPUC Avoided Costs Calculator. The model forecasts long-term marginal avoided costs to assess the impact of reducing load at different time intervals on utility costs. The marginal avoided costs were generated using the default settings for 2018 in SDG&E territory. Only data for climate zone 7 (CZ7) was used since a majority of SDG&E revenue comes from this zone and the marginal avoided costs were similar across all zones. The marginal emissions data indicate the change in emissions for a given load increase or decrease and were generated for the CAISO electric grid region SP-15, which contains the SDG&E territory, with the Automated Emissions Reduction model from WattTime. The data are hourly and provided in MT/MWh.

Figure 21 shows the mean percentile rank (99^{th} percentile would correspond to a value that is greater than 99% of all the values in the corresponding time-series) and 95% confidence intervals for marginal avoided costs and marginal emissions by month and hour for weekdays. The marginal rates were closely correlated by hour across all months (See correlation coefficient and p-values in upper left corner of subplots in Figure 21).

[13] Utility avoided costs from the Avoided Cost Calculator were used to determine utility costs.

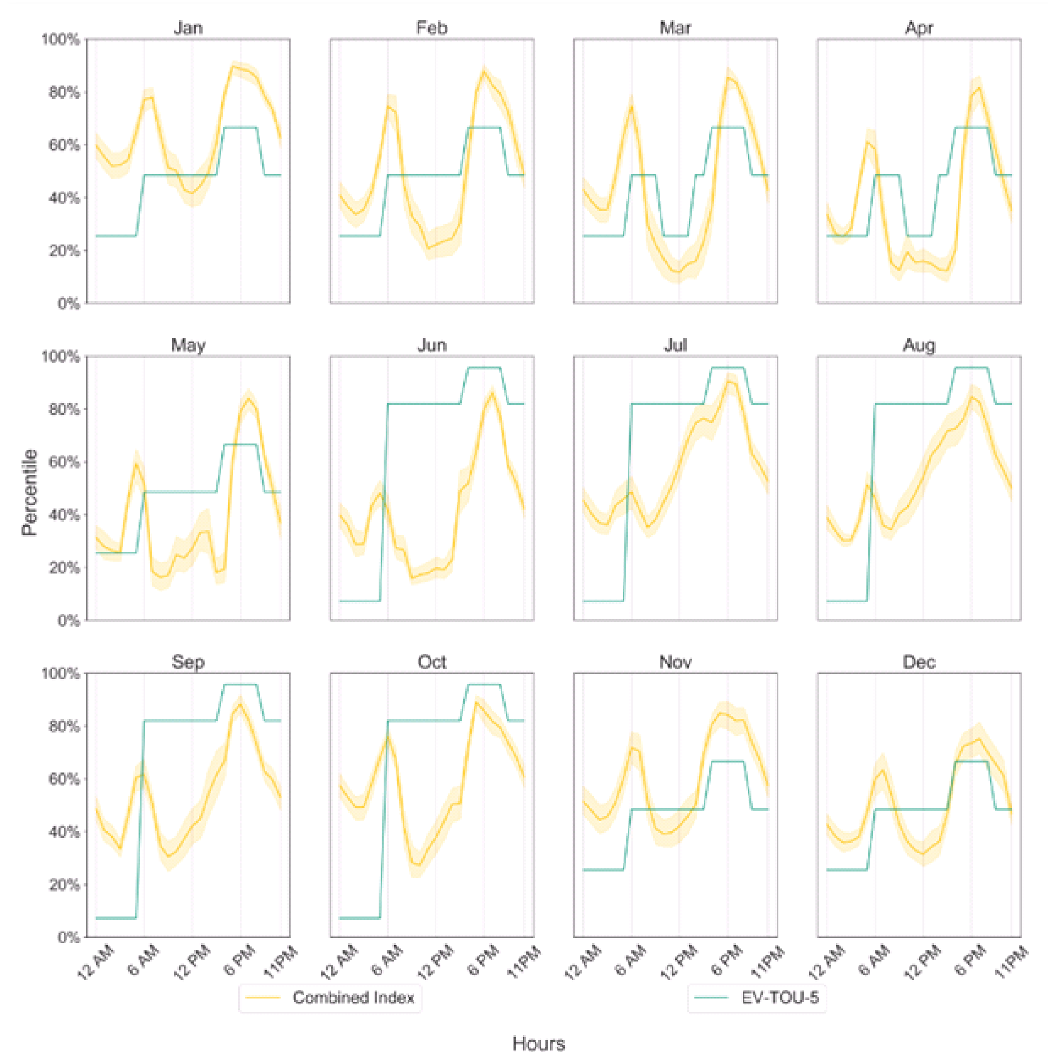
Figure 21: Weekday Marginal Avoided Costs and Marginal Emissions, by Month



Source: CSE

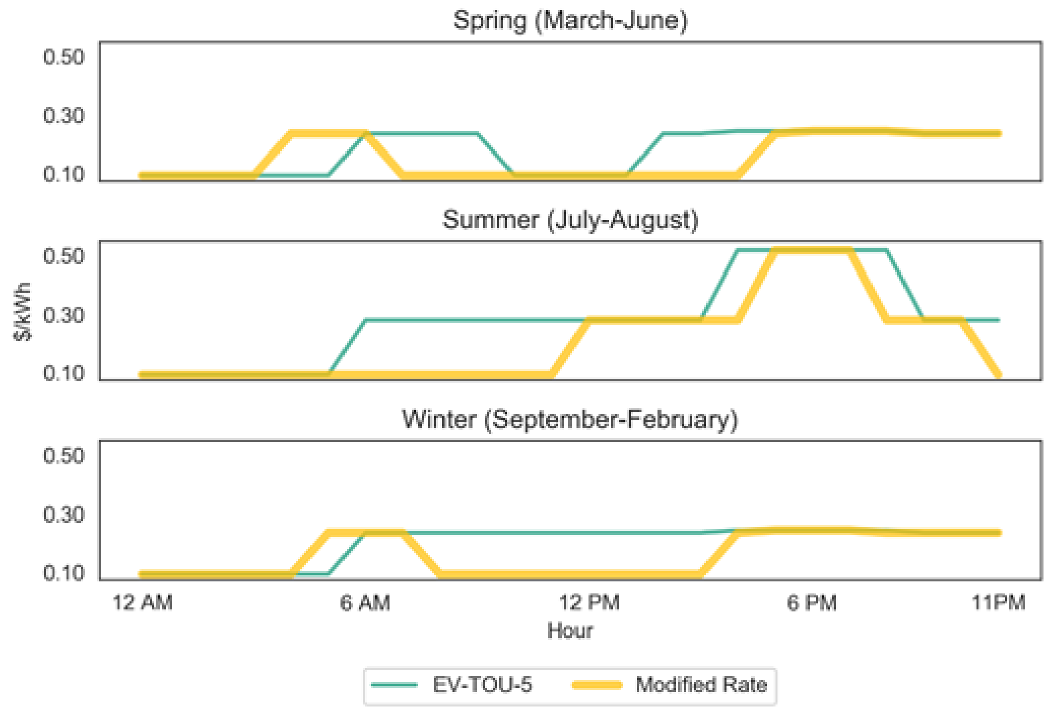
The project team then created a combined marginal emissions, or "combined index", and avoided cost rate that balanced utility costs with greenhouse gas emissions. Specifically, the research team calculated the average of the scaled marginal emissions and marginal avoided costs by hour and season to generate an index. Basically, a high index value likely indicates that both marginal avoided costs and emissions are high; and when the index is low it likely means that both marginal avoided costs and emissions are low. When the values are moderate it either means both marginal avoided costs and emissions are moderate, or one of them is high and the other low. A comparison of the combined index to EV-TOU-5 is shown in Figure 22. The figure shows that the existing EV-TOU-5 rate structure is generally aligned with utility costs and emissions, but there are opportunities to modify EV-TOU-5 so it corresponds even more closely with the combined index. Figure 26 shows how slight modifications to EV-TOU-5 can more effectively align with the combined index. Further, the analysis showed that the year can be divided into three unique seasons based on differences in the daily cycles of the combined index across months (Figure 24), which are slightly different than the seasonal definitions in SDG&E rate structures. Simulation with BESS and observed customer profiles showed that the modified rate structure creates a price signal that encourages consumption of cleaner electricity (such as, an average decrease of 0.03 metric tons of carbon dioxide per year for an optimized 8-kWh energy storage system), without substantially affecting utility costs.

Figure 22: Combined Index vs. EV-TOU-5 by Month and Hour for Weekdays



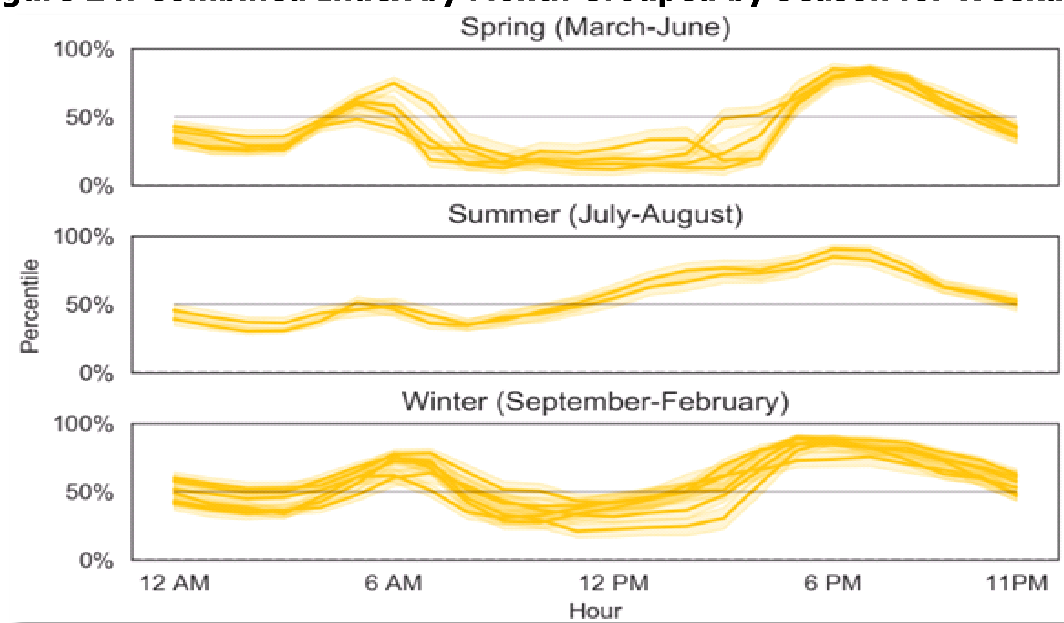
Source: CSE

Figure 23: Weekday Rate Structure Comparison (Combined Index and EV-TOU-5)



Source: CSE

Figure 24: Combined Index by Month Grouped by Season for Weekdays



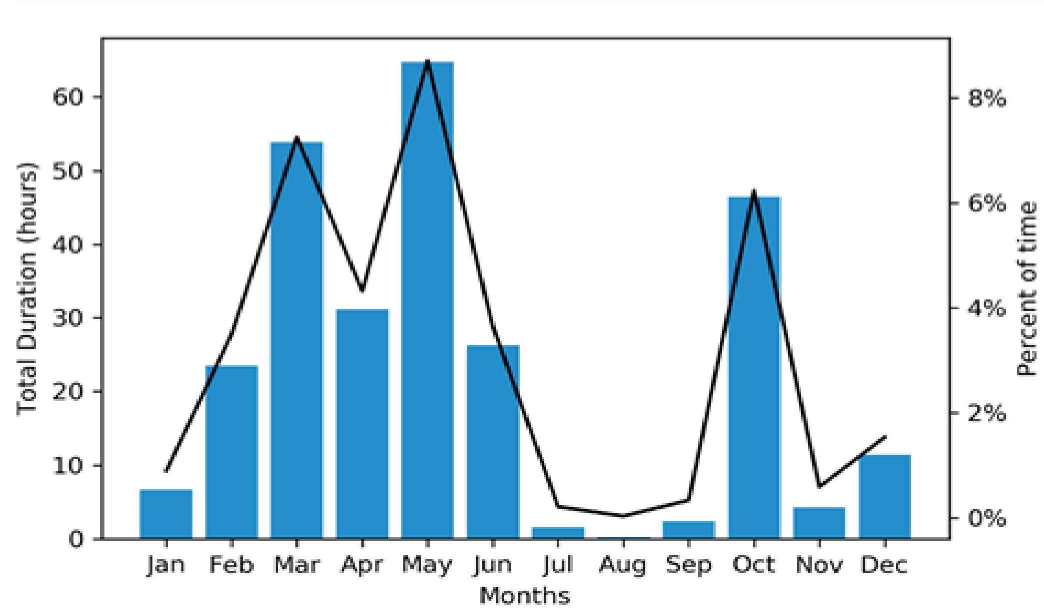
Source: CSE

Wholesale Market Mechanism

For the wholesale market mechanism analysis, negative wholesale-pricing trends were evaluated. Then the project team assessed the potential economic benefits to customers participating in the California Independent System Operator's (California ISO) proposed Load Shifting Resource product, which could allow customers with behind-the-meter energy storage to receive compensation through the wholesale market by increasing load during negative pricing periods. The researchers used 2018 California ISO real-time market prices for the SDG&E Sub-Load Aggregation (DLAP_SDGE_APND) price node.

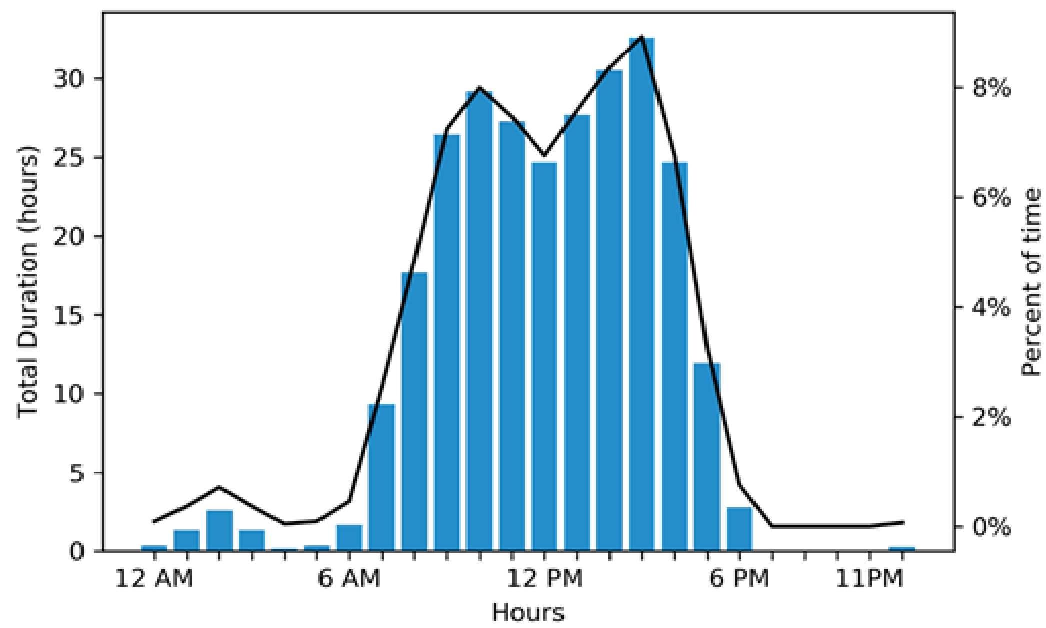
Seasonal variations in negative price frequencies are due to energy generation and demand patterns. Electricity demand is highest in the summer due to AC loads, which reduces the likelihood of oversupply and increases electricity costs. However, months that have both moderate temperatures and sunny skies have relatively low demand (limited cooling loads) and high solar generation, resulting in more frequent oversupply and negative pricing. Indeed, the total duration and frequency of California ISO negative prices by month occurred most frequently in the spring months and the least frequently in the summer (Figure 25). In all, negative pricing occurred for 273 hours (equivalent to more than 11 days) of the year. In addition to monthly and seasonal trends, there was substantial diurnal variability. Figure 26 shows the total time of negative prices (i.e., the sum of the duration of all negative price events in 2018) by hour of the day for 2018. Most of the negative price events were during daylight hours with negative prices present more than 5 percent of the time from 8 a.m. to 5 p.m. Negative pricing events peaked near 3 p.m. and represented 9 percent of all intervals during this period. There were also periods of negative pricing at night likely due to low demand and relatively high wind related generation.

Figure 25: Total Time of Negative Price Events by Month in 2018



Source: CSE

Figure 26: Total Time of Negative Price Events by Hour in 2018



Source: CSE

The results of the Load Shifting Resource product analysis showed that the economic benefit of increasing load during negative pricing intervals is relatively negligible. The maximum potential economic benefit for customers was $1.87/kW of load-shifting capacity per year. Thus, the forthcoming Load Shifting Resource product offered by California ISO will likely be insufficient to incentivize residential customers to invest in the DERs that would be required for customers to participate in the wholesale market, although it may be sufficient for households that already have the resources required to participate. However, the added cost of contracting scheduling coordinators and demand response providers would likely be more than the compensation of participating in the market Additionally, times of negative pricing may not coincide with customers' lowest retail rates. As discussed with SDG&E's EV-TOU-5 rate, some tariffs have their lowest-cost rates during overnight hours, which do not correlate with frequent times of negative pricing in the wholesale market. This complicates the value proposition given the uncertainty of a negative pricing event occurring (i.e., does energy storage charge overnight during the lowest rates or wait for potential negative prices during the day?). As such, TOU rates could be revised so that the lowest-cost hours are during solar generation hours, which have the highest occurrence of negative pricing and tend to be the periods of the lowest marginal emissions and avoided costs. This analysis does not, however, consider the economic value of providing energy or ancillary services in the wholesale market, so the Load Shifting Resource product, coupled with providing energy and ancillary services, could prove economic for customers. Additionally, curtailment and negative pricing are expected to increase in the coming years, which could allow the Load Shifting Resource product to increase in value.

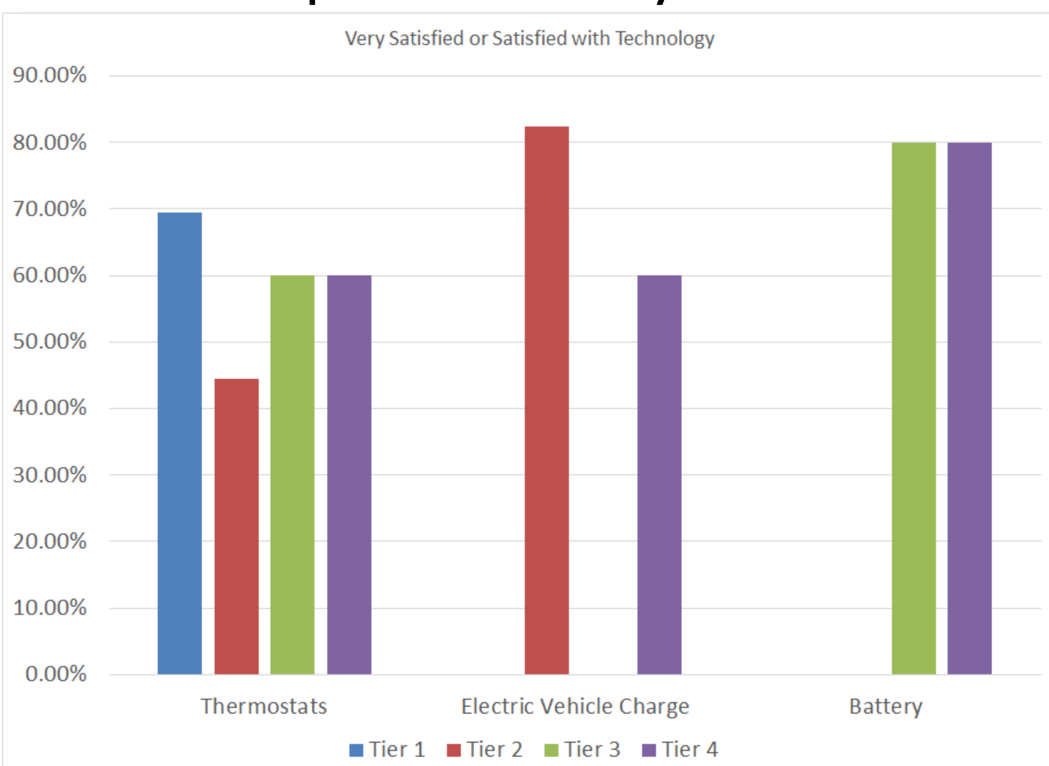
In summary, two types of price signals that encourage residential customers to shift demand to periods of high renewable generation in SDG&E's service territory were investigated: retail rates and a wholesale market mechanism. Incentivizing customers to shift loads to these periods through price signals could increase the consumption of renewable energy without increasing utility costs. Although this research showed that compensation from negative prices in the wholesale market by themselves currently do not offer a strong enough economic signal for behind-the-meter customers to participate in the California ISO's proposed Load Shifting Resource product, relatively minor adjustments to existing TOU rates in the SDG&E territory could build load during these hours and also reduce emissions.

Benefits Questionnaires

The project team asked participants questions regarding their experiences and feedback near the end of the study. A copy of the questionnaire appears in Appendix C. This questionnaire was administered using Survox. This service allowed the project team to start with an online survey and then use project team staff to call participants who did not either complete or open the questionnaire. Participants received a gift card for completing the survey.

Following the conclusion of the SHS, participants were surveyed to determine their satisfaction with the study. The survey included questions about the technologies, and their electric bill changes, and to determine if participants would continue to use the technologies. The survey began with general questions about how the participants learned about the study, what motivated them to sign up, and the anticipated benefits and concerns participants had prior to the study. The survey also questioned all participants about their satisfaction with the application and installation processes. Figure 27 presents the participant's satisfaction with the technologies, illustrating that over 80 percent of Tier 2 participants were satisfied or very satisfied with the Level 2 electric vehicle (EV) charger, while 80 percent of Tier 3 and Tier 4 participants were equally happy with their BESS.

Figure 27: Share of Participants Satisfied or Very Satisfied With the Technologies



Source: Itron

The technology controls in the SHS were designed to shift customer loads out of high-cost periods and into lower-cost TOU periods. The study asked participants to sign up for one of SDG&E's TOU rates if they were not already on one. To increase the likelihood that participants would change to a TOU rate, the study provided one year of bill protection and information on available TOU rates and how their bills would likely change under a TOU rate. The survey found that 80 percent of Tier 3 and 4 participants were satisfied or very satisfied with the information that the SHS provided concerning SDG&E's TOU rate options, while 61 percent of Tier 1 and Tier 2 participants registered this level of satisfaction. If participants changed to a TOU rate, they were questioned about their satisfaction with the new rate. No Tier 2, 3, or 4 customers stated that they were dissatisfied or very dissatisfied with the new TOU rates and only 3 percent of Tier 1 customers were very dissatisfied. The responses to these two questions show that SHS participants were generally well-informed concerning SDG&E's TOU rates, and that very few customers were dissatisfied with their decisions to change to a TOU rate. When provided the opportunity to state the primary benefits of the TOU rates, many customers commented on both their ability to save money and the low cost of EV charging. Dissatisfactions with the TOU rates included the high cost of AC during peak hours, the high cost to charge the EV, and the increased cost of using appliances.

At the end of the Tier-specific questions, participants were asked how satisfied they were with the experience of participating in the SHS. Survey responses show that 100 percent of Tier 4 participants, approximately 88 percent of Tier 3 and 2 participants, and 76 percent of Tier 1 participants were satisfied or very satisfied with their SHS experience.

The following subsections describe technology-specific survey results.

Smart Thermostats

All but two participants received a smart thermostat. Participants were asked about their satisfaction with the smart thermostats and about the features they used the most. Thermostat features commonly used by participants included setting HVAC schedules, using a phone app to change and monitor temperatures, and manually turning their HVAC on or off using the thermostat. Over 60 percent of participants in all tiers reported that they used the thermostat to manually turn their HVAC system on and off. The high share of participants manually operating their thermostat may be due, at least in part, to the temperate climate in San Diego and generally low HVAC usage.

SHS participants were asked if they would continue to use their smart thermostats to control the temperature in their home following the study. The results show that 86 percent of Tier 1 participants (SHS participants who only received smart thermostats), stated that they would continue to use their smart thermostats following the study. When asked to describe the benefits of the smart thermostats, many participants mentioned the ability to use their phones to control and monitor their HVAC system. When asked to describe the primary drawback of the thermostats, the most common response was "none," though some participants mentioned the thermostat's difficulty maintaining WiFi connectivity and difficulty programming the thermostat.

Level 2 Electric Vehicle Chargers

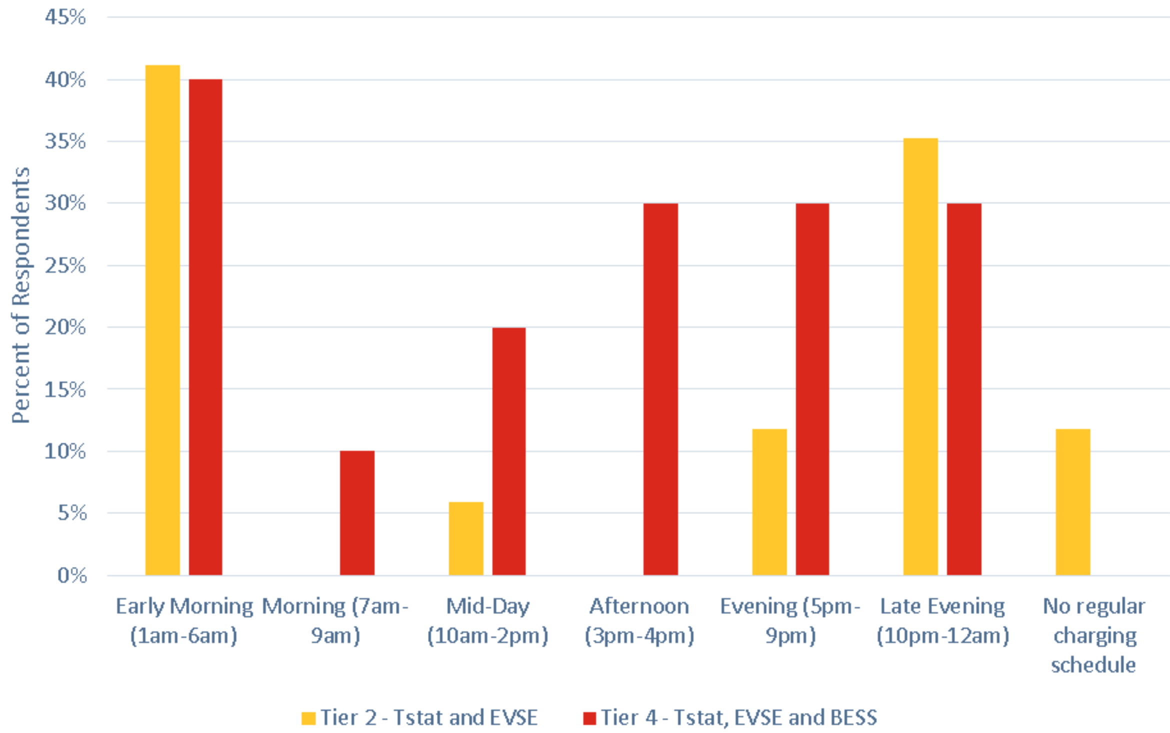
Participants in Tier 2 and 4 received level 2 EV chargers. The EV chargers had a magiclink delivered to their smartphone or email that informed participants that their vehicle would charge starting at midnight unless the pre-set charging time was overwritten. At the beginning of the EV survey questions, Tier 2 and 4 participants were asked about the benefits and drawbacks of having a level 2 EV charger. Faster or quicker charging time was a benefit most frequently mentioned (63 percent of responses). Additional benefits included the convenience of charging at home ("Essentially enables us to have an electric car"), and (" The L2 charger enabled me to change from the plug-in hybrid electric vehicle to a battery electric vehicle without any charging inconveniences"). Most participants stated that there were no drawbacks to having a level 2 charger. When comparing survey respondents' benefits to drawbacks, the new Level 2 chargers provided considerable benefits and that these benefits may have increased the incidence and amount of charging occurring at the participants' homes because of greater convenience and the ability to charge larger car batteries overnight.

When these participants were asked to rate their new EV chargers relative to their previous chargers, 64 percent of Tier 2 participants and 70 percent of Tier 4 participants stated that they were satisfied or very satisfied with the new chargers. In addition, 53 percent of Tier 2 participants and 80 percent of Tier 4 participants stated that it was easy or somewhat easy to postpone charging to midnight using the magiclink functionality. When asked if they would continue to use the charger following the study, 100 percent of Tier 4 responded "yes," as did 94 percent of Tier 2.

Shifting the timing of EV charging to midnight is crucial for minimizing the participants' electric bills if the participant is on a TOU rate. The survey asked a series of questions concerning previous charging times, charging times during the study, and the likelihood that the participant would charge after midnight following the study.

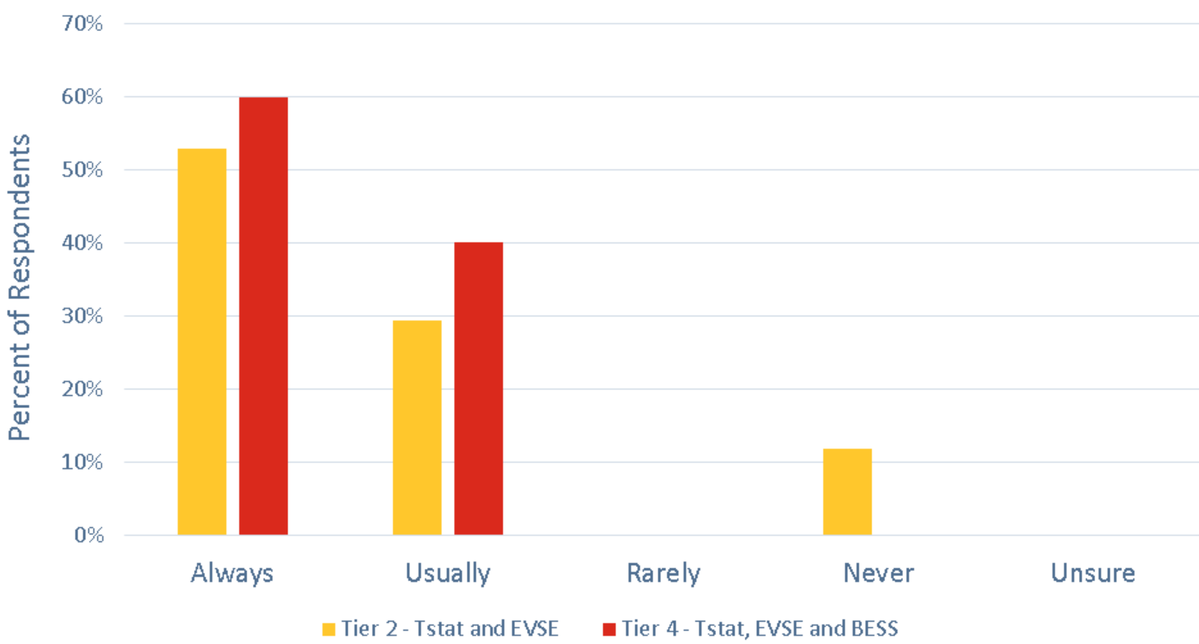
Figure 28 illustrates the typical EV charging start time prior to the study while Figure 29 presents the share of participants who stated that they follow the app's suggestion to charge their EV after midnight. These data indicate that approximately 40 percent of the Tier 2 and 4 participants were charging their EVs at midnight prior to the study and that the share charging at midnight increased during the study. In addition, 40 percent of Tier 4 participants and 53 percent of Tier 2 participants stated that they plan to always charge their car after midnight following the study (an additional 60 percent and 24 percent, respectively, stated that they would usually charge after midnight). These results imply that the participants' charging behavior changed and that many participants plan to continue with these behaviors following the end of the study.

Figure 28: Share of EV Charging Start Time Prior to the SHS



Source: Itron

Figure 29: Share of Tier 2 and 4 Participants Who "Charge After Midnight"



Source: Itron

Battery Energy Storage Systems

Participants in Tier 3 and Tier 4 received a BESS. During Phase 1, the batteries were charged during off-peak hours (midnight to 6 a.m.) and discharged to eliminate or reduce the participant's need to import electricity from SDG&E during the peak hours (4 to 9 p.m.).

Shifting the load using the BESS was implemented to reduce the participants' electricity bills. At the beginning of the battery survey questions, Tier 3 and 4 participants were asked about why they wanted a battery and the benefits and drawbacks of having a battery. Tier 3 and Tier 4 participants stated that they wanted a battery to reduce their electricity bills, store their excess PV production, and enable them to island or get off the grid in the future. Benefits of the battery included the ability to time-shift their usage, reduce their peak energy, decrease bills, and future islanding. Drawbacks of having a battery included the use of space in the garage, noise while charging, and energy use.

When Tier 3 and Tier 4 participants were asked if they noticed a change in their electric bills following the installation of the battery, 47 percent of Tier 3 and 60 percent of Tier 4 customers stated that their bills had changed. Of the Tier 3 participants, 40 percent stated that their bills had decreased while all the Tier 4 participants stated that they noticed a decline in their bills. The larger share of Tier 4 participants who noticed a change stated that the decline in their bills was likely due to the simultaneous impact of the battery and EV charger shifting from peak to off-peak periods. Battery participants were also asked if they would continue to use the batteries in the summer months when it is cost-effective to shift usage from peak to off-peak hours. Fifty three percent of Tier 3 participants stated that they would definitely use the battery next summer and 27 percent stated that they would probably use the battery to shift load, while 70 percent of Tier 4 participants replied definitely, and 30 percent stated that they probably would do so.

Energy Costs and Impacts

The field demonstration phase of the project ran from December 1, 2018, until November 30, 2019. To assess the results of the study during that period, the project team completed the following steps:

- Collect data: load, rate and billing data from the utility, telemetry data from devices, and survey data from participants
- Identify correlating baseline and study periods: Equipment was installed, and data collected over the entire 12-month study period. However, not all equipment was under full control for the entire study period. To accurately reflect the impact of the RDERMS, the project team identified when equipment was under control and used this information to identify the corresponding analysis period. The baseline period was then limited to the months available during the study period. The intent was to make sure that only similar months were used before and during the study periods.
- Weather normalized load data: To normalize for the effects of year-to-year weather on participant load, the project team developed regression models that described the impact of weather on load during the baseline and study periods. The model was run separately for each participant to determine the weather sensitivity for each participant during the pre and post installation time periods. The regression model used the following specification:

$$net\ kWh_t = \beta_0 + \beta_1 CDH_t + \beta_2 HDH_t + \beta_3 PV_t + \beta_4 WeekEnd_t + \sum_{m=1}^{12} \beta_{5m} Month_{tm} + \epsilon_t$$

Where

Net kWh is the individual's hourly net energy consumption

CDH is the cooling degree hours

HDH is the heating degree hour

PV if the customer has PV, is the global horizontal irradiance

Weekend is a binary (1/0) indicator that the time is a weekend or holiday

Month is a set of binary variables that equal 1 if time t is month m, 0 otherwise

B_0 is the individual's average non-weather sensitive net electricity usage

B_1 is the impact of a one unit change in CDH on net electricity usage

B_2 is the impact of a one unit change in HDH on net electricity usage

B_3 is the impact of a one unit change in irradiance on net electricity usage

B_4 is the impact of it being a weekend on net electricity usage

B_{5m} is the impact of it being month m on net electricity usage

The regression model analyzed net electricity consumption because PV production was not metered, thus it was not possible to develop an estimate of whole house electricity consumption. Given that PV production was not metered, irradiance proxies for PV production, with B_3 describing the relationship between irradiance and net load for each participant.

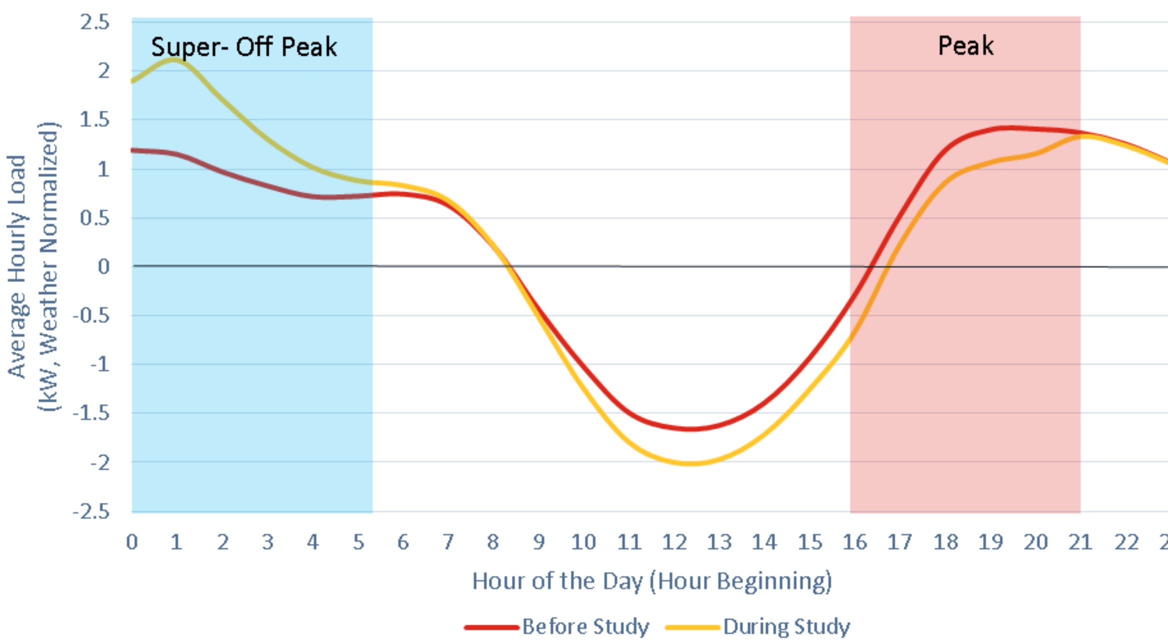
The weather data for the regression analysis was collected from two weather stations maintained by the National Oceanic and Atmospheric Administration (NOAA). For the regression model, actual weather from the baseline and study periods were used to estimate the net load model.

The regression model was estimated using the PRISM methodology for each participant in the baseline and study periods. The first step in the analysis determines the basis for the cooling and heating degree days that yields the highest model R^2. Once the baseline and study period heating and cooling basis is chosen, the parameter estimates for the independent variables and normalized weather (cooling degree hours (CDH), heating degree hours (HDH), and irradiance) are used to simulate the participants' weather normalized net usage in the baseline and study periods. Normalizing the baseline and study period net consumption controls for the impact of weather differences the net electricity consumption during these two periods.

To weather normalize consumption, Itron needed to create an estimate of normal weather.[14] Itron used 5 years of historical weather data from NOAA to develop an estimate of normal temperature and irradiance. temperature and irradiance. The development of normal weather used Itron's rank and average methodology. The rank and average approach maintains the peaks and valleys of temperature and irradiance, while developing an average. The rank and average method ranks the days within a month by maximum temperature, from highest to lowest. Over 5 years of weather data, there are 60 months of ranked data from highest to lowest temperature. For each hour, the average was calculated across the 5 years leading to 12 months of hourly averages ranked from highest to lowest. The study and baseline period weather are ranked by month from highest to lowest. The 5-year average monthly rank of weather is then merged onto the study and baseline period calendar rank, creating normalized weather. The normalized temperature and irradiance were then used to develop weather normalized CDH, HDH, and PV. Those were used with the previously estimated coefficients from the baseline and study period models to create estimates of weather normalized energy consumption during the baseline and study periods.

The study had a noticeable impact on average customer electrical load as shown in Figure 30.

Figure 30: Average Participant Load Shapes Before and During Study



Source: Itron

[14] Given that it was not possible to meter PV production, irradiance and the estimated coefficient on irradiance was used to estimate the PV production for each participant with PV. It was necessary to weather normalize PV production using the same approach as is commonly used to normalize the impacts of temperature on electricity usage. The need to develop an estimate of normal irradiance led Itron to use similar approach to estimate both normalized CDH, HDH, and irradiance. Using a previously develop TMY temperature to develop CHD and HDH would have caused the temperature to deviate from the irradiance.

Comparing the average participant load shapes before and during the study shows a few general traits:

- Consumption during the peak period was slightly lower during the study period in comparison to the baseline/before study period.
- Consumption increased during early-morning super off-peak hours. This was intended to move loads to cleaner and cheaper times and is primarily due to charging batteries during periods with low energy costs.
- On average, midday energy export slightly increased. Rates in both phases 1 and 2 did not incentivize reduction of export from excess solar generation to the electric grid.

Challenges

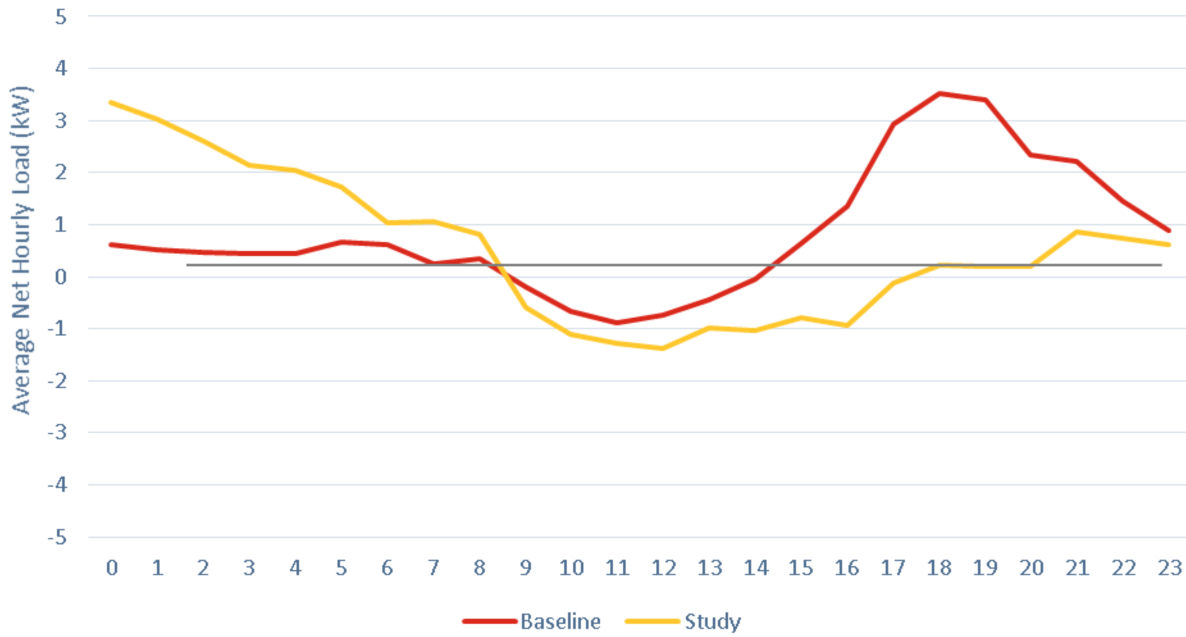
The project team encountered several challenges including baseline conditions, communications, and controls that limited the project team's ability to effectively shift loads. These challenges, while reducing the average impact of the study, provided critical lessons for similar efforts to control DERs in the real world.

Baseline Conditions, Behavior, and Load Shapes

The baseline averages in Figure 31 show the absolute maximum that could be eliminated from a customer's peak energy use by manipulating DER control. Future rules allowing BESS to export to the grid could increase the reduction in usage during peak demand hour but may require larger BESS which would be less cost-effective. Additionally, electricity usage can increase for participants who were not charging EVs at home after they received a Level 2 charger; participants that were charging elsewhere are more likely to charge at home with the move from Level 1 to Level 2 functionality. The electrical load impact of more charging at home can be further exacerbated if the participant does not have a direct financial incentive to charge at scheduled times.

Figure 31 shows a scenario where customers were charging vehicles at home and switched to a TOU rate to shift their charging to later hours. This is a site that received 'Tier 4 equipment' including thermostat, EV charger and BESS. This site showed substantial changes to its load shape with significant shifts from peak (4-9 PM) periods to off peak (midnight – 6 AM) hours.

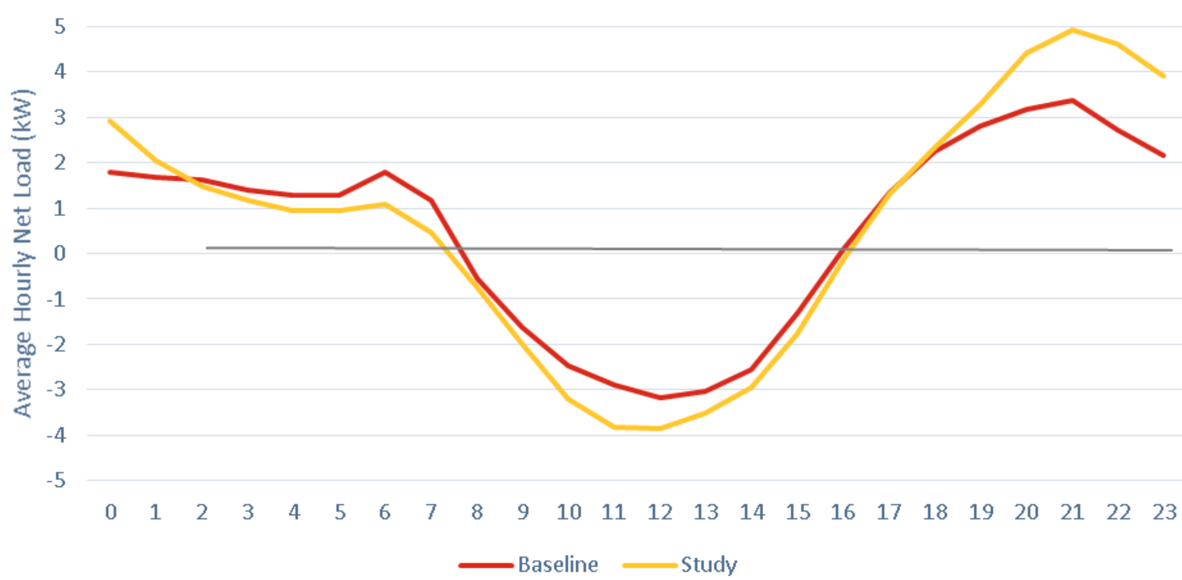
Figure 31: Site with Significant Baseline (pre-Study) Peak Load that could be and was Shifted



Source: Itron

Figure 32 shows a scenario where the customer was not charging an EV at home before the study but started charging at home after receiving a Level 2 charger. This customer did not choose to switch to a TOU rate and appears to have overridden the smart charging profile on a regular basis to start charging in the late evening, leading to an increase in load during peak hours. This site also has noticeably lower peak afternoon load than the other example.

Figure 32: Site that did not Shift Load as Desired



Source: Itron

The project team targeted equipment based on the participant’s load shape baseline (or the load shape before the study) by examining potential participant’s load shapes and selecting participants with substantially higher afternoon loads than loads at midnight. The goal was to install battery storage at sites that had sufficient afternoon load that could be shifted and avoid installing Level 2 chargers at sites that were already charging after midnight.

In addition to targeting equipment by load shape, the project team analyzed the potential bill impacts of participants if they were to switch to a TOU rate and the project team used that analysis to not recruit participants who would be adversely impacted by that shift after the end of the study.

Communications and Control

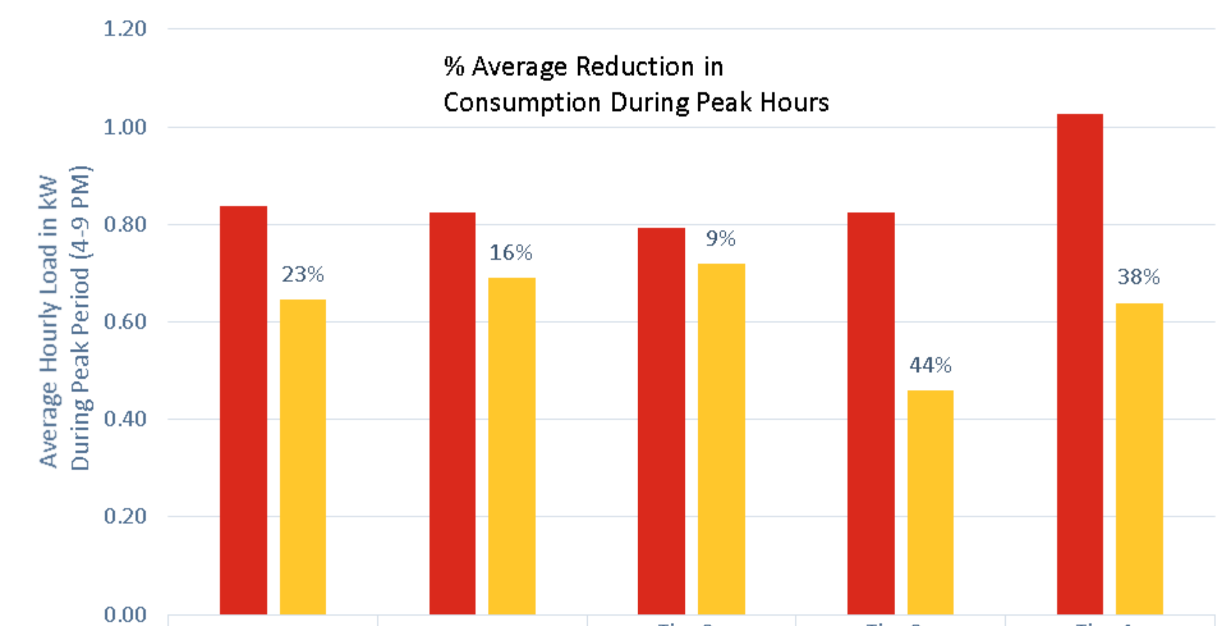
Any load control project must be reliable and incorporate robust communications and controls. This research team used the proven IntelliSOURCE load-control platform but had to stretch control capabilities to meet project objectives. As discussed in Chapter 2, the project team chose to use a fine control approach with the ability to change set points individually every hour of the day. An ‘event based’ control when the setpoint is changed by X degrees for Y hours is more commonly used within demand response platforms for thermostats. This finer control should have provided hourly adjustments of thermostat set points but proved to be unreliable in the field and many thermostats did not respond to these fine control signals.

In addition, demonstration of EV charging controls beyond a single station in Phase 2 was not successful due to the multiple steps required between the EV, the EV charger, the charge cloud, and the central RDERMS cloud. Originally, EV charging was intended to be controlled from the charge cloud directly with only oversight from the RDERMS cloud but that approach proved unworkable due to charge cloud resource constraints. The project team elected to try to move all charge control to the RDERMS cloud but could not get dynamic Phase 2 control to function correctly.

Impacts by Tier

The average impacts can be broken down further by tier of equipment installed. Figure 33 shows the average load before and during the study by tier, during the peak period (4-9 p.m.) On average, all tiers showed a reduction in consumption during peak hours.

Figure 33: Average Baseline and Study Load During Peak Period for Different Equipment Levels or Tiers

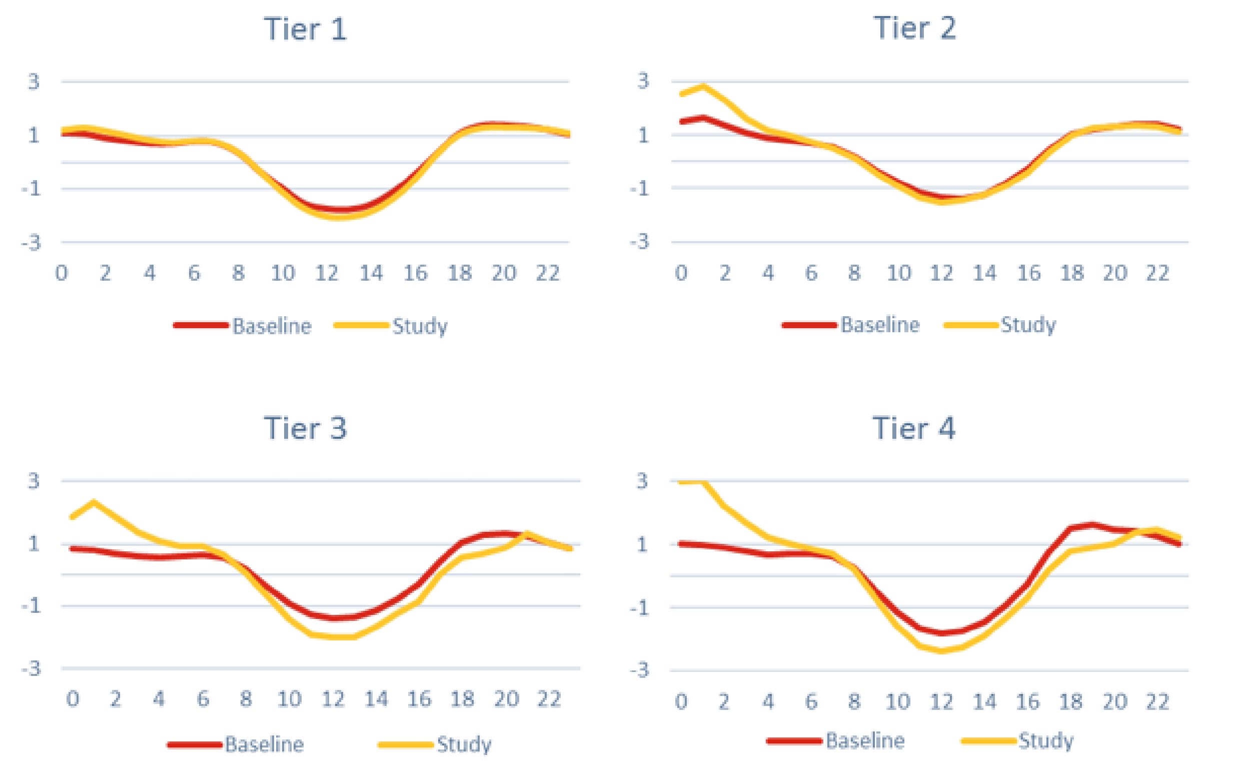


	Entire Study	Tier 1 - Only Thermostat	Tier 2 - Thermostat and EVSE	Tier 3 - Thermostat and Battery	Tier 4 - Thermostat, EVSE and Battery
Baseline	0.84	0.83	0.79	0.82	1.03
Study	0.65	0.69	0.72	0.46	0.64

Source: Itron

The average reduction in consumption during the peak period was just under 23 percent. Participants in Tier 4, who received the most equipment, displayed the largest average relative peak period reduction at 0.39 kW, which also represents a 38 percent reduction in peak consumption. Larger energy storage systems could have enabled a near 100 percent reduction in consumption during peak hours, but budgetary constraints limit the size of these systems. Figure 34 shows additional detail of the load shapes before and during the study, by tier.

Figure 34: Load Shapes Before and During Study by Tier

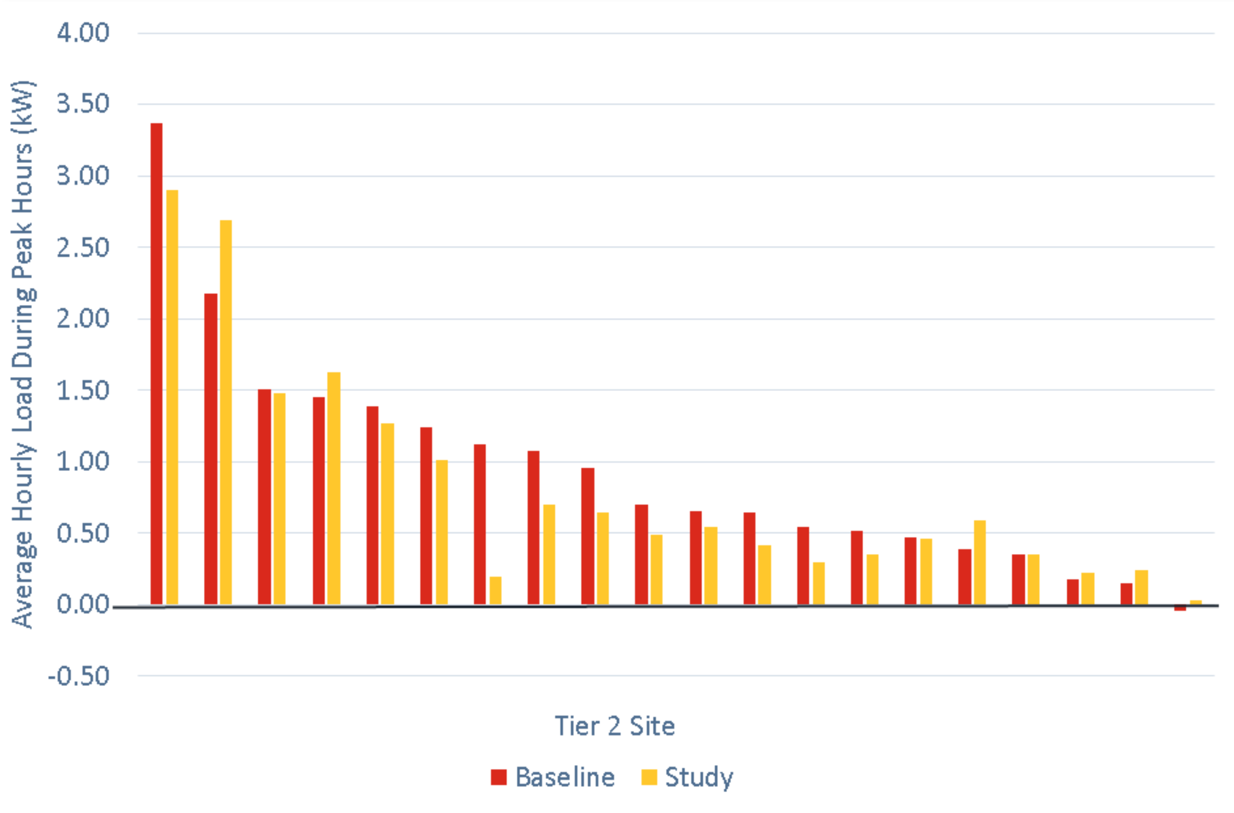


Source: Itron

Tier 1 (thermostat only) participants did not show substantial load-shape changes for two reasons: mild San Diego weather and the technical control issues noted in Chapter 2.

The average customer that received a thermostat and an EV charger (or equipment Tier 2) did not show substantial declines in average peak demand after the installation and control of Level two chargers. Some individual sites, however, did show substantial decreases in consumption during peak hours, as shown in Figure 35.

Figure 35: Tier 2 (Thermostat and EV Charger) Net Load by Site During Peak Hours (4–9 p.m.)



Source: Itron

Within both Tiers 2 and 4, many participants increased their charging at home, adding load after midnight. Other participants were already charging after midnight so did not show appreciable changes in either load shape or peak impact. Finally, some early participants experienced charging reliability issues and asked to have smart charging disabled. Table 9 shows the reduction (or increase) in energy use during peak hours and, where available, the baseline charging behavior at sites that received both a thermostat and EV charger (or equipment Tier 2).

Table 9: Tier 2 Customers Peak Reduction and Baseline Behavior

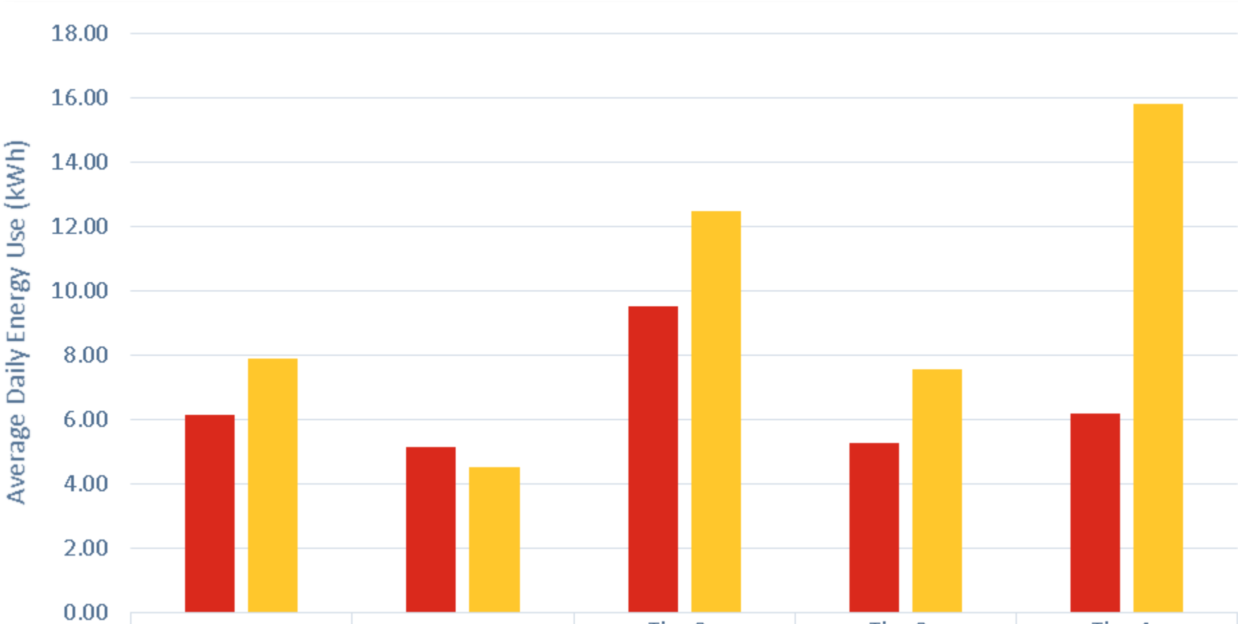
Peak Period Reduction kW)	Baseline Charged at Home?	Baseline Charging Time
0.93	No prior EV	Started Charging in afternoon before Control
0.47	Yes	7:00:00 p.m.
0.37	Yes	12:00:00 p.m.
0.31	Yes	Unknown
0.25	Yes	Unknown
0.23	Yes	5:00:00 p.m.
0.23	Unknown	Unknown
0.21	Yes	10:00:00 p.m.
0.17	Yes	2:00:00 p.m.
0.12	Yes	8:00:00 p.m.
0.12	Yes	Always
0.03	Yes	7:00:00 p.m.
0.01	No EV prior	12:00:00 a.m.
0.00	Yes	8:00:00 p.m.
–0.05	Yes	12:00:00 a.m.
–0.07	Yes	12:00:00 p.m.
–0.10	Yes	Unknown
–0.17	Yes	12:00:00 a.m.
–0.20	Yes	6:00:00 p.m.
–0.52	No	12:00:00 a.m.

Source: Itron

The Tier 2 sites with the greatest reduction in peak energy usage tended to either charge at unknown or self-reported start charging in the early evening during the baseline period (likely when the participant got home from work, on weekdays). Customers like this have the greatest potential to shift charging from peak hours to cheaper and cleaner overnight hours. Participants who are already charging at midnight or not charging at home do not offer the same potential to shift loads. The participants with the largest increase in usage (0.52 kW) was not charging at home during the baseline period, but started charging at home following receipt of the charger. In addition, this participant did not switch to a TOU rate and appears to have overridden the delayed charging to charge when they plugged in. Therefore, to maximize impact, smart charging should target participants already charging at home but not charging on what would be an optimal TOU (after midnight; this could be due to not being on a TOU rate or the participant/customer not). Providing chargers to participants not already charging at home can increase household consumption as participants move to charging at home.

Figure 36 shows the daily energy use during the baseline and study periods. Many of the tiers saw an average increase in daily energy use. This growth was due to increased vehicle charging at home and energy storage round-trip efficiency losses; the energy a BESS discharges is always less than the energy used to charge a BESS due to losses in the batteries and inverter.

Figure 36: Participant Average Daily Electricity Use (kWh)

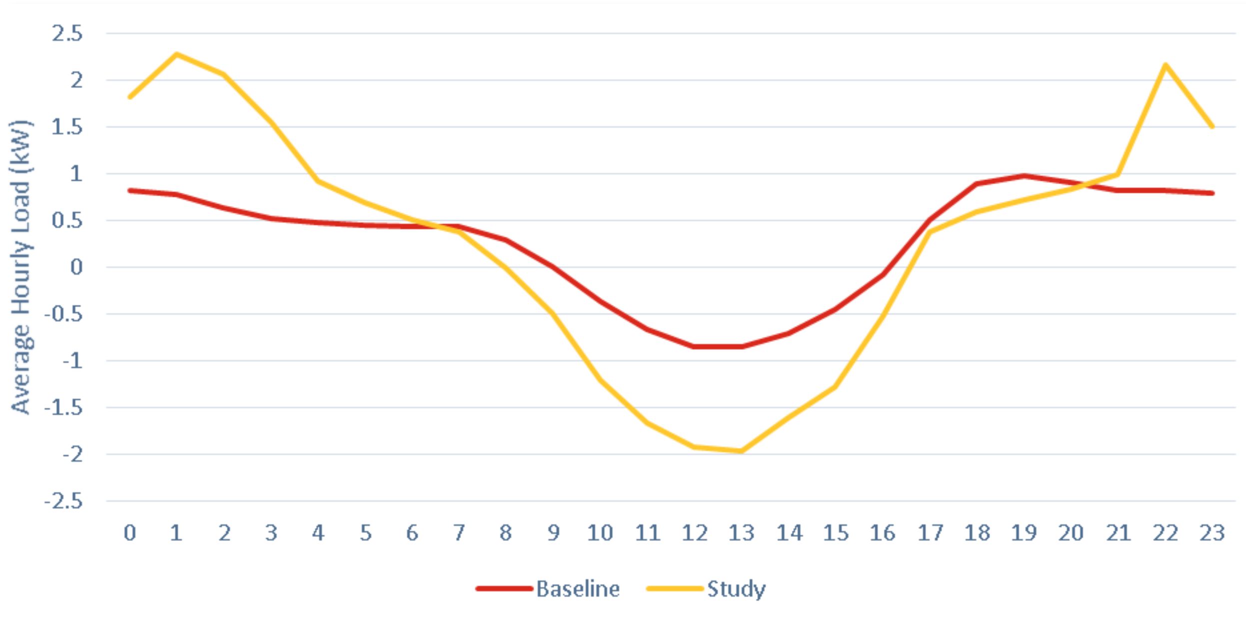


	Overall Study	Tier 1 - Thermostat Only	Tier 2 - Thermostat and EVSE	Tier 3 - Thermostat and Battery	Tier 4 - Thermostat, EVSE and Battery
Baseline	6.15	5.14	9.51	5.25	6.17
Study	7.87	4.51	12.47	7.56	15.81

Source: Itron

Figure 37 shows some of the change participants made during the time period from baseline through the end of the study. This site was not charging an electric vehicle at home before the study, and once the Level 2 charger was installed, load increased. Additionally, the participant added substantially to the PV-system size midway through the study, resulting in more midday exports. This customer's energy usage illustrates that even with the ability to control or modify the electricity usage of some end uses, the customer can still make unplanned changes.

Figure 37: Net-Load of Customer That Added PV but Also Started Charging an EV at Home

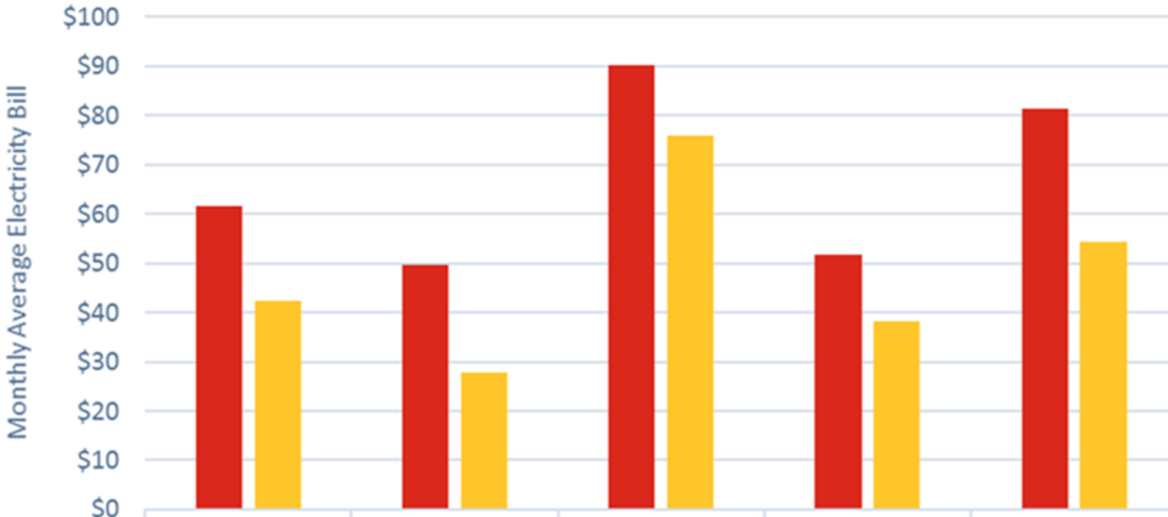


Source: Itron

Customer Cost

Energy consumption and customer load shapes provide insight into the energy impacts of the study. However, key goals of the study focused more on minimizing customer and utility costs. To evaluate the results in the cost arena, the project team combined customer load shapes with utility-rate data to assess the impact of the study on customer bills. This differs from the analysis previously presented in that it combines actual load and rate data. Figure 38 shows average participant bills before and during the study. The baseline bills before the study were calculated based on actual load and participant utility rates at the time. The bills during the study are based on participant load and the suggested rate the participant was advised to switch to as part of the study: EV-TOU2/DR-SES or EV-TOU5. Note that only 49 participants ended up on one of those rates; 33 started and an additional 16 switched to one. For the remaining 51 participants, the project team assigned the recommended TOU rate for this analysis. Technologies were controlled to minimize customer bills on the recommended TOU rates. Technology was controlled to optimize to that TOU rate regardless of if the participant decided to switch or not.

Figure 38: Average Participant Bills Before and During the Study

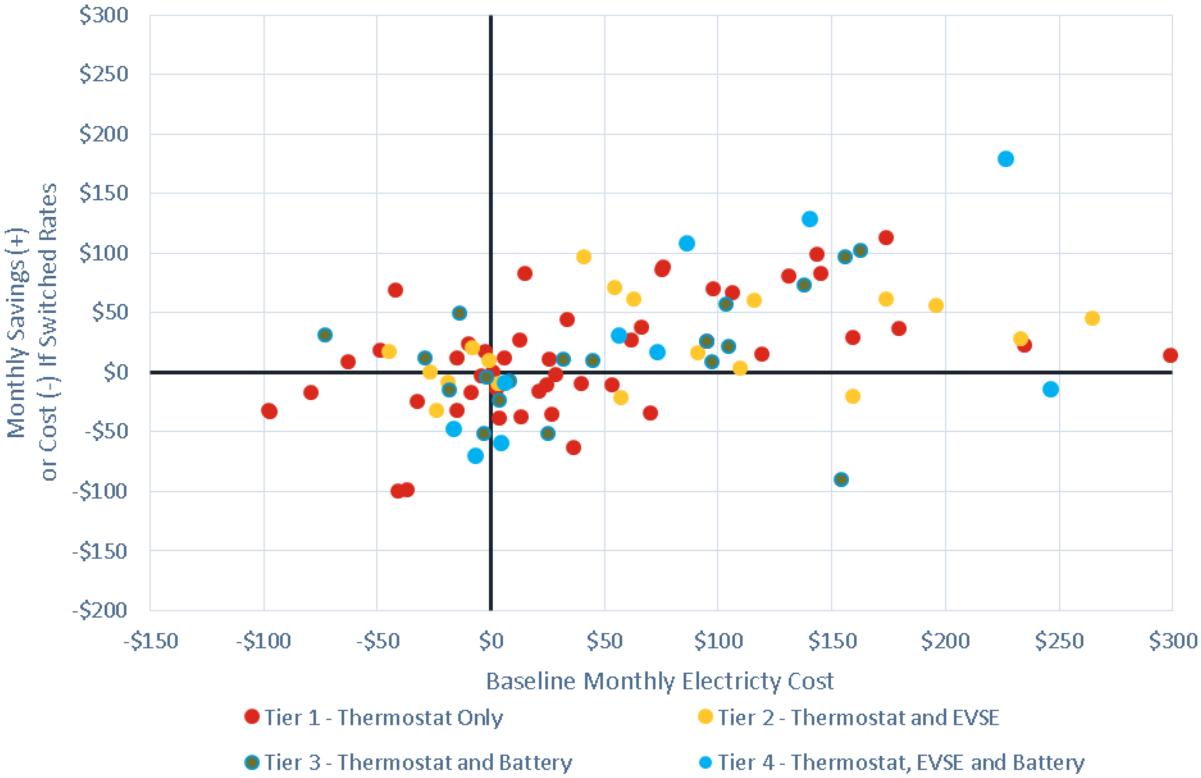


	Overall Study	Tier 1 - Thermostat Only	Tier 2 - Thermostat and EVSE	Tier 3 - Thermostat and Battery	Tier 4 - Thermostat, EVSE and Battery
Baseline	$61	$50	$90	$52	$81
Study	$42	$28	$76	$38	$54

Source: Itron

Six of the tier 3 and two of the tier 4 participants had negative monthly average electricity bills before the study, which means that in an average month these participants received a credit on their electricity bill. A tiered volumetric rate provides no incentive for a customer to shift consumption from one period to another since all electricity is charged at the same rate regardless of the time of consumption. Figure 39 shows the monthly pre-study electrical bills and the monthly savings (or additional costs) for all participants, by tier.

Figure 39: Participant Bills Pre-Study and Monthly Cost Impacts from the Study



Source: Itron

Participants who had negative average monthly electrical bills during the baseline period (the left of Figure 39) almost all experienced bill increases after switching to a TOU rate (the bottom left of Figure 39). The increase in bills occurred even with the benefits of BESS load shifting and smart EV charging. In short, customers who have NEM grandfathered on a tiered volumetric rate and have, or have almost, zeroed out their electrical bills, have no financial incentive to switch to a TOU rate or to shift their consumption patterns.

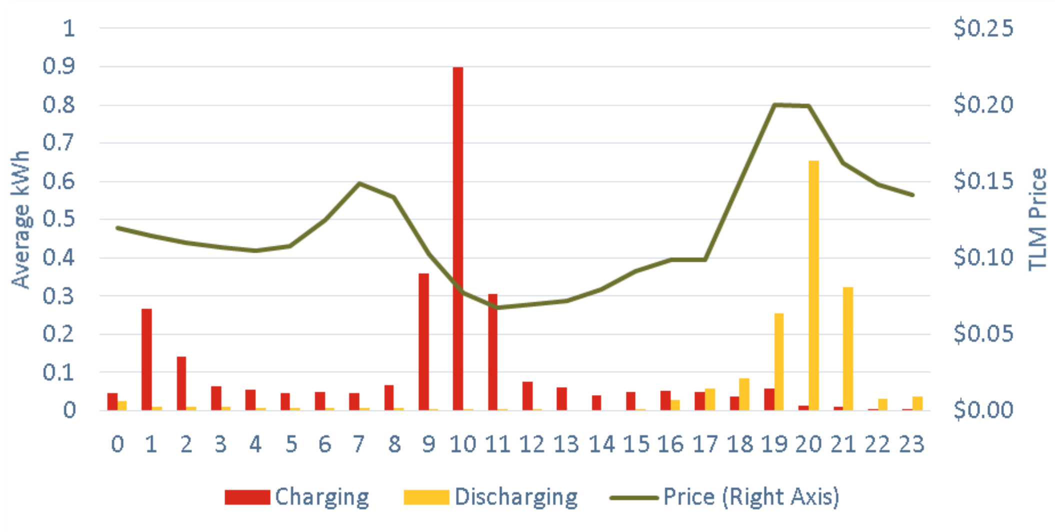
Phase 2: Dynamic Transactive Load Management

The project team completed multiple Phase 2 demonstrations to test and investigate RDERMS in response to a TLM rate. As described in Chapter 2, the periods of Phase 2 varied somewhat depending upon the device being controlled. Energy storage systems were controlled in September and November 2019. Test trials of EV charging controls were performed in June 2019.

Phase 2 Energy Storage Results

Figure 40 shows the average response of energy storage systems during the first Phase 2 period in September of 2019, during the utility's summer period. During this demonstration, the batteries were charging primarily during low-cost periods. The energy-storage systems were limited in their ability to discharge during high-cost periods in the late afternoon (hours 17 and 18 or 5 p.m. to 7 p.m.) because of insufficient participant net load. Current interconnection rules do not allow the energy-storage system to discharge back to the grid. Batteries sending energy to the grid is a violation of customer interconnection agreements with SDG&E at the time of the study.

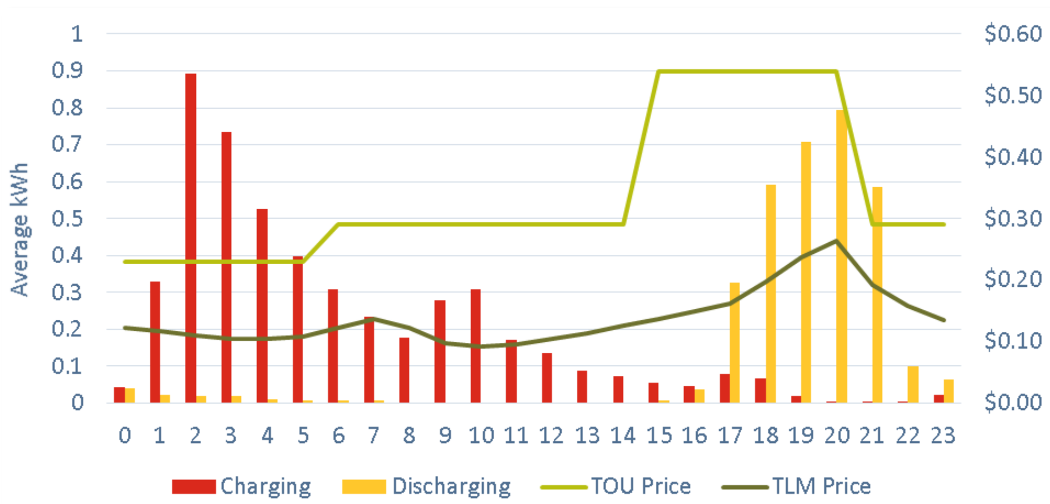
Figure 40: BESS Response in September (summer) Phase 2



Source: Itron

Figure 41 shows energy storage charge and discharge during Phase 1 (TOU)

Figure 41: BESS Response During Phase 1 (Time-of-Use)

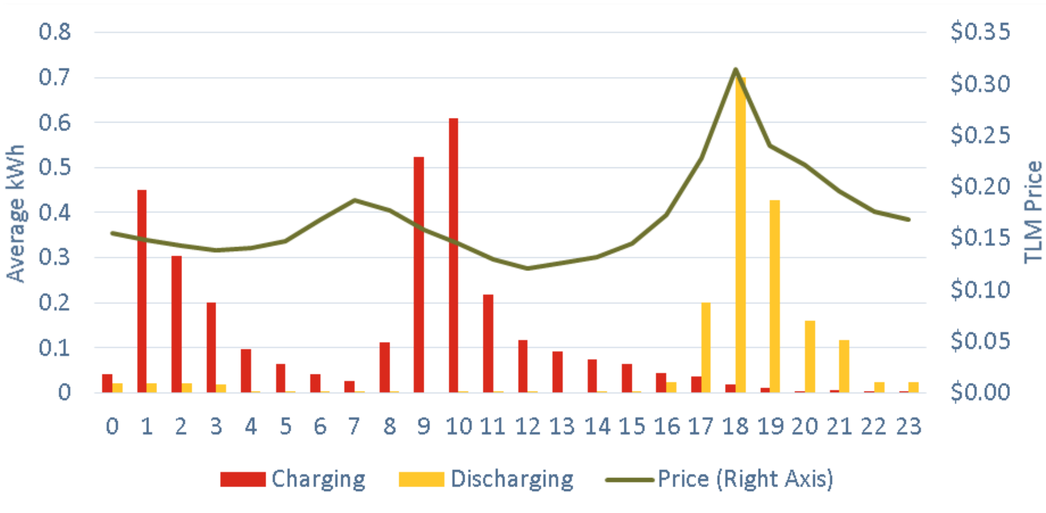


Source: Itron

Energy storage discharge was similar between phases 1 and 2 but Phase 2 discharge was more focused during high TLM (and utility cost) cost hours. Charging was very different between the TOU and dynamic rates (phases 1 and 2, respectively), however, with most Phase 2 charging during mid-morning to coincide with the lowest costs in those two weeks in September. Whereas Phase 1 (TOU rate) charging was entirely after midnight.

The second Phase 2 (response to dynamic rates) energy-storage period was in late November 2019 and the results are shown in Figure 42. Unlike in the summer when most participant loads limited discharge in the late afternoon, the energy storage systems were largely able to discharge in a pattern matching the TLM signal since, in winter, solar generation has already decreased enough to cause a substantial enough net load to allow the energy-storage systems to discharge during this period.

Figure 42: BESS Response in November (winter) Phase 2

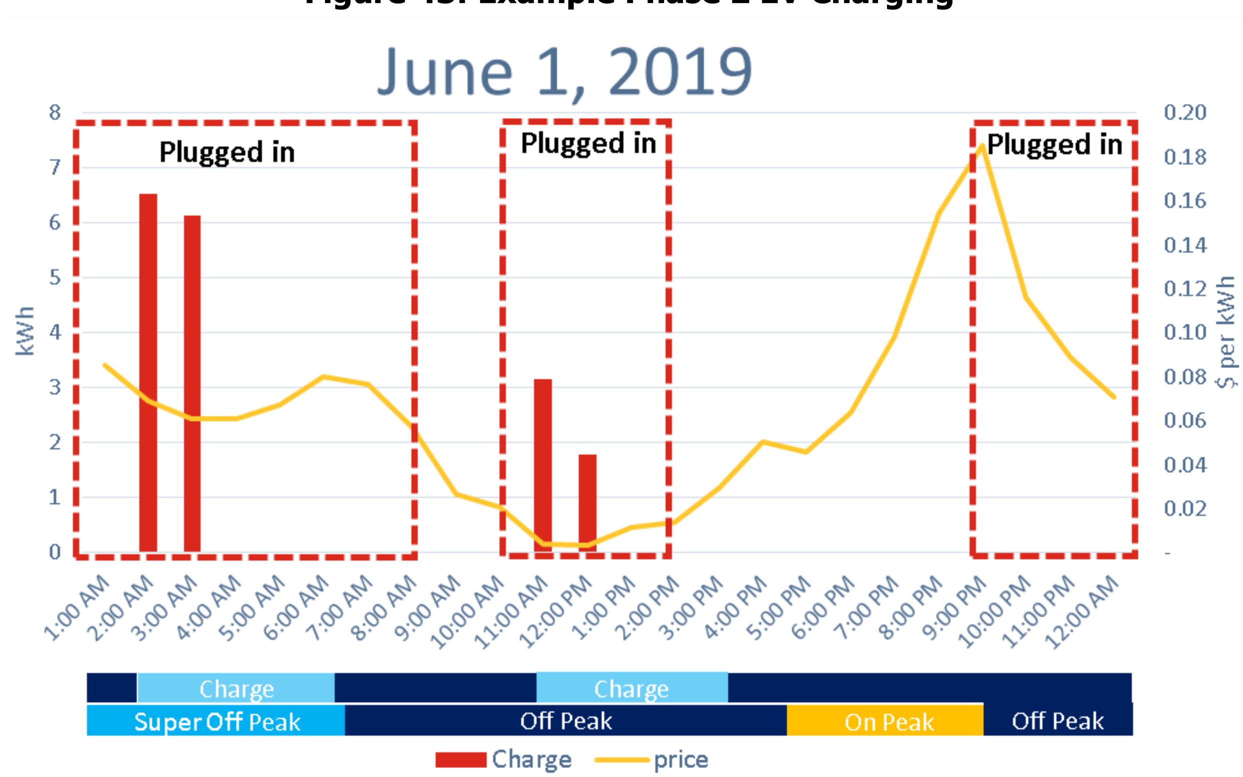


Source: Itron

Phase 2 EV Charging Results

The project team tested Phase 2 EV charging controls in June 2019 and those results appear here. During this period, the charge cloud algorithm calculated and scheduled the four hours with the lowest energy cost before the vehicle's assumed departure at 7 a.m. Figure 43 shows an example day during the testing of EV charging in Phase 2, using dynamic pricing from the TLM.

Figure 43: Example Phase 2 EV Charging



Source: Itron

This example shows that the vehicle was able to take advantage of lower-cost charging during the lowest-price hours through multiple trips and charge sessions. The project team's intention was to expand this demonstration to all Tier 2 and Tier 4 sites with site-specific charge durations and departure times, but the project team was unable to demonstrate charging across the sample due to communication and signal delay issues.

Success Parameters

The foremost goal of the Smart Home Study was to improve management of residential electricity usage while alleviating the volatility depicted by the duck curve. Crucial steps for achieving that goal are to use technology[15] that will automate energy management, and to optimize customer usage to lower customer costs without compromising a customer's lifestyle. To gauge the impact of the program, the project team created a list of success parameters to evaluate. A scoring process was developed and appears in Appendix D.

Summary of Parameters

The following list of parameters was developed as the methodology for judging the success of this applied research project. The associated criteria were scored based on the clarity, relevance, transparency and comprehensiveness of project processes, including related calculations and discussions. Specific parameter and criteria details appear in Appendix D.

- Impact on Grid Reliability: Achieve a better understanding of the potential for technology-enabled improvements that impact grid reliability.
- Potential to Commercialize: Assess how IntelliSOURCE RDERMS could be commercialized on a larger scale.
- Impact on Customer's Lifestyle: Demonstrate achievable energy cost savings for customers while maintaining their comfort and individual preferences.
- Achieve Representative Sample: Recruit and maintain a robust participant sample, given the acknowledged limitations.
- Obtain TAC Recommendations: Assess recommendations that enhance project success.
- Analyze Tariff Structures: Thoroughly test current and potential tariff structures.
- Effective Operation: Demonstrate effective operation of the technology.
- Complete Project Deliverables: Submit all project deliverables, including a comprehensive final report, with findings and recommendations.

Self-Assessment Scores

To evaluate success, a subjective scoring survey system captured the SHS project team's self-assessment of the level of attainment for each success parameter (see appendix D).

Three criteria are included with each parameter and were scored on a scale of 1-5 (Low to High), with five indicating the criterion was fully achieved in clarity, relevance, transparency, and comprehensiveness.

[15] IntelliSOURCE residential distributed energy resource management system (RDERMS)

One lead member from each of the SHS stakeholders listed below was asked to fill out a survey in March 2020.

Evaluators were selected from each of the following stakeholders:

- Alternative Energy Systems Consulting
- Itron
- Center for Sustainable Energy
- SDG&E

The overall averaged resulting score from the self-assessment survey was 4.13 and is detailed in Appendix D.

CHAPTER 4: Conclusions and Recommendations

State of Technology

Ready for Deployment

RDERMS is integrated into the IntelliSOURCE suite of products and consists of a commercially available, ready to deploy, cloud-based platform to integrate and control a variety of commercially available demand response and distributed energy resources. These products allow fast deployment and scale-up of new implementations. Future implementations would likely use proven simpler thermostat control schemes such as the use of 'events' built into thermostat API's that change setpoints by a set number of degrees over a set number of hours to ensure higher reliability. That approach is broadly used in demand response and has proven to be more reliable than the very granular control the project team attempted to use.

Itron and its partners are actively pursuing opportunities to deploy this system with utilities throughout the nation. Note that all manufacturing is done by third parties producing commercially available devices.

Future Development

Although this system is currently commercialized, Itron continues to consider enhancements, based on customer and program requirements such as included equipment and program objectives.

One effort currently underway by Itron is to enable the use of open standards protocols to facilitate broader equipment integrations and minimize component-specific integration requirements. One standard for DER communication and control is OpenADR, an open, highly secure, and two-way information exchange model and Smart Grid standard. Itron plans to obtain OpenADR certification soon.

Control and optimization algorithms will likely require customization for each utility's rates and goals when implementing a RDERMS. The costs to do so will vary based on the degree of customization or enhancements requested by each utility.

State of Regulatory Support

Residential Rate Reform and Load Shift Products

Optimizing dispatch of DERs, such as smart electric vehicle chargers and energy storage, can make the grid more efficient, flexible, and clean. However, traditional rate structures, such as flat-rate pricing and tiered rate structures, do not sufficiently incentivize customers to shift flexible loads. Utilities can provide incentives by offering TOU and dynamic rate structures that better align customer costs with grid impacts, but these rate structures are subject to state policy and are continually changing.

In 2013, Assembly Bill 327 was enacted to reform residential rates. A later California Public Utilities Commission (CPUC) decision (D.15.07-001) provided direction to investor-owned utilities on how to implement residential rate design structures and subsequently required those utilities to switch all customers to TOU rates beginning in 2019 (however, residential customers will have the option to opt out of TOU rates and remain on tiered rates).[16] These utilities have already begun refining their TOU rate structures, shifting peak-energy use periods (when rates are highest) from midday to evening. For example, SDG&E has shifted its peak to 4–9 p.m. However, the effects of this change on encouraging customer load shifting are currently unknown. SDG&E began rolling out its new TOU rate structures in March 2019, while Southern California Edison and Pacific Gas and Electric (PG&E) were delayed until the fall of 2020. This transition could have effects on customer costs, utility programs, and utility costs as load profiles are potentially altered and impact grid requirements. CPUC rules require that specific actions be taken to understand several of these potential effects. For example, bill protection provisions will closely monitor the impact on customer costs. For example, SDG&E customers are provided a monthly comparison of the TOU plan to the standard rate plan, and will be credited the difference if they have paid more under the TOU plan at the end of the first year. Moreover, the CPUC decision requires that investor-owned utilities provide regular updates on progress toward rate reform.

The CPUC also continues to explore opportunities that encourage load shifting through price signals. Directed by Decision 17-10-017, the Load Shift Working Group submitted a final report proposing six new models of demand response to the CPUC in January 2019.[17] Proposals focused on aligning load with zero-marginal cost renewable generation, which is consistent with the state's mandates to lower the electric grid's carbon footprint. While there has not yet been a final decision regarding these load-shift products, the CPUC held workshops in October 2019 to review dynamic and real-time pricing options for consideration.

In addition to retail rates and demand response products, the wholesale energy markets managed by the California ISO offer additional value streams for load shifting. California ISO's Energy Storage and Distributed Energy Resources Phase 3 initiative focused on energy storage and included a proposed proxy demand resource-load shift resource product.[18] The Load Shifting Resource component of the product will compensate customers who employ behind-the-meter resources to bid load increases into the wholesale market during times of negative marginal pricing—an indicator of renewable electricity curtailment. Policies developed in the Energy Storage and Distributed Energy Resources Phase 3 were approved by the California ISO Board of Governors in September 2018 and filed with the Federal Energy Regulatory Commission for approval in September 2019. The proposed changes are expected to remove barriers to demand-response participation in the wholesale markets; and the California ISO

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[16] California Public Utilities Commission. *Residential Rate Reform.* http://www.cpuc.ca.gov/general.aspx?id=12154.

[17] California Public Utilities Commission. January 31, 2019. Final Report of the California Public Utilities Commission's Working Group on Load Shift. https://gridworks.org/wp-content/uploads/2019/02/LoadShiftWorkingGroup_report.pdf.

[18] California Independent System Operator. 2018. Energy Storage and Distributed Energy Resource Phase 3. http://www.caiso.com/Documents/DraftFinalProposal-EnergyStorage-DistributedEnergyResourcesPhase3.pdf

launched Energy Storage and Distributed Energy Resources Phase 4 in February 2019 to consider additional operational refinements for proxy demand resources.[19]

Rule 21 and Energy Storage

Historically, behind-the-meter energy storage systems have been prohibited from discharging to the grid, as mandated by Electric Rule 21 interconnection policies.[20] While solar PV can export electricity to the grid and receive NEM credits for these exports, energy storage has not been permitted to export electricity to the grid. However, a recent CPUC decision (D.19-01-030) has offered a new option for energy storage systems to discharge to the grid if the systems are charged only from the on-site NEM generator.[21] This could allow storage systems to shift solar export from midday to evening peak hours and receive NEM credit for storage export. Given that this is a recent development, it remains unknown whether storage systems will be operated in this manner and what the customer benefits might be. Future research will likely be needed to better understand round-trip efficiency through measurements in the field, both in terms of acceptable efficiency costs from energy losses and customer willingness to operate storage systems in this manner.

Low-Income Customers

Investor-owned utilities in California offer three programs to low-income customers requiring long-term bill assistance: California Alternate Rates for Energy, Family Electric Rate Assistance, and the medical baseline program.[22] All three programs offer monthly bill discounts to income-qualifying customers on tiered rates, but not TOU rates, which must be considered as SDG&E transitions residential customers to TOU rates. SDG&E plans to exclude customers living within certain ZIP codes in "hot zones" where the percentage of customers eligible for these rates is at or above the average (percentage of Family Electric Rate Assistance-eligible customers in hot zone ZIP codes is 2.6 percent).[23] So, if California Alternate Rates for Energy customers are within a ZIP code not identified as a "hot zone", then those customers would not be excluded from TOU. In addition to customers who may be accidentally enrolled in TOU rates because they are not excluded through the ZIP code analysis, there are customers who could be

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[19] California Independent System Operator. *Energy Storage and Distributed Energy Resource.* http://www.caiso.com/informed/Pages/StakeholderProcesses/EnergyStorage_DistributedEnergyResources.aspx

[20] California Public Utilities Commission. 2014. Decision Regarding Net Energy Metering Interconnection Eligibility for Storage Devices Paired with Net Energy Metering Generation Facilities (14-05-033).

[21] California Public Utilities Commission. 2019. Decision Granting Petition for Modification of Decision 14-05-033 Regarding Storage Devices Paired with Net Energy Metering Generating Facilities. https://static1.squarespace.com/static/54c1a3f9e4b04884b35cfef6/t/5c5a02ff104c7b5f073745dc/1549402881064/STORAGE+DEVICES+PAIRED+WITH+NET+ENERGY+METERING+GENERATING+FACILITIES.PDF

[22] Pacific Gas and Electric. *Longer-Term Assistance*. https://www.pge.com/en_US/residential/save-energy-money/help-paying-your-bill/longer-term-assistance/longer-term-assistance.page

[23] SDG&E. 2018. Rebuttal Testimony of Horace Tantum IV on Behalf of San Diego Gas & Electric Company. https://www.sdge.com/sites/default/files/regulatory/A1712011%20and%20Related%20Matters%20-%20SDGE-%20Tantum%20-%202018%20RDW%20Rebuttal%20Testimony.pdf

enrolled in the California Alternate Rates for Energy program or Family Electric Rate Assistance program but are not, so they will be automatically defaulted to TOU rates starting in 2019. The CPUC recently considered proposals to restructure the California Alternate Rates for Energy program within the residential rate structure proceeding but concluded that no alternative structure should be adopted at this time due to statutory limitations and available data. However, it noted that it may revisit the issue of restructuring the California Alternate Rates for Energy program in the future.

Lessons Learned

DER Installations Can be Challenging

Not all homes can have DERs installed without expensive upgrades to their electrical panels, which can require moving the panel and trenching to upgrade the electrical wiring from the utility. Not all homes have physical locations that are well suited for the installation of DER. The model of BESS used requires room in an enclosed garage that is not on a wall adjoining the home. The BESS installation must also be relatively close to the electrical panel. Installation of an electric vehicle charger may not be allowed within some multifamily parking. Placement of an electric vehicle charger may also be limited by the ability to place a high voltage outlet near the vehicle's parking place. Large scale expansion of DER technologies is likely to require additional investments in public and private infrastructure.

Net Energy Metering Grandfathering Complicates DER Optimization

NEM grandfathering provides some customers with up to 20 years on a tiered volumetric rate. If a grandfathered customer's PV electricity production exceeds or is close to that customer's electricity consumption, it may be in the customer's best interest to remain on a grandfathered tiered rate given current TOU rates. A person on a tiered rate will see an increase in his or her electricity bill if a BESS is installed and there are no financial incentives for the customer to move to EV charging to hours that are advantageous to the grid. Financial incentives to shift electricity consumption using DER are difficult with the grandfathered tiered-NEM rate structure.

DER Solutions Should be Customized to Maximize Benefits

If DER technologies are going to be used to reduce customer electricity bills, the mix of technologies installed must be specific to customers' load shapes and their utility rates. Batteries are designed to shift consumption from expensive peak periods to inexpensive super off-peak periods. If a customer does not have consistent energy demand during the peak period, that customer's load will not support the intent of the BESS. During the SHS, some batteries were installed in locations where a large PV system was paired with low household consumption during the peak period. For these homes, the net load was minimal during the 4-9 PM peak, and since the BESS is not allowed to export the grid, this minimal peak period load reduced the BESS impact on peak net load.

Vehicle-Grid Integration Communications Should be Standardized

The SHS demonstrated a smart control system that could intelligently manage, and time electric vehicle loads in concert with:

1. Other home loads and on-site solar output
2. Location marginal pricing (LMP) signals from the day-ahead hourly CAISO market

Our efforts could have been substantially improved with a common interoperability standard for vehicle-grid integration (VGI). As an example, when an EV owner connects to a charging station, two critical pieces of information are required to set up a grid-friendly charging plan:

1. Needed kWh for the vehicle
2. Planned departure time

In CEC Docket 17-EVI-01, Energy Commission staff underscored this need in a presentation submitted on November 19, 2019, titled "CALeVIP Future Equipment Technology Workshop"[24]

It follows, therefore, that distributed intelligence will be needed to automate grid-friendly charging. Consumers will benefit from a plug-and-play experience that ensures that their vehicle's primary purpose, transportation, isn't negatively impacted. Communications standards are currently being considered by the Energy Commission that will:

1. Leverage EV loads and, eventually, EV batteries as a large virtual power plant capable of multiple grid support applications such as peak shifting and absorption of solar oversupply during midday.
2. Enable these aggregated DERs to be certified and dispatched by either the local utility or balancing authority.
3. Ensure reliability as the state moves to higher and higher RPS levels without excessive costs by leveraging the time flexibility of EV charging.

Utility Rates or Other Incentives Are Key Determinants in Driving DER Operation

SDG&E's TOU rates have a summer weekday peak period from 4 a.m. to 9 p.m., an off-peak period from 6 a.m. to 4 p.m. and 9 p.m. to midnight and a super off-peak period from midnight to 6 a.m. For customers who are attempting to minimize their electricity bills, the rates structure encourages charging EVs and batteries from midnight to 6 a.m. and discharging batteries from 4 p.m. to 9 p.m. The current TOU rate structures do not encourage charging EVs or batteries to increase customer demand from 10 a.m. to 4 p.m. or to increase demand to push up the "belly" of the duck curve. This rate structure could encourage pre-cooling during the 6 a.m. to 4 p.m. time period, but temperatures in San Diego limit the days when pre-cooling is valuable for most customers.

While the current SDG&E TOU rates do not encourage charging batteries from 6 a.m. to 4 p.m., the federal investment tax credit does incentivize most BESS owners to charge their BESS from their excess solar. The investment tax credit provides a tax credit of 30 percent of the BESS cost if BESS owners charge their BESS from their excess solar production. Charging from excess solar increases customer demand for electricity, reduces customers' export of

[24] https://www.energy.ca.gov/event/workshop/2019-11/staff-workshop-future-equipment-requirements-calevip

electricity and pushes up the belly of the duck. Participants that received a free BESS as part of the SHS are not eligible for the investment tax credit, and therefore, do not have financial incentives to charge their BESS from their excess solar. The results from open-ended questions within the end of study survey, however, indicate that some participants plan to make the necessary adjustment to their BESS's electrical installation to enable islanding, and plan to adjust BESS charging to consume their excess solar. The future usage of the batteries installed by the SHS may not always be consistent with electric bill minimization.

Batteries provide the most shiftable loads in this study but the potential to do so is limited by current Rule 21 requirements that prohibit export of energy from the BESS to the electrical grid. As noted in the Although this system is currently commercialized, Itron continues to consider enhancements, based on customer and program requirements such as included equipment and program objectives.

One effort currently underway by Itron is to enable the use of open standards protocols to facilitate broader equipment integrations and minimize component-specific integration requirements. One standard for DER communication and control is OpenADR, an open, highly secure, and two-way information exchange model and Smart Grid standard. Itron plans to obtain OpenADR certification soon.

Control and optimization algorithms will likely require customization for each utility's rates and goals when implementing a RDERMS. The costs to do so will vary based on the degree of customization or enhancements requested by each utility.

State of Regulatory Support subsection, changing requirements under Rule 21 could substantially increase the impact from batteries to reduce utility load during peak hours.

The cost savings of the SHS were mixed due to NEM grandfathering, the installation of some technologies in homes with load shapes that made cost savings difficult and participants who chose to remain on tiered rates. At the initiation of the SHS, potential participants were told that they would be required to change their SDG&E rate to a TOU rate. The project team also reviewed the load shapes of initial applicants to determine if the applicant's load shape provided the opportunity to shift load to reduce electricity bills. While it was possible to identify some applicants, who were willing to change rates and who had baseline load shapes with load shifting potential, the timeline of the study necessitated the broadening of some initial study criteria. Expanding the participant pool to customers unwilling to change to a TOU rate, and to homes with load shapes where it is difficult to shift to reduce costs, however, may provide better insights into the potential electric bills savings of the general population. DERs will not save on energy costs in all homes given current rates and actual load shapes.

Communications and Device Control can be Challenging

The project team dealt with many challenges in ensuring reliable communications and control.

- The cellular hotspots that were expected to increase reliable communications over participant broadband did not appear to provide the envisioned increase in reliability. Future studies should consider alternative approaches ranging from leveraging the utility advanced metering infrastructure network to the use of customer broadband.
- Device control should be tested and verified in a controlled subset. The project tested device connectivity before deploying into the field. However, the specific control

strategies for thermostat and electric vehicle supply equipment control were still in development as installations were underway. More schedule flexibility would have allowed the project team to more fully test and verify all operating modes and configurations.

- Control of each device needs to be customized and optimized to that device. The project team initially planned to use manual mode to control BESS energy storage. This approach could result in the batteries discharging to the grid without regard to participant load and therefore could violate customer interconnection agreements. Understanding the details of each device is critical in successfully integrating DERs. An alternative approach may be to send less prescriptive commands via open standards such as OpenADR to tell each device to try to use more or less energy within the parameters of each device's abilities.

Recommendations for Future Work

Further Investigation Into the Cost-Effectiveness of DER Control

For this study, customers were provided smart residential technologies with smart controls. Customers were not required to pay for the technologies. The results from the study show that these technologies can be used to provide customers with modest bill savings and utilities with cost savings when combined with TOU rates. The study, however, did not investigate the cost-effectiveness of these technologies from society's, the utilities', or non-participants' points of view. In addition, the study did not determine an incentive level for the technologies that would make them cost-effective to the customer. As RDERMS and smart homes increase, determining the cost-effectiveness of these measures and potential incentive levels will be important if these measures and controls become eligible for utility-funded programs. These analyses must be grounded in real-world performance (and not only optimal dispatch scenarios) to ensure realistic assessments, since simulations can only go so far and often overestimate the impacts of load control.

Investigate and Develop Other Pricing Signals

During phase 1 of the SHS, technologies were controlled to minimize customer bills assuming the customers had switched to one of SDG&E's TOU rates. During phase 2, technologies were dynamically controlled based on a day ahead TLM price signal, but customers did not actually pay bills based upon this signal. Using both pricing approaches, it was possible to use technologies and controls to minimize customer bills while reducing utility costs. The available TOU price signals, however, do not encourage customers to increase electricity consumption during the middle of the day when excess electricity generated from PV may be available. Investigating alternative price signals that could be sent to customers and their technology controls could increase electricity consumption during the middle of the day. Developing, offering, and evaluating alternative pricing signals that encourage customers, and their technologies, to shift their usage of electricity to low cost periods could help increase electricity demand during periods of low demand. Strategies that may be appropriate for low cost signals may include pre-cooling of homes, timing of pool pumps, and the timing of heating for electric water heating. The increasing use of smart technologies that offer the opportunity to receive pricing signals may open the opportunity for innovating pricing signals and controls in the future.

Resurvey and Analyze SHS Participants in One or Two Years

The SHS participants each received smart technologies and education about both these technologies and SDG&E's TOU rates. The technologies were also tailored to minimize the customers' bills. Going forward, participants will have the opportunity to change their SDG&E rates and to further determine how they want to use, or not use, their technologies. Resurveying participants, and collecting electricity usage information from them, is a low-cost opportunity to learn how customers use these technologies without third-party control. How do participants' satisfaction levels, for instance, change when the technologies are no longer controlled by a third party? Do participants go back to charging their cars when they get home from work, or do they continue to charge after midnight? Do BESS owners use batteries to minimize their bills yet forego usage in the winter months? Alternatively, do they charge the batteries with excess solar and discharge during the peak period even though this will increase their winter electricity bills? Do customers with batteries take the additional steps necessary to island?

LIST OF ACRONYMS

Term	Definition
AC	Air conditioning
BESS	Battery Energy Storage System
CAISO	California Independent System Operator
CPUC	California Public Utilities Commission
DER	Distributed energy resource
DRes	Domestic Residential
DRes-LI	Domestic Residential-Low Income
DR	Distributed resource
EPIC	Electric Program Investment Charge
EV	Electric vehicle
GHG	Greenhouse Gas
kWh	Kilowatt hours
MSP	Main Service Panel
NEM	Net energy metering
OEHHA	Office of Environmental Health Hazard Assessment
PG&E	Pacific Gas and Electric
PV	Photovoltaic
PYD	Power Your Drive
RDERMS	Residential Distributed Energy Resource Management System
SDG&E	San Diego Gas & Electric
SGIP	Self-Generation Incentive Program
SHS	Smart Home Study
TAC	Technical Advisory Committee
TLM	Transactive load management
TOU	Time of use

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APPENDIX A:
Customer Recruitment Collateral

View this email in your browser

Organization Here,

Recently, Alternative Energy Systems Consulting (AESC), Oxygen Initiative, Center for Sustainable Energy® (CSE), and Itron were selected by the California Energy Commission to conduct the Smart Home Study to research how customers in the SDG&E service territory will benefit from energy-saving technologies by switching to a Time of Use (TOU) rate plan. As part of the study, 100 homes will be selected.

How It Works:

- The study runs from June 2018 to October 2019
- The focus will be on personal savings: you will receive bill protection to ensure you won't spend any more than you would have under a standard rate plan, but you'll keep any savings you achieve
- Each participant must have either an electric vehicle or solar panels on their home
- Each participant will receive installation of one or more home energy-saving devices
- All participants will receive a free Honeywell web-programmable thermostat with a personalized energy portal so you can control your home climate remotely, as well as monitor your daily use
- If you possess an electric vehicle for daily use, you may be eligible for installation of a free AeroVironment Level 2 EV charging station
- Your home may be eligible for installation of a free Sonnen eco compact solar battery, with up to 8 kilowatt-hours of energy storage
- Participants who receive the thermostats alone will receive a $150 installation cash bonus
- All participants will receive $100 for completing survey questions upon completion of the study
- Participants will be chosen based on answers to a brief online questionnaire and their potential energy savings
- Total number of participants must be limited to 100

If you believe you are a good match for this study, visit www.smarthomestudy.com to answer the online eligibility questionnaire or call 855-434-7161.

SMART STUDY

APPENDIX B: Installation and Field Service Details

Figure B-1 illustrates an example of a hotspot and a house and solar gateway installed on a constant switch in a participant's garage.

Figure B-1: Hotspot and Gateways

Source: Itron

Figure B-2 shows an Itron solar meter installed between the solar inverter and main panel to record alternating current voltage.

Figure B-2: Solar Meter, Inverter, and Disconnects

Source: Itron

During the installation visit the field technician would once again test the existing thermostats to confirm they completed a 10°F rise and drop. The Honeywell smart thermostats would then be installed, and a 10°F temperature rise, and drop would be tested upon installation. With the thermostat installed, the field tech connected the thermostat to the customer's Wi-Fi and had the customer download the Honeywell app on their phone so they could control their thermostats remotely. The final step for thermostat installation was to commission the thermostat in IntelliSOURCE to correlate with customer site IDs and allow for monitoring and control in subsequent phases of the project.

Figure B-3 shows a Honeywell Lyric T6 thermostat installed at a customer's home.

Figure B-3: Smart Thermostat

Source: Itron

The installation of the Sonnen batteries required coordination between the project team and the electricians. The project team was responsible for collecting information and providing it to the electricians. The electricians were responsible for drawing up plans and submitting for permits to get approval for the BESS installation. Once the permits were approved, the electricians and the project team would coordinate a site visit with the customer where the electricians would install the BESS and any other electrical equipment. The project team would then install the other equipment and connect all technologies online. The BESS were connected to the hotpot via an ethernet cable, and the project team would commission them to the Sonnen interface while on-site.

Figure B-4 shows a BESS installed at a customer's home.

Figure B-4: BESS

Source: Itron

During the preliminary visit, the field technician would determine whether a house with an electric vehicle was prewired for a Level 2 electric vehicle charger. If the customer was not prewired, the electricians would go through steps similar to a BESS to acquire a permit and install an additional electrical circuit. With Level 2 circuits installed, the Itron field technician would mount and install the Webasto Level 2 electric vehicle charger. The field technician would then connect the electric vehicle charger to the hotspot via Wi-Fi and commission the charger through the Oxygen Initiative interface. Customers were informed of the smart charging protocol and customer phone numbers were collected to receive smart charging texts.

Figure B-5 shows a Webasto Level 2 electric vehicle charger install at a customer's home.

Figure B-5: Level 2 Electric Vehicle Charger

Source: Itron

Field Service Visits

Occasionally, some of the installed equipment was not operating properly. Field visits were primarily required for hotspots, gateways, thermostats, and electric vehicle chargers. If a phone call or guidance via email did not solve the problem, an on-site troubleshooting visit was performed. During these visits, the on-site engineer would attempt to repair or troubleshoot the existing equipment. In cases where the equipment could not be repaired, replacement equipment was installed and recommissioned appropriately.

Systems Integration and Testing

Systems integration and testing was performed on every device at each site. Devices were tested to ensure proper communications and operations. Checklist integration tests were performed prior to the installation phase of the program.

Meters and Gateways

Every participating household received a gateway that connects to the utility smart meter via Zigbee and records each household's energy consumption (kWh) data. For participants with PV systems the project team installed an OpenWay CENTRON meter and an additional ZigBee gateway unit to record the PV production, when possible. These gateways are connected via an ethernet cable to a Cradlepoint hotspot that provides internet access.

For participating households with poor cellular service, a Wi-Fi range extender was used in place of the Cradlepoint hotspot. These connect to the customer Wi-Fi to provide internet access for the equipment.

Integration testing, involving meters and gateways as well as the hotspot and range extenders, is detailed in Table B-1 and Table B-2.

Table B-1: ZigBee Gateway Integration Test

Item	Description
Goal	To connect via Wi-Fi to the hotspot, Zigbee to the OpenWay (OW) CENTRON or utility smart meter.
External Dependencies	• Proximity of OpenWay CENTRON for Zigbee to be effective. • External power source. • Preloaded Wi-Fi certs. • Wi-Fi connection to hotspot. • Ability to create a TLS tunnel (stunnel).
Test Description	1. Joining of gateway to meter's Zigbee HAN. 2. Verify that gateway is pulling metrology data and successfully transmitting it to the cloud using gateway smartphone app. 3. Check for interval metrology data from meter.
Expected Results	• Hotspot and gateway will create and maintain secure connection on main Wi-Fi. • Gateway-meter will have active Zigbee communications once a minute.

Source: Itron

Table B-2: Hotspot or Range Extender Integration Test

Item	Description
Goal	To provide internet connectivity for the gateways, electric vehicle charger, and Sonnen batteries.
External Dependencies	• Hotspot: Good cellular connection. • Range extender: Pre-existing in home Wi-Fi. • Both: Laptop for configuring, predetermined SSID and pre-shared key (PSK) for main Wi-Fi (Riva and gateway).
Test Description	1. Connect to cellular NWK (AT&T or Verizon) or pre-existing Wi-Fi. 2. Configure both networks with appropriate Wi-Fi and PSK. a. Connect with Riva and gateway on main Wi-Fi, edge devices on guest wi-fi. Connect with net2grid and IntelliSOURCE via broadband connection. b. Push control messages to gateway, Riva, Wi-Fi edge devices (devices on guest Wi-Fi). c. Pull metrology and status messages from devices.
Expected Results	• Data received from devices and pushed to cloud. • Communication link between gateway, Riva, and cloud.

Source: Itron

Smart Thermostat

Thermostats were installed in each house. If the home had multiple air conditioning systems, the project installed a thermostat to control each system. Thermostats needed to connect to the customer's Wi-Fi and later the IntelliSOURCE system. Cradlepoint hotspots were used to mimic the customer's Wi-Fi in the integration tests.

Integration testing involving the smart thermostat is detailed in Table B-3.

Table B-3: Smart Thermostat Integration Test

Item	Description
Goal	To connect with the hotspot and send reporting data to the cloud.
External Dependencies	• Wi-Fi connection to hotspot range extender. • Distance to hotspot/range extender. • Operational Honeywell interface.
Test Description	1. Pair with hotspot guest Wi-Fi using WPA2-PSK 2. Register thermostat to Honeywell using Lyric app 3. Enroll thermostat into IntelliSOURCE using enrollment URL 4. Send reporting data via the hotspot's Wi-Fi to the Honeywell Lyric app and IntelliSOURCE
Expected Results	• Data received from devices and pushed to cloud. • Communication link smart thermostat, Honeywell internet-based control, and cloud.

Source: Itron

Electric Vehicle Charging Stations

The SHS installed 30 Level 2 electric vehicle charging stations. These chargers needed to connect to Wi-Fi and be commissioned through Oxygen Initiative's internet-based control system.

Integration testing involving the electric vehicle charger is detailed in Table B-4.

Table B-4: Electric Vehicle Charger Integration Test

Item	Description
Goal	To connect with the hotspot and send reporting data to the cloud.
External Dependencies	• Wi-Fi connection to hotspot range extender. • Distance to hotspot/range extender. • Successful connection to Oxygen Initiative's internet-based control system.
Test Description	1. Pair with hotspot guest Wi-Fi using WPA2-PSK. 2. Send reporting data via the hotspot's Wi-Fi to the Oxygen Initiative internet-based control. 3. Deliver data from Oxygen Initiative internet-based control to RDERMS cloud.
Expected Results	• Data received from devices and pushed to cloud. • Communication link electric vehicle charger, Oxygen Initiative's internet-based control, and cloud.

Source: Itron

Advanced Battery Energy Storage System

SonnenBatterie eco BESS units were installed at 30 participant sites. The Sonnen BESS requires a wired ethernet connection to access the internet. The connection enables communications with the Sonnen server and enables their intelligent charge management system.

Integration testing involving advanced BESS is detailed in Table B-5.

Table B-5: Advanced BESS Integration Test

Item	Description
Goal	To connect with the hotspot and send reporting data to the cloud.
External Dependencies	• Ethernet connection from hotspot range extender. • Distance to hotspot/range extender. • Successful connection to Sonnen intelligent charge management system.
Test Description	1. Connect with hotspot using ethernet cable. 2. Send reporting data via the hotspot's Wi-Fi to the Sonnen internet-based control. 3. Deliver data from Sonnen internet-based control to Sonnen BESS.
Expected Results	• Data received from devices and pushed to cloud. • Communication link Sonnen BESS, Sonnen internet-based control, and cloud.

Source: Itron

Operations and Maintenance

The SHS responded to the growing requirement for smaller resources in distribution and transmission grid management. It relied upon customer participation to develop strategies for overcoming barriers to DER expansion in California. Because of this reliance on customer participation, an effort was made to ensure customer satisfaction with a focus on convenience, cost savings, and safety. The following section includes the operational procedures for both on-site equipment and system programming support as well as the telephone and emergency contact support.

Call Center

The SHS call center aimed to provide customer service through enrollment aid, scheduling assistance, and technical support throughout the length of the study. The call center had varying requests as the participants moved through the different steps of the study. Because of this, all call center staff had to be knowledgeable about all aspects of the study. The call center could be reached at a toll-free 855 area code number, and there was staff available to answer calls Monday-Friday 8 a.m.-6 p.m.

The call center had two distinct services: to provide program enrollment and general question support and to provide technical assistance. When the call center number was dialed the caller received one of the following messages.

Business Hours Greeting

- You have reached the Smart Home Study program administered by Itron.
- This is a voluntary program designed to help shift electricity consumption in your home from peak price periods to low price periods, reducing your SDG&E electricity bill.
- For program enrollment and general questions press 1
- For technical assistance press 2 (menu driven options will be played here)
- For assistance with your Honeywell thermostat please press 1 DEM Call Center
- For assistance with your Oxygen electric vehicle charger please press 2 858-746-9222
- For assistance with your Sonnen BESS storage please press 3 818-824-6363
- For assistance with your pool pump switch please press 4 DEM Call Center
- For assistance with any other technical issue please press 5 DEM Call Center

After Hour and Holiday Greeting

- You have reached the Smart Home Study program administered by Itron. Our offices are currently closed.
- Customer care representatives are available from 8 a.m. to 6 p.m. Monday through Friday to help you enroll in the program and to answer your questions. Please call us back during normal business hours.
- If you are already a participant in the California Energy Commission's Smart Home Study program and need immediate technical assistance, please press 2. (menu driven options will be played here)
- For assistance with your Honeywell thermostat please press 1 DEM TECHNICIAN

- For assistance with your Oxygen electric vehicle charger please press 2   858-746-9222
- For assistance with your Sonnen BESS storage please press 3   818-824-6363
- For assistance with any other technical issue please press 5   DEM TECHNICIAN

Program Enrollment and General Question Support

Once a caller selected the option for program enrollment and general question support, their call was forwarded to the project team. Support staff was directed to provide information consistent with what is found in the study website (https://smarthomestudy.com/) whenever possible. The call center tracked all incoming calls, recording the reason and response to each call, so a consistent direction was provided to all incoming questions.

All effort was made to answer incoming calls Monday through Friday, 8 a.m. to 6 p.m. If a call came outside those hours, or while the call center was assisting others, they were directed to a voicemail box. This voicemail was checked regularly, and the study aimed to return all messages within one business day.

Program Enrollment: The study's applicant tracking system relied on all prospective participants filling out the qualification survey online. The call center guided all prospective participants through the online survey. Additionally, if an applicant was unable or unwilling to use the web-based survey, the call center staff attempted to help enter the information into the website on their behalf.

The online survey asked the potential participant to upload their Green Button data. While the website provided explicit instructions for accessing Green Button data, the call center helped callers with this process.

General Question Support: The most commonly expected questions are outlined, along with their answers, in the Frequently Asked Questions section of the website: https://smarthomestudy.com/frequently-asked-questions/. The call center staff are very familiar with verbiage presented on the website and were directed to provide consistent responses.

Redirect for Technical Support: If the participant reached this portion of the call center, but the nature of the call was technical, they were directed to the best resource for the technology in question.

Technical Support

Once the 100 study participants were selected and enrolled, various smart energy saving technologies were installed in their homes. During the installation period, the call center was available to answer participant questions concerning their technologies.

Honeywell Thermostat: The call center provided all callers with questions or concerns about their Honeywell thermostat direct technical support related to the installation or programming of the thermostat. A technician was dispatched to resolve any outstanding customer issues.

Oxygen Initiative Electric Vehicle Charger: The call center provided all callers with questions or concerns about their electric vehicle charger the direct line to Oxygen Initiative. Their staff served as the subject matter experts and provided solutions to any problem faced by participants.

Sonnen BESS: The call center provided all callers with questions or concerns about their BESS the direct line to Sonnen. Sonnen is the subject matter expert and provided solutions to any problem faced by participants.

On-Site Maintenance Visits

As the study progressed, most of the ongoing maintenance of the on-site equipment was handed through the SHS call center and email address. Participants in the program were provided information on how to get ahold of call center staff, either via phone as described or via email (support@smarthomestudy.com). If customer's technical issues were unresolved via the call center options, an on-site visit was scheduled with an engineer to try and resolve all equipment problems. The support staff maintained a comprehensive log of site visits and customer communication to keep informed on the status of all sites.

APPENDIX C: Benefits Questionnaire

Current Version of Benefits Questionnaire

Dear XXXX,

Thank you for your participation in the Smart Home Study. The study will end on December 1st, 2019, and the Smart Home Study Consortium is very grateful for your participation. We would now like to collect some feedback from you about the study. Please answer these questions as completely and honestly as you can to allow us to better learn from your experiences and improve the technology for use in the future.

Please note that you agreed to complete this end of study survey in return for a $100 gift card as part of the terms and conditions. We will also be reaching out to transfer ownership of all the equipment to you.

Sincerely,

Stephan Barsun, Itron Smart Home Study Project Manager

1) How did you learn about the Smart Home Study?
2) What motivated you to participate in the Study (list all that apply)?
    a. Desire to save energy
    b. Desire to reduce my electricity bill
    c. Opportunity to receive free advanced technologies
    d. Potential ability to island my home using a battery
    e. Ability to charge my car automatically
    f. Ability to charge my car when electricity is less expensive
    g. Concern about the environment
    h. Desire to participate in a research project
    i. Desire to learn more about my electricity use
    j. Other

3) By participating in this program, did you expect to ______?

	Yes, definitely	Yes, probably	Maybe	No, probably not	No, definitely not	Not Sure	NA
Save money on your utility bill?							
Help the environment							
Use less electricity							
Have more control over your electricity usage							

4) What benefits have you received from participating in the study?
   a. The installation of technologies that were free to me
   b. Education about when it is best to use electricity
   c. Third-party control of my energy usage to reduce my utility bill
   d. Reduced electricity bill
   e. Receipt of participation check
   f. Other
5) What concerns do you have associated with your participation in the study?
   a. Potential increases in my energy bill
   b. Changing to a utility rate that may increase my energy bill in the future
   c. Advanced technologies that may be difficult to fix/use once the study is completed
   d. Third-party control of my energy usage, can I take over control?
   e. My car may not be charged when I need it

6) How satisfied were you with the following?

	Very Dissatisfied	Somewhat Dissatisfied	Somewhat Satisfied	Very Satisfied	Not Sure	NA
The application process						
The installation process						
The installation technician						
Your new thermostat						
Your new electric vehicle charger						
Your new Battery						

7) If you changed to a TOU rate as part of the Smart Home Study, how satisfied are you with your new rate?
   a. Very satisfied
   b. Satisfied
   c. Dissatisfied
   d. Very dissatisfied
   e. Not sure
   f. NA

Thermostat Questions for Tier 1-4 (all participants)

8) Since your smart thermostat was installed, what features of the thermostat do you use (list all that apply)
   a. Set a cooling schedule
   b. Set a heating schedule
   c. Use the phone app to change the temperature or schedule
   d. Use the phone app to monitor the temperature while away for the home
   e. Use the phone app to monitor the HVAC use while away from the home
   f. Set different temperatures for different times of day
   g. Use the geofencing option
   h. Other
   i. Turn it on and off when need heating or cooling
   j. Don't use the smart thermostat
   k. Other (please provide)
   l. NA

9) After the study, will you continue to use the smart thermostat to control the temperature in your home?
    a. Yes
    b. No
    c. Not sure
    d. Not currently using the thermostat
10) Have you noticed the Smart Home Study's adjustment to your thermostat setting?
    a. Yes
    b. Not
    c. Not sure
11) If you have noticed a change in your thermostat setting, did the change improve, not change, or diminish your level of comfort?

Electric Vehicle Level 2 Charger Questions (Tier 2, Tier 4)

12) Please list the primary benefit associated with the level 2 electric vehicle charger installed for the Smart Home Study.
13) Please list the primary drawback associated with the level 2 charger installed for the Smart Home Study.
14) Since your new electric vehicle charger was installed, how easy has it been to keep your car at the desired charge?
    a. Very easy
    b. Somewhat easy
    c. Somewhat difficult
    d. Very difficult
    e. Not sure
15) How easy is it to use the electric vehicle charger text message to postpone charging your vehicle until midnight?
    a. Very easy
    b. Somewhat easy
    c. Somewhat difficult
    d. Very difficult
    e. Not sure
16) Prior to the study, what time of day did you typically begin charging your electric vehicle?
17) Prior to the study, how many times a week did you typically charge your electric vehicle at home?
18) Prior to the study, how often did you begin charging your electric vehicle at midnight?
    a. Very Seldom
    b. Seldom

c. Somewhat often
d. Often
e. Usually
f. Not Sure

19) After the study, how often do you plan to charge your electric vehicle at midnight?
a. Very Seldom
b. Seldom
c. Somewhat often
d. Often
e. Usually
f. Not Sure

20) If you plan to change your typical charging schedule after the study, why do you plan to change your schedule?

21) Have you noticed a change in your electricity bill since your started using the level 2 electric vehicle charger?

22) How has your electricity bill changed?
a. Electricity bill has declined a lot
b. Electricity bill has declined a little
c. Electricity bill has remained the same
d. Electricity bill has increased a little
e. Electricity bill has increased a lot
f. Not sure

Electric Battery Questions (Tier 3, Tier 4)

23) What was your primary motivation for wanting to receive a battery from the Smart Home Study?

24) What are the primary benefits you have received from having a battery?

25) What is the primary drawback you have experienced from having a battery?

Note: The batteries were primarily charged with electricity after midnight (during the summer rate season) and discharged during the on-peak summer period.

26) Have you noticed a change in your electric bill during the summer period?

27) How has your summer electricity bill changed?
a. Electricity bill has declined a lot
b. Electricity bill has declined a little
c. Electricity bill has remained the same
d. Electricity bill has increased a little
e. Electricity bill has increased a lot
f. Not sure

28) What is the likelihood that you would have purchased a battery without participating in the study?

   a. Very likely
   b. Somewhat likely
   c. Unlikely
   d. Never
   e. Already had a smart thermostat
   f. Not sure

29) After the study, will you continue to use your battery to shift your electric load?

   a. Yes
   b. No
   c. Not sure

30) How satisfied are you with your battery?

   a. Very satisfied
   b. Satisfied
   c. Dissatisfied
   d. Very dissatisfied
   e. Not sure

Monthly Bill Reports (All Participants)

Starting in February 2019, the Smart Home Study began providing participants with Monthly Bill Reports. The reports included information on the estimated impact of the study on your electric bill and tips on how to further reduce your electric bill

31) Did you review the Smart Home Study bill reports when they were provided?

   a. Yes, always
   b. Yes, frequently
   c. Occasionally
   d. No, infrequently
   e. Never
   f. Not sure

32) How satisfied are you with your Smart Home Study bill reports?

   a. Very satisfied
   b. Satisfied
   c. Dissatisfied
   d. Very dissatisfied
   e. Not sure

33) Did you find the billing information provided in the Smart Home Study bill report helpful?

a. Yes
b. No
c. Not sure

General Overview (all participants)

34) How satisfied were you with the experience of participating in the Smart Home Study?

a. Very Satisfied
b. Satisfied
c. Dissatisfied
d. Very dissatisfied
e. Not sure
f. Yes
g. No
h. Not sure

APPENDIX D: Success Parameters and Evaluation Process

The following parameters were developed as the methodology for judging the success of the Smart Home Study (SHS). The associated criteria were scored based on the clarity, relevance, transparency, and comprehensiveness of project processes, including related calculations, and discussions. The total averaged score was 4.13 out of a scale of 1-Low to 5-High.

- Impact on Grid Reliability: Achieve a better understanding of the potential for technology-enabled improvements to impact grid reliability. The technology of interest (IntelliSOURCE RDERMS) is expected to demonstrate that grid reliability can be improved through automated optimization. To be deemed successful, SHS must yield practical information that improves the current understanding of the ability of the IntelliSOURCE RDERMS to manage grid costs and reduce peak load, regardless of whether the evidence confirms or refutes expectations. This applied research project must provide increased confidence in realistic estimates of peak load reduction potential.
  - **Criterion #1: Peak Load Estimates.** One or more estimates of achieved peak load reduction should be developed based on collected project data. If applicable, separate estimates will be specified for key differentiating factors, such as home equipment mix. Estimates should be accompanied by robust written discussion, including explanation of the calculation methodology and references to any materials that help support the validity of the selected estimation method. The relationship between project estimates and the expected values (reasons for being consistent or divergent) should be well understood.
  - **Criterion #2: Challenges & Limitations.** Observed challenges and limitations (technical or otherwise) affecting peak load reduction potential should be documented thoroughly. Lessons learned should help judge the significance of such challenges and the feasibility of potential improvements.
  - **Criterion #3: Customer & Site Attributes.** Do key customer attributes change the potential for peak load reduction? Are certain types of customers or equipment more effective or efficient at reducing peak load? SHS results should be informative about how grid improvements vary from one customer or site to another. Results should include identification of interesting factors that meaningfully affect the value and impact of the IntelliSOURCE RDERMS technology.
- **Potential to Commercialize: Assess how IntelliSOURCE RDERMS could be commercialized on a larger scale.** For the technology to be used in a manner that meaningfully benefits ratepayers and accelerates California's progress toward environmental/energy sustainability goals, large-scale adoption will be necessary. SHS will document the expected technical, regulatory, customer preference, economic barriers, and opportunities affecting large-scale adoption potential in a real-word laboratory. To be considered successful, the associated project recommendations will be useful in guiding efforts to support the required market activity.

- **Criterion #1: Rate Structures.** The project should evaluate how new or existing rate structures, when combined with the technology of interest, could better drive benefits for customers and the grid. These benefits could include peak demand reduction, improved renewable integration, or heightened customer satisfaction, for example. The project should examine 3-4 rate structures (tiered volumetric, time-of-use, and one or two dynamic rates) with sufficient variety such that the observed outcomes are relevant and practical for understanding real-world commercialization prospects.
  - **Criterion #2: Cost-Effectiveness.** SHS data should be analyzed to evaluate the cost-effectiveness of different equipment mixes in a way that informs how return on investment could affect commercialization.
  - **Criterion #3: Scalability.** SHS results should provide an understanding of various potential improvements, including technical improvements to the technology itself, which will yield practical insight into potential future scalability issues, with support from clear and relevant observations from the project period. If SHS results are favorable, they could pave the way toward large-scale commercialization of the technology.
- Impact on Customer's Lifestyle: Demonstrate achievable energy cost savings for customers while maintaining comfort and preferences. The purpose of the energy management system extends beyond simple cost savings; IntelliSOURCE RDERMS should also work within customer preferences to better optimize energy consumption. The system will need to operate within constraints based on customer preferences such as thermostat limits, electric vehicle charge levels at certain times of the day, and pool pump run times.
  - **Criterion #1: Customer Experience.** SHS should compile information on the most prevalent customer preferences (including the degree to which adherence constrained potential energy savings), the level of customer satisfaction throughout the project based on surveys of each customer, and the clarity with which customers recognized the benefits of the technology. The importance of behavioral issues affecting the technology's efficacy should be acknowledged and considered throughout the project where appropriate.
  - **Criterion #2: Evidence of Savings.** Customer cost savings should be quantified and provided along with transparent, thorough documentation. The estimates and accompanying analysis should provide educational value that enhances the understanding of the technology's potential impacts.
  - **Criterion #3: Adaptability.** SHS should explore the RDERMS technology's effectiveness at maintaining savings while adapting to customer preferences. Furthermore, the resulting analysis should provide a sufficiently comprehensive understanding of ways in which customer preferences can affect the benefits of the technology and vice versa.
- **Achieve Representative Sample: Recruit and maintain a robust participant sample, given the acknowledged limitations.** The scope of the SHS is to obtain a sample of at least 100 homes to be studied to assess the impact of the technology. To be successful, the sample's composition for the real-world laboratory should allow a variety of load configurations to be understood while representing relevant climate

zones. The sample could include different equipment such as solar photovoltaic (PV), pool pumps, electric vehicle (EV) chargers, and BESS. The sample households will be equipped to provide diverse data allowing sensitivity analysis with respect to changing configurations. Recognized limitations prevent proper generalization of findings to the entire utility territory population; therefore, the sample will be considered successful if it yields valuable information about the feasibility of IntelliSOURCE RDERMS technology.

  - **Criterion #1: Size.** Per the project scope, at least 100 homes will be recruited, enrolled, and—to the extent possible—retained throughout the entirety of the project period. Given that this will be a sample of convenience, and not necessarily the optimal sample size, a successful project will gain as much insight from this size as is reasonably possible.
  - **Criterion #2: Composition.** The participant sample should include enough variation in terms of customer use cases/technology profiles and climate zones. There should be a good mix of electric vehicle owners/leasers and PV owners. Overall, the sample's composition should be highly consistent with the goals established in the project Sampling Plan (January 2018).
  - **Criterion #3: Data Collection.** The project should collect and analyze each customer's energy data including enough historical utility bill data and sufficient energy data measured during the project period.

- **Obtain Technical Advisory Committee (TAC) Recommendations: Assess TAC recommendations to enhance project success.** The purpose of the TAC is to ensure that expertise from diverse perspectives will guide the project. Input from the TAC is expected to keep project priorities on track, achieve synergy with similar efforts where possible, and generally seize all opportunities to improve the usefulness of findings. A successful project will demonstrate incorporation of TAC recommendations, where relevant and actionable, into strategic decisions throughout the project timeline, exceeding the possibilities that would otherwise be available without such valuable guidance. The project will be considered successful when it is demonstrated that support from the TAC has improved the ability to achieve identified project objectives.
  - **Criterion #1: Meeting Schedule.** SHS should comply with the established Technical Advisory Committee schedule by conducting all scheduled meetings consistent with the previously selected dates. The project should sufficiently use the expertise of the committee members given the established schedule.
  - **Criterion #2: Feedback.** The SHS project team should collect feedback by transmitting relevant project materials to TAC members and soliciting comments and suggestions at each full meeting. Such materials may include draft project deliverables, draft marketing materials, and overall progress reports. Decisions about which materials to transmit—and when—should ensure that committee members' time is being used wisely and that their feedback is solicited in a manner that is most beneficial for the project.
  - **Criterion #3: Recordkeeping.** Maintain notes and records summarizing discussions from Technical Advisory Committee meetings, and document substantial revisions that result from committee feedback. All records and notes should balance appropriate levels of detail and clarity with conciseness, respect for privacy, and project relevance.

- **Analyze Tariff Structures. Thoroughly test current and potential tariff structures.** Central to the motivation of the Energy Commission's funding is the need to test how groups of distributed energy resources (DERs) can respond to price signals. Therefore, to be successful, a variety of price structures must be investigated in conjunction with the technology of interest along with a variety of end-use devices. To be successful, SHS should evaluate costs, energy consumption, customer experiences under current block tariffs, newly implemented static time-of-use (TOU) tariffs, and future dynamic price signal tariffs. As of the date of this document, SDG&E does not offer dynamic price tariffs to residential customers. With that, from summer 2018 to spring 2019 (otherwise known as Phase 1) the project will examine participants' energy use and costs associated with customer behavior in response to TOU price signals. Then, beginning in spring 2019 (Phase 2), the project team will conduct multiweek experiments that will incorporate experimental periods of DER operation in response to dynamic utility rates. For this phase, day-ahead forecasts will be fed into the cloud database and appropriate control strategies for the components will be implemented dynamically.
    - **Criterion #1: Transactive Signals.** Per the SHS scope, the IntelliSOURCE RDERMS should test a transactive price signal that reflects grid conditions and optimizes impacts based on bidirectional information flow. If a fully transactive signal is not available, the project should test the closest available alternative. Project conclusions, as well as the design of the project itself, should sufficiently address the issue of transactive energy within any unavoidable constraints.
    - **Criterion #2: Rate Comparisons.** SHS should perform comparisons among each of the tested rate structures. The set of rates tested should be chosen carefully enough and with enough variety that the resulting insight is realistic and worthwhile.
    - **Criterion #3: Customer Bill Impacts.** SHS should achieve an understanding of possible future situations that could lead to substantial customer cost increases resulting from the IntelliSOURCE RDERMS. This understanding should yield useful insight about impacts to protect customer bills during large-scale commercialization.
- **Effective Operation: Demonstrate effective operation of the technology.** A successful project will demonstrate that the IntelliSOURCE RDERMS operated reliably enough to achieve the strategic goals. In addition, the technology should demonstrate effective communications and control; this will involve continuously using communication and control capabilities to support efficient energy management.
    - **Criterion #1: Reliability.** The technology should maintain consistent operation after successful commissioning.
    - **Criterion #2: Efficacy.** SHS should demonstrate effective communications and control, including pricing signal transfer and control of devices such as smart thermostats, pool pumps, electric vehicle chargers, and batteries. Communications and control capabilities should be maintained reliably and consistently.
    - **Criterion #3: Practicality.** Operation of the technology should serve the needs of customers effectively.

- Complete Project Deliverables: Submit all project deliverables including a comprehensive final report with findings and recommendations. All project deliverables will be submitted as proposed. The project will culminate in a final report that thoroughly documents all findings including technical analysis of collected data and thoughtful responses to strategic questions. The report will answer key questions about transactive energy, opportunities and challenges for commercialization, realistic costs and benefits of deployment, and the potential for increased integration of renewable energy across California.
    - **Criterion #1: Punctuality.** SHS project team will work to complete project deliverables quickly and efficiently.
    - **Criterion #2: Clarity.** Written reports and quantitative analysis deliverables will be presented clearly in terms of how they relate to one another as well as their role in the overall context of the project objectives.
    - **Criterion #3: Final Report Quality.** The final project report will provide substantive analysis through a balanced combination of measured data, calculations, and qualitative analysis. Responses to key strategic questions will be thoughtful and well-rounded, providing specific examples and clear evidence.

Table D-1: Success Scoring Table

Parameter	**Criterion**	**Description**	**#**	**Score (1-5)**
Achieve a better understanding of the potential for technology-enabled improvements to grid reliability.	Peak Load Estimates	Peak load reduction estimates are well-developed, detailed, and accompanied by thorough analysis.	1.1	**4**
	Challenges & Limitations	Key conclusions provide useful lessons about significant peak load reduction challenges and the feasibility of potential improvements.	1.2	**4.5**
	Customer & Site Attributes	Important factors significantly affecting the technology's value and impact (e.g... customer attributes, etc.) are clearly identified and thoughtfully examined.	1.3	**4.25**
Assess how the technology of interest could be commercialized on a larger scale.	Rate Structures	The variety of examined rate structures leads to a more realistic understanding of commercialization prospects and customer benefits	2.1	**4.25**
	Cost-Effectiveness	Analysis of project data significantly enhances the understanding of how equipment costs affect customer impacts and long-term market viability.	2.2	3.75
	Scalability	Project observations and conclusions yield important new lessons about scalability issues that could arise during commercialization, both technical and otherwise.	2.3	**3.75**

Demonstrate achievable energy cost savings for customers while maintaining comfort and preferences.	Customer Experience	The project leads to a greater understanding of customer attitudes and other behavioral issues that affect the benefits of the technology.	3.1	**3.75**
	Evidence of Savings	Cost savings estimates and analysis significantly enhance the understanding of the technology's potential impacts.	3.2	**4.25**
	Adaptability	The project sufficiently analyzes the ways in which customer preferences are served by the technology's adaptability, including the effects of changes in preferences.	3.3	**3.5**
Recruit and maintain a robust participant sample, given the acknowledged limitations.	Size	The project has recruited at least 100 homes and gained as much insight as possible from the sample, given the limited size.	4.1	**5**
	Composition	The project has obtained and leveraged a desirable mix of customer use cases, technology profiles, and climate zones in the recruited homes.	4.2	**4.5**
	Data Collection	The project has collected and analyzed enough historical bill data and project period energy data from all participants.	4.3	**5**
Assess Technical Advisory Committee recommendations to enhance project success.	Meeting Schedule	The project has sufficiently used the expertise of the Technical Advisory Committee members, while adhering to the established schedule.	5.1	**4**
	Feedback	Project materials have been effectively and efficiently shared with Technical Advisory Committee members, allowing them to carefully review and provide ample feedback.	5.2	**4.75**
	Recordkeeping	Notes and records from Technical Advisory Committee meetings are clear, detailed, concise, relevant, and respectful of any applicable privacy concerns.	5.3	**4**
Thoroughly test current and potential tariff structures.	Transactive Signals	Research and analysis throughout the project sufficiently explore the potential of transactive energy, subject to realistic limitations.	6.1	**3.25**
	Rate Comparisons	Rate structures are evaluated and compared in enough detail.	6.2	**4.5**
	Customer Bill Impacts	Potential future mechanisms to protect customer bills have become better understood.	6.3	**4.25**
Demonstrate effective operation of the technology.	Reliability	The technology operates reliably after successful commissioning.	7.1	**3.75**

	Efficacy	The technology maintains communications and control consistently.	7.2	**3.5**
	Practicality	The technology satisfactorily serves the needs of customers.	7.3	**4**
Submit all project deliverables including a comprehensive final report with findings and recommendations.	Punctuality	Deliverables have been completed quickly and efficiently:	8.1	**3.75**
	Clarity	Reports and analysis are presented, organized, and compiled clearly while maintaining focus on the project objectives.	8.2	**4.25**
	Final Report Quality	The final report effectively weaves together data, calculations, and written commentary with enough examples and evidence to support key conclusions.	8.3	**4.5**

Source: AESC