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Residential Demand Response

Emerging Opportunities in Southern California

Residential Demand Response

Emerging Opportunities in Southern California

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ABSTRACT

With the introduction of increasing amounts of renewable energy into California's wholesale electricity market and the growth of customer adoption of "smart" residential technologies, the emerging market opportunity for new models of demand response (DR) is rapidly evolving. This research study examines which residential electrical end uses could be dynamically enabled by innovative communicating DR technology, and how these household systems could facilitate both customer benefits and a more flexible demand side energy market. The report includes an exploration of secure communication protocols and transport mechanisms expected to be effective in providing the load flexibility to both satisfy customer wants and needs, and to safely manage a changing customer-grid relationship. The report also examines methods to drive price-elastic communications through load modifying tariffs and delivery of cost benefits of those tariffs to customers.

The continued development of smart appliances and new residential technologies presents several opportunities to facilitate the customer's role in achieving California's ambitious greenhouse gas (GHG) goals, deliver value to customers and the grid, and ultimately enhance DR program participation. The advent of the modern grid and increased renewables in California will provide an opportunity for residential customer uses to provide new grid services, while simultaneously meeting customer needs. These rapidly emerging changes will lead to an increasingly complex and significant partnership between customers and Southern California Edison (SCE) and will require a number of key DR enabling technologies solutions to be developed and adopted to be successful.

Keywords

Demand response (DR)
Direct load control
Automated DR
Distributed energy resources
Residential
Energy efficiency

EXECUTIVE SUMMARY

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PRIMARY AUDIENCE: Electric Utilities - demand response program implementors, Energy service providers, Aggregators, distribution system operators (DSOs), Independent systems operators (ISOs)

KEY RESEARCH QUESTION

Important changes in energy patterns, such as the increase of renewables, participation of equipment manufacturers as aggregators, customer preferences, and the convenience of new smart devices such as Alexa to manage energy usage, are constantly changing the opportunities for utilities like Southern California Edison (SCE) to engage their customers with DR programs. This project is an in-depth system to better understand the residential DR market and to identify optimal ways to enhance residential DR in Southern California.

RESEARCH OVERVIEW

Demand response (DR) encompasses a variety of utility programs and incentivized efforts in the industrial, commercial, and residential electricity sectors to reduce power at specified times to modify the electric utility system demand (or load). This report focuses on mass market residential electric uses and emerging communications and control technologies to determine which of these might provide useful DR resources in Southern California, especially for Southern California Edison (SCE). This research focuses on appreciating a better understanding of the emerging markets for residential DR enabling technology, and to identify optimal ways to enhance residential DR customer engagement through communication and coordination. It begins with a detailed look at what constitutes the residential sector within the territory served by SCE, and an estimate of electric end uses within that space. Next, it examines communication technologies and architectures needed to support DR in that sector. Finally, consistent with SCE's interest in short-term applications of residential DR technologies, with further interest in research that is currently ongoing, it reviews the available options and proposes useful approaches to DR in the residential sector over the next two to five years. The report also summarizes public policy and regulatory developments that affect residential DR.

KEY FINDINGS

This report identifies:

- A variability in the DR program eligibility within the demographics of customers.
- End use products that customers are most likely to modify to participate in DR programs.
- Communication architectures prevalent to communicate a DR signal.
- Research initiatives and industry forums that influence the relevance of technologies.
- Applications of electric vehicle loads that are moving from charging in commercial buildings to residential buildings.
- Customer preference for using smartphone applications and smart platforms to manage their energy usage.

EXECUTIVE SUMMARY

WHY THIS MATTERS

Important changes in energy patterns, such as the increase of renewables, participation of equipment manufacturers as aggregators and other players, and customer preference for using new smart devices such as Alexa to manage energy usage, are constantly changing the market and opportunities for utilities to engage their customers with DR programs. This research focuses on appreciating a better understanding of the emerging markets for residential DR enabling technology and identifying optimal ways to enhance residential DR customer engagement through communication and coordination. It reviews the available options and proposes useful approaches to DR in the residential sector over the next two to five years, given the technology options available at the time of writing. The report also summarizes public policy and regulatory developments that affect DR.

HOW TO APPLY RESULTS

This report provides an in-depth study on residential markets, DR enabling technologies, smart end uses, and policy and regulations to improve the DR in SCE's residential sector. This report also proposes useful approaches to DR in the residential sector over the next two to five years. These results can therefore be used by any utility DR program implementor to understand the DR market in order to create engaging DR programs for their customers.

LEARNING AND ENGAGEMENT OPPORTUNITIES

- The project results were transferred to different stakeholders from Emerging Markets and Technology (EM&T) Program to DR Programs, Codes and Standards group etc., and groups within SCE.
- The results can also be used by CAISO, CPUC and other IOUs to better engage customer participation in DR and, in turn, reduce the demand on the grid.

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ACRONYMS

AHRI	Air Conditioning, Heating, and Refrigeration Institute
AMI	Advanced Metering Infrastructure
API	Application Programming Interface
BPM	Brushless Permanent Magnet
BYOD	Bring Your Own Device
BYOT	Bring Your Own Thermostat
CAISO	California Independent System Operator
CCA	Community Choice Aggregation
CEC	California Energy Commission
CPP	Critical Peak Pricing
CPUC	California Public Utility Commission
DER	Distributed Energy Resources
DLC	Direct Load Control
DR	Demand Response
DRAM	Demand Response Auction Mechanism
EPIC	Electric Program Investment Charge Program
EPRI	Electric Power Research Institute
GEB	Grid Interactive Efficient Buildings
GMLC	Grid Modernization Lab Consortium
HP	Horsepower
HRR	High-Rise Residential
HVAC	Heating ventilation and air conditioning
IHD	In-Home Displays
IoT	Internet of Things
kWh	Kilowatt-Hours
LBNL	Lawrence Berkeley National Laboratory
LCA	Local Capacity Areas
NIST	National Institute of Standards and Testing
NREL	National Renewable Energy Laboratory
PCT	Programmable Communicating Thermostat
PSG&E	Pacific Gas & Electric
PEV	Plug-in electric vehicles
RASS	Residential Appliance Saturation Survey (CEC 2010)

RECS	Residential Energy Consumption Survey (DOE 2015)
RDS	Radio Data System
SCE	Southern California Edison
SDG&E	San Diego Gas and Electric
SDP	Summer Discount Program, a direct load control program for air conditioners
SEP	Smart Energy Program
SHEMS	Smart Home Energy Management System
SMUD	Sacramento Municipal Utility District
TDV	Time Dependent Valuation
TOU	Time-of-Use
USNAP	Utility Smart Network Access Port [Alliance]

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INTRODUCTION

Purpose of Study

Demand response (DR) encompasses a variety of utility programs and incentivized efforts in the industrial, commercial, and residential electricity sectors to reduce power at specified times to modify the electric utility system demand (or load). This report focuses on mass market residential electric uses and emerging communications and control technologies to determine which of these might provide useful DR resources in Southern California, especially for Southern California Edison (SCE).

This research focuses on appreciating a better understanding of the emerging markets for residential DR enabling technology and to identify optimal ways to enhance residential DR customer engagement through communication and coordination. It begins with a detailed look at what constitutes the residential sector within the territory served by SCE and an estimate of electric end uses within that space. Next it examines communication technologies and architectures needed to support DR in that sector. Finally, consistent with SCE's primary interest in technologies and processes that can be put in place in the next two years, with further interest about research that is ongoing now that could influence the residential DR market over the next 3-10 years, it reviews the available options and proposes useful approaches to DR in the residential sector over the next two to five years, given the technology options available at the time of writing. The report also summarizes public policy and regulatory developments that affect DR.

The Changing Energy Landscape

SCE's Emerging Markets and Technologies program has sponsored this study with EPRI in response to the important changes - in the state's energy policy that will both make residential DR more critical for the future of the state's green energy goals, and how residential DR operates with the new dynamic pricing tariffs . Among those key changes are:

1. A growing adoption of distributed renewable energy sources (solar and storage) that has already been shown to accurately predict important changes in the daily cost of the supply of energy. These changes have shifted the time period when DR is needed during the peak of the day. Now, wholesale market costs are ramping up in the early evening hours and loads need to "shift" into the middle of the day.
2. Recent experience in the SCE territory clearly showed that customers prefer DR coordination by third parties (e.g., Google and OhmConnect) rather than via a home area network concept with a coordinating device that communicates directly with the utility. However, local grid needs may change that approach, as SCE examines how to manage the distribution grid effects
3. New devices being introduced to the residential market (e.g., Amazon Echo, Tesla Powerwall, Samsung Hub) have the potential to create "smart homes" that can fine tune energy use while providing increased comfort to consumers.

4. Other new technologies (e.g., heat pump water heaters) can store energy in ways that may facilitate new ways to use DR by providing local energy storage for controlled release when needed by the grid.
5. The emergence of local energy storage "behind the meter" should not be underestimated. Market forecasts of the increased adoption of residential batteries "paired" with household solar systems are continuing to rise.

Each of these key changes in technology and consumer preferences implies a need to better understand the residential DR emerging markets for enabling technology and to identify optimal ways to enhance residential DR customer engagement though communication and coordination.

2

OVERVIEW OF RESIDENTIAL MARKET IN THE SCE SERVICE TERRITORY

Background

The U.S. Energy Information Administration reports[1] that in 2017, California ranked first in the nation as a producer of electricity from solar PV, solar thermal, biomass, and geothermal installations, with the solar resources providing about 16% of the state's net electricity generation. According to EIA,[2] despite having the fifth largest economy in the world, and the second highest total energy consumption in the nation,[3] residential energy use in California, per person, is below that of any state other than Hawaii. In fact, as per data in 2016, the state's per capita energy consumption ranked 48th, due in part to its mild climate and its energy efficiency programs. So is the residential sector in California, with its highly efficient housing and appliances (and relatively mild weather), an adequate opportunity for DR going forward?

To properly assess the opportunities for residential DR, it is important to *define* this category of housing, as it is characterized by government agencies, consumer markets, and electricity tariffs. This report also addresses the issues associated with demand response (DR) technologies for residential buildings, including the *definition* of this form of dwelling. This report defines residential buildings as follows: a dwelling, not for transient occupation, that contains single family accommodations with cooking facilities.

Diversity of SCE Territory

Southern California Edison (SCE) is the primary investor-owned utility provider of electric service for over four million residential customers, primarily located in southern California coastal, inland, and mountain regions. The SCE service territory expands out into the central valley counties of Tulare, Kern, and Fresno as well as more remote areas of Mono and Inyo counties. In total, SCE service territory spans approximately 14 counties and 9 California Public Utility Commission (CPUC) baseline climate zones. (Here, "baseline" refers to the baseline quantity of residential electricity for which utility customers pay a lower rate, which varies by climate zone.)

Within SCE, the bulk of residential customer accounts are in the metropolitan area, but SCE territory spans multiple regions of California as shown in Figure 2-1 below. Within these regions are a diverse, wide range of climates, as well as a population with widely varying technological

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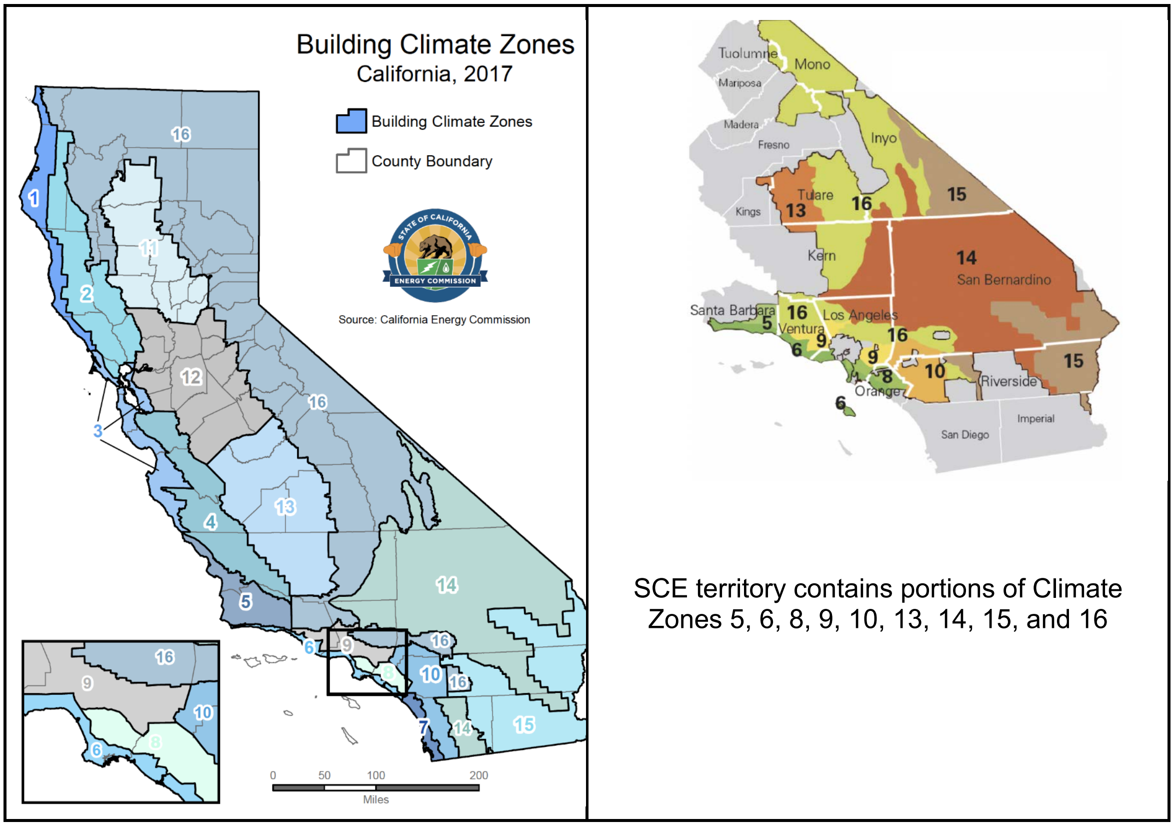
[1] https://www.eia.gov/state/index.php?sid=CA retrieved on March 27, 2019.

[2] https://www.eia.gov/state/analysis.php?sid=CA.

[3] EIA reports that December 2018 residential electricity sales in California totaled $1.377 Billion (9% of US total for same time period), a 7.4% increase from December 2017 (California residential electricity sales represented 8% of the US total in 2017).

literacy, connectedness, and income. This section examines each of these factors as it might impact residential DR.



SCE territory contains portions of Climate Zones 5, 6, 8, 9, 10, 13, 14, 15, and 16

Figure 2-1
Building Climate Zones: Left, California; Right, SCE territory (Source: California Energy Commission)

The SCE climate zones can be grouped into four geographic categories: Mountain, Central, Desert and Coastal. Some of the key distinctions in these areas as related to residential DR are outlined in Appendix A to this report.

Geographic Adoption of New Technology

A recent report to SCE proposed five categories (see Figure 2-2) to describe residential customer behavioral characteristics and their capacity to adopt new electronic technology:[4]

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[4] Customer Experience. (2016). *Attachment to SCE Notice of Ex Parte Communication 10-17-16 in R.12-06-013*. Retrieved from http://www3.sce.com/sscc/law/dis/dbattach5e.nsf/0/534C7966F964108B882580510080A32A/$FILE/R1206013-SCE's Notice of Ex Parte Communication 10-17-16.pdf.

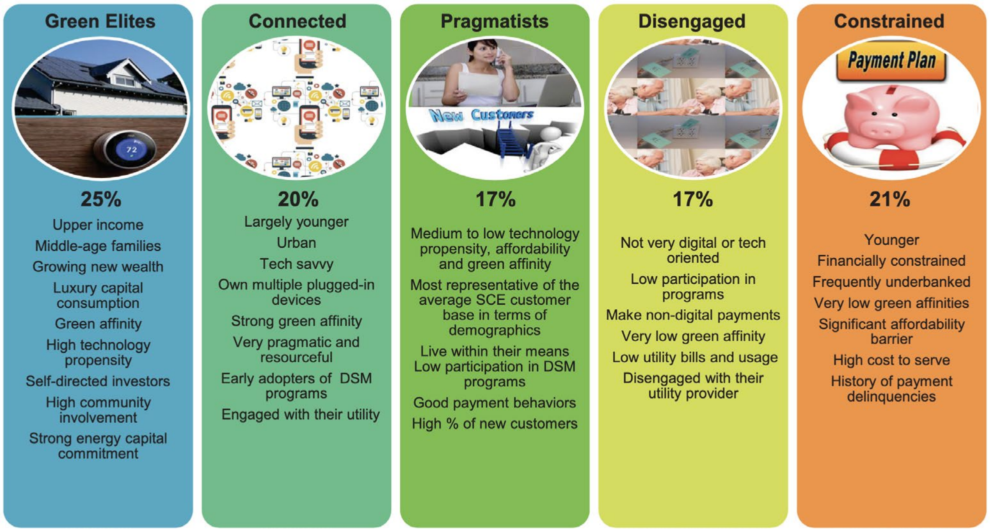

Figure 2-2
Residential customer segmentation in SCE territory (Source: Southern California Edison)

The report estimated the relative number of customers from each climate zone (except the small number of customers in climate zone 5) in each of the five customer segmentation categories. Figure 2-3, below, from the customer segmentation report shows that, in general, customers in climate regions 6, 8, and 9 tend to be more willing to adopt new technology while those residing in the lesser populated climate regions of 10, 13, 14, and 15 tend to be less likely to do so.

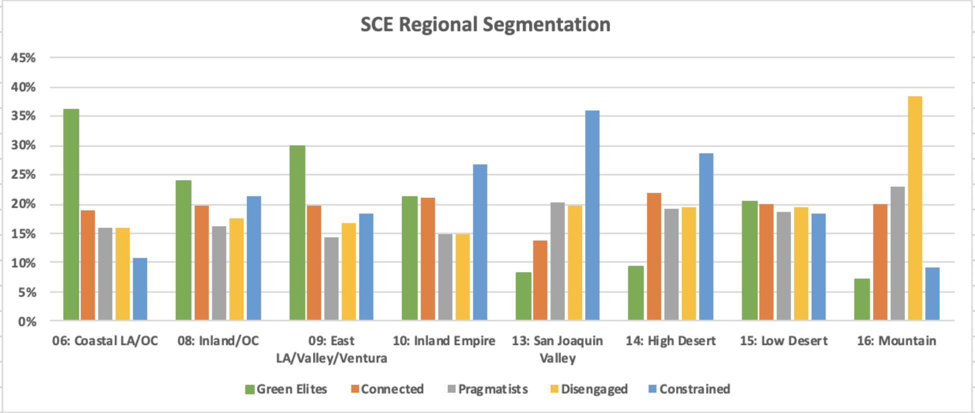

Figure 2-3
Distribution of customer segments by climate region within SCE territory

Table 2-1 identifies a correlation between household income and subscriptions to broadband internet service by county, with Mono County as an outlier with fewer than expected broadband subscriptions, possibly due to its more remote location.

Table 2-1
Median income and internet subscription rates by county (2019) (Source[5] - Census)

County	Median Income ($)	Households with Broadband Internet Subscription, 2013-2017(%)
Tulare	46,266	70
Kings	49,742	74
Kern	49,854	74
Inyo	51,500	76
San Bernardino	60,420	79
Mono	60,595	72
Riverside	60,807	83
Los Angeles	65,006	80
Ventura	82,857	85
Orange	86,217	88

Appendix B describes the residential DR tariffs currently available in the SCE territory, and Appendix C provides information about how often each of these was called recently. As an imperfect surrogate for new technology adoption (not all regions have the same need for air conditioning), SCE's Smart Energy Program (SEP) requires enrolling customers to have a central AC, an internet connection, and an SCE-approved smart thermostat.

Figure 2-4 shows that SEP enrollment numbers by load aggregation point (LAP) are greater in Coastal and LA areas, SCEC and SCEW, which account for 92% of enrolled customers [1]. Summer Discount Plan (SDP) enrollment numbers show similar trends, with 94% of enrollees residing in the LA Basin and Ventura local capacity areas (LCAs) [2]. Table 2-2 lists the number of customers enrolled in SEP and SDP within and outside the LA basin

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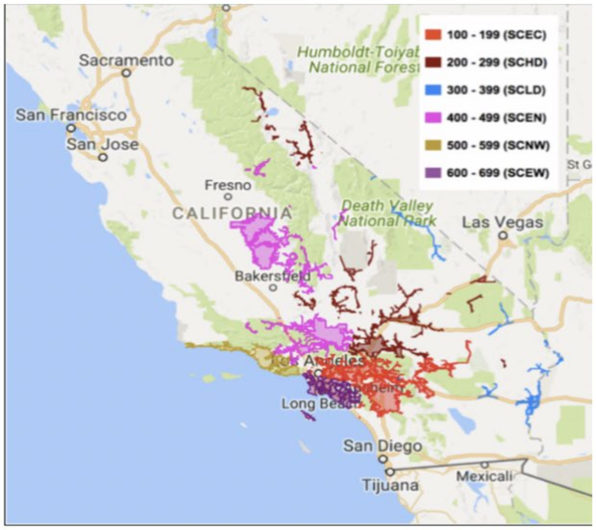
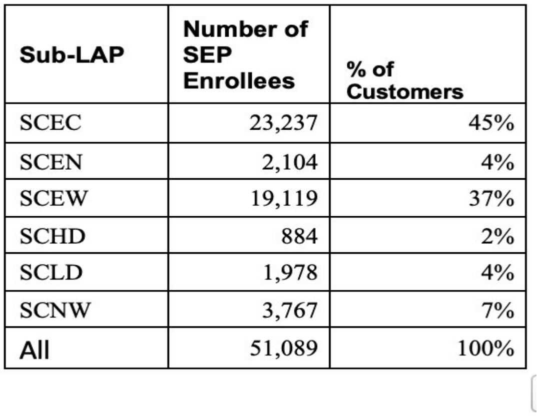
[5] https://www.census.gov/quickfacts/fact/map/CA,US/INT100217. Accessed 11/03/2019.





Sub-LAP	Number of SEP Enrollees	% of Customers
SCEC	23,237	45%
SCEN	2,104	4%
SCEW	19,119	37%
SCHD	884	2%
SCLD	1,978	4%
SCNW	3,767	7%
All	51,089	100%

Figure 2-4
Smart Energy Program enrollment density and customer numbers by SCE Sub-Load Aggregation Points (Sub-LAP). (Source: Nexant, 2019 [1] [2])

It is also important to note that these DR programs only apply to residential homes with central AC. This means residential customers in multifamily properties of five or more units, which account for 1.2 million or 30% of SCE's customer base and are predominantly renters, are excluded from participating. Adding customers that live in properties with 2 to 4 units raises the number to 1.84 million customers, or 46% of SCE's residential customer base (Southern California Edison, 2017) as demonstrated in Table 2-2.

Table 2-2
SCE customers enrolled in Smart Energy Program (SEP) and Summer Discount Plan (SDP) by Local Capacity Area

Local Capacity Area	Number of SEP Enrollees	% of SEP Enrollees	Number of SDP Enrollees	% of SDP Enrollees
LA Basin	43,921	80%	184,559	77%
Ventura	9824	18%	39,706	17%
Outside LA Basin	1,084	2%	15,554	6%
All	51,089	100%	239,819	100%

Source: Nexant 2019

Energy Use by Residence Types[6]

California Residential Definitions and Classifications

From a utility perspective (reference SCE tariff (U 338-E) designated California PUC Sheet No. 60125-E), residential refers to a dwelling that can be "a single-family unit, multi-family unit, mobile home, or similar living establishment." A single-family dwelling is "a house, an apartment, a flat, mobile home, qualifying recreational vehicle, qualifying residential unit, or any other permanent residential dwelling with contains cooking facilities (not necessarily electric) and which is used as a residence by a single family either in a multifamily accommodation or a single-family accommodation." Examples of these structures are shown in Figure 2-5.

Single family detached	Single family attached	Multi-family small – 3 stories or less	Multi-family large – 4 or more habitable stories	Mobile home
				

Figure 2-5
Types of residential units

Multifamily buildings contain multiple dwelling units that share common walls (townhomes) and may also share common floors or ceilings (apartments), but hotel or motel buildings are not considered multifamily in part because occupancy is transient. Large multi-family dwellings qualify for (typically lower) commercial rates and are typically not on residential tariffs. Within larger structures, if a unit is individually metered, it may qualify for (residential) domestic service.

SCE Residential Definitions

SCE defines residential (domestic service) as being applicable to a single-family dwelling premise (flat, apartment, house, mobile home, qualifying recreational vehicle or residential unit, or any other permanent residential dwelling that contains cooking facilities and that is used as a residence by a single family either in a multifamily or single-family accommodation. SCE notes that "In a multi-family dwelling like an apartment building or a mobile home park, the landlord will receive a 'master meter' electric bill broken into 'sub-meter' bills for each unit. The landlord uses this master bill to charge tenants for each unit's electricity use."[7] If there are no submeters, then the electric charge conveyed from a landlord to a tenant cannot vary month to month.

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[6] Data discussed in this section relies primarily on two key sources:

The U.S. DOE Energy Information Administration 2015 Residential Energy Consumption Survey (RECS2015)

The CEC California Residential Appliance Saturation Studies (RASS2010). A 2019 study is in development at the time of writing, but its results are not available, so the numbers presented here refer to the previous 2004 and 2010 reports.

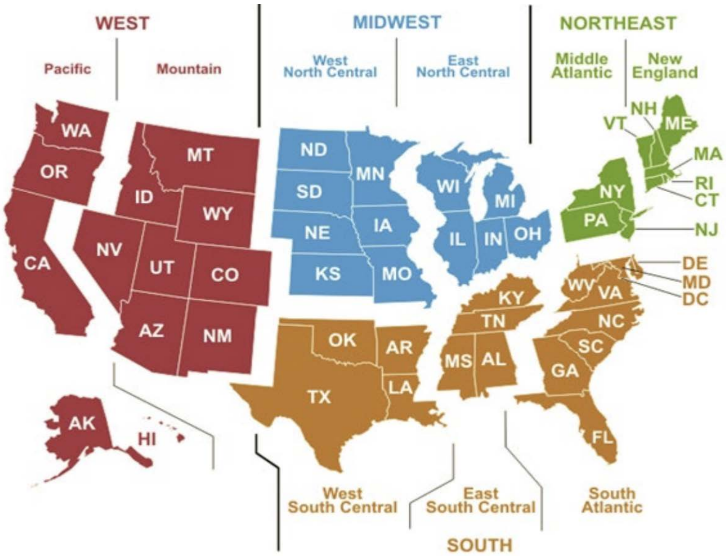
[7] https://www.sce.com/residential/rates/multi-family.

Explicitly excluded in the SCE tariff definition of "residential" are enterprises that rent to transient tenants or provides transient accommodations such as hotels, motels, residential hotels, guest or resort ranches, marinas, tourist camps, halfway houses, boarding houses, dormitories, rest/nursing homes, military barracks, etc.

Note that residential is defined within RECS2015 as "primary housing units as defined by the U.S. Census Bureau's American Community Survey" and excludes vacant, seasonal, or vacation homes, as well as group quarters such as prisons, military barracks, dormitories, and nursing homes. This is generally consistent with the definitions in the previous section.

U.S. Residential Data

RECS2015 data is the most recent comprehensive data on energy use, including residential electricity use, but the level of disaggregation is less than optimal for this work. Within RECS2015, the western United States is subdivided into Mountain and Pacific sectors at the lowest level of disaggregation (see Figure 2-6) The Pacific sector includes Washington, Oregon, Hawaii, and Alaska in addition to California.



Source: U.S. Energy Information Administration

Figure 2-6
U.S. Census divisions used in RECS2015. (Source: U.S. Energy Information Administration)

Table 2-3 identifies the relative distribution of residential units in the Pacific/Western segments of the country, representing, respectively, the smallest disaggregation available in RECS and RASS. The distinction in Table 2-3 between the number of units in an apartment building appears to be related to the size of the encompassing structure. The California energy code requires that residential structures with more than four or more floors must comply with commercial, rather than residential, building energy codes. This requirement is due, in part, to the fact that larger structures can be served by larger equipment to provide common tenant services such as space heating and cooling and in some cases water heating. In general, large multi-family dwellings without individual meters for dwelling units are not considered in residential statistics because they are metered under general service tariffs more commonly applied to commercial space.

Table 2-3
Relative distribution of residential units

Types of residential units	Number of residences in survey (M = million)	
	West (total 26.4 M residences)	Pacific (total 17.9 M residences)
Single family detached	16.2 M (61.4%)	10.6 M (59.2%)
Single family attached	1.6 M (6.1%)	1.1 M (6.1%)
Apartments (2-4 units in building)	1.9 M (7.2%)	1.4 M (7.8%)
Apartments (5 or more units in building)	5.3 M (20%)	4.0 M (22.3%)
Mobile homes	1.4 M (5.3%)	0.8 M (4.5%)

To look more closely at California, one can review the Residential Appliance Saturation Survey, which disaggregates the data in terms of utility territory. However, its data is almost a decade old. A new RASS is underway.

3

OVERVIEW OF DR ENABLING TECHNOLOGIES

Introduction

The emergence of smart home technologies, and the development of technology standards to facilitate consistent communications, has made the prospect of automated residential demand side management more feasible. This section contains information regarding the state of the art of technology in residential DR.

Evolution of DR Technology

Early DR Programs

Electric utilities have been developing and deploying DR programs as early as the 1960's [3], but DR gained widespread adoption around the 1980's [4]. Traditional programs relied on direct load control (DLC) using one-way broadcast technology such as paging or FM radio. This technology, while relatively inexpensive to deploy at scale, had several drawbacks including limited customer control and no feedback to the utility. The utility, indeed, did not receive any acknowledgment of message delivery, nor any direct information about customer response.

Devices using one-way communication were not designed to provide the DR, utilities expected. Several problems emerged: the utility did not know when the equipment was broken or turned off, or when the DR controller was removed (e.g., equipment replacement) or bypassed, or when the signal was not received by the unit due to a weak signal. Furthermore, studies have pointed out relatively low participation in these DLC programs may be attributed to customer distaste for relinquishing control and distrust towards utility programs, a sentiment that was exacerbated by the lack of two-way communication [5]. This type of program design was particularly problematic in determining cost effectiveness as the customers were paid regardless of their actual response and contribution to the grid.

Smart Grid and Advanced Metering Infrastructure

Federal policies such as the Energy Policy Act of 2005 and the 2007 Energy Independence and Security Act defined steps for the development of smart metering as well as the concept of a "smart grid," which initiated efforts for grid modernization. These policies led to the emergence of advanced metering infrastructure (AMI), a collection of technologies that enabled more granular and effective data transfer and communication between electric utilities and individual customers. The 2009 American Recovery and Reinvestment Act led to a significant influx of funding for the widespread deployment and testing of AMI technologies and demand side management strategies, which included smart meters, programmable controllable thermostats (PCTs), direct load control (DLC) devices, and in-home displays (IHDs) [6].

After the deployment of AMI systems in the 2000s, several utilities across the country attempted to use the AMI network to send DR signals, since, by design, smart meters are capable of two-way communication. Since most new smart meters in the United States were built to support the ZigBee Smart Energy Profile 1.0 (SEP) cluster, the meters conveyed the dispatch of DR signals to compatible devices [7]. After initial attempts it became clear that the latency in the downlink direction (up to several hours) limited the possibility of dispatching resources rapidly and dynamically. In addition, this latency negatively impacted the ability to commission the home controllers and delayed the feedback to a DR signal.

Other issues related to the use of smart meters for DR dispatch were:

1. Unreliable connection in homes where the smart meter was far from controllable devices
2. Limited functionalities supported by the SEP 1.0 protocol (e.g., no thermostat setpoint control or runtime feedback for a thermostat)
3. Possible loss of information during firmware updates

For these reasons, many utilities decided to use their AMI infrastructure for metering purposes, to send price information, and for other operational functions (e.g., remote disconnect), but not for DR dispatch.

Automated Demand Response: Smart Home and Home Energy Management Systems

Emergence of Programmable Communicating Smart Thermostats

Programmable communicating thermostats (PCTs) emerged in the mid 2000's as a method of controlling residential HVAC demand by changing thermostat settings. The significant impact of reducing HVAC load is undeniable; however, direct AC control only goes so far due to the unidirectional nature of the strategy. Direct AC control does not allow for customer-facing relationships that promote DR participation.

On the other hand, screens on programmable thermostats provide a user interface which allows for increased customer engagement and information transfer such as DR event information or pricing. Additionally, occupant comfort can be partly maintained by modifying heating and cooling setpoints instead of directly cycling the compressor or fan on the customer's HVAC system. After finding that PCT's in their territory could achieve 0.3-0.4 kW of demand reduction per unit [8], SCE investigated the feasibility of adding a Title 24 requirement that new buildings must install PCTs with the ability to receive DR signals and pricing. The requirement would have also involved standardizing communications to ensure interoperability via wireless protocols such as Zigbee, Z-Wave, Wi-Fi, and FM radio [9].

Studies conducted in 2008 by Sacramento Municipal Utility District in conjunction with Lawrence Berkeley National Laboratory (LBNL) demonstrated the use of a one-way FM radio data system (RDS) to transmit DR events including price and emergency events. FM radio stations were effective in transmitting pricing and event information and could be used with high probability of success when signals were sent multiple times. This process would take a short time [10]. Florida Power & Light conducted a pilot study in 2008 with Internet-enabled PCTs which demonstrated two-way communication of DR signals. This study found 0.93 kW of demand reduction per unit controlled and resulted in customers being generally satisfied with the new technology [11].

Second Generation of IP-Based Technologies (IOT Devices)

In the early 2010s, a few startups proposed a new generation of Wi-Fi smart thermostats, characterized by better interfaces, connectivity with smart phones and other web-interfaces, and more intelligence (e.g., occupancy sensors, energy efficient algorithms). In the next few years these products became popular and were the precursor to a new wave of smart home products (e.g., lights, appliances, plugs). Some of these products were not marketed for their energy efficiency characteristics, but for other benefits to the users (e.g., convenience, protection, nurture). In particular, smart thermostats such as Nest and ecobee began to be used in utility pilots and energy efficiency programs to determine the feasibility of their technology for demand side management [12].

Smart Home Platforms: Residential DR Opportunities

In recent years, major technology companies such as Google, Amazon, Apple and Samsung have entered the smart home market, all with their own flavor of platforms and ecosystem. These platforms are able to connect large ecosystems of devices using IoT infrastructure with a variety of integration levels. In 2014, Google acquired Nest, which had already achieved significant success in the smart home market through its smart thermostat [13], while Samsung Electronics acquired smart home platform SmartThings [14]. In the same year Amazon released Alexa alongside its smart speaker the Amazon Echo in response to Apple's Siri voice assistant, which slowly started to serve as a hub for smart home devices [15]. In 2016, Google released its voice assistant Google Assistant along its smart speaker the Google Home [16] while Apple joined in the smart home market with its release of the Apple Home Kit and its own smart speaker, the Apple HomePod in 2017 [17].

Along with improved customer interfaces using smartphone applications, customers now can obtain the ability to interface with their technology through voice commands, which has made the smart home experience more approachable and appealing. Adoption of smart speaker technology is rapidly increasing, with some reports estimating ownership up to 76 million units in the United States. As of 2019, of these smart speakers sold, approximately 70% of the market share is held by Amazon's Echo product line, while Google's smart speaker market share is at just under 25%, while Apple holds about 5% [18].

Following this trend toward smart home energy management, utility programs involving these devices have started to emerge. Applications that enable functionality with other products or services—such as Amazon's Alexa Skills and Google Actions— have been developed by a number of utilities including retail energy providers TXU Energy and Direct Energy, as well as utilities like Baltimore Gas and Electric. These applications allow customers to check their utility bills, usage history, and TOU durations [19].

In addition to these applications, utilities such as BC Hydro and Delmarva Power have launched smart speaker pilots to further define this technology's role in demand-side management [20].

Every major smart home platform currently on the market has a presence on the cloud. Figure 3-1 illustrates how smart home devices communicate with the cloud through direct manipulation from the user, or through the device's corresponding mobile application. Both methods use IP-based physical layer protocols, Wi-Fi or cellular, to communicate with the manufacturer's cloud to complete tasks. Aside from their proprietary nature, these systems also raise the question of whether these devices will operate optimally or at all when internet connectivity is lost.

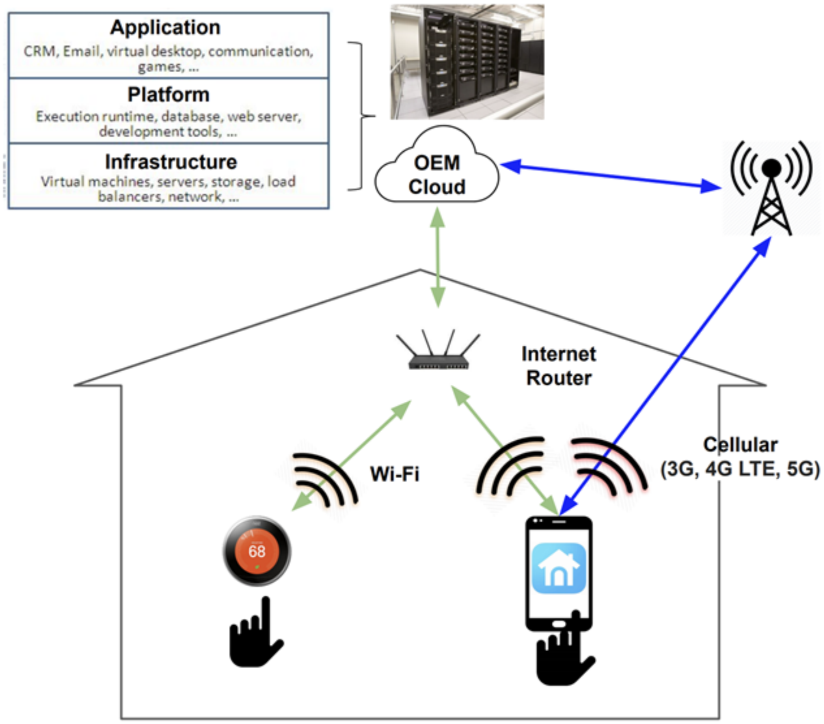


Figure 3-1
A smart home, smart end use and cloud communication

Overview of Communication Protocols, Platforms, and Communication Interoperability

Every smart home product (connected device) use various communication technologies and protocols to exchange information between various other devices and systems for monitoring and controlling purposes. Communication protocols allow connected devices to communicate between devices within a home and allow the devices to communicate with devices and systems outside the home. These communication protocols enable connected devices to deliver personal convenience, increased access, data collection, and control []. For example, a connected refrigerator can communicate to several in home and outside home devices/ systems using different communication protocols. This allows a customer, grid service provider and a utility with an ability to monitor and control the connected refrigerator. Figure 3-1 illustrates a smart home with connected refrigerator and communication protocols.

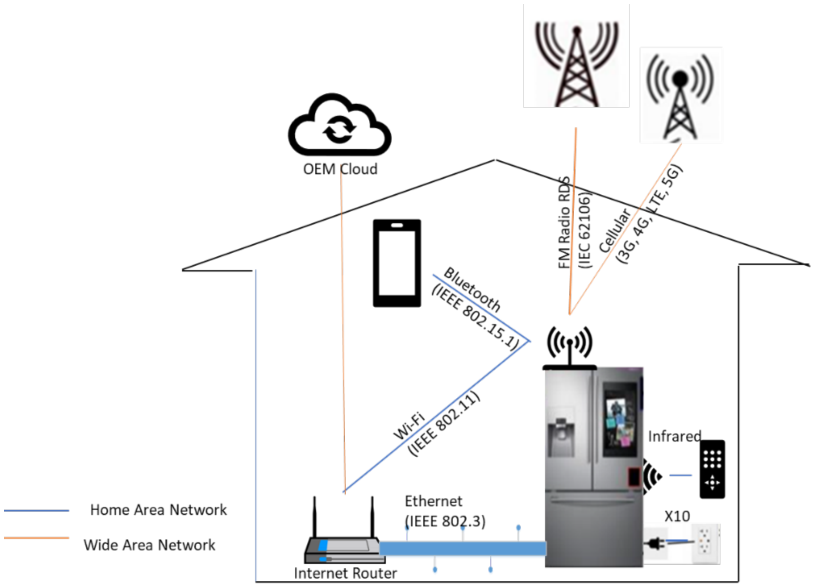
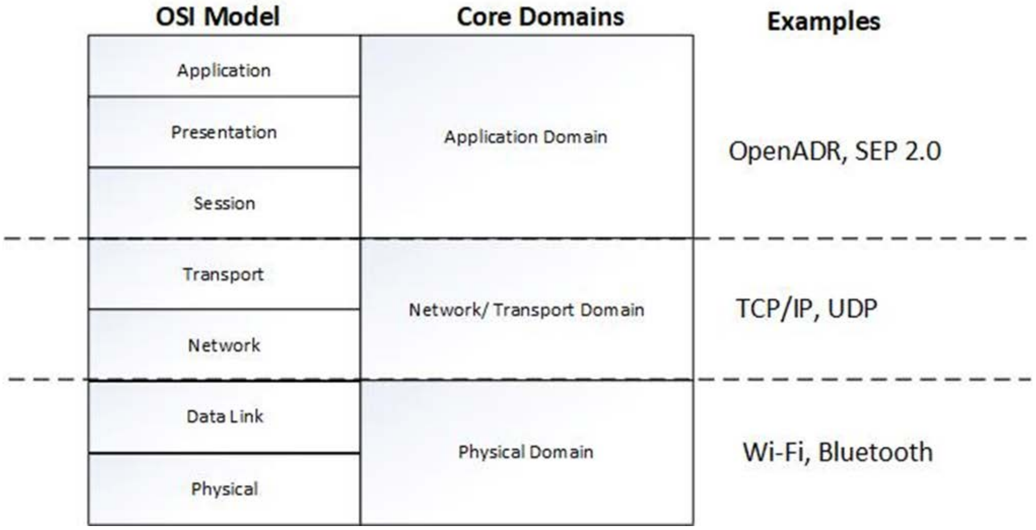


Figure 3-2
Smart home, connected devices and communications technologies

These communication protocols are referenced in the context of Open Systems Interconnection Reference Model (OSI model) to show how the information is exchanged between different layers. This OSI model is further collapsed into three core domains: (1) Physical Domain, (2) Network and Transport domain, and (3) Application domains, as shown in Figure 3-2.



OSI Model	Core Domains	Examples
Application	Application Domain	OpenADR, SEP 2.0
Presentation		
Session		
Transport	Network/ Transport Domain	TCP/IP, UDP
Network		
Data Link	Physical Domain	Wi-Fi, Bluetooth
Physical		

Figure 3-3
OSI model - Communication Protocols (Source: Lawrence Berkeley National Laboratory)

Therefore, OSI stack is the multi-layer representation of the path of information from a device to a user from physical domain to application domain through network domain. A protocol can be explained as a of rules controlling the information (data) exchange from one point to another. A connected device is a device that can receive and send information to other devices/ systems using communication protocols. For example, a web page displayed on a phone or computer is the information available using Hypertext transfer protocol (HTTP) at the application domain and one of the underlying stack layers protocols such as Wi-Fi, cellular, or ethernet.

In the context of demand response, there are a few application domains protocols that are significantly adopted and used in the industry today. These protocols are developed to enable a utility or a grid service provider to send appropriate information in the form of a signal to the connected device in order to monitor and control its energy consumption. Some of these communication protocols are discussed below.

Demand Response Communication Protocols

The late 2000s also saw the development of new smart home technologies based on new local communication protocol stacks such as ZigBee [21] and Z-Wave [22] that allowed users to connect local devices to the Internet through a central home gateway. With this setup, a DR provider could theoretically send DR signals directly to each device through a gateway taking advantage of the home broadband. An additional advantage of a gateway-supported ZigBee Home Area Network (HAN) is that it can collect smart meter information and present it to the customer in real time. In-Home energy displays (i.e., displays showing instantaneous energy consumption to the user) became popular in utility pilot programs around 2010, using this networking infrastructure. While this setup was a significant step forward for utilities and customers, several problems limited its widespread adoption from a customer perspective:

- Resistance of consumers to relinquish control over home appliances and equipment
- Limited adoption of ZigBee and Z-Wave devices among consumers

From the perspective of the utility:

- Lack of compatibility of smartphones, tablets, and laptops with HAN protocols (except for Wi-Fi), limiting the ability of utilities to communicate with the customer in real-time and using preferred interfaces
- Reliance on customer-controlled networks for DR dispatch may lead large number of devices being disconnected during DR events
- The gateway is another potential point of failure in the system
- Broadband penetration may be low in rural areas
- Need for a third-party vendor to provide grid-facing functionalities to the home network technology (originally designed for consumers)

OpenADR

OpenADR, originally developed at LBNL, is an application layer data standard that facilitates communication of DR events between the utility or energy service provider and the utility customer.

OpenADR has gone through multiple iterations, with OpenADR 1.0 being an open specification and geared towards specific DR programs and events. OpenADR 2.0 is a much more articulated standard, which conforms to the NIST Smart Grid Interoperability Framework and expands the standard to include information such as price, event duration, and magnitude of the load to be controlled. Some, however, believe the current iteration of OpenADR is too complex and burdensome on devices that only require a price signal (about 90%) [23].

To gain more widespread use of OpenADR in cost sensitive locations such as residences, researchers at LBNL have proposed a subset OpenADR 2.0b dubbed “OpenADR Lite,” which aims to reduce vendor costs and burden by sending stripped-down DR commands. These simpler command signals contain essential information such as price and widely used DR commands such as Shed. Price signals require only one-way communication [24]. This concept is still in development.

IEEE 2030.5 (Smart Energy Profile 2.0)

Zigbee’s Smart Energy Profile (SEP) was originally developed as part of the application layer of the Zigbee’s stack, created for energy management of smart grid home devices such as smart thermostats, plugs, lighting, and appliances. SEP has gone through a number of iterations since its inception, with SEP 1.0 in 2007, 1.x in 2012, and 2.0 in 2015 [25]. Version 2.0 of SEP (officially known as IEEE 2030.5) is network agnostic and able to be used over any IP-based physical layer, including powerline communications, ethernet, Wi-Fi, and the Zigbee physical layer standard. Zigbee itself has gained considerable traction with its growing alliance of manufacturer’s who have worked to create products that communicate through Zigbee’s SEP.

Vendors are designing devices to be upgradeable to IEEE 2030.5, which enables utilities to take advantage of SEP 1.1’s feature set now and upgrade to IEEE 2030.5 in the future. While primarily used for smart inverters, IEEE 2030.5 could be used to control end-use devices in residential or commercial buildings. The type of information sent between devices includes price of electricity, electricity usage, and alerts [26].

CTA-2045

CTA-2045 is a standard developed by the Consumer Technology Association and is promoted, certified, and advanced by the Utility Smart Network Access Port (USNAP) Alliance. The standard provides a line of communication between certain residential products and any load management system through a plug-in communication module. CTA-2045 is like putting ears and vocal cords on an appliance, or USB ports on a computer. The standard allows utilities to communicate with end-use devices over a standard physical interface that is agnostic to any current or future communication protocol. Initial end-use devices for which CTA-2045 communication requirements are being developed include:

- Electric resistance and heat pump water heaters
- Variable-speed pool pumps
- Thermostats
- Electric vehicle supply equipment.

The CTA-2045 specification includes two elements: the primary device (smart grid device, SGD) and the hardware or end-use module (universal communication module, UCM). CTA-2045 is comprised of three layers: physical, data-link and application layer (Figure 3-4). CTA - 2045 specifies its own physical layer socket standards, which includes variations for both AC and DC powered modules. There is current consideration of using UCB-C as a new, more modern socket.

The UCM plugs into a socket in the end-use device, which then communicates with the building energy management system or utility grid entity. In 2016, SkyCentrics developed Wi-Fi based

CTA-2045 communication modules for both AC and DC form factors [27]. The standard supports providing appliance metadata such as a model number, firmware version, and communication protocol (if a separate application layer protocol is tunneled through the CTA-2045 link). This metadata support allows for effective translation and communication between the end-use device and the incoming DR signal (OpenADR, SEP, BACnet). The application layer allows a DR command to reach the end-use device through the UCM. Utilities around the country have collaborated to create functional requirements for each type of end-use device specific to the capabilities of each device and the needs of participating utilities [28].

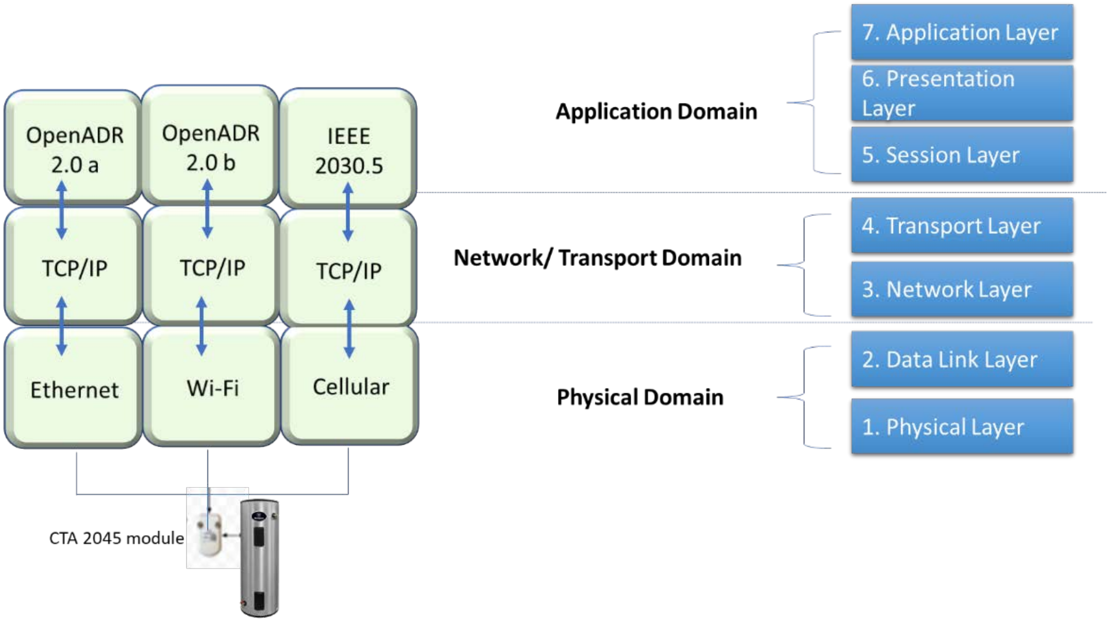


Figure 3-4
A smart water heater exchanging data between different domain protocols.

Applying the open systems interconnection (OSI) stack concept to DSM protocols becomes clearer and more comprehensive when thinking of where these protocols and technology lie within a stack. Figure 3-4 shows how a smart water heater will communicate and exchange data using a CTA 2045 (physical domain) module with other above domains. IEEE 2030.5 and OpenADR 2.0 are IP-based application-layer protocols that can send messages through TCP/IP and reach a home's end-use device via wireless communication such Wi-Fi or cellular or a wired protocol like ethernet. Interoperability is the ability to mix and match these protocols to ultimately deliver a DR (e.g., event or pricing) message to an end-use device such as a pool pump. The CTA-2045 UCM is agnostic to the physical layer it attaches on the other side of the device, and is able to receive these DR event data and convert them to device-specific function sets to actuate load modification in the end-use device.

Communication Architectures

A communication architecture shows the pathway on how a DR related signal initiated by a electric grid operator gets to the end use to alter its energy consumption. This data exchange happens between the DR ecosystem players—energy service provider (ESP) or aggregator, independent system operator (ISO), an electric utility or distributed system operator (DSO) and, end use (customer) in a home. To enable a successful DR event, there are 4 communication architecture pathways identified through which a DR related information can be communicated.

The 4 identified communication pathways are:

1. Utility/ ISO to End Use – Direct Control: In this architecture, a utility/ ISO directly communicates with the end uses such as water heating system, thermostat, etc at home as shown in Figure 3-5 to control the energy use through utility programs (such as water heater programs, thermostat program).

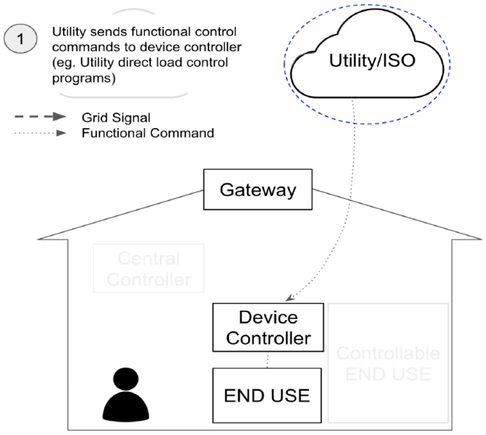


Figure 3-5
Communications architecture- Utility/ ISO to End Use – Direct Control

2. Utility/ISO-Gateway- End Use- indirect control: In tis architecture, the gateway (such as home energy management system (HEMS)) receives the DR signal directly from the utility or ISO using a nonproprietary protocol. This gateway sends the signal to the device controller in turn converts the DR signal into functional signal and communicates the energy altering controls to the end use. This is shown in Figure 3-6.

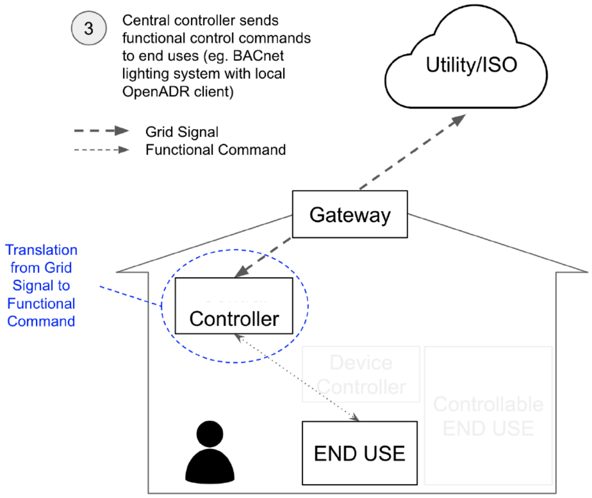


Figure 3-6
Communications architecture-_Utility/ISO-Gateway- End Use- indirect control

3. Utility/ ISO- ESP-End Use- control: In this architecture utility or ISO notifies an ESP(aggregator) that the grid needs a demand reduction, and the aggregator acts as a gateway and sends the functional signal to a device controller such as a smart thermostat, as shown in Figure 3-7.

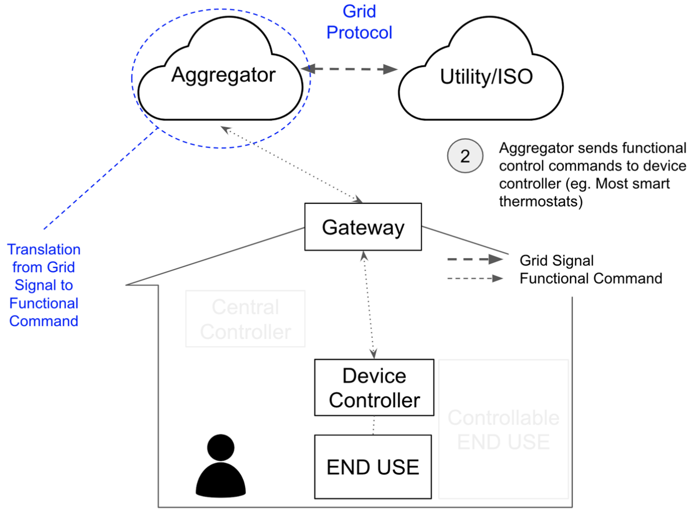


Figure 3-7
Communications architecture-Utility/ ISO- ESP-End use- control

4. Utility/ISO- Device Controller-End Use: In this architecture, the device controller receives the DR signal without passing through a gateway, and the device controller can be internal or external to the device as shown in Figure 3-8. Typically, the device controller data is monitored and controlled by the equipment manufacturer. For example, Ecobee manufactures thermostats that are monitored and controlled by Ecobee.

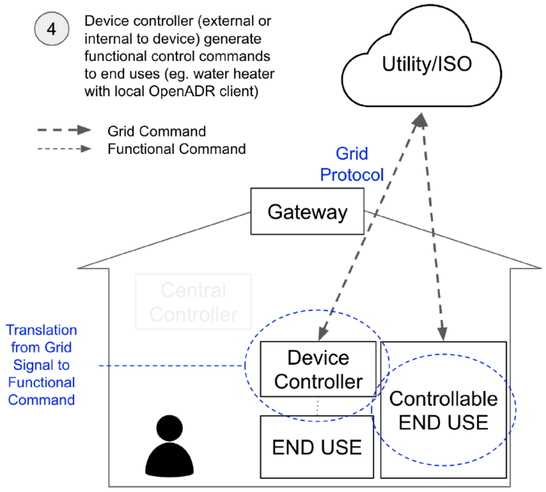
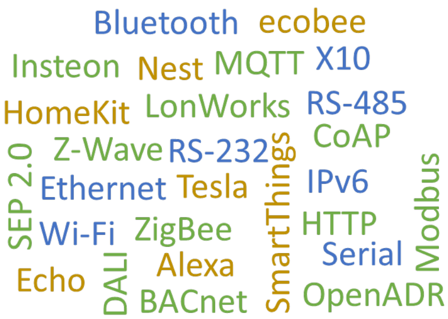


Figure 3-8
Communication architecture- Utility/ISO- Device Controller-End Use

With the development of several protocols to communicate data though helped us communicate and control the end uses effectively. There is a growing challenge in how these end uses will communicate and interoperate with one another.

Communication Interoperability

Interoperability in smart home products was and still is a significant issue. Most smart home products and platforms that crowd the market use closed and proprietary communications. Customers buying multiple products (e.g., a smart lock and a smart thermostat) find it difficult to navigate the different aspects of compatibility between devices. Two products using the same Wi-Fi network may not be accessible from the same app. Two products may be able to exchange data (e.g., the thermostat can infer occupancy based on the use of the lock) directly or using external services (e.g., IFTTT). Some devices stop being supported by companies and become obsolete. Figure 3-5 captures the “alphabet soup” of acronyms that consumers face when choosing smart home products.



- Products are Proprietary
- Communication Protocols
  - Protocol Stack
  - Local (HAN/LAN) vs Remote protocols (WAN)
- Data Models
- Platforms
- Application Programming Interface (API)
- User Interfaces (UI)

Figure 3-9
Confusing array of smart home products to the customers

Therefore, to secure the DR communications, it is highly recommended to use the open source protocols and standards and interoperability among these standards and protocols has to be encouraged. To maintain interoperability among technology options likely to become available to SCE customers, SCE should remain agnostic to brand names and architectures and move away from local, short-range application layer protocols (such as earlier Zigbee HAN efforts that proved unfruitful) and focus instead on architectures that are more suitable for Wi-FI or cellular connection (possibly 5G), as this seems to be the path forward for cloud-based services.

4

EMERGING MARKETS FOR RESIDENTIAL DR IN SCE SERVICE TERRITORY

This section describes options for implementing residential DR more effectively in the SCE territory. Within this context, the report examines residential loads for which DR is most appropriate or most likely to provide a significant opportunity for load modification. It then examines DR programs, describing a progression by which customers could be guided to improve their DR performance. Finally, recognizing that individual residential device responses may need supporting structures to effectively aggregate them into meaningful responses at the grid level, the report examines technologies and consumer apps that can coordinate or facilitate DR participation.

Current DR Market Penetration in SCE Service Territory

In 2018, U.S. utilities reported mass market DR (DR) program-based load reductions of 7.4 GW [29]. Current SCE residential DR programs include the Summer Discount Program (SDP), a direct load control program for residential air conditioners, and the Smart Energy Program (SEP), providing benefits via authorized service providers to residential customers who have purchased a pre-qualified communicating thermostat (list of service providers and associated communicating thermostats is available on the SCE website). Of the two programs, SDP has approximately four times the participants in SEP, and yields approximately twice the load reduction per account per event as SEP [30] (ILP for SCE, 2019), as shown in Table 4-1**:**

Table 4-1
Comparative details of SCE residential demand response programs (2019)

Southern California Edison Residential Demand Response Program	Smart Energy Program (thermostats)	Summer Discount Program (air conditioning load control)
Number of participants (number possible)	53K (1.98M)	220K (2M)
Demand reduction events (Jan-Sept 2019)	104	88
Hours of demand reduction	213	195
Average load reduced during events (per account)	0.4 kW	0.7 - 1.0 kW

Navigant Research [31] (Mehrhoff, 2019) recently identified three key factors driving residential DR:

- As more **intermittent renewables** connect to the grid, they cause a large midday dip in demand and the grid peak shifts towards early morning and late evening hours when solar energy is not available.
- **Technological developments** across advanced metering and data analytics, program management software, and end-user technologies allow stronger end-use targeting and can facilitate enhanced customer interactions.
- The growing **integration of more distributed energy resources** (DER) into the grid can allow participants to both consume and produce energy.

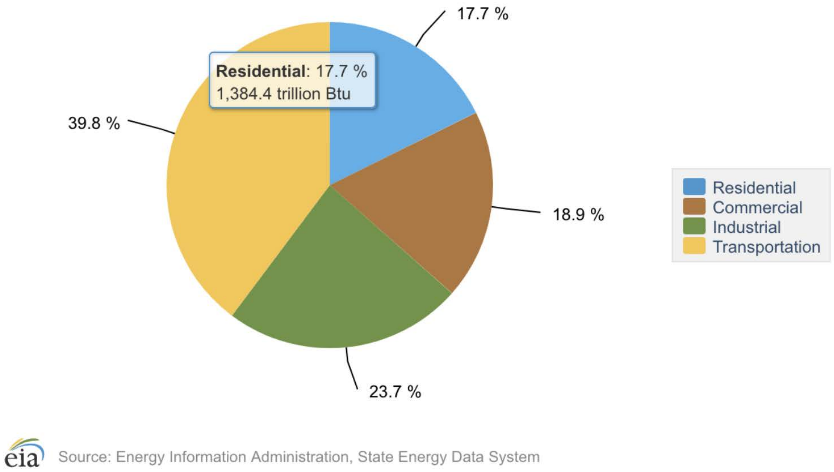
Previously SCE DR events occurred primarily from 2 to 6 p.m., impacting commercial and industrial accounts more directly than residential. Recently the peak load time has shifted to 5 to 9 p.m., which more acutely impacts residential accounts. Previously the bulk of that DR focused on reducing (shedding) air conditioning and business processes by means of signals to central building or process controllers. Today, residential DR can sometimes take advantage of load **shift** actions such as pre-cooling spaces or running schedulable loads such as pool pumps or ventilation at times other than peak. This reflects a marked change from historical residential DR that has focused on load **shed**.

There are several drivers changing the SCE residential DR market in addition to the three factors just cited:

- New communication and control technology provide both one- and two-way communication that wasn’t available previously.
- California Assembly Bill 117 signed into law in 2002, defined community choice aggregation (CCA) programs that allow cities, counties, and joint power authorities to procure electricity for individual customers within a defined jurisdiction. Customers not wishing to participate may opt out. Many residential customers in the SCE territory are now being moved by default into CCAs, with the option to return to SCE (opt-out) if they choose. (For a list of CCAs in the SCE territory as of January 2020, please see Appendix F),
- There is a growing set of policy directives to electrify space and water heating end uses and reduce the use of carbon-based energy sources such as natural gas.

Data Trends

As shown in Figure 4-1, EIA reports that California residential energy consumption was about 18% of the state’s total energy consumption (2016 data from EIA).



Source: Energy Information Administration, State Energy Data System

Figure 4-1
Estimated California energy use by sectors

By contrast with the state, residential sales of electric energy comprise 35% of SCE's total sales, as shown in Figure 4-2 [32]. (Note, however, that there are different tariffs for each sector in other areas of California as well as different weather, so the comparison is limited.

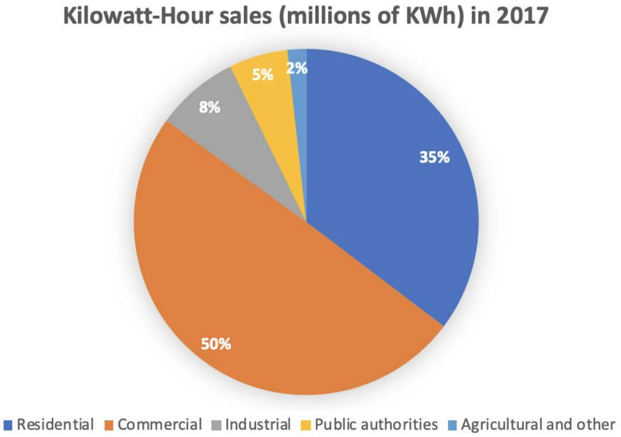


Figure 4-2
SCE energy sales by sector (2017)

In 2015, SCE residential customers used electricity primarily for heating, cooling, and ventilation, according to data from RECS2015 [33] (released May 2018).[8] As shown in Figure 4-3, all other end uses consume less than 50% of total residential electricity used.

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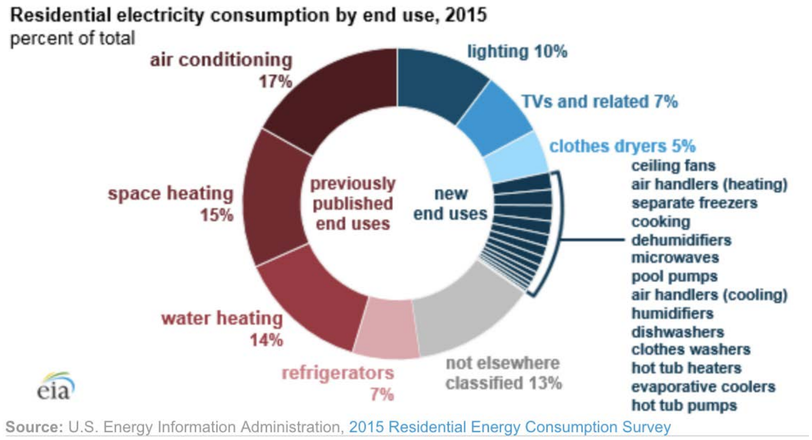
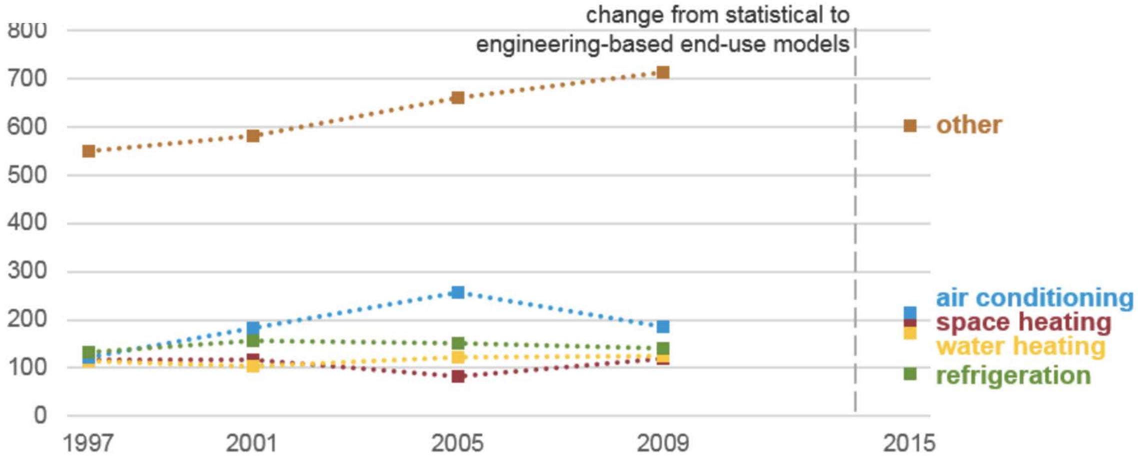
[8] https://www.eia.gov/consumption/residential/.



Source: U.S. Energy Information Administration, 2015 Residential Energy Consumption Survey

Figure 4-3
U.S. residential electric energy by end use percentages

Figure 4-4 shows trends in energy consumption across the United States. Air conditioning continues to lead consumption in the surveyed categories, with "other" (combined total of lighting, appliances, etc.) showing some decline in the recent [33] survey.



Source: U.S. Energy Information Administration, Residential Energy Consumption Surveys

Figure 4-4
Residential end use consumption trends (RECS2015)

Natural gas is the dominant heating source in the West, providing heat for 59% of homes compared with electricity in 33% of homes. According to RECS2015, "across all housing types, central warm-air furnaces were the most common in the United States. Built-in electric units and steam or hot water systems, which use a central boiler to heat water that is circulated through radiators, were more prevalent in apartments than in other housing types. Mobile homes accounted for the widest use of portable electric heaters as main space heating equipment." According to RECS2015, about 40% of homes keep the thermostats at a constant temperature, but 17% of the heated homes used a programmable thermostat (compared with 26% where thermostat adjustments were made manually, and 15% of heated homes simply turned equipment off or on as needed).

Focusing just on California, according to a 2017 survey by the U.S. Census Bureau, more than 25% of California homes use electricity for space heating [34]. RECS2015 reports that over 40% of California residents do not use air conditioning and approximately 14% do not use space heating. Within the SCE region, a larger percentage of residents than in California as a whole use air conditioning. RECS2015 notes that, in general, newer homes (built since 2000) are more likely to be in warmer areas, and are more likely to have ceilings higher than eight feet, typically associated with higher heating loads, but more likely to have double or triple paned windows, which reduce thermal losses from heated or cooled air.

Sources of Residential Electrical Use

Figure 4-5 shows that Southern California Edison's monthly residential electricity use is similar to homes in the San Diego area and in Northern California except in August through October,[9] which are warmer months. This section examines the possible contributions of different residential electric end uses and the extent to which they might participate in DR efforts.

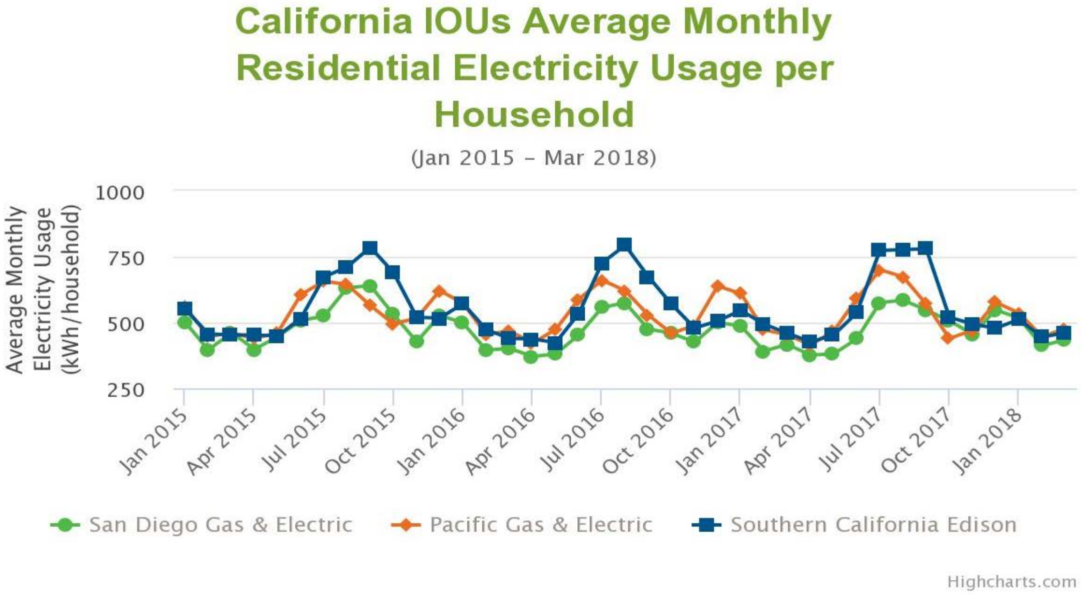


Figure 4-5
Comparison of residential electricity use per household by customers of California investor-owned utilities (IOUs) (Source CSE, 2018)

Demand response, by definition, aims to change power at specified times to modify the utility system load. This report characterizes and compares residential loads to determine which might provide useful DR resources for SCE. This section begins by looking at four (and a portion of a fifth) categories of end uses (in bold) that are most likely to contribute to DR (Figure 4-6):

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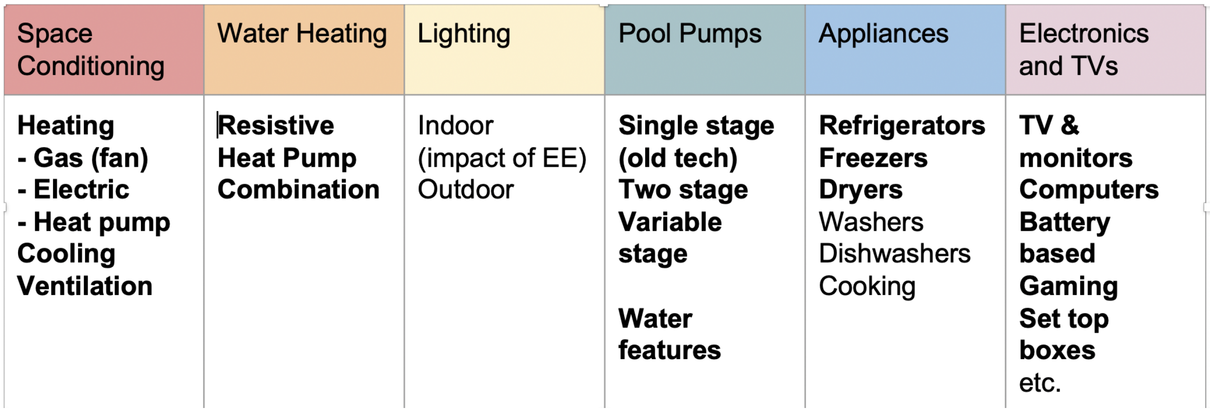
[9] https://energycenter.org/equinox/dashboard/residential-electricity-consumption, based on these data sources: *Pacific Gas and Electric, Usage Reports*, 2018; *San Diego Gas and Electric, Energy Data Worksheets*, 2018; *Southern California Edison, Quarterly Customer Data Reports*, 2018.



Space Conditioning	Water Heating	Lighting	Pool Pumps	Appliances	Electronics and TVs
Heating **- Gas (fan)** **- Electric** **- Heat pump** **Cooling** **Ventilation**	**Resistive** **Heat Pump** **Combination**	Indoor (impact of EE) Outdoor	**Single stage (old tech)** **Two stage** **Variable stage** **Water features**	**Refrigerators** **Freezers** **Dryers** Washers Dishwashers Cooking	**TV & monitors** **Computers** **Battery based** **Gaming** **Set top boxes** etc.

Figure 4-6
Types of residential end uses of electricity

Two larger surveys, RECS2015 and RASS (2004 and 2010) [35], each list a number of electric energy consuming end uses, and each identifies the primary end uses of electric energy use as space conditioning and water heating. Moderate energy use is reported for refrigeration, clothes dryers, electronic equipment (including TVs), and lighting. However, lighting energy use is declining as incandescent lighting is being replaced by fluorescent and LED lights that are less energy intensive. RECS2015 provides relatively recent data for the entire United States, disaggregated in part to the level of a Pacific slice of the western United States that also includes Oregon, Washington, and Northern California.

The following sections describe the expected load from each key end-use category by geographical region, describing the territory covered by SCE based on the best data currently available from RECS and RASS. Appendix D further summarizes relative residential electrical use, and Appendix E identifies predicted trends in residential electric energy use. Of particular interest are the flexibility options for the end-use operations, especially as impacted by recent changes in TOU tariff time periods. In general, the shift of the peak from noon-6 p.m. (TOU-D-T) or 2-8 p.m. (TOU-D-A or B) to 4-9 p.m. (or 5-8 p.m.) moves the time window away from typical business operating hours towards hours when residential activities are more common. (See Appendix B for SCE tariffs for TOU-D-T, etc.)

Significant load reductions could be derived from shifting or shedding residential loads that might otherwise happen at the end of the day. But not all loads are typically used at the end of the day, and some residential loads have more flexibility than others.

Space Conditioning

Space conditioning (heating and cooling) represents the bulk of energy use in residences. Space heating costs may decline in the future as a result of improvements in building envelopes (double and triple pane windows and better insulation) and improved efficiencies in equipment providing residential heat [36]. Space heating is provided from a variety of energy sources: natural gas is the most common form of heating in California, but heat energy also comes from electricity, propane, or wood.

The new TOU time periods recently introduced in SCE residential tariffs make the cost of heating or cooling residential space during evening hours more costly. However, pre-heating or pre-cooling (as appropriate) during the hours preceding those time periods could reduce the need to heat or cool during peak periods. In addition, it is possible to store thermal energy using existing thermal mass in residences or in residential dedicated storage devices. Thermal storage technologies include ice, chilled water, other phase change materials, or ceramic blocks.[10]

Space Cooling and Air Conditioning

The recent change in TOU periods within SCE tariffs suggests residential air conditioning will be an end use where mechanisms for shifting or shedding load will be of great interest. Two current program options:

- Direct load control Summer Discount Plan, in which a remotely controlled device installed on a residential air conditioning unit allows SCE to turn off or cycle that air conditioning unit (compressor) during energy events throughout the year based on the customer’s previously chosen program preferences
- A mechanism by which the residential space could be (ideally automated) pre-cooled prior to the TOU period, then allowing occupants to maintain comfort using less energy intensive ceiling or space fans

As noted earlier, the shift in time period for TOU peak periods moves the high-priced period closer to the end of the day. This TOU time shift moves the higher price TOU period to a time when a residence is more likely to be occupied; on the other hand, the average outdoor temperature during the new window is lower than earlier in the day.

Space Heating

There are a variety of options for space heating, and most residential space heating in California uses natural gas. The high cost per BTU of most electric resistance heating makes it generally non-compliant with Title 20 (1605) and Title 24 energy codes [37]. The two most common forms of residential heating—natural gas/propane and electric heat pump systems—are compared in Figure 4-7 below [37].

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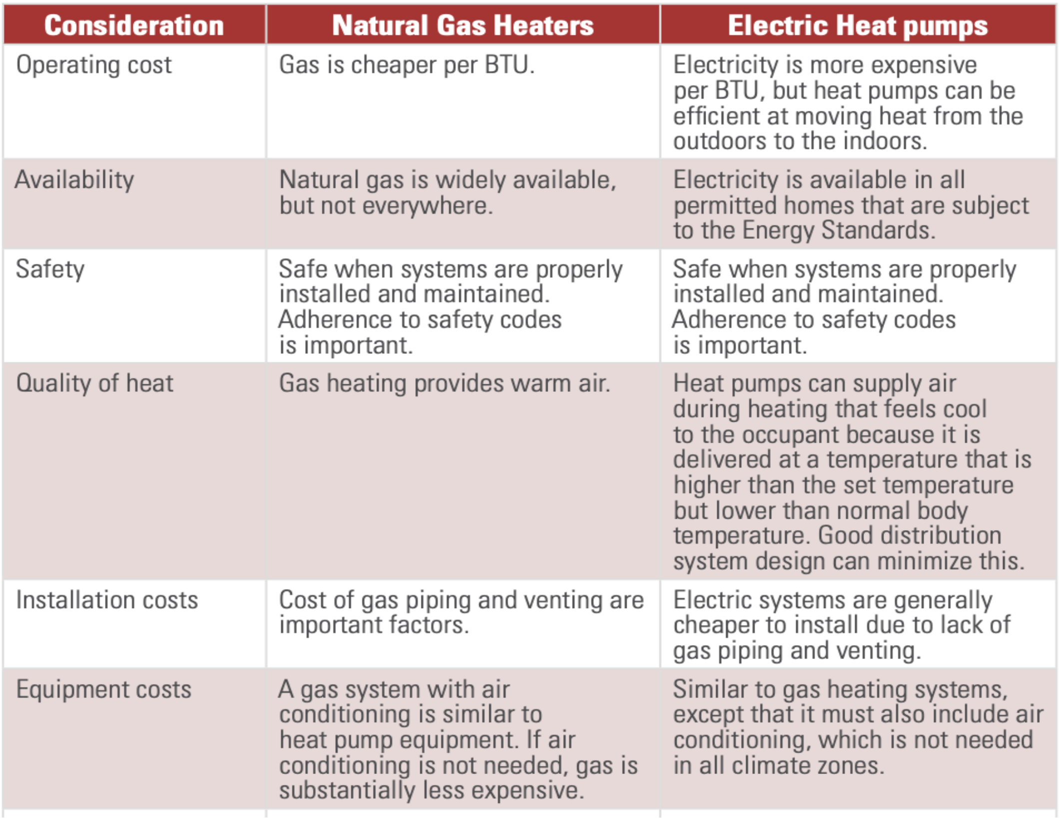
[10] https://www.greentechmedia.com/articles/read/how-does-thermal-energy-storage-reach-scale#gs.2zkx09.



Consideration	Natural Gas Heaters	Electric Heat pumps
Operating cost	Gas is cheaper per BTU.	Electricity is more expensive per BTU, but heat pumps can be efficient at moving heat from the outdoors to the indoors.
Availability	Natural gas is widely available, but not everywhere.	Electricity is available in all permitted homes that are subject to the Energy Standards.
Safety	Safe when systems are properly installed and maintained. Adherence to safety codes is important.	Safe when systems are properly installed and maintained. Adherence to safety codes is important.
Quality of heat	Gas heating provides warm air.	Heat pumps can supply air during heating that feels cool to the occupant because it is delivered at a temperature that is higher than the set temperature but lower than normal body temperature. Good distribution system design can minimize this.
Installation costs	Cost of gas piping and venting are important factors.	Electric systems are generally cheaper to install due to lack of gas piping and venting.
Equipment costs	A gas system with air conditioning is similar to heat pump equipment. If air conditioning is not needed, gas is substantially less expensive.	Similar to gas heating systems, except that it must also include air conditioning, which is not needed in all climate zones.

Figure 4-7
Comparison of gas and electric heat pump space heating (source Code ACE, 2017)

RECS2015 notes that electric heat pumps are better suited for heating in areas where winters are relatively mild. RECS2015 reports that of the 11.8 million households in 2015 that used electric heat pumps across the United States, 8.4 million (71%) were in the South. Because the dominant heating fuel in California is natural gas, and possibly because heat pumps were not sufficiently prevalent at the time of the surveys, RASS (2004 and 2010) [35] focused only on the electric fans that blow hot air from gas heating systems.

Water Heating

RASS2010 identified electric water heating as a relatively large load (over 2 MWh per unit) that is only found in 5% of all residences. The dominant fuel for water heating in California is natural gas. Within the electric water heater category, RASS made no distinction between resistive and heat pumps. Where electricity is used for water heating, the hot water can serve as thermal storage of electric energy.

Electric heat pump water heaters are an emerging technology in California. While heat pump water heaters are more expensive initially, they can save money over the long term because the operating costs are lower than other forms of water heating. Heat pumps move ambient heat, whereas other forms of water heaters generate heat (resistive with electricity or combustion with natural gas).[11] DOE estimates heat pump water heaters for swimming pools, for example, can

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[11] https://www.energy.gov/energysaver/water-heating/selecting-new-water-heater.

save users up to $800 annually[12] compared to the cost of electric resistance or natural gas heaters. However, a heat pump heats water more slowly than electric resistance or gas water heaters, so a residence requiring frequent use of large quantities of hot water may need a larger storage tank.

Water heaters were not modeled explicitly in the Phase 2 California DR Potential Study [38], although that study estimated about 15% of water heaters in California IOU service territories are electric. The report notes that this load can act as thermal storage, and postulated that if aggregated in large enough quantities, could provide flexible and fast DR (shift or shimmy DR service). The soon to be published Phase 3 DR Potential Study does explore the DR available from electric water heating, but it will be many years before this flexible load is large enough to be significant because of the time needed to deploy this technology.

Lighting

Shifting the TOU periods to later hours increases the likelihood that residential lighting will be used during the more expensive time periods. Lighting manufacturers have developed a variety of DR strategies for commercial lighting systems, including dimming of lights and turning off zones. Some of that work could be used in residential settings. However, RECS2015 notes that "The major trend in U.S. household lighting has been the shift from less-efficient lighting—primarily incandescent bulbs—to more energy-efficient lighting—including compact fluorescent lamps (CFLs) and light emitting diode bulbs (LEDs)." According to a 2017 post by Lucas Davis,[13] Director of the Energy Institute at the Haas School of Business at the University of California, Berkeley:

"American households use less electricity than they did five years ago… No other household technology is as disruptive as lighting. Incandescent bulbs don't last long, so the installed stock turns over quickly. Air conditioners, refrigerators, dishwashers, and other appliances, in contrast, all have 10+ year lifetimes." He continues: "Is this really big enough to matter? Yes! Suppose that between LEDs and CFLs there are now one billion energy-efficient light bulbs installed in U.S. homes. If operated 3 hours per day, this implies savings of 50 million megawatt hours per year, or 0.16 megawatt hours per capita."

Statistics vary on the relative percentage of electric energy used annually for residential lighting, possibly because of this rapid decline in overall power requirements by bulbs and the strong push to encourage the replacement of incandescent bulbs with more efficient options. As a result, other residential end uses appear to be more promising for DR.

Ventilation

2016 Title 24 Prescriptive standards in California requires specified levels of ventilation in new residential construction. A recent LBNL study (Less et al., 2019) found that smart ventilation controllers can contribute to demand response peak demand savings, largely by reducing the ventilation portion of the cooling load during the hottest times of day. The study examined whether the ventilation could be shifted in time to reduce energy costs while maintaining other ventilation requirements. Temperature-based controls were found to be effective, with the most

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[12] https://www.energy.gov/energysaver/heat-pump-swimming-pool-heaters.

[13] https://energyathaas.wordpress.com/2017/05/08/evidence-of-a-decline-in-electricity-use-by-u-s-households/.

successful smart controls reducing weighted average site ventilation energy use by about 40%, while TDV weighted average ventilation energy reductions were higher, up to roughly 60%. Results were also normalized to ensure identical indoor air quality in all cases, and the weighted average site and TDV ventilation savings increased, up to 55% and 72% ventilation savings, respectively, for the top-performing temperature-based controls. Climate zones were chosen to reflect the variety of heating and cooling demand throughout California.

The most successful smart controls in this study (focused on 2-6 pm period) shifted ventilation rates seasonally, rather than over the course of the day or month. Although controller performance varied substantially by climate zone, airtightness and house prototype, the study was able to provide guidance on which control approaches are best suited to different climates.

Pool Pumps[14]

The CEC estimates that there are over 1.5 million residential swimming pools in California. In 2012, according to Opower, as reported by ThinkProgress,[15] "homes with those pools use 49% more electricity each year than homes without." SCE estimates that just under one million of those pools is in territory that it serves, with an approximate 15% turnover in equipment each year. It has been estimated that for a typical pool with 20,000 gallons of water, 2500 kWh is needed each year to circulate and filter the water.[16]

In addition to providing water motion for fountains or other water features, the bulk of pool pumps use electricity to filter and circulate pool water. Pumps for water features outside of pools tend to be lower power (less than 1 HP) than those associated with pool water maintenance. Pool pumps primarily clear debris from the water and mix chemicals into the water by pushing water into and out of the filtration system.[17] Pump size and operating time is dependent in part on pool size and use. According to SCE, pool pumps can use more energy than most devices and appliances in a home. However, pool pump operations can be scheduled or interrupted. It is generally recommended that all pool water be filtered once every twenty-four hours, but with different pump speeds, that filtration process can take differing amounts of time and energy. Mixing of chemicals into pool water can be scheduled as needed.

In fact, single speed pumps are being phased out in California by regulations in Title 20 of the California Building Code. Specifically, Section 1605.3(g)(5) of California's Appliance Efficiency Regulations (Title 20) requires:

- Pool Pump Motors – Pool pump motors manufactured on or after January 1, 2006 cannot be split-phase or capacitor start-induction run type. Residential pool pump motors with a pool pump motor capacity (or total horsepower) of 1 horsepower (HP) or greater manufactured on or after January 1, 2010, must have the capability of operating at two or more speeds with a low speed having a rotation rate that is no more than one-half of the motor's maximum

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[14] See also https://www.etcc-ca.com/sites/default/files/reports/dr07_01_pool_pump_demand_response_potential_report.pdf.

[15] https://thinkprogress.org/homes-with-swimming-pools-use-49-more-electricity-than-homes-without-but-is-the-pool-really-to-blame-8a24b60594d6/.

[16] Ibid.

[17] https://home.howstuffworks.com/swimming-pool-pumps-run-all-the-time.htm.

rotation rate. The pump motor must be operated with a control capable of running the pump at a minimum of two speeds.

- Pool Pump Motor Controls – Pool pump motor controls manufactured on or after January 1, 2008 and sold for use with a two- or more speed pump must be capable of operating at two or more speeds. The control's default circulation speed setting cannot be more than one-half of the motor's maximum rotation rate. Any high-speed override capability must be for a temporary period not to exceed one 24-hour cycle without resetting to default settings.

This regulation provides a critical control opportunity for pool pumps in SCE territory. These standards were designed to save up to 80% of the electricity needed to circulate and filter the water in residential swimming pools. However, pressure cleaner booster pumps, commercial pool pumps and motor combinations, and auxiliary pumps are not regulated by Title 20. The 2017 DR Potential study research assumed "costs of the pool pump controls themselves are low: about $141 fixed installation cost per site and $4 per site annual operating costs.[18]

Pool pump energy consumption is related to how fast the pump operates. Different operating speeds reflect a variety of end uses related to their role in maintaining a pool. For example:

- Salt chlorinators require faster operation (higher RPM) to close the mechanical flow switch to generate chlorine.
- If the pool is heated, in some designs there is a flow pressure switch that determines when a heater turns on.
- In-floor cleaning systems, waterfalls, or water features may also require higher speeds.

A 2013 study sponsored by San Diego Gas and Electric investigated the DR capability and potential of a controller that could reduce the speed of pool pumps [39]. It found that the vast majority of pool pumps at that time were single speed, so the only DR would be to turn the pumps on or off for selected periods of time. However, where pump speed could be controlled, significant demand flexibility could accrue. As an example, variable speed pool pumps have the ability to reduce pumping speeds while maintaining minimum filtration rates and eliminating the risks of power cycling and health safety concerns. A variable speed pool pump can run from, for example, 1-½ HP to ¼ HP, and save up to 75% of the energy used by a single- or two-speed pool pump. During a DR event, such a pump could conceivably keep operating, but at a greatly reduced speed.

Of importance is the time during which the pool pumps operate. According to an earlier SCE report [40], the dominant use is mid-day except in the Inland area, where there is a secondary peak in the late afternoon as shown in Figure 4-8:

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[18] Private communication, Brian Gerke, LBNL, 26 March 2019.

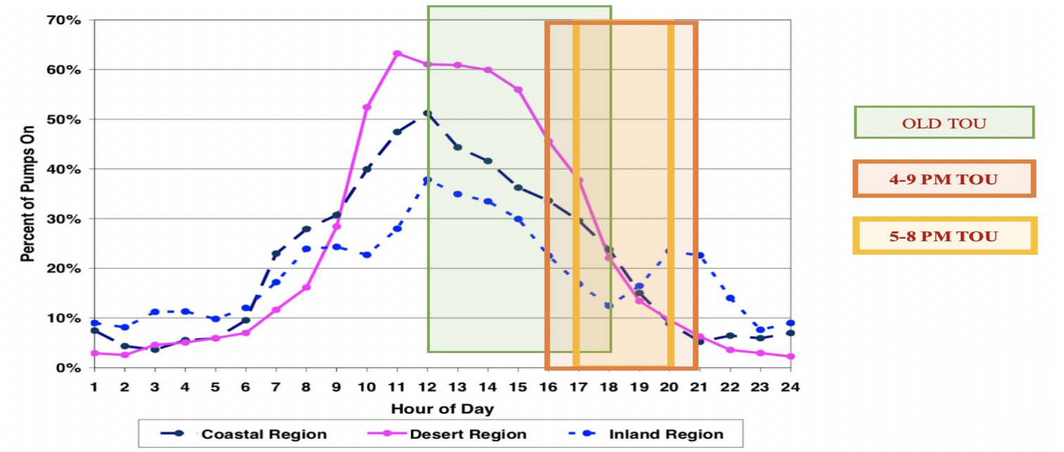

Figure 4-8
Pool run time vs. percentage of pumps running. (SCE 2008, with TOU periods added)

Except for pool operations in the inland region, the bulk of the time when pool pumps operate is predominantly during the older TOU time periods in the early afternoon, rather than the later afternoon time periods associated with new TOU tariffs.

Appliance Loads

Several of the larger electric loads found in a residence are related to food and clothing maintenance. NREL conducted a study examining the DR capability of typical household appliances in 2013[19] that found:

- Not all appliances are suited to DR controls (e.g., because of their function, some end uses cannot shift load to off-peak hours, regardless of the TOU rates imposed)

  A utility's TOU schedule and rates will have a large impact on the cost effectiveness of DR appliance technology and how willing people will be to participate in DR programs.

Even with a TOU rate schedule with high on-peak prices and low off-peak prices, the cost effectiveness of DR varies with different end uses, with some simple payback periods (in the devices studied by NREL) in excess of 40 years.

Generally, DR controls can be replicated manually without expensive communication hardware. Consumers are really paying for convenience with the DR products, as they would not have to keep track of their rate schedule and actively reduce consumption during peak hours.

Refrigerators

Refrigerators are common to all residences. RECS2015 notes that approximately 30% of households across the US now have two or more refrigerators, with 86% of these in single family detached homes. RECS2015 found a correlation between household income and the number of refrigerators in a home. Separate freezers had an even higher electric load but were found in fewer than 20% of all homes.

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[19] https://www.nrel.gov/docs/fy14osti/60383.pdf.

Despite dramatic improvements in efficiency (more insulation, tighter door seals, larger coil surface area, better controls, and improved compressors and motors) since the 1970's, refrigerators remain among the largest energy consumers in the home.[20] A typical new refrigerator is larger and has more features than a typical older model, while using a fraction of energy used by an older model.

Refrigerators offer some measure of thermal storage and, as a DR resource, can be turned off for short periods of time as long as the food contents remain below a designated temperature. The Irvine Smart Grid Demonstration project[21] found that raising the freezer setpoint (allowing the refrigeration components to turn off for a short time), disabling anti-sweat heaters, and delaying the defrost cycle lead to an average load reduction of approximately 90 W. However, the actual response depended upon ambient conditions and the operational status of components. In general, the load reduction time was longer than anticipated, but never more than an hour due to food safety issues.

Clothes Washers

In general, energy attributed to clothes washers does not include the energy to heat the water because the hot water is delivered from the water heater. New resource-efficient washers provide excellent wash performance while cutting energy and water use by half or even more. These resource-efficient models also use higher spin speeds to extract more water from each load of clothes, saving significant dryer energy as a result.22 EnergyStar certified washers reportedly use four times less energy than conventional units built prior to 2000.

The Irvine Smart Grid Demonstration project included a test of the DR potential of clothes washers[23] that focused on delaying the start of washing or reducing the load (by reducing the duty cycle of the wash motor and heater to 50% upon receipt of a DR signal). It found that the timing of the signal was critical. If the particular process had already started, the appliance ignored the signal. However, if a load reduction signal was received in time, up to 50% load reduction could be achieved. For the particular model tested by the Irvine Smart Grid Demonstration project, when responding to a DR signal, the load reduction was 100 watts per washer accompanied by an increase in wash time. The shift in TOU on-peak time period from mid-day to later in the day suggests there may be a need to explore more options for incorporating DR into clothes washers than are currently available.

Clothes Dryers

Like clothes washers, the shift in TOU on-peak time period from mid-day to later in the day suggests there may be a need to explore more options for incorporating DR into clothes dryers than are currently available. EPA EnergyStar criteria[24] for clothes dryers were established on May 19, 2014 to set thresholds on the energy required to dry a standard sized load in lbs/kWh: electric dryers with 4.4 cubic foot capacity must be less than 3.93 (nominal energy to dry a

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[20] Smarterhouse.org.

[21] http://www.apep.uci.edu/research/partnership_ISGD.aspx.

[22] Smarterhouse.org.

[23] http://www.apep.uci.edu/research/partnership_ISGD.aspx.

[24] https://www.energystar.gov/products/appliances/clothes_dryers.

pound of clothes); if the dryer is smaller capacity, the value must be less than 3.8 (120V), 3.45 (240V, vented), 2.68 (240V, without a vent). According to EnergyStar, a full-sized certified dryer will save $200 in energy bills over the life of the product. Although heat pump clothes dryers are about 50% more efficient in drying clothes, they are not expected to become more widely deployed through 2040 [36].

Cooking Appliances

Within California, according to RASS2010, the preferred fuel for cooking was natural gas: 63% of residential ranges used gas (34% used electricity); 53% of residential ovens used gas (44% used electricity). According to smarterhouse.org, a project of the American Council for an Energy-Efficient Economy: "Cooking patterns have changed considerably over the past few decades, with many Americans dining out more, cooking less, and using a microwave oven instead of a stove for preparing and heating many dishes." Cooking is unlikely to be an end-use that lends itself to becoming a DR resource.

Dishwashers

RECS2015 found that "compared with clothes washers, dryers, and cooking appliances, dishwashers were by far the most unused device in homes." When dishwashers are used, more than half of the energy used by a dishwasher goes towards heating the water (beyond the already heated water delivered from a home storage tank). In fact, water heating accounts for approximately 60% of total energy use by dishwashers. Models that use less water also use less energy.[25]

Studies conducted as part of the Irvine Smart Grid Demonstration examined the DR energy savings possible from dishwashers and found that by delaying the operating wash mode or eliminating the heated dry mode, approximately 1 kW of demand could be delayed or eliminated. The heating element alone adds 40% to the energy consumption of dishwasher using the normal wash mode alone.[26] Due to the national efficiency standards, first effective in 1994, the energy and water consumed by dishwashers has dropped dramatically. Energy use is now capped at 307 kWh/year and while older models typically used 8 to 14 gallons of water, new models can use no more than 5.0 gallons per cycle. ENERGY STAR models can use no more than 4.25 gallons; the best units use as little as 2.0 gallons per cycle.[27]

TVs and Other Electronics

An estimated 10 to 15% of all electricity used in American homes can be attributed to the large and growing number of electronic devices found in residences, especially home entertainment systems, set top boxes, and home office equipment. Many of these products continue to draw power when apparently turned off via standby modes that support remote control, channel memory, and LED clock displays. Associated power supplies and battery chargers also contribute to standby power consumption.[28]

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[25] smarthome.org.

[26] http://www.apep.uci.edu/research/partnership_ISGD.aspx.

[27] https://www.energystar.gov/products/appliances/dishwashers.

[28] smarterhouse.org.

RECS2015[29] included 25 questions related to home electronics, up from only two questions in 1990. The survey notes that "The pace of computer saturation in the United States over the past 20 years has been dramatic. In 1990, just 16% of households owned a computer. In 2015, ninety percent of homes had at least one desktop, laptop, tablet, or smartphone, and 79% have more than one." By contrast, RECS2015 reported that "more than twice as many households reported not using a television in 2015 compared to 2009." This stands in contrast to RASS2010 findings of increasing TV and PC load from 2003 to 2009 in SCE territory. Other electronics were not cited in RASS (2004 or 2010). Most TV or other electronics usage is not easily shed or shifted. However, some TV companies have developed low-power mode TVs.

Electric Vehicles

As per Consumers Energy CEO Patti Poppe [41], "Every electric vehicle that is added to the grid, as long as it is not charging on peak, lowers the average cost of electricity. . . If we can smart charge [EVs] and optimize heating and cooling with a smart thermostat and a smart meter, we can, for the first time ever, optimize demand."

Plug-in electric vehicles (PEVs) require charging to maintain their ability to travel. It doesn't matter whether the car battery is charged five minutes or five hours before it is driven, as long as there is sufficient charge to get to the destination. Residential chargers are available in Level 1 and Level 2 formats, the former corresponding to 110/120V circuits and the latter to 220/240V circuits. Level 3 chargers are available that can charge even faster, at higher power, but those are confined to commercial applications. When electric rates that are not time based, workplace and residential charging show distinct patterns as illustrated in Figure 4-9:

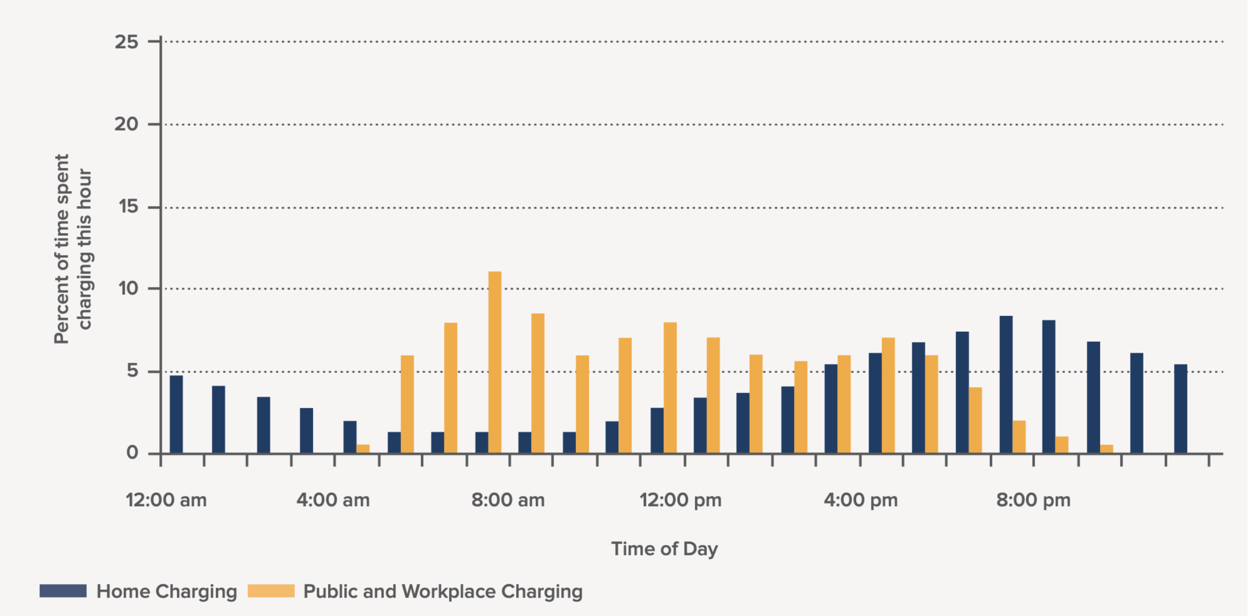

Figure 4-9
EV charging patterns without time varying rates. Source [42] (Nelder et al., 2016)

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[29] US Energy Information Administration, 2015 Residential Energy Consumption Survey (Release date May 2018).

Time-of-use (TOU) pricing has proven effective in moving the charging time of electric vehicles as shown in Figure 4-10:

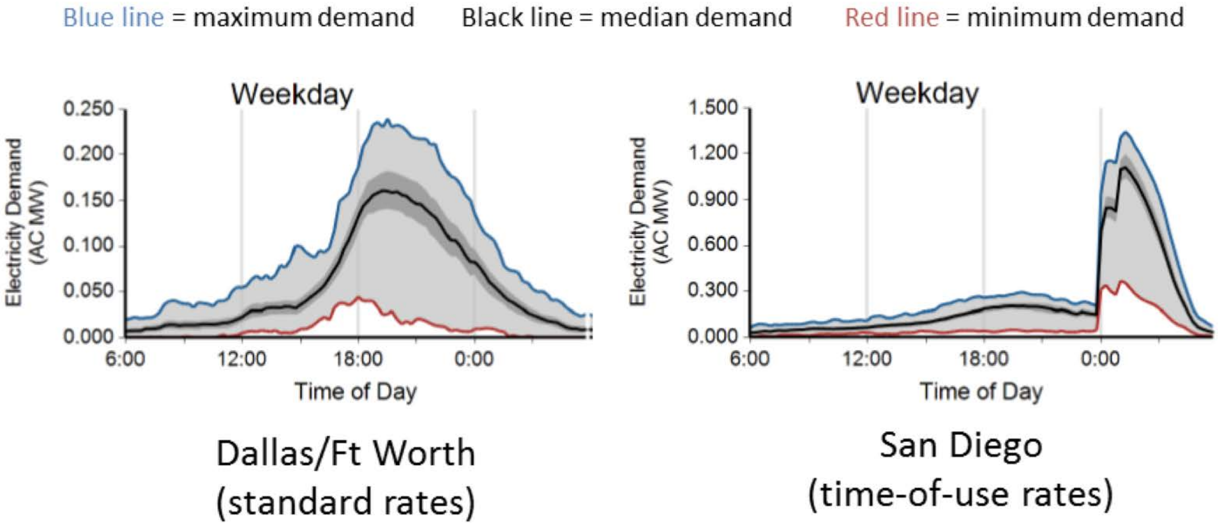

Figure 4-10
Impact of time varying rates on EV charging times. Source (Bradley & Associates, 2017)

In Figure 4-10, the graph on the left shows the plug-in electric vehicle charging load in the Dallas/Ft Worth area where no off-peak charging incentive was offered to drivers. The graph on the right shows the (larger) plug-in electric vehicle charging load in the San Diego region for fleet vehicles, where the local utility offered drivers a TOU rate with significantly lower costs ($/kWh) for charging during the “super off-peak” period between midnight and 5 a.m.

In a commercial setting, business practices may work against such time flexibility. For example, real-time pricing pilots with electric vehicles in a shuttle van fleet in San Diego noted that variable prices were “problematic … because the business may not have the flexibility to curtail on peak, due to the operational needs and limited range of the [magnetohydrodynamic drive] electric vehicles.” [43]

Residential EVs are not constrained by this business model and can generally be expected to have greater flexibility in choosing when to charge their individual vehicles. In addition, many residential EVs are charged during the day at chargers associated with commercial accounts [44] and can generally shift residential charging overnight when costs are lower. A CEC staff report [45] estimates, by 2025, about 121,000 PEV drivers will reside at multifamily dwellings, suggesting a need for dedicated or shared charging solutions at multifamily dwellings. Based on this, the report estimates the total number of chargers needed to support PEVs in California ranges from 229,000 to 279,000. However, as the tariff discussion Appendix B notes, multifamily accommodations fall under a variety of tariffs, some residential (if submetered) and some general service (commercial, usually not submetered). This report does not address EV chargers attached to general service/commercial tariffs. For submetered residential accounts, as noted above, the emergent technology provides mechanisms for residential customers to take advantage of reduced nighttime electrical rates when DR is not typically called.

A recent report by Rocky Mountain Institute [42] noted that EV adoption tends to be concentrated in some regions, particularly certain residential neighborhoods, noting that in San Diego, four zip code areas have over 3% EV ownership, in contrast to eighty-four zip code areas with less than 1% EV ownership. In these areas, the concern is that clustering of EV chargers behind a single transformer could create an overload if multiple chargers operate simultaneously. As shown below, there are technologies that can coordinate residential charging overnight to minimize potential overloads. However, the same report notes that EV sales create an increase of 70-120 MWh of storage capacity each month, building on a 2016 base of 4 GWh, and representing up to 700 MW of peak shiftable load. This peak load, occurring during the day when system peak occurs, arises primarily from commercial, not residential, chargers.

A recent BMW study [46] provided limited proof that participants were generally willing to modify charging habits to supply load when called as long as the vehicle is available and charged when needed. However, participants were not eager to sell back energy from the EV battery. Of note is that the study had to supplement its participation with batteries when it was unable to enroll sufficient EVs to meet the contractual minimum load (from the report: "On average 20% of the total contribution [to 209 called demand response events, totaling 19,500 kWh] was attributed to the vehicle pool and 80% from the 2nd life stationary battery system" [46].

EV charging, then, is a relatively new technology with at least two technology developments that can facilitate charging flexibility: a network of EV chargers for home and away (FordPass) and the use of Internet of Things technology to coordinate shiftable electric loads represented by electric vehicles (JuiceBox/JuiceNet), discussed below.

Ford Charging Stations and FordPass

Ford is reportedly spending $11.5 billion between now and 2022 to develop and introduce charging support across the United States [47] comprising:

1. An extensive charging network, with over twelve thousand charging stations, including fast charging, and over thirty-five thousand charge plugs.
2. A mobile charger that can charge on the road using either 120 volts or 240 volts as a standard package with each of their electric vehicles.
3. Collaboration with Amazon to install support equipment as needed (from "240V outlets to the Connected Charge Station").
4. A means by which customers can monitor at home charging as well as pay for charging at Ford Connected Charging Network stations (developed in conjunction with GreenLots).

In doing so, Ford's goal is to "make EV home charging as easy as charging a smartphone." Based on engineering simulations, Ford estimates that a 150-kilowatt charger can add approximately 47 miles of range in 10 minutes or that a vehicle's battery can be charged from 10 percent to 80 percent full charge in 45 minutes using one of their fast chargers. While charging rates are not linear (they slow as the battery approaches full capacity), in general the distinction between fast and slow charging is that 120- volt charging provides an estimated three miles per charging hour whereas 240 volt charging provides 22 miles per charging hour.

In addition, the FordPass app alone (or with FordPass Alexa Skill or Google Assistant when equipped with FordPass Connect™) allows users to start, stop, lock, or unlock their vehicle, check vehicle status, service history, etc. It also provides access to roadside assistance and provides for electronic payment of vehicle related services. Ford recently (October 7, 2019) announced the app would remain free to users (estimated at over 1.5 million presently) as implementing an opt-out program would reduce the quantity of data available to Ford for resale. [30]

JuiceNet and JuiceBox[31]

JuiceNet is a cloud-based Internet of Things platform for EV load management and optimization developed by E-MotorWerks (an Enel X Company, formerly EnerNOC) and used by a variety of charging station and vehicle manufacturers to coordinate shiftable electric loads associated with electric vehicles. Its communication, control, and intelligence platform dynamically matches drivers' historical charging patterns, real-time input, and signals from grid operators to effectively aggregate charging station loads and coordinate their availability with grid conditions. JuiceNet can control any connected charging station and coordinates periodic, minor changes in charge rate and timing, which the driver can override at any time.

JuiceNet works with JuiceBox, a series of smart charging stations, and the JuiceNet app to coordinate charging schedules. As a bonus, in some locations, JuicePoints offer users in some locations the option to achieve financial benefits in exchange for flexibility in their charging habits.

Improving DR with Technology

While TOU and other DR rates can encourage shifting or shedding of loads according to grid needs, additional support from technology or behavioral DR programs can further provide peak load reduction as shown in Figure 4-11[48].

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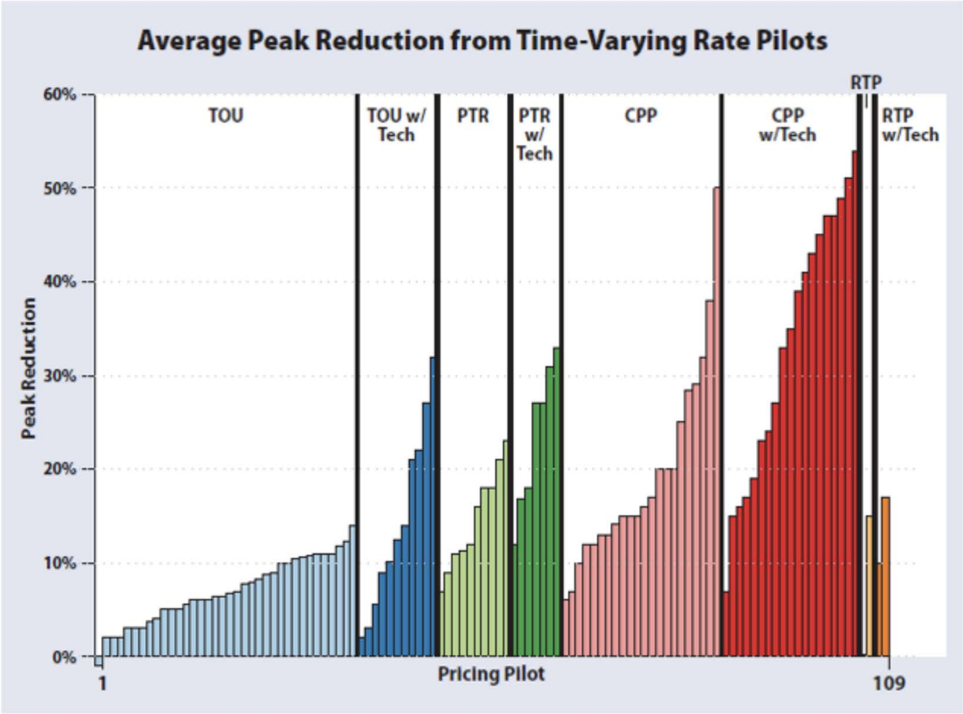
[30] https://www.autonews.com/technology/ford-says-fordpass-connect-telematics-will-remain-free.

[31] https://evcharging.enelx.com/products/juicenet-software/juicenet.



Regulatory Assistance Project (RAP)®

Figure 4-11
Average peak reduction with and without supporting technology for different tariffs

In part this is due to the fact that the response of a single residential device will not rise above the noise floor (inherent variability) of grid resources, so there is a need for some form of aggregation, formal or otherwise, to coordinate residential responses and thereby effectively amplify the individual response.

Several approaches are possible: one is to coordinate the human interactions via behavioral interventions and the other is to coordinate the actions of the devices themselves.

Residential DR needs to be coordinated in some way to provide the magnitude of load modification expected by utilities. There are benefits to aggregating, residential demand responses formally or by default without an active aggregator. Individually the responses are relatively small, but if aggregated, officially via an outside aggregator, or by default because an entire residential group is receiving the same DR signals, individual load changes will effectively be magnified to some extent by the group action. Different aggregators may actively manage the aggregation process to meet different agendas, however.

Time varying rates provide aggregation by coordinating the responses in time. By concentrating the responses into a given time period, they are effectively aggregated with the price setting entity as the aggregator but may not be optimally coordinated.

Alternatively, there are a variety of aggregation options, from coordination of individual devices (e.g., NEST[32]) to coordination of devices within a home (see below)

Awareness of Carbon Impact

WattTime—a non-profit organization focused on giving people the "power to choose cleaner electricity"—has developed MIDAS, a market-informed platform to facilitate emissions reduction through identification of the best time to use energy to meet grid needs, cost, comfort, and carbon objectives [49]. MIDAS conveys the best times to charge EVs and the most appropriate thermostat settings to interested residential customers. Curiously, in a test of 300 randomly selected participants (from 30 US states), environmental concerns outpaced financial gains as a motivator: "contrary to researcher expectations, [automated emissions reduction] increased signups even more than financial gain ($600/month per thermostat) did."

Additional research[33] identifies other models or methods for optimizing residential device operations by balancing occupant comfort and variable energy costs signaling DR needs.

Bring Your Own Device

SCE's SEP encourages customers to acquire, enroll, and use communicating thermostats from a list of pre-qualified options.[34] This facilitates residential DR at the same time it provides customers with a thermostat they can program according to their personal household needs. Other utilities are also considering bring your own device (BYOD) programs[35] to encourage customers to provide, maintain, and connect a variety of devices: Wi-Fi connected water heaters, pool pumps, EV chargers, and batteries all have the potential to be harnessed for DR programs. The key is a common interface with utility communications so that DR program messages such as changes in energy prices can be conveyed consistently and reliably in a confirmable way.

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[32] https://support.google.com/googlenest/answer/9244031?co=GENIE.Platform%3DAndroid&hl=en.

[33] For example:

O'Neill, Daniel et al. Residential Demand Response Using Reinforcement Learning. 2010 First IEEE International Conference on Smart Grid Communications. 4-6 October 2010. Gaithersburg, MD.

Namit Chauhan, Namit et al. A Comparison of Reinforcement Learning Based Approaches to Appliance Scheduling.*Contemporary Computing and Informatics (IC3I) 2016 2nd International Conference on*, pp. 253-258, 2016.

Alessandro Di Giorgio, Francesco Liberati, "Near real time load shifting control for residential electricity prosumers under designed and market indexed pricing models", *Applied Energy*, vol. 128, pp. 119, 2014.

Ivana Dusparic, Adam Taylor, Andrei Marinescu, Fatemeh Golpayegani, Siobhan Clarke, "Residential demand response: Experimental evaluation and comparison of self-organizing techniques", *Renewable and Sustainable Energy Reviews*, vol. 80, pp. 1528, 2017.

[34] https://pages.email.sce.com/scesmartbonus/.

[35] See, for example (although the first of these is for energy storage, a potential supplement to DR programs) https://greenmountainpower.com/bring-your-own-device/ https://www.utilitydive.com/news/comverge-brings-byod-demand-response-pilot-to-arkansas/441194/https://smartenergycc.org/wp-content/uploads/2017/10/CS_WhiskerCenterpoint_10.5.17.pdf. https://www.bge.com/MyAccount/MyBillUsage/Documents/Electric/BGE%20Semi-Annual%20EmPOWER%20Maryland%20Report%20%28Q1-Q2%202019%29.pdf.

Internet of Things: Hubs and Other Forms of Device Coordination

Coordination of electric consuming devices can be subdivided into coordination of like devices (e.g., NEST thermostats) versus coordination of all (or most) responding devices within a residence. The latter option can be further subdivided by coordination by a hub versus coordination by common response to a DR signal.

Internet of Things (IoT) technology provides a platform for the coordination of devices. With the introduction of alliances such as those discussed below, device coordination may be enhanced through common agreements on communication mechanisms.

- One option within the IoT space is the Open Connectivity Foundation (OCF) Smart Home Project[36] that is premised on the idea that if devices can communicate with each other without direct customer interaction, there can be greater efficiency and a better user experience than having a unique application for each device. The underlying principle is that manufacturer, operating system, chipset or physical transport should not determine independent device to device or device to service interactions because the synergy of common interactions benefits all.[37]
- A second, similar, option is the Connected Home over IP project, which simplifies development for manufacturers and increases compatibility among devices for consumers. The project aims to make it easier for device manufacturers to build devices that are compatible with smart home and voice services such as Amazon's Alexa, Apple's Siri, Google's Assistant, and others. The Connected Home project is built around a shared belief that smart home devices should be secure, reliable, and seamless to use.[38]

Of note: the second-generation Echo Plus and Echo DOT includes a temperature sensor that collects the ambient room temperature where the device is located. Previously, Google Home was a Wi-Fi only hub, without Zigbee or Z-Wave radios, and required a SmartThings Hub (or a similar device) to expand capabilities to allow temperature sensing.

Universal Devices was one of the early developers and testers of a hub to coordinate devices within a home. The company used an Amazon Alexa to provide the common focal point for device actions.[39] Through a recent SCE pilot, this hub was shown to be able to provide monitoring, controlling, and automating of a home's energy usage on a per device basis based on the occupant's preference for savings or more comfort.[40]

Special Case: Multifamily Buildings

Although this paper focuses on residential DR, in which occupants of multifamily buildings have individual accounts for each residence and can thereby make decisions based on the needs of their individual residence, recent research examines how to balance and optimize the provision

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[36] https://openconnectivity.org/certified-products/.

[37] https://openconnectivity.org/foundation/faq/smarthome-faq/.

[38] https://www.apple.com/newsroom/2019/12/amazon-apple-google-and-the-zigbee-alliance-to-develop-connectivity-standard/.

[39] https://www.universal-devices.com/#about.

[40] https://www.universal-devices.com/rates/#about.

of DR with occupant comfort, in the context of solar and storage. The work addresses "decision-making in the context of energy consumption for a multi-unit building" by addressing "two conflicting objectives, cost and comfort, via the compromise solution. The proposed approach balances the two objectives while providing DR to the grid: "The optimization works in combination with a price structure based on time and level of use that encourages load shifting and benefits the participants. Computational experiments and an extensive sensitivity analysis validate the performance of the proposed approach and help to clarify its strengths, its limits, and the requirements for ensuring the desired outcome."

"This is possible because of the combination of the available resources (solar and storage), active user participation, and a cost structure that provides incentives for load shifting and peak reduction" [50]. The proposed method is confirmed computationally and could form a framework for future technology to benefit occupants of multifamily buildings with a common meter (which could constitute a commercial account) or could be extended for use in large residences with EVs.

Locational DR

When there is a need for load reduction solely in a particular area, can it be conveyed only to residential devices in that area? Yes, OpenADR2.0b contains parameters by which the VTN (typically initiated at the utility level) can specify the location at which a particular DR service is needed via the EiEvent schema targeting elements serviceArea and serviceLocation. The parameter serviceArea uses a latitude-longitude polygon whereas a single latitude/longitude value must be provided for serviceLocation (data interpretation is governed by the **OpenGIS**® Geography Markup Language Encoding Standard). The default values for serviceArea and serviceLocation targets are the customer premises [51].

DR and Data Analysis

Recent research indicates that analysis of data from smart meters can help identify suitable targets for DR participation.

One study found that HVAC penetration patterns can be characterized with spatiotemporal resolution (i.e., at the census tract level) by combining smart meter data with local ambient temperature records. As a test, analyzing records from 180,476 households over two years, using the proposed method found the overall AC penetration rate in the Greater Los Angeles Area is 69%, consistent with other studies [52].

A second study found that a different group of researchers using the average annual consumption of customers and the shapes of their load profiles [53] claims to be able to identify suitable residential candidates in demand-response programs who can be incentivized to curtail their peak period consumption, leading to significant aggregate peak-shaving for the utility.

A third study [54] found that user-reported consumption data is generally consistent with that measured by smart meter but questions the ability to discern distinct user activities from that data. The reported work examined monitored vs. reported energy-related activities in fifteen households and found that while there is significant variation across households, self-reported activity tends to be a reasonably good predictor of electricity demand but that thermostat control on some high use devices (e.g., water heaters) makes actual demand an imperfect indicator of occupant activity.

New apps and APIs that might be useful to DR programs are being developed at a growing rate. It is impossible to identify all of them, but Appendix H contains a selected set of currently available options that can help residential customers become more aware of their minute by minute use of energy and how to curtail it when needed. Appendix I identifies companion technology that, while not directly focused on DR, may help residential customers control energy use.

Summary of Residential DR Potential

At the present time, DR potential in residential end uses is mixed. In some cases, DR capabilities are limited because of either inherently low power use or inflexible times of use. In other cases, DR options could change if the relative price difference between electricity and natural gas were sufficient to warrant a change to electricity-based home appliances. In most cases, the DR capability is in part dependent on the ability to aggregate similar resources from other residences.

Residential Load Considerations—Overview

Central air conditioning has been SCE's most significant source of voluntary demand reduction in the residential sector. SCE has more than 2.5 million central air conditioning units and about 1 million room air conditioners in its territory [55]. The majority of SCE's customers reside around the densely populated Los Angeles, Ventura, and Orange counties (baseline regions 6, 8, 9, and 10). The majority of these regions' residential customers live in single-family homes; however, nearly 1.4 million residential customers live in multifamily units. In numerous pilot program impact reports, Nexant has identified baseline regions 13, 14, and15 as the "hot" region; baseline regions 5, 9, and10 as the "moderate" region; and baseline regions 6, 8, and 10 as the "cool region" [56]. These climate differences impact each region's contribution to peak electrical demand and its ability to moderate load via DR when needed.

Putting SCE's residential end-use loads in terms of peak time demand (4-9 p.m.) in SCE's peak summer season, SCE reports and EPRI's load shape library show that central air conditioning, and end uses such as pool pumps are major contributors to peak load [40] [57]. It is in SCE's best interest to investigate not only making these additional end uses smart grid enabled, but also developing a system or interface in which the customer is engaged and feels empowered to make cost effective grid-friendly choices.

- The dominant loads for which DR can impact net residential load are cooling, ventilation, pool pumps, and, to a limited extent, heating. Other loads may also contribute in an aggregated form via home hubs and behavior-based programs.
- Residential loads are anticipated to be largest in the hours coincident with the new TOU peak price periods, providing a useful introduction to residential customers regarding time dependent rates.
- If peak demand occurs later in the day, there will be different options for residential DR, including the increased possibility of shifting load.
- The additional communication options provided by new technology facilitate user control of residential devices, either directly or passively via agreements with manufacturers or service providers. These same communication options may provide additional features of benefit to customers and the utility in the future.

Determining dominant loads requires consideration of what loads are most commonly found in residences in the SCE territory, their power requirements, and when they are most likely to use power. Actual active home electric loads vary significantly between households, with the following relative percentages being a good estimate of the relative contribution to the total from each [58]:

- 20-25% of total: always on loads such as TVs, WiFi routers, printers, etc.
- 15-25% of total (each): cooling, pool pumps
- 10-15% of total: entertainment (electronics and TV)
- 5-10% of total (each): cooking, laundry, refrigerator, lighting – note that while some of these loads are relatively large, most operate only for a relatively small proportion of the day

Further, the EPRI load profile (see Figure 4-12) for weekday residential loads shows that central air conditioning loads are most likely to increase going into the higher priced TOU period, so DR measures that can curtail that load will be especially useful. In the United States, direct load control of air conditioning units (e.g., SCE's Summer Discount Program) represents the largest enrolled capacity of any mass market DR technology (4.5 GW, or 60% of total U.S. residential DR). However, this is declining: 2018 data showed a decrease in the number of enrolled customer devices, down about 10.7% from 2016 and 2017 numbers [29]. For SCE, SDP comprises a substantial portion of proxy DR or PDR (73.7%) and of combined reliability DR resource (RDRR) and PDR (18.4%) (Pollock and Fogel, 2019).

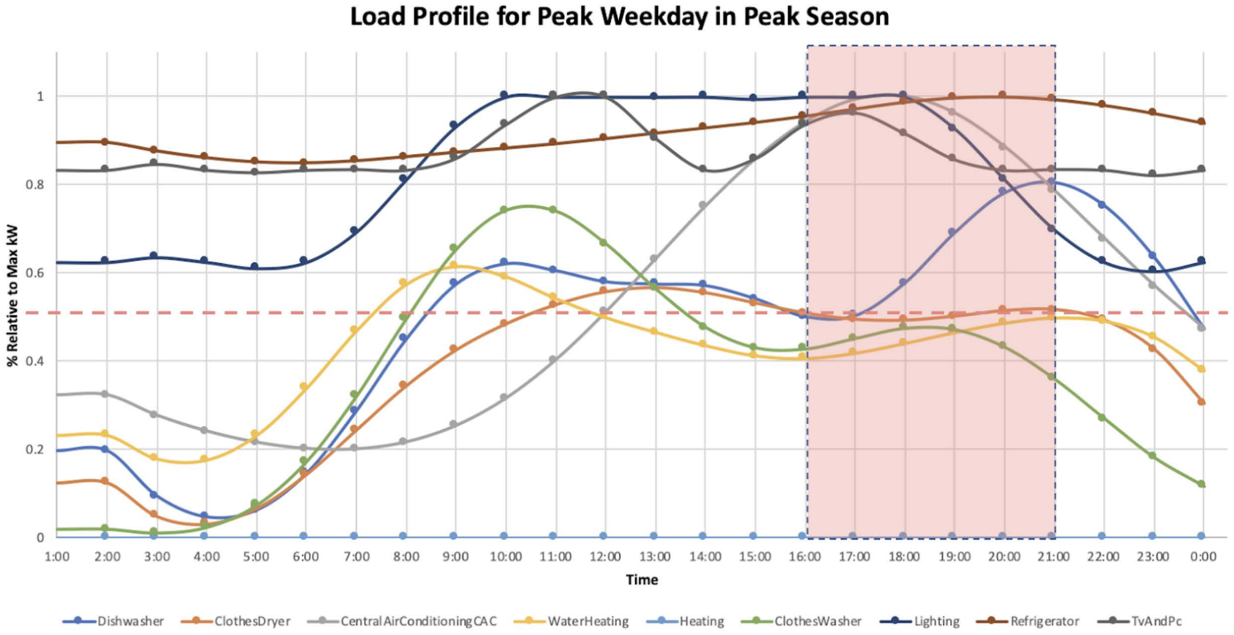


Figure 4-12
Load Profile for typical residential end uses during peak weekend in peak season [57]

In general, the EPRI load profiles suggest the following about appliance abilities to modify load when requested:

- Appliances were found to generally be 25% shiftable for several hours, and this level remained fairly constant through 2040. Because these loads necessarily include a wide range of end uses, they will be discussed below in the context of home hubs or behavior-related DR programs.
- Space cooling and ventilation were found to be 75% shiftable for minutes to an hour with this value remaining fairly constant through 2040. (See this discussion of this category of load directly below.)
- Water heating (25% shiftable for several hours) and space heating (100% shiftable minute-by-minute up to 4+ hours) are both seen as increasing in the available resources after 2025, according to the EPRI load profile. This change is likely due to an anticipated shift from natural gas to electricity as the dominant fuel source. As this shift has not yet occurred, these end uses are not addressed here.
- Additional significant shiftable loads can be expected from ventilation and pool pumps.
- Lighting and cooking are not assumed to be shiftable, so they are not addressed here. While some lighting load can be shed, the magnitude of that shed has generally declined with the introduction of larger numbers of energy efficient bulbs in residences. Therefore, any lighting shed is covered

Summary of Residential DR Options by End Use

Table 4-2 identifies the DR options for each end use, while Table 4-3 elaborates on the DR options for the end uses most likely to produce significant load modifications when needed. Of the loads available for DR, cooling, pool pumps, and ventilation appear to be the best options. However, home coordination hubs and behavioral DR programs, addressed in a later section, may offer additional residential DR options. End uses in grey below are not considered useful residential DR targets at this time.

Table 4-2
Residential DR options by end use (shading identifies less preferred options)

Residential end use (More to less DR potential)	DR options	Limitations	Shift or Shed or both?
HVAC with smart thermostat	Precool or preheat Change setpoint	Occupant comfort	Both
Ventilation fans	Reschedule, reduce speed	Air quality	Both
Pool pumps	Reschedule, reduce speed	Water clarity and cleanliness	Both
Electric vehicle charging	Already shifted to low peak times or to commercial chargers	Limited numbers, schedules already optimized	Unlikely in either category
Refrigerators	Duty cycle	Food safety	See coordination section below
Cooking	Reduce or reschedule; generally, not assumed to be shiftable	Occupant needs	Limited shed of shift options
Always on/vampire	Limited	Continuity needs	See coordination section below
Laundry, dishwashing	Move operating time	Household needs	See coordination section below
Lighting	Daylighting, on/off, dimming; generally, not assumed to be shiftable	Occupant safety and visual needs	See coordination section below
Natural gas -> electric	Water heating, cooking	Not yet happening in significant numbers	Similar to natural gas options
Electronics/TV	Limited	User needs	See coordination section below

Table 4-3
Shift vs. shed DR options for key residential loads

Residential end use category	Shift strategies	Shed strategies
HVAC, with smart thermostat	Precool during lower priced times during the day when renewable resources are available	Change setpoint to reduce load for selected periods of time; can result in increased loads overall to make up for temperature changes during reduced load
Ventilation	Ventilate during lower priced times during the day when renewable resources are available	No: Ventilation is required in new construction (Title 24), so any reduction must be compensated.
Pool pumps	Run filtration and other pump-based tasks during lower priced times of the day when renewable resources are available	No: Most pool pump functions are required to occur within a 24-hour period, so they can't be shed without a compensating run time later.

Table 4-4 lists the physical communication protocols currently available for the most common residential end uses.

Table 4-4
Market Availability of Physical Communication Protocols for Residential Devices

End Use Category	Data/Physical Layer Communication protocols
Lighting	Wi-Fi, Zigbee, Z-Wave
efrigerators/Freezers	Wi-Fi, Zigbee
Misc. Plug Loads (TV, etc)	Wi-Fi,Zigbee,Z-Wave,IR
Dishwasher	Wi-Fi, Zigbee
Space Conditioning (Central Cooling)	Wi-Fi, Zigbee, Z-Wave, IR
Space Conditioning (Room Cooling)	Wi-Fi
Clothes Washer	Wi-Fi
Dryers (Electric)	Wi-Fi
Pool Pumps	Wi-Fi (CTA-2045)
Water Heating (ER and HP)	Wi-Fi (CTA-2045)

5

PUBLIC POLICY, LEGISLATIVE, AND REGULATORY IMPACTS ON DR

Demand Response Risks and Considerations

A number of risks and considerations must be considered for SCE to effectively and safely expand its DR programs and offerings to offer IoT technology and smart grid-enabled appliances. These risks and considerations are discussed below.

Cybersecurity/Customer Privacy

SCE and associated third-party smart home providers must ensure that customer home networks are secure from device hijacking or denial of service attacks. Vulnerable systems have the potential to be infiltrated, which compromise home security systems, cameras, or other devices being compromised [59]. Figure 5-1 describes several typical cybersecurity threats and countermeasures.

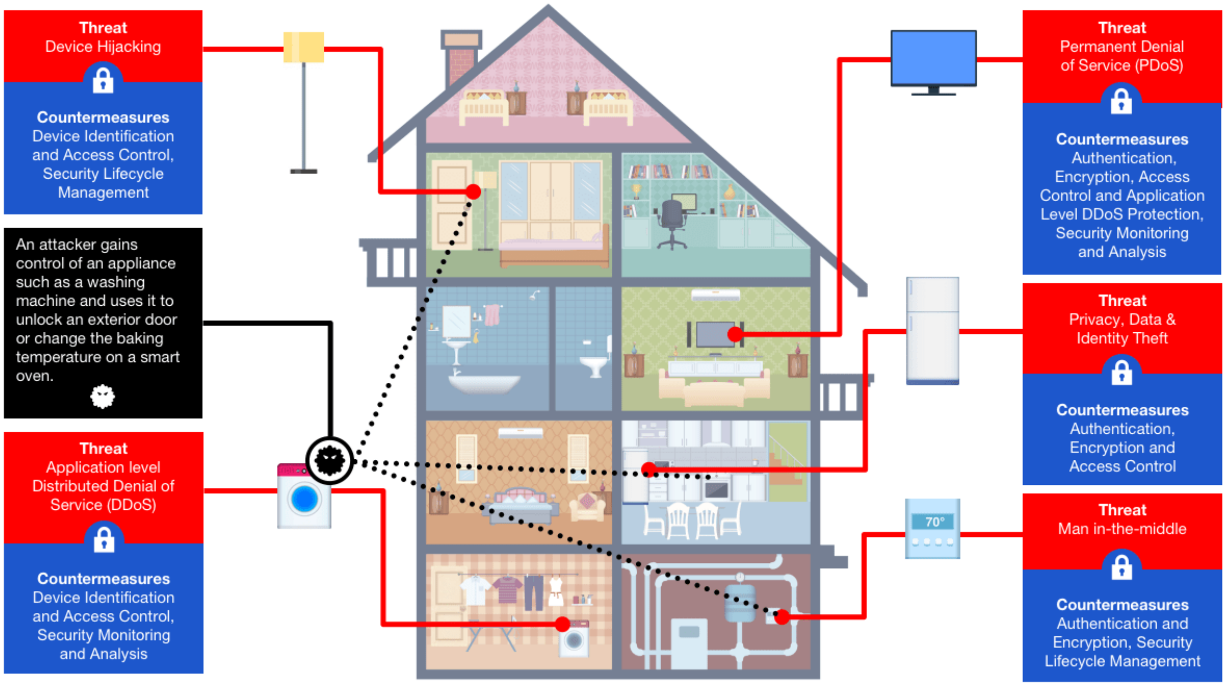
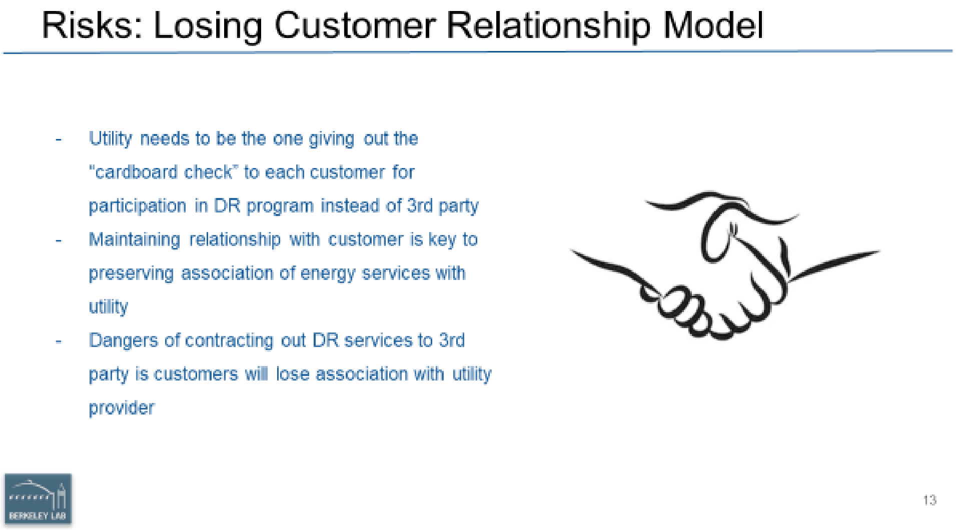


Figure 5-1
Typical residential cybersecurity threats and possible countermeasures

Customer Relationship Model

SCE recognized the importance of its customer relationships and would like to ensure that any benefits that result from customers' participation in DR programs are associated with the utility. The inclusion of third-party entities in the DR landscape means customers may lose association with their energy provider. SCE would like to prioritize providing their customers choice in participating in DR programs while directly playing the role of DR program curator and facilitator. Figure 5-2 summarizes these customer relationship risks.



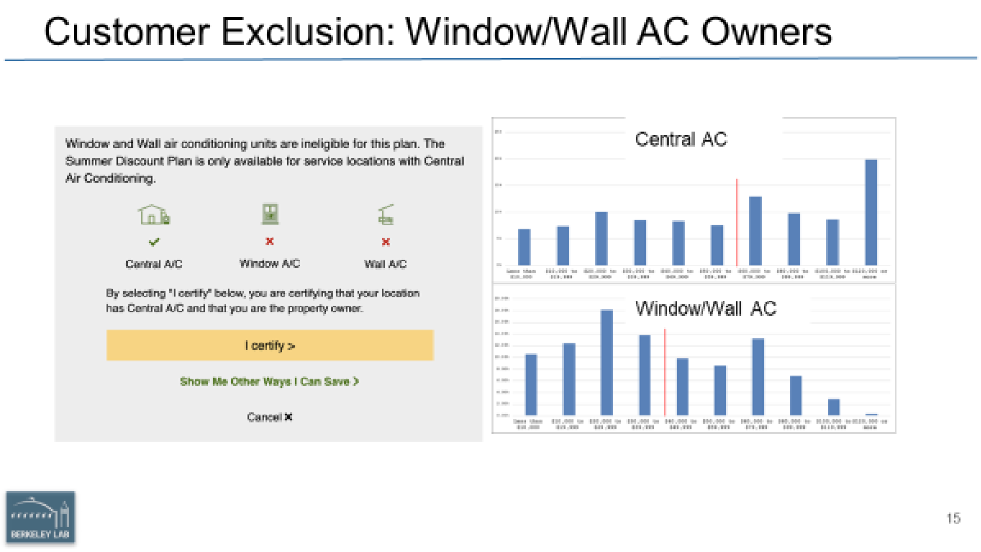
Risks: Losing Customer Relationship Model

- Utility needs to be the one giving out the "cardboard check" to each customer for participation in DR program instead of 3rd party
- Maintaining relationship with customer is key to preserving association of energy services with utility
- Dangers of contracting out DR services to 3rd party is customers will lose association with utility provider

Figure 5-2
Customer relationship risks with non-utility DR services

Customer Exclusion

SCE's current residential DR offerings consist of both direct load control and bring your own device (BYOD, often focused solely on thermostats, in which case they may be designated BYOT) programs. These programs target single-family detached homes with central air conditioners and may require internet access. According to the RASS2010, only 49% of SCE's customers own central AC, and only 60% of residences are single-family detached homes [55]. The American Housing Survey shows that the median income of central AC unit owners is higher than that of room AC owners, indicating that most lower income homes are excluded from SCE's DR offerings. Figure 5-3 shows a detailed breakdown of the relationship between income levels and window/wall versus central air conditioning


Customer Exclusion: Window/Wall AC Owners

Window and Wall air conditioning units are ineligible for this plan. The Summer Discount Plan is only available for service locations with Central Air Conditioning.

By selecting "I certify" below, you are certifying that your location has Central A/C and that you are the property owner.

Figure 5-3
Utility customers with window/wall AC are excluded from some DR programs

A portion of SCE's customers also suffer from the "digital divide," with areas such as Los Angeles and Central Valley having approximately 25% of residences with only mobile phone internet access or no access to broadband services [60]. Figure 5-4 graphs this digital divide. Future DR offerings should try to address the diversity of SCE's residential customers.

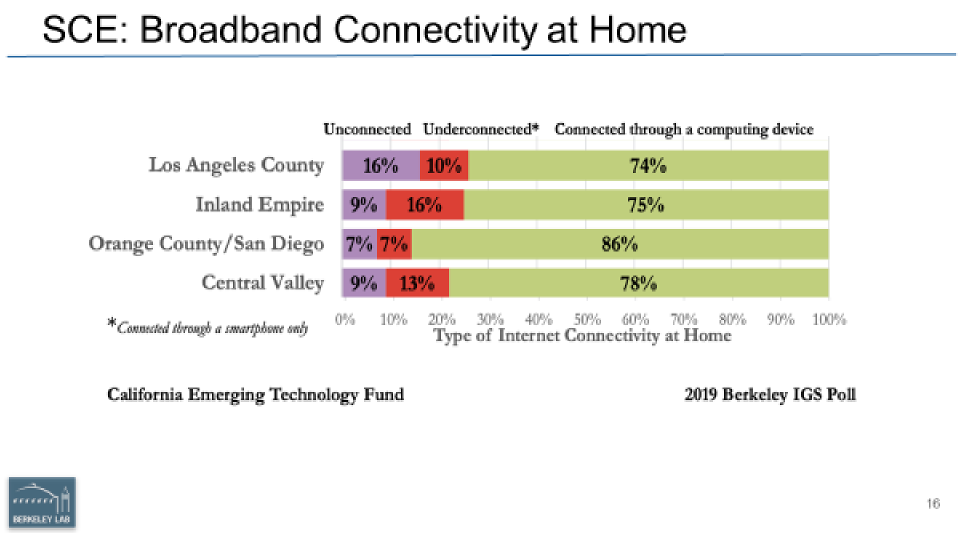
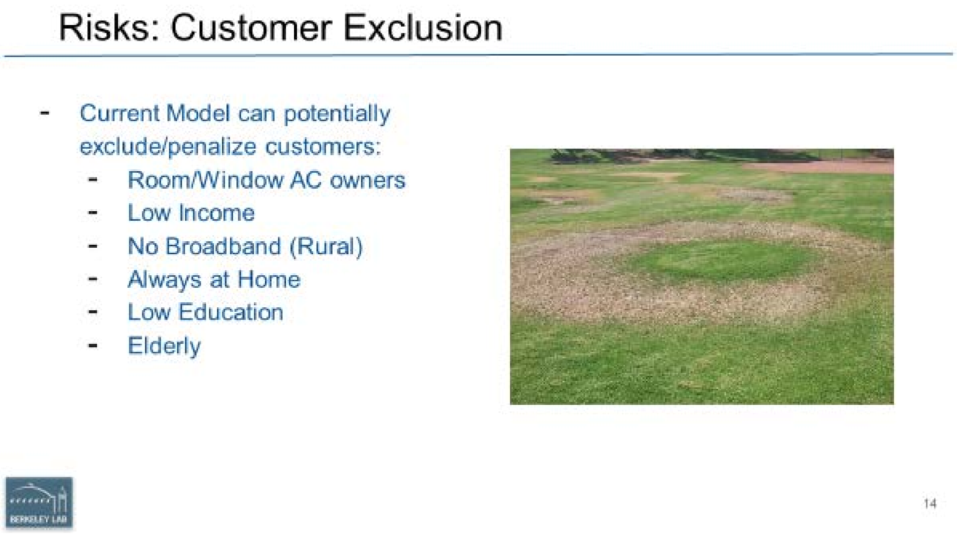

SCE: Broadband Connectivity at Home

Figure 5-4
Inadequate broadband service excludes some customers from DR offerings

Figure 5-5 summarizes the reasons why many customers do not qualify for or seek DR offerings from electric utilities including SCE.



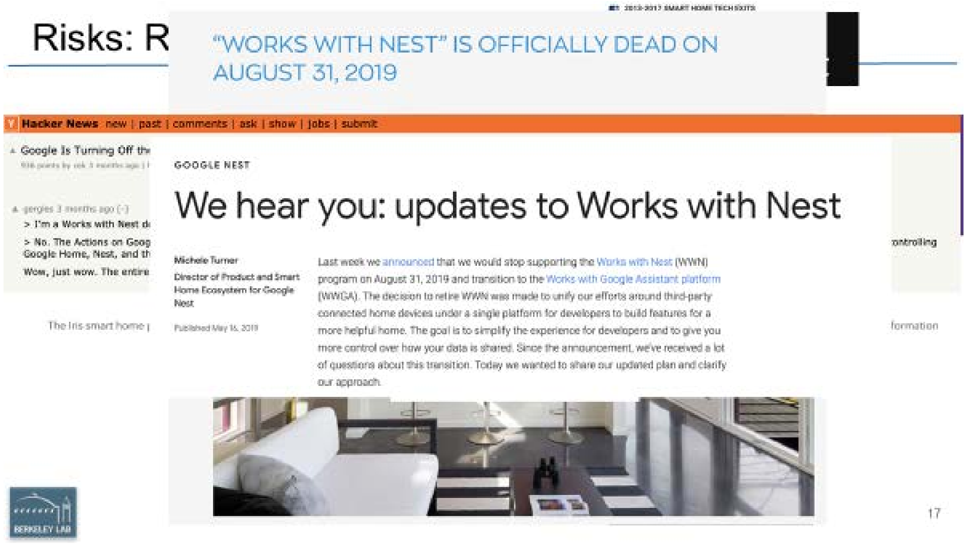
Risks: Customer Exclusion

- Current Model can potentially exclude/penalize customers:
  - Room/Window AC owners
  - Low Income
  - No Broadband (Rural)
  - Always at Home
  - Low Education
  - Elderly

Figure 5-5
Reasons for customer exclusion from utility DR offerings

Obsolescence/Stranded Assets/Technology Lifetime or Change of Business Models

The smart home landscape is a rapidly changing market, which has evolved substantially in the past decade and is likely to keep changing in the near future. The first home area networks were provided by Zigbee, Z-Wave and AMI networks; however, as the availability of wireless broadband internet has increased, Wi-Fi-enabled smart home platforms have become the norm. As technology progresses, however, the risk of obsolete and stranded technological assets will become an issue when considering deployment of millions of units. Google's rapid acquisition and termination of home energy platforms such as Revolve and the Works-with-NEST program (see Figure 5-6) are examples.



Risks: R

2013-2017 SMART HOME TECH EXITS

"WORKS WITH NEST" IS OFFICIALLY DEAD ON AUGUST 31, 2019

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GOOGLE NEST

We hear you: updates to Works with Nest

Michele Turner

Director of Product and Smart Home Ecosystem for Google Nest

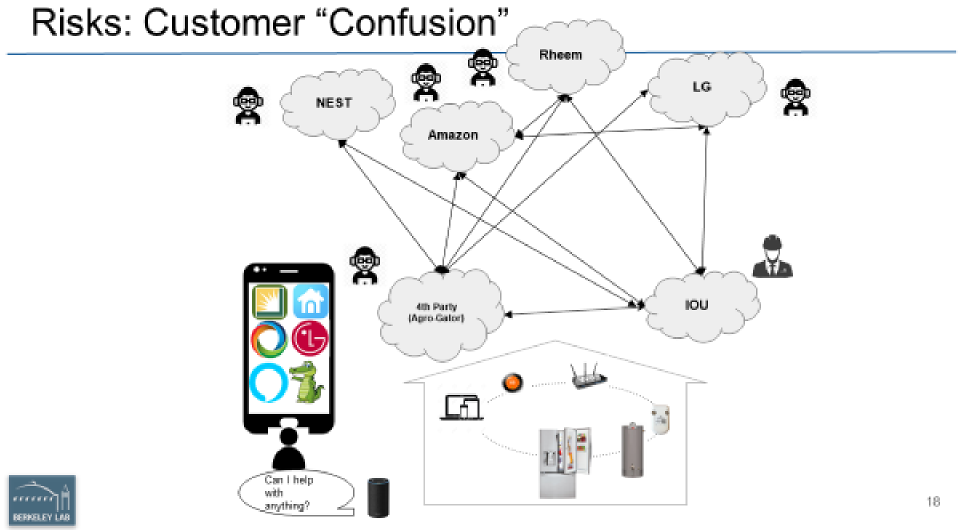
Published May 16, 2019

Last week we announced that we would stop supporting the Works with Nest (WWN) program on August 31, 2019 and transition to the Works with Google Assistant platform (WWGA). The decision to retire WWN was made to unify our efforts around third-party connected home devices under a single platform for developers to build features for a more helpful home. The goal is to simplify the experience for developers and to give you more control over how your data is shared. Since the announcement, we've received a lot of questions about this transition. Today we wanted to share our updated plan and clarify our approach.

Figure 5-6
Rapidly changing technology can result in obsolescence, leaving residential customers with worthless devices

Customer Overload/Confusion

To date, most utility DSM programs focus on modifying the load of one device, most often the central AC and/or the thermostat. Future "Bring Your Own Device" (BYOD) programs may require customers to purchase, connect, and enroll other smart grid-enabled devices to enhance their participation for larger energy cost savings. In some cases, these products may interact with smart home platforms, while at the same time maintaining their own clouds and mobile applications. A situation may occur in which a customer may become overloaded or confused with an increasing number of applications and devices to manage in addition to their original device such as a smart thermostat. Figure 5-7 illustrates this risk in more detail.



Risks: Customer "Confusion"

Figure 5-7
Confusion about smart home products deters some customers from participating in DR programs

DR-Related Initiatives and Projects

Emergence of 5G and Low Bandwidth Networks

A small number of non-connected customers are still present in SCE territory, but 5G could close this digital divide. Low Power Wide Area Network (LPWAN) technologies such as LoRA, SigFox, LTE-M, and NB-IOT could enable cost-effective, high range, low latency connectivity to once disconnected populations [61]. The smaller-sized data transfers provided by LPWANs may enable the transmission of price signals or event start and end times. The U.S. 5G market is still developing; however, LTE-M seems to be the dominant cellular-based player in the United States [62].

California Energy Commission (CEC) Programs

The CEC's recent investment in emerging energy research and technology development through its Electric Program Investment Charge (EPIC) Program has spurred a number of developments in the residential DR space. This includes LBNL’s Device Energy Reporting effort to make available individual device energy use and the proposed development of a requirement for devices to self-report energy consumption [63]. In addition, LBNL is developing temperature and occupancy-based smart ventilation strategies that have the potential to shift demand and reduce energy consumption related to residential ventilation [64]. Figure 5-8 lists an array of CEC initiatives related to DR in buildings.

Related Initiatives: California Energy Commission DSM in Buildings

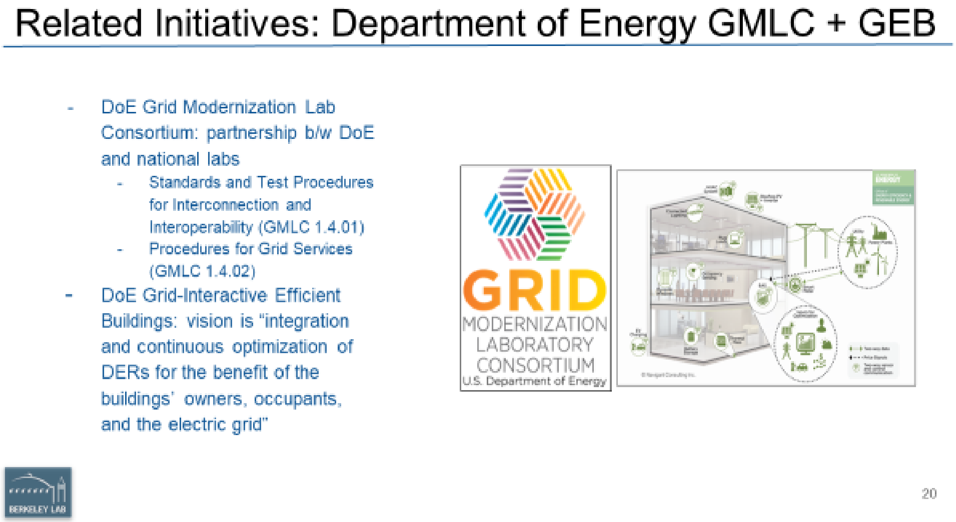
- Title 24 Building Energy Efficiency Standards
    - Specifies OpenADR compatible smart thermostats
    - Specifies schedulable,TOU enabled Heat Pump Water Heaters
- Title 20 Appliance Efficiency Standards: Load Management Standards
    - Specifies peak load management programs for Central AC and Water Heaters
    - Off-Peak, limited running of pool pump use
- EPIC Program
    - CEC investment in emerging energy research and technology development

Figure 5-8
The CEC has issued regulations and invested in R&D to accelerate DR in California

U.S. Department of Energy Projects

The U.S. Department of Energy (DOE) has a number of recent initiatives dedicated to developing flexible, grid-interactive buildings with interoperability, including the Grid Modernization Lab Consortium (GMLC) as well as its Grid-Interactive Efficient Buildings (GEB) initiative. DOE’s GMLC is a partnership among its national laboratories as well as industry groups and panels such as the National Institute of Standards and Technology (NIST). Relevant past GMLC projects include Standards and Test Procedures for Interconnection and Interoperability (GMLC 1.4.01), which identified gaps and necessary changes to improve compatibility and coordination between DR technologies as well as promoting the development of new conformance testing for these technologies and grid services [65]. Another relevant past project, Definitions, Standards, and Test Procedures for Grid Services from Devices (GMLC 1.4.02), addressed the need for an accurate assessment of the ability of end-use devices to provide reliable and high-performance grid services by defining test procedures and performance metrics [66].

The vision of DOE's Grid-Interactive Efficient Buildings initiative is the integration and continuous optimization of DERs for the benefit of the buildings' owners and occupants, and the electric grid. This initiative includes projects related to residential DR, including the use and availability of residential appliances for grid services and interactions [67]. Figure 5-9 summarizes DOE's two major DR-related initiatives.



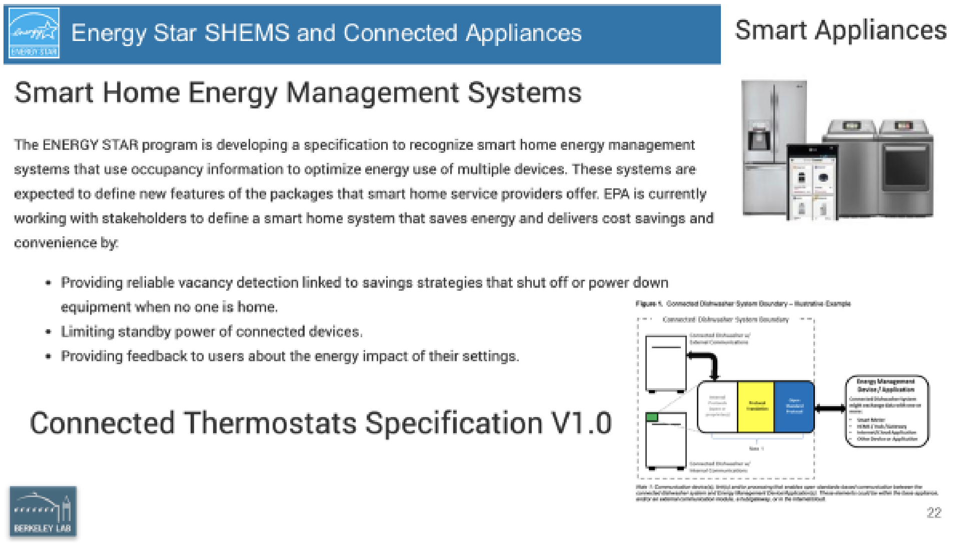
Related Initiatives: Department of Energy GMLC + GEB

- DoE Grid Modernization Lab Consortium: partnership b/w DoE and national labs
  - Standards and Test Procedures for Interconnection and Interoperability (GMLC 1.4.01)
  - Procedures for Grid Services (GMLC 1.4.02)
- DoE Grid-Interactive Efficient Buildings: vision is "integration and continuous optimization of DERs for the benefit of the buildings' owners, occupants, and the electric grid"

Figure 5-9
The U.S. Department of Energy and its national laboratories are pursuing two major DR-related initiatives

EPA EnergyStar SHEMS

EPA's EnergyStar program is in the process of developing a Smart Home Energy Management System (SHEMS) specification. The specification is not for a single product, but rather a package of offerings including EnergyStar-certified products in addition to energy services provided by a third-party entity. The package must manage home electricity loads through a user interface, include an orchestration device or hub that can monitor plug loads, respond to occupancy, and provide grid services based on events or time-varying price [68]. A certified SHEMS package should also provide interoperability at the device boundary using open standard protocols to ensure it is able to interact with existing smart home platforms as well as utility signals. Figure 5-10 conveys the major features of the EPA's EnergyStar SHEMS program and provides an example of how it works with a dishwasher.



Energy Star SHEMS and Connected Appliances

Smart Appliances

Smart Home Energy Management Systems

The ENERGY STAR program is developing a specification to recognize smart home energy management systems that use occupancy information to optimize energy use of multiple devices. These systems are expected to define new features of the packages that smart home service providers offer. EPA is currently working with stakeholders to define a smart home system that saves energy and delivers cost savings and convenience by:

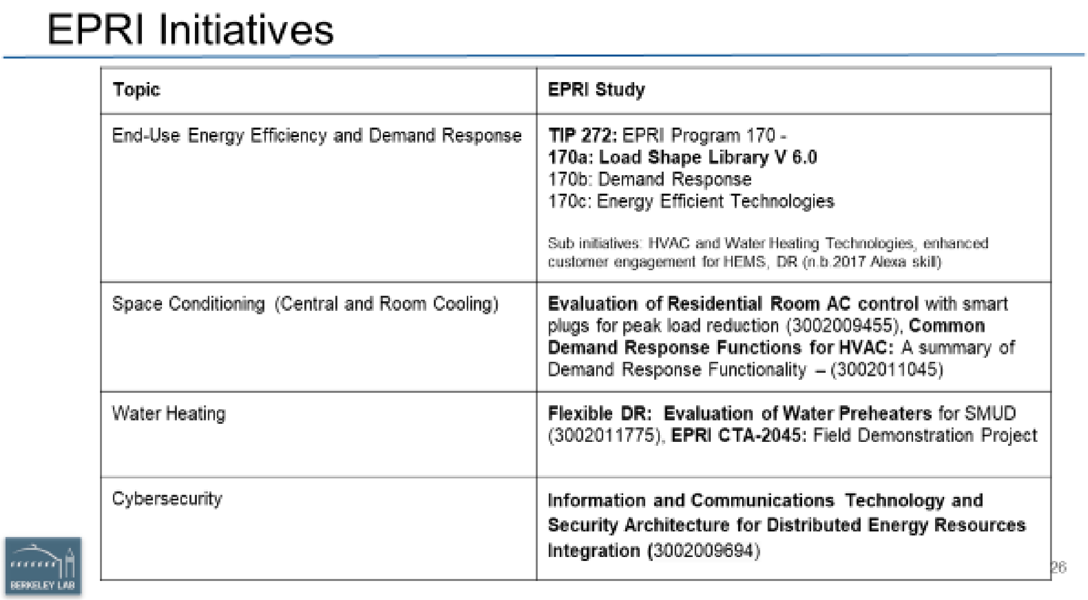
- Providing reliable vacancy detection linked to savings strategies that shut off or power down equipment when no one is home.
- Limiting standby power of connected devices.
- Providing feedback to users about the energy impact of their settings.

Connected Thermostats Specification V1.0

Figure 5-10
EPA's Smart Home Energy Management System will reduce energy use when a residence is vacant

EPRI's Initiatives

EPRI has carried out several DR-related research projects in recent years. Under its Technology Innovation Program, EPRI performs ongoing research into end-use energy efficiency and DR, including development and maintenance of a load shape library used in this report. Other recent research related to DR include an evaluation of the peak load reduction potential of room AC using "smart plugs." EPRI evaluated the potential of flexible DR with water preheaters. EPRI also investigated cybersecurity issues associated with integrating distributed energy onto the grid. EPRI's research efforts related to DR are summarized in Figure 5-11.



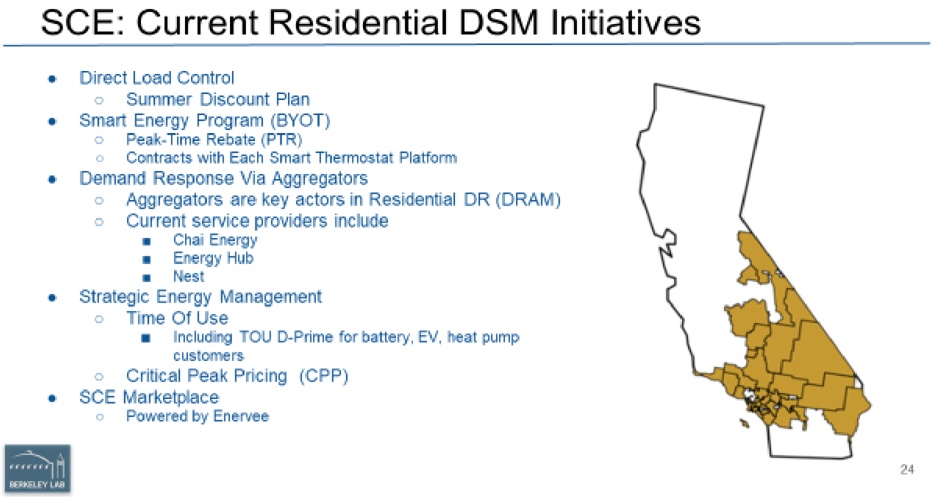
EPRI Initiatives

Topic	EPRI Study
End-Use Energy Efficiency and Demand Response	**TIP 272:** EPRI Program 170 - **170a: Load Shape Library V 6.0** 170b: Demand Response 170c: Energy Efficient Technologies Sub initiatives: HVAC and Water Heating Technologies, enhanced customer engagement for HEMS, DR (n.b.2017 Alexa skill)
Space Conditioning (Central and Room Cooling)	**Evaluation of Residential Room AC control** with smart plugs for peak load reduction (3002009455), **Common Demand Response Functions for HVAC:** A summary of Demand Response Functionality – (3002011045)
Water Heating	**Flexible DR: Evaluation of Water Preheaters** for SMUD (3002011775), **EPRI CTA-2045:** Field Demonstration Project
Cybersecurity	**Information and Communications Technology and Security Architecture for Distributed Energy Resources Integration** (3002009694)

Figure 5-11
Summary of EPRI's recent DR-related research

SCE's Initiatives

In addition to SCE's current DR offerings, including its DLC Summer Discount Plan and its BYOT Smart Energy Program, SCE contracts aggregated load reduction from third-party aggregation companies through the demand response auction mechanism (DRAM). Current residential service providers under contract with SCE include Chai Energy, Energy Hub, and Nest. SCE also plans to roll out TOU rates for residential customers, offer rebates for customers participating in critical peak pricing events, and also provide customers an opportunity to purchase energy efficient and smart home-enabled products through its online SCE Marketplace website. Figure 5-12 lists current SCE DR initiatives.

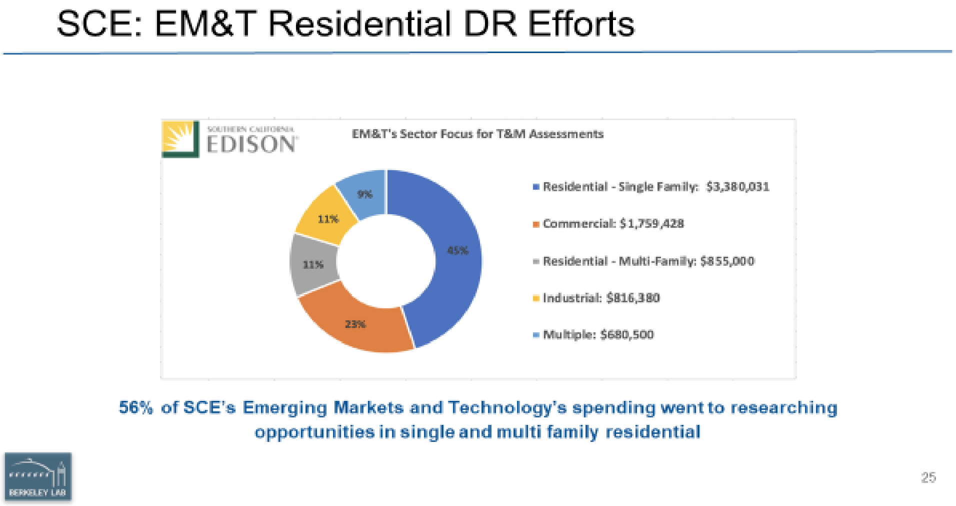


SCE: Current Residential DSM Initiatives

- Direct Load Control
    - Summer Discount Plan
- Smart Energy Program (BYOT)
    - Peak-Time Rebate (PTR)
    - Contracts with Each Smart Thermostat Platform
- Demand Response Via Aggregators
    - Aggregators are key actors in Residential DR (DRAM)
    - Current service providers include
        - Chai Energy
        - Energy Hub
        - Nest
- Strategic Energy Management
    - Time Of Use
        - Including TOU D-Prime for battery, EV, heat pump customers
    - Critical Peak Pricing (CPP)
- SCE Marketplace
    - Powered by Enervee

Figure 5-12
Current SCE DR initiatives

SCE's Emerging Markets and Technology Program spends a larger portion of the DR budget in assessing opportunities in the residential sector. Figure 5-13 shows a recent R&D effort of the EM&T Program.



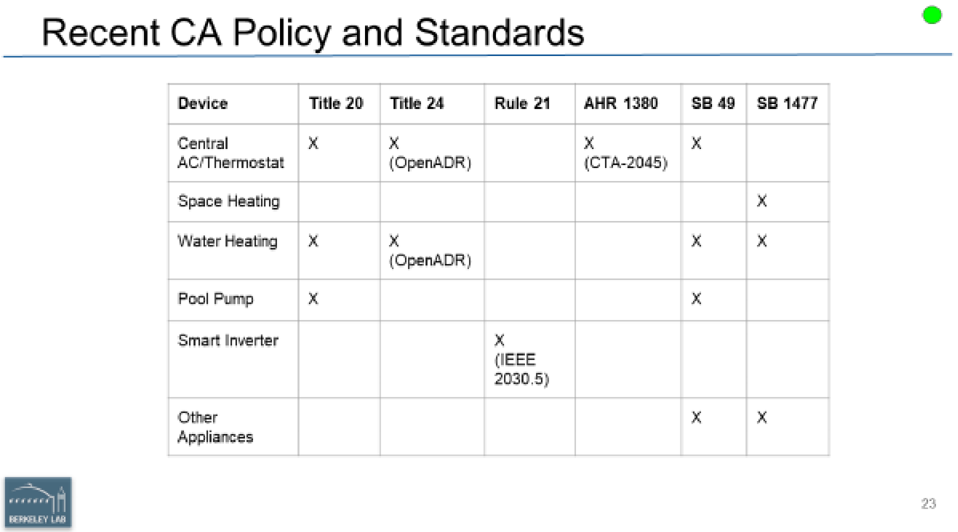
SCE: EM&T Residential DR Efforts

56% of SCE's Emerging Markets and Technology's spending went to researching opportunities in single and multi family residential

Figure 5-13
SCE's Emerging Markets & Technology Program's R&D spending

DR-Related Legislation and Regulations

This section reviews recent major DR legislation and regulatory initiatives in California. Figure 5-14 pinpoints the major residential end uses affected by the legislation and regulations discussed below.



Recent CA Policy and Standards

Device	Title 20	Title 24	Rule 21	AHR 1380	SB 49	SB 1477
Central AC/Thermostat	X	X (OpenADR)		X (CTA-2045)	X	
Space Heating						X
Water Heating	X	X (OpenADR)			X	X
Pool Pump	X				X	
Smart Inverter			X (IEEE 2030.5)			
Other Appliances					X	X

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Figure 5-14. Residential end uses affected by recent California legislation and regulatory standards

DR-Related Legislation

Senate Bill 100 (SB100)[41]

California SB100 (the 100 Percent Clean Energy Act of 2018, signed into law September 10, 2018) requires that eligible renewable energy resources and zero-carbon resources supply 100% of retail sales of electricity to California end-use customers and 100% of electricity procured to serve all state agencies by December 31, 2045, with intermediate targets of 25% of retail sales by December 31, 2016, 33% by December 31, 2020, 40% by December 31, 2024, 45% by December 31, 2027, and 50% by December 31, 2030.

This law is expected to impact future residential DR efforts as appliances traditionally fueled by natural gas (e.g., water heaters and space heaters) move towards an electric energy source.

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[41] https://leginfo.legislature.ca.gov/faces/billNavClient.xhtml?bill_id=201720180SB100.

Senate Bill 1477 (SB1477)[42] [69]

SB1477, enacted into law September 13, 2018, allocates $50 million each year until 2023 from utility cap-and-trade auction revenue to support two programs to encourage the development of advanced technologies that reduce emissions from buildings:

- BUILD (Building Initiative for Low-Emissions Development) aimed at new construction.
- TECH (Technology and Equipment for Clean Heating) focused on the development of low-emission space and water heating technologies via incentives to distributors and retailers to make equipment available.

As with SB100, the impact from this law is expected to be on future residential DR programs, outside of the 2- to 5-year focus of this report.

Senate Bill 49 (SB49)[43] [70]

SB49, enacted into law October 9, 2019, amends the California Public Resources Code, Section 25402(f), to require the adoption and periodic update of standards for appliances that facilitate the deployment of flexible demand technologies based on feasible and attainable efficiencies or feasible improvements that will enable appliance operations to be scheduled, shifted, or curtailed to reduce emissions of greenhouse gases associated with electricity generation. These regulations may include labeling provisions to promote the use of appliances with flexible demand capabilities. For device security, the law points to the National Institute of Standards and Technology's reliability and cybersecurity protocols, or other cybersecurity protocols that are equally or more protective, and requires the adoption of, at a minimum, the North American Electric Reliability Corporation's Critical Infrastructure Protection standards.

SB49 contains this important definition, expanding traditional DR: "Flexible demand" means the capability to schedule, shift, or curtail the electrical demand of a load-serving entity's customer through direct action by the customer or through action by a third party, the load-serving entity, or a grid balancing authority, with the customer's consent.

This law paves the way for enhanced residential DR because it explicitly identifies how flexible demand technologies must be cost effective and specifies consultation with the CPUC and load-serving entities to "better align the flexible demand appliance standards with DR programs administered by the state and load-serving entities and to incentivize the deployment of flexible demand appliances." It specifically calls for such appliances to be easy to control with a simple setup and connection process, and use "interoperable or open source" connection mechanisms.

DR-Related Regulations

CPUC Ruling 21 [25]

In 2017, CPUC enacted Rule 21, which specified IEEE 2030.5 as the default communication standard for inverters in California that connect DER to the bulk power grid. This ruling could, in the future, allow DER to help moderate system peak loads (in addition to residential loads).

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[42] https://leginfo.legislature.ca.gov/faces/billTextClient.xhtml?bill_id=201720180SB1477.

[43] https://leginfo.legislature.ca.gov/faces/billNavClient.xhtml?bill_id=201720180SB49.

Title 24, California Building Code (2019)

Appendix G identifies the sections of the California Building Code relevant to DR. Within that, California's 2019 Title 24 Building Code, Section 110.12 and Joint Appendix 5 specify mandatory requirements for certified, OpenADR VEN occupant-controlled smart thermostats that are capable of communicating through Wi-Fi, ZigBee, Ethernet, or other hard-wired physical layer protocols. The California Building Code goes a step further to address the state's need for more intelligent water heater control, with Title 24's Joint Appendix 13, which specifies requirements for schedulable, TOU-enabled heat pump water heaters [71].

The recently adopted 2019 California Building Code (latest version released this year with an effective date of Jan 1, 2020) focused on zero net energy as the goal. Beginning in 2022 and in subsequent Building Code cycles, building decarbonization will be the primary goal. This new emphasis will align the Building Code with California's goals to mitigate climate change through energy decarbonization. It is not yet clear how, or if, these changes will impact residential DR. The change in emphasis is expected to focus on the following goals:

1. Encourage decarbonization by removing barriers to building electrification
2. Maintain and encourage thermal-resilient building envelope features that perform well in both heating and cooling climate zones, even as the planet warms up
3. Encourage self-utilization of onsite PV generation and DR measures
4. Maintain the status quo of residential building standards for one code cycle

Current analysis to verify compliance with Title 24 building code using time dependent valuation energy (TDV) is expected to shift in the next three years as a result of new renewable energy sources, reduced dependence on natural gas, and new measurement categories. TDV reflects a 'perfect' marginal cost of service which is a long-term signal for retail rates. Under Title 24, a demand flexibility measure is defined as an action that reduces TDV energy consumption using communication and control technology to shift electricity use across hours of the day to decrease energy use on-peak or increase energy use off-peak, including but not limited to battery storage, or HVAC or water heat load shifting.

CEC Title 20, Chapter 4, Article 5 [72]

In addition to Title 24, 2019's Title 20 contains specifications for residential load management standards. Chapter 4, Article 5 specifies utility peak load management programs for central AC and water heaters as well as time limitations for residential pool pumps, more specifically 2 hours daily during the off-peak season, and 4 hours during peak seasons. The standards also recommend the utility provide time clocks to customers that may need them to monitor the timing of their pool pump usage (State of California, 2019).

Air-Conditioning, Heating, and Refrigeration Institute (AHRI) 1380[44] [73]

This performance standard establishes voluntary requirements for variable capacity HVAC systems (rated 65,000 Btu/hour and less) that are capable of supporting DR strategies to benefit the electric grid in a predictable manner and to facilitate end user participation in DR, price response, or similar incentive programs offered by electric utilities or related entities. It

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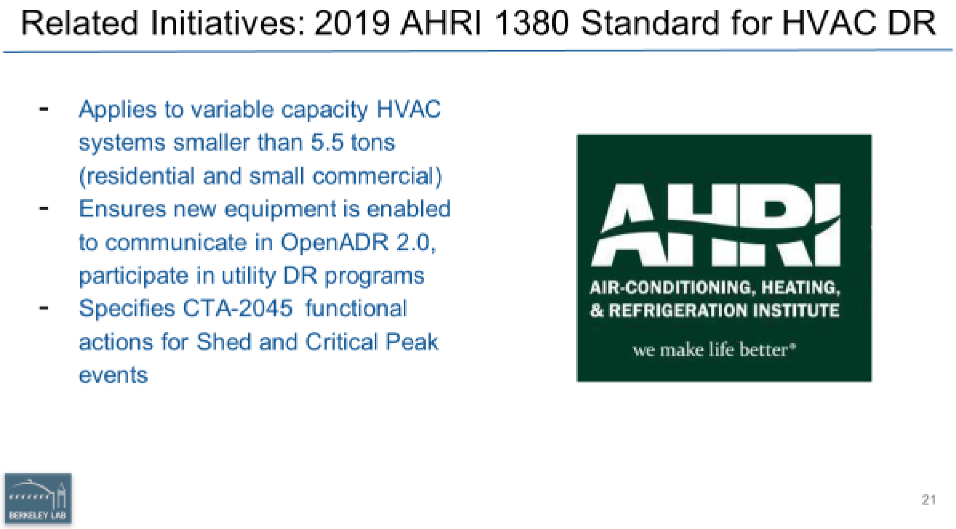
[44] http://www.ahrinet.org/App_Content/ahri/files/STANDARDS/AHRI/AHRI_Standard _1380_I-P_2019.pdf.

establishes the communication protocol(s) by which covered appliances can receive shed, critical peak, or pricing signals. In 2019, the Air-Conditioning, Heating and Refrigeration Institute (AHRI) released standard 1380 for demand responsive HVAC in residential and small commercial buildings. Standard 1380 applies to variable capacity HVAC systems smaller than 5.5 tons and ensures new equipment can communicate in OpenADR 2.0 as well as participate in utility DR programs. The standard also specifies CTA-2045 functional actions for shed and critical peak events for these systems [73].

Figure 5-15 summarizes AHRI's DR initiatives for residential HVAC.



Related Initiatives: 2019 AHRI 1380 Standard for HVAC DR

- Applies to variable capacity HVAC systems smaller than 5.5 tons (residential and small commercial)
- Ensures new equipment is enabled to communicate in OpenADR 2.0, participate in utility DR programs
- Specifies CTA-2045 functional actions for Shed and Critical Peak events

Figure 5-15
AHRI's DR initiatives related to residential HVAC

Community Choice Aggregations

Recent legislation has encouraged the development of Community Choice Aggregations (CCAs: local, not-for-profit, public agencies that take on the decision-making role about sources of energy for electricity generation). These organizations are effectively reducing the customer base for Southern California Edison. Once established, CCAs become the default service provider for the power mix delivered to customers while the incumbent utility (SCE) continues to own and maintain the transmission and distribution infrastructure, metering, and billing. This report covers only DR tariffs that SCE can negotiate, and therefore does not address any modification of delivery agreements for CCAs. However, choices offered by CCAs point to market interests that can guide SCE tariff designs and approaches. Appendix F identifies the CCAs in the SCE territory as of January 2020.

Tariffs and DR Programs

While most residential electricity use has historically been measured and settled on a monthly volumetric basis for service account management, smart meters now provide time-stamped energy usage reporting more frequently. Commercial and industrial customers have long been included in electric tariffs that charged different prices by season and time of day, usually the highest in summer mid-day periods. Smart meters for residential customers now support SCE's recent introduction of TOU tariffs, which have now shifted the on-peak, higher price billing periods to late afternoon and evening hours, when wholesale energy costs are high, but when many residential customers typically consume the most electricity.

Background on Tariffs

Residential customers have historically paid for electricity effectively at a monthly consumption rate ($/KWh) with some tiered distinctions to reflect higher rates for higher consumption. In large part this is due to the fact that prior to smart meters, the time period for electrical consumption measurement was defined by the monthly meter read.

"Though still relatively rare, a number of new rate structures are now available to residential consumers thanks to smart grid technologies. For example, demand-based rates charge the customer separately for both the energy used and the capacity required to meet their load. A demand-based rate structure imposes a per-kW (not per-kWh) charge based on the customer's peak demand during each billing cycle. A demand charge is used to pay for the cost of building and maintaining the generation, transmission, and distribution capacity to meet that customer's peak demand. A separate energy charge covers the cost of fuel and other costs associated with operating generators and other parts of the grid. With these more direct price signals, consumers have more information to adjust their demand or usage patterns, which can reduce the need for new capacity."

"Alternatively, utilities can also use energy prices that vary throughout the day as generation costs change. This structure is typically referred to as TOU pricing. With TOU pricing, utilities charge different rates for electricity during different parts of the day. Other options include real-time pricing and other rate structures that tie consumption patterns to actual costs. Real-time prices are established by the actual cost of generating and delivering electricity during any given moment in time. When prices are high, smart appliances and devices could be programmed by the consumer to reduce load, reducing the need for new generation capacity." [75]

Note that residential customers may initially be ill-equipped to handle TOU rates given the billing options previously offered to them that did not require them to be aware of time-based rate changes.

- Because most residential customers have been historically billed monthly, it may make sense to structure tariffs in a way that experience with one tariff (e.g., TOU) provides an easier transition to another (e.g., CPP). Consider a plan by which customer experience with one tariff provides a foundation for better informed transition to another tariff.
- Residential participation in DR will require (a) familiarity with participation in time varying rates (TOU can provide this as a starting point), (b) supporting equipment to make things happen at the right time, and (c) motivation to make changes.

- TOU programs provide the starting point for enhanced dialogues between the utility and consumer about when energy is used. Smart meters provide essential communication infrastructure to provide the time marker for these interactions.
- Residential DR, to make a meaningful contribution to load flexibility in the future, will need to be coordinated via a common time reference and will require timely conveyance and receipt of clear messages indicating load modifications requested of residential customers.
- Tariffs, as the contractual agreement upon which those interactions are based, will also need to change to provide more load flexibility options for residential customers. A range of options is possible: it is not required that all residential customers be on the same program if the orchestration of residential DR efforts is sufficiently coordinated.

Tariffs define the agreement between the electric consumer and electric service provider for reimbursement of services provided. For DR, there are two general types of programs: price-based and incentive/event based, the latter being more commonly offered to resources with larger loads (e.g., industrial loads) that can commit to reducing load upon request and thereby receive an incentive to be ready to do so. Direct load control programs such as SDP are incentive programs in which the customer is paid an incentive to allow the utility to control HVAC equipment. Residential DR tariffs other than SDP-like programs tend to be predominantly price based, where grid need for load reduction is signaled by price changes.

As distributed energy resources become more prevalent, tariffs are likely to become more complicated because traditional consumer/service provider entities can change over time with both roles played by the same entity at some time. Table 5-1 identifies a possible progression of tariffs by which customers can provide more load flexibility.

Table 5-1
DR tariff progression

Possible Tariffs (from low to high tech)		Support needed	Incentive options	Limitations
Status quo	Direct load control	Control device	Pay user to allow direct control when needed	On/off or duty cycling can be out of sync with user needs
	Flat/Block/ Tiered rates	Basic meter	Default tariff	Variations not considered or recorded
New	Time of Usage	Meter, calendar, clock = smart meter	Price variations encourage load shifting	Fixed time periods may not align with grid needs
Next step	Critical Peak Pricing /Variable Peak Pricing	Smart meter (SM) + communications	Additional price changes motivate load shifts at key times	Fixed time periods may not align with grid needs
Event based – select an incentive or reward	Real Time Pricing	SM + fast communications	Prices aligned with wholesale prices	Time scale determined by communications and reaction time
	Peak Time Rebates	Rebates or incentives aligned with load reductions	Some customers respond more favorably to incentives	Better for shed, could be adapted to shift
Subscription based - create a tariff from set of options for fuel and for usage pattern	Transactive energy	SM, fast comms, audit trail for reconciliation	Open market rather than regulated system	Still in development; several competing designs
	Subscription or service contracts	List of options, mechanism for choosing	Customer designed	Unanticipated consequences of choices?

Although this progression ultimately suggests customers eventually participating in the energy markets through transactions involving private energy resources such as electric vehicle batteries, this report focuses on the traditional utility (service provider) and consumer (residential customer) roles.

Tariff Packaging and Delivery

There are three new tariff delivery mechanisms that may be relevant to SCE's offerings to residential customers:

1. Digital tariffs
2. Subscription tariffs
3. Deemed incentives

Digital Tariffs

Digital tariffs convey tariff information electronically. First implemented in Germany in October 2018 [75], digital tariffs provide all pricing information electronically based on smart meter communications. In Germany, customers in a limited geographical area can opt into the digital tariff. The energy service provider, Mark-E, has contracted with Fresh Energy GmbH in Berlin to use an app that provides costs of energy based on an algorithm to maximize energy savings based on information from the smart meter about consumption at any given time. Billing at this time remains monthly and is based on measured time-based consumption. This proof of concept could pave the way for future digital tariffs with different algorithms reflecting agreed upon mechanisms for purchasing electric energy that are responsive to local issues.

Subscription Tariffs

Subscription tariffs are offered in different areas for different reasons but essentially allow consumers access to a selected set of resources over a specified time. An example is the solar subscription tariff offered by Georgia Power that "enables customers to purchase a monthly subscription block of the energy produced from a portfolio of Company-owned solar facilities."[45] More complicated subscription tariffs allow consumers in CCAs to determine which energy sources they wish to use in return for agreements on how use of those resources will be billed.

The most recent SEPA Demand Response report [29] notes that utilities are incorporating programs that leverage multiple technology types (for example, thermostats and battery storage) to create a portfolio of integrated DR programs, as opposed to individual programs. Compared to traditional DR programs, these subscription tariff programs aim to provide larger savings, appeal to more customers, provide multiple grid services, and to be called on more frequently due to their flexibility. New software and increased penetration of DERs are enabling this approach.

Deemed Incentives

Deemed incentives provide a fixed agreement on the settlement amount for a given load reduction in lieu of actual measurement and verification of the actual load reduction. Because detailed confirmation of load reductions from individual residential customers are typically not cost effective for the utility, efforts are under way to identify fixed price agreements for automatically connecting DR capabilities of individual electrical consuming equipment so that

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[45] Georgia Power Community Solar Schedule CS-1 https://www.georgiapower.com/content/dam/georgia-power/pdfs/residential-pdfs/community-solar-tariff.pdf.

they can receive a signal from the utility that could trigger a reduction of electrical energy use in exchange for a previously agreed upon reduction in cost to the consumer.

Deemed incentives assume a similar response from similar equipment to similar triggers, but must be designed with three goals: (1) the user must be sufficiently incentivized to purchase and actually connect the equipment in a verifiable way so that its operation can be automatically modified when needed, (2) there should be a verifiable way to confirm usage modification coordinated with utility signals over time, and (3) the user must be able to opt out when needed and such non-reduction confirmed for both the user and the energy supplier (utility) so that deemed incentives apply only when connected residential equipment responds to a utility-signaled DR event or price change.

As a result, deemed incentives are typically a mix between fixed cost (to pay for or incent the one-time costs associated with equipment purchase and/or installation) and an ongoing cost to encourage participation on an ongoing basis. In some behavioral DR programs, the deemed incentive may increase with regular participation to encourage reliability of the response over time.

6

CONCLUSIONS AND RECOMMENDATIONS

In Southern California, there are a wide variety of communities, lifestyles, cultural norms and geographical environments that can influence how customers can effectively participate in DR programs from utilities, energy service providers, and third parties. This report identifies the end use appliances and emerging technologies that customers are most likely to moderate in order to participate in DR programs. In the near term, these end use technologies are space conditioning (HVAC controlled by programmable communicating thermostats), ventilation fans, pool pumps, and, to a limited extent, some control of large appliance loads. Appliance and space conditioning loads represent time sensitive loads, so load reduction approaches (and pre-heating or pre-cooling) may yield more customer acceptance. By contrast, pool pumps (except for those associated with waterfalls or other water features) and ventilation fans represent loads that can, for the most part, be time shifted as long as total run time is sufficient to provide the essential functions of these end uses.

There is also a wide range of variability in the DR program eligibility within the demographics of customers served by SCE. The company could develop different solutions for different customer groups, such as the provision of smart thermostat programs for CARE ratepayers and remote customers, with a possible subsidy for broadband service or 4G connection where needed. For customers with smart home technology already installed, or for more tech savvy customers, SCE could consider a bring-your-own-device program involving real-time grid signals with an SCE phone app or other form of internet-based communication.

Moving forward, there is a great deal of work on interoperability expected from national initiatives – such as DOE's GMLC and Grid-Interactive Efficient Buildings programs and changes to Energy Star SHEMS requirements. These could significantly influence the relevance of certain technologies such as CTA-2045 and cloud-based SHEMS platforms in the longer term. SCE is already participating in many of these research initiatives and industry forums as a research partner and stakeholder and is supportive of the OpenADR protocol which is used for DR programs through California and across the country.

One of the original concepts of OpenADR was that, as an application-layer communication protocol, the long-term vision was that it could be embedded or available in many end-use control systems as a standard feature. If this were the case, the costs to enable a building customer would be extremely low because the communication would be available at little or no cost. Achieving this vision is supported by the requirement in Title 24 that requires OpenADR capability in some new building end-uses. However, experience to date suggests that more research is needed to understand how to achieve the long-term goal of using this protocol in most or all home end-use control systems.

To maintain interoperability among technology options likely to become available to SCE customers, it may be appropriate for the utility to remain agnostic to brand names and architectures and move away from local, short-range application layer protocols (such as earlier Zigbee HAN efforts). Instead, the company could focus on architectures that are more suitable for Wi-Fi or cellular connection (possibly 5G), as this seems to be the path forward for cloud-based services.

In addition, new combinations of technology (such as Universal Devices' use of Amazon's Alexa and Google Home to coordinate various loads within a home to minimize costs) suggest that flexibility will be key in the future. Future technology designs may facilitate the home in general to be more readily treated as a price-sensitive load that the customer can coordinate to optimize both price and comfort.

Although cloud-based connections and home gateway coordination of end uses have advantages and disadvantages, researchers were not able to conclude one is better than the other because each offers different customer benefits. There is no inherent reason why an OpenADR cloud system would perform better or worse than an on-site gateway with OpenADR. The difference in demand reduction is likely to be related to other factors such as which end-use loads the DR is controlling.

Cloud services are becoming more pervasive in the residential end-use DR space (due to platforms such as those of Google, Amazon, and Apple expanding their suite of services). It is safe to assume that cloud-based home energy management will be preferable for *some* customers, especially those who have already adopted this architecture to control other non-energy services in their homes. Local controls may be more appropriate in other situations and may be necessary for services such as CTA-2045 modules and smart grid, IEEE 2030.5-compatible appliances that are not yet widely available in the current market.

Although the market can vary in the product design and prices as needed to gain customer share, the costs for cloud-based systems should be lower than on-site gateways because the automation is often easier to install. With a cloud-based system, there is less customization needed and labor costs should be lower. However, a cloud architecture can also set the stage for stranded assets because a cloud system has a direct link to a vendor, but an on-site gateway will generally need to provide open protocols so that it can interact with a wider variety of end uses.

Electric vehicles, while representing a growing electric load in the SCE service territory, were not found to be a compelling residential DR load because most day-time charging is presently done at facilities in commercial accounts. Due to the pandemic, there is a shift in this trend and EV load is growing. Residential charging is typically done using apps that coordinate the EV timing to minimize costs. However, because this emerging market is still testing different ways to engage customers, researchers were unable to predict its DR capabilities in the longer term. As an emerging technology, residential EV charging systems have provided user interfaces that are generally cognizant of TOU electric tariffs and thereby generally take advantage of nighttime charging to reduce overall costs to the consumer. We have seen that residential charging stations currently operate over an extended time, allowing them to take advantage of reduced nighttime electrical rates when DR is not typically called, and the market potential for these systems as a DR resource will continue to grow as more customers adopt EV charging systems.

With the introduction in California of increasing amounts of renewable energy into the wholesale electricity market and the customer adoption of dynamic pricing and "smart" residential technologies, this report shows that both the emerging market opportunity and the future potential for new models of DR program design are rapidly evolving. There is an urgent need to better understand new applications and use cases for emerging and innovative technology that provides ways for customers to manage their residential DR loads and maximize their energy savings . Beyond “smart” technology, there is also a need to design secure communication protocols and transport mechanisms to be effective in providing the load flexibility needed to both satisfy customer wants and needs, and to safely manage changing grid needs.

The continued development of smart appliances and new residential technologies presents a number of opportunities to facilitate customers’ role in achieving California’s ambitious GHG goals, deliver value to customers and the grid, and ultimately enhance DR program participation. The advent of the modern grid and increased renewables in California will provide an opportunity for residential customer uses to provide new grid services, while simultaneously meeting customer needs. These changes that are now rapidly emerging will lead to an increasingly complex and significant partnership between customers and SCE to be successful, requiring several key DR enabling technologies solutions to be developed and adopted.

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- https://www.gsma.com/iot/narrow-band-internet-of-things-nb-iot/
- https://www.nrel.gov/docs/fy14osti/60383.pdf
- https://www.raponline.org/wp-content/uploads/2017/12/rap_linvill_nwpcc_rate_design_demand_response_2017_dec_06.pdf
- https://www.sce.com/residential/rates/multi-family
- https://www.smart-energy.com/industry-sectors/business-finance-regulation/mark-e-germanys-first-offer-digital-electricity-tariff/
- https://www.universal-devices.com/#about
- https://www.universal-devices.com/rates/#about
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- http://www.siliconvalleypower.com/for-residents/save-energy/appliance-energy-use-charth
- https://www.sparkenergy.com/en/blog/archive/appliance-electricity-usage-guide/

Private Communications

- Doug Black of LBNL, November 2019.
- Clay Collier of Chargepoint, December 2019.
- Brian Gerke of LBNL, March 2019.
- Glen Sharp of CEC, March 2019.

A

AREA DISTINCTIONS WITHIN SCE TERRITORY THAT MAY IMPACT RESIDENTIAL DEMAND RESPONSE

Coastal (Los Angeles/Ventura)

The majority (around 2.7 million) of SCE’s residential customer base resides in Los Angeles, Orange, and Ventura counties [77]. The region is densely populated, highly connected (84% average), and has the highest average regional median annual income ($78,000) within SCE’s territory.[46]

Within this region, the biggest impact to residential DR has been the introduction of the Clean Power Alliance, consisting of 29 cities and unincorporated parts of LA and Ventura counties. Clean Power Alliance is the largest Community Choice Aggregator (CCA) to be formed in the state to date. Approximately 1 million customers have departed to Clean Power Alliance CCA as of early 2020 (according to the Los Angeles Times).

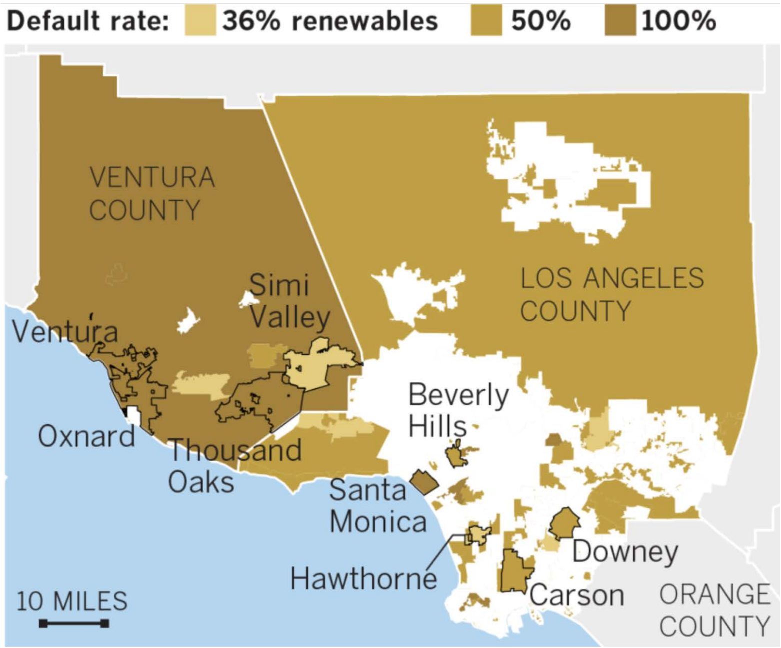

Figure A-1
Map of Clean Power Authority area

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[46] https://www.census.gov/quickfacts/fact/map/CA,US/INT100217.Accessed 11/03/2019.

San Joaquin Valley (SJV) [77]

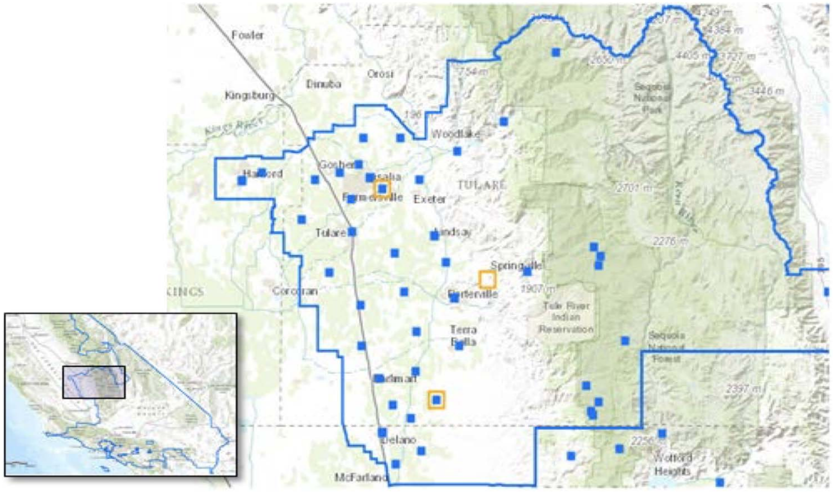

Figure A-2
SCE's service territory in SJV

SCE's service territory in the San Joaquin Valley includes approximately 153,000 residential customers in Tulare County, with some parts of Kings and Kern counties. Electric load (approximately 570 MW) in this region is mostly supplied by a series of hydroelectric plants rated at 1 GW, named Big Creek. This power source is highly susceptible to drought, however, with the plant producing a quarter of its average annual output in 2015.

SCE has recently worked to bolster its DER portfolio in the area. SCE also developed three pilots recently, aimed at (1) installing new electric appliances to reduce traditional reliance on propane or wood burning as a fuel source, and (2, 3) instituting "Shift" (grid responsive heat pump water heaters) and "Shed" (HVAC compressor cycling) DR programs involving 450 residential customers in three communities: California City, Ducor, and West Goshen.

Desert (San Bernardino, Riverside) [78]

SCE's Desert region, consisting of San Bernardino and Riverside counties, is the second largest section of SCE's service territory with 1.3 million customers. The low desert region has one of the highest potentials for renewable energy production in the state, so it has historically been selected as the location for large-scale renewable projects. Therefore, the residents of this area are generally more familiar with the benefits of distributed energy resources. CCA's are also emerging in this area, with the Rancho Mirage Energy Authority serving residential customers in the Coachella Valley, while other municipalities in this region (e.g., San Jacinto and Apple Valley) also formed CCA's in 2018.

Sierras (Inyo/Mono) [77]

The Eastern Sierras region, with approximately 80,000 residential customers predominantly located in Mono and Inyo counties, contains the smallest, most geographically remote customer population in SCE's service territory. Customers in this region commonly use alternative fuels, such as wood and propane, to power furnaces, stoves, and water heaters. The area is also served by two propane suppliers (Amerigas and Eastern Sierra Propane). Electrification in this region is limited because of residents’ concerns about fuel resiliency. Despite the lower rates of customer engagement and participation in DR programs in this region, SCE has worked to promote integrated demand side management strategies, including DR and energy efficient technologies, by way of the Eastern Sierra Energy Leadership Partnership.

B

SCE RESIDENTIAL TARIFFS RELATED TO DR

Currently (March 2019), all commercial, industrial, and agricultural customers in California are required to be on a TOU rate plan. Residential customers can choose to be on to TOU plans.

In contrast with commercial and industrial rates, residential tariffs have traditionally not included demand charges (i.e., have focused on total energy consumption over a billing period rather than the rate at which that energy is delivered), because of a lack of metering infrastructure to measure time-based consumption.[47] This situation is changing with the widespread introduction of smart meters.

SCE offers 15 residential rates, five of which (in bold below) could be considered related to DR because they are time dependent (includes TOU):

Default Rates

- Schedule D: Domestic Service (default rate for domestic service including lighting, heating, cooking, and power or combination thereof in a Single-Family Accommodation or an individually metered Single-Family Dwelling in a Multifamily Accommodation)
- Schedule DM: Multifamily Accommodation - Residential Hotel - Qualifying RV Park (Closed to new installations as of June 13, 1978, except for Residential Hotels and Qualifying RV Parks. Multifamily Accommodations built prior to December 7, 1981 and served under this Schedule may also be eligible for service under Schedule DMS-1.)
- Schedule DMS-1: Domestic Service, Multifamily Accommodation, Submetered (Generally closed to new construction as of December 7, 1981 with some exceptions as noted in the rate book.)
- Schedule DMS-2: Domestic Service, Mobile home Park Multifamily Accommodation, Submetered (closed to new mobile home parks, manufactured housing communities, and Owner Lot RV Parks for which construction has commenced after January 1, 1997)
- Schedule DMS-3: Domestic Service, Qualifying RV Park Accommodation, Submetered (where all the RV spaces of the park, or all of the RV spaces in a specific section of the park, are separately sub-metered and reserved for prepaid month to-month tenants)

Qualified Populations

- Schedule D-CARE: California Alternate Rates for Energy, Domestic Service
- Schedule D-FERA: Family Electric Rate Assistance
- Schedule DE: Domestic Service to Utility Employees
- Schedule MB-E: Medical Baseline - Exemption

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[47] Hledik, Ryan. Rediscovering Residential Demand Charges. *The Electricity Journal*. Vol. 27, No. 7, August/September 2014, pp. 82-96.

- Schedule ESC-OO: Edison SmartConnect Opt-Out (for customers who do not wish to have a wireless, communicating meter; these customers are not eligible for the Smart Energy Program Incentive.)

Load Modifying Options – Demand Response

- Schedule D-SDP: Domestic Summer Discount Plan (available to customers residing in an individually metered single-family accommodation who have agreed to allow 100% or 50% cycling (temporary load disconnection) of their central air conditioning during SDP called events)
- Schedule SEP: Smart Energy Program *(an optional program to allow enrollment in an SCE authorized direct load control available to customers receiving service under Schedules D, D-CARE, D-FERA, TOU-D, or TOU-D-T)*
- TOU – Note most of these changed on 1 March 2019 to 4-9pm or 5-8pm options, each with CPP sub-option
  - Schedule TOU-D: TOU Domestic (option available to customers enrolled under Schedule D, D-CARE, or D-FERA; most but not all enrolling in this option are not eligible to enroll in any other demand response program offered by SCE or any third-party administered demand response program; Options A, A-CPP, B and B-CPP of this Schedule are available subject a cap of 200,000 customer accounts)
  - Schedule TOU-D-T: TOU Tiered Domestic (AKA Off Peak Savings Plan; has same inclusions and exclusions as above except for the cap on amount of accounts)
  - Schedule TOU-EV-1: Domestic TOU, Electric Vehicle Charging (no longer open to customer enrollment, available only if grandfathered in due to previous enrollment – was exclusively available for the charging of electric vehicles on a separate meter provided by SCE in Single Family Dwellings concurrently served under a Domestic schedule.)

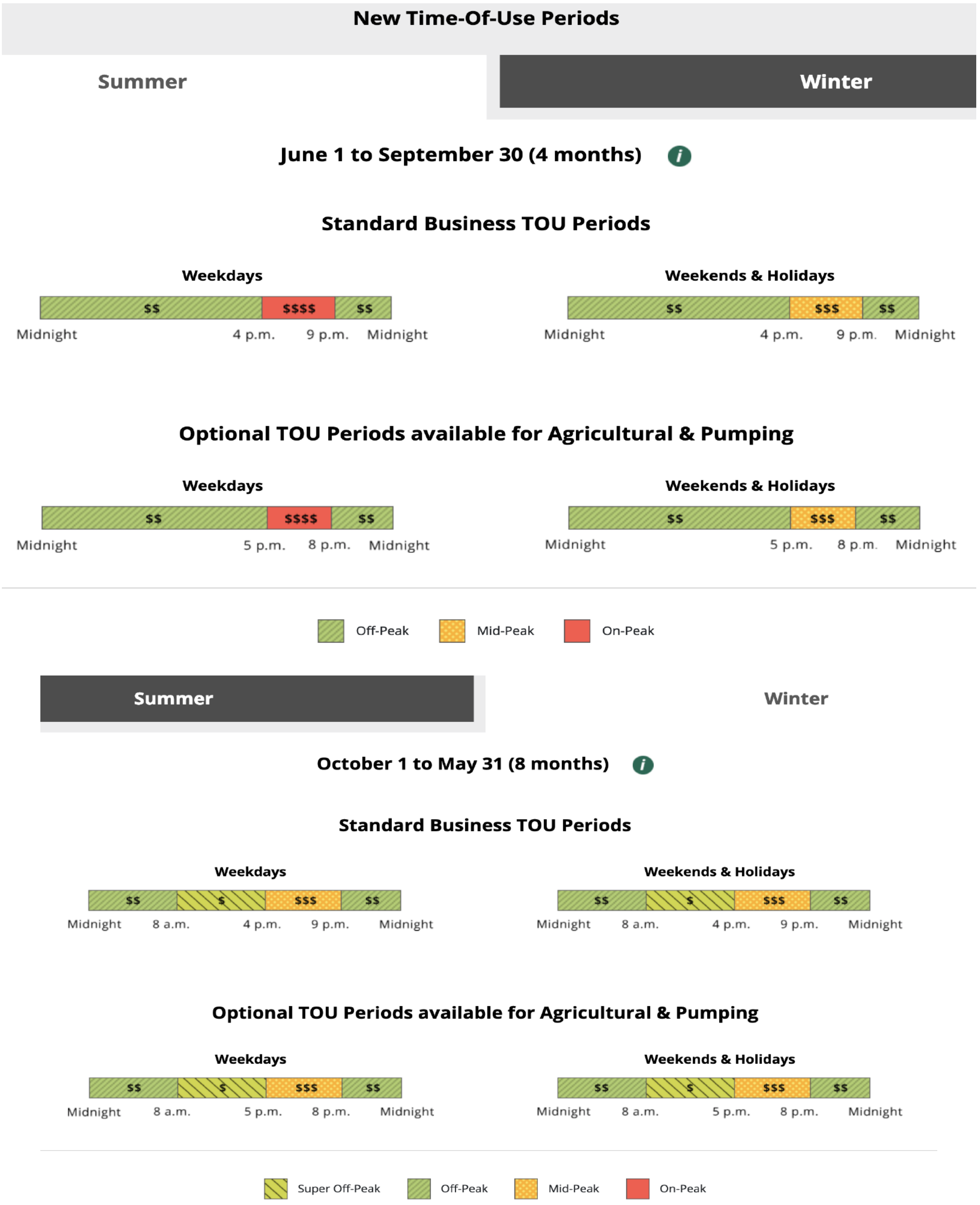
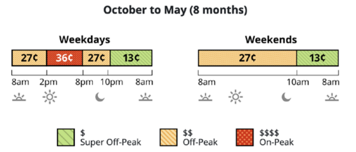
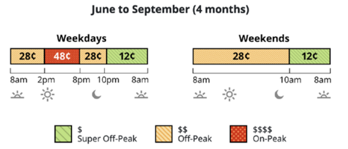
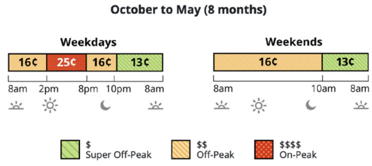
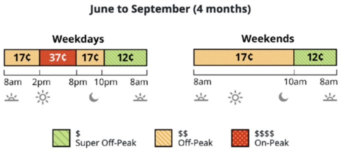
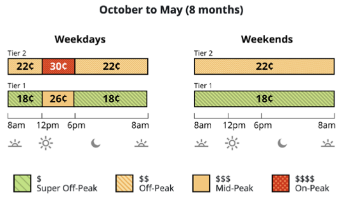
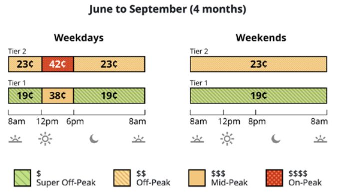
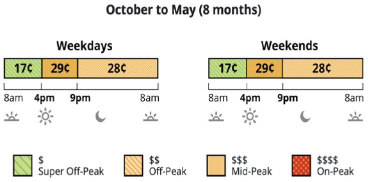
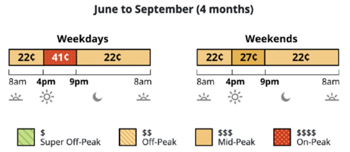
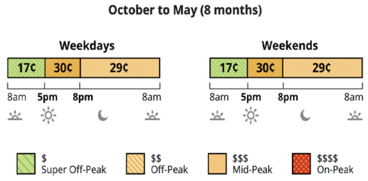
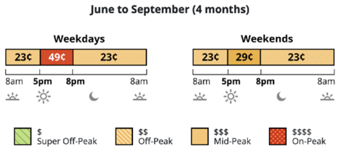


Figure B-1
New TOU Tariff Time Periods

Diagrams comparing old and new TOU tariff time periods and rates with notes indicating targeted populations for each tariff are shown below.

Table B-1
Diagrams comparing old and new TOU tariff time periods and rates

Program	Winter	Summer	Target Population
TOU-D-A			Low and medium energy users (less than 700 kWh/month) Apartment dwellers who do not use A/C NEM Customers
TOU-D-B			Higher usage customers (more than 700 kWh/mo.) Large households with children or seniors Homes with A/C or a swimming pool
TOU-D-T			Households who can keep energy usage low throughout the month Households who use energy in the early morning or evening during the week
TOU-D-4-9PM			Customers who use energy before late afternoon or the late evening Small to moderately-sized (rented) homes; coastal areas
TOU-5-8PM			Customers who use energy before 5 p.m. Customers who are home during the day Small homes or condos
	Summer Advantage Incentive (CPP) options available with TOU-D-4-9PM and TOU-D-5-8PM		

C

DEMAND RESPONSE EVENTS CALLED BY SCE BY TARIFF (2016-2018)

SCE Smart Energy Program (SEP) events called since January 1, 2016: Six events were called, all in 2018. All except one lasted 4 hours. One event (June 8, 2018) was 2 hours in duration.

Table C-1
SEP events called since January 1, 2016

Date	Start Time	End Time
06/08/2018	02:00PM	04:00PM
08/07/2018	02:00PM	06:00PM
09/13/2018	02:00PM	06:00PM
09/14/2018	02:00PM	06:00PM
09/20/2018	02:00PM	06:00PM
10/02/2018	02:00PM	06:00PM

Summer Discount Program (SDP) events called since January 1, 2016: 8 days in 2016, 13 days in 2017, and 20 days in 2018.

Twelve Critical Peak Pricing (CPP) Residential events were called since January 1, 2016, each 2-6 p.m., one coincident with SEP, one coincident with SDP.

D

SUMMARY OF RELATIVE RESIDENTIAL ENERGY USE

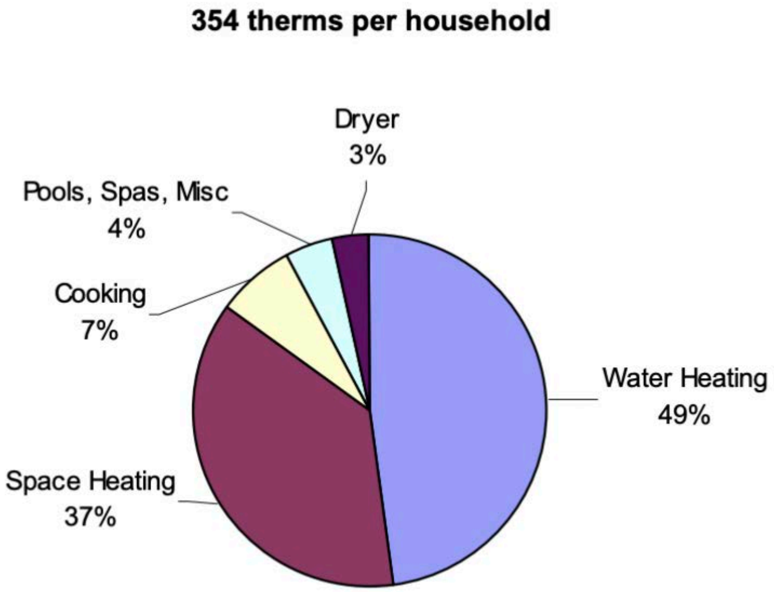
Overview

While DR focuses primarily on load (power) resources, most residential electric end uses have historically been characterized in terms of energy used. This is due, in large part, to the fact that most residential electricity consumption is metered by energy use during a given month, not power demand on a more detailed time scale.

The data sources used here are imperfect: the U.S. Department of Energy's Residential Energy Consumption Survey, RECS2015, provides the most up-to-date information, but at a larger granularity (best resolution is Pacific, which includes Washington, Oregon, and California). California's Residential Appliance Saturation Study, RASS2010, gives data at the utility (SCE) level, but that data is almost ten years old. A new RASS is underway, but its results will not be available until 2020. This report uses two references for residential energy use measures, chosen because (a) each provided a comprehensive list that allowed consistent comparison across a wide range of end-uses, and (b) each reflects data for a region similar to, although not the same as, that served by SCE.

Data below is provided for each of six end use categories: space conditioning, water heating, lighting, pool pumps, appliances, and TV or electronics.

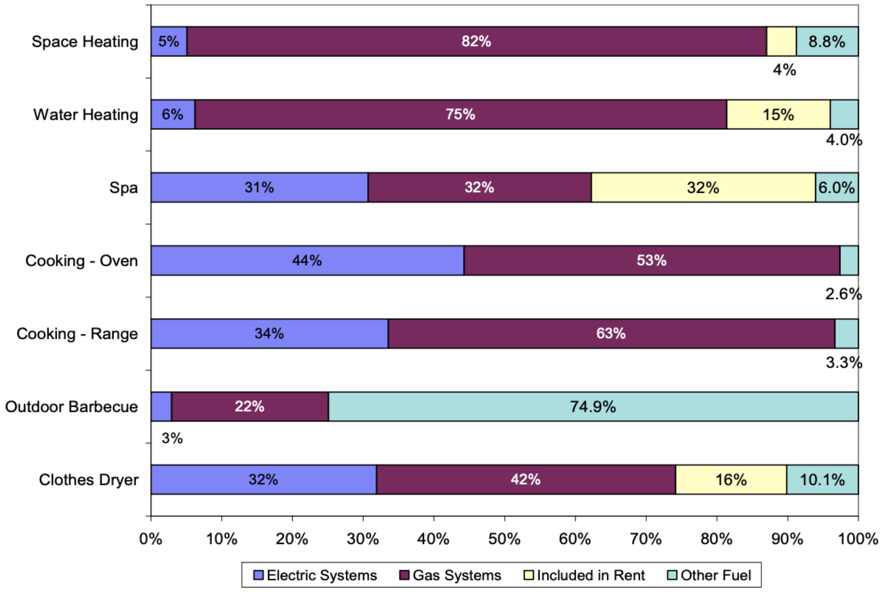
A note on fuel choice: all end use consumption values shown here are for electricity use. For context, RASS2010 provided the following graphs that identify the fuel split between residential end uses:



Source: *2010 California Residential Appliance Saturation Survey*

Figure D-1
Statewide Natural Gas Energy Consumption

From the perspective of natural gas consumption, space heating and water heating are relatively large consumers of natural gas, with cooking ranking third in relative use. RASS2010 then translates this into relative percentages for certain key end uses:



Source: *2010 California Residential Appliance Saturation Survey*

Figure D-2
Relative energy consumption type by end-use

Space Conditioning – Air Conditioning, Heating, Ventilation

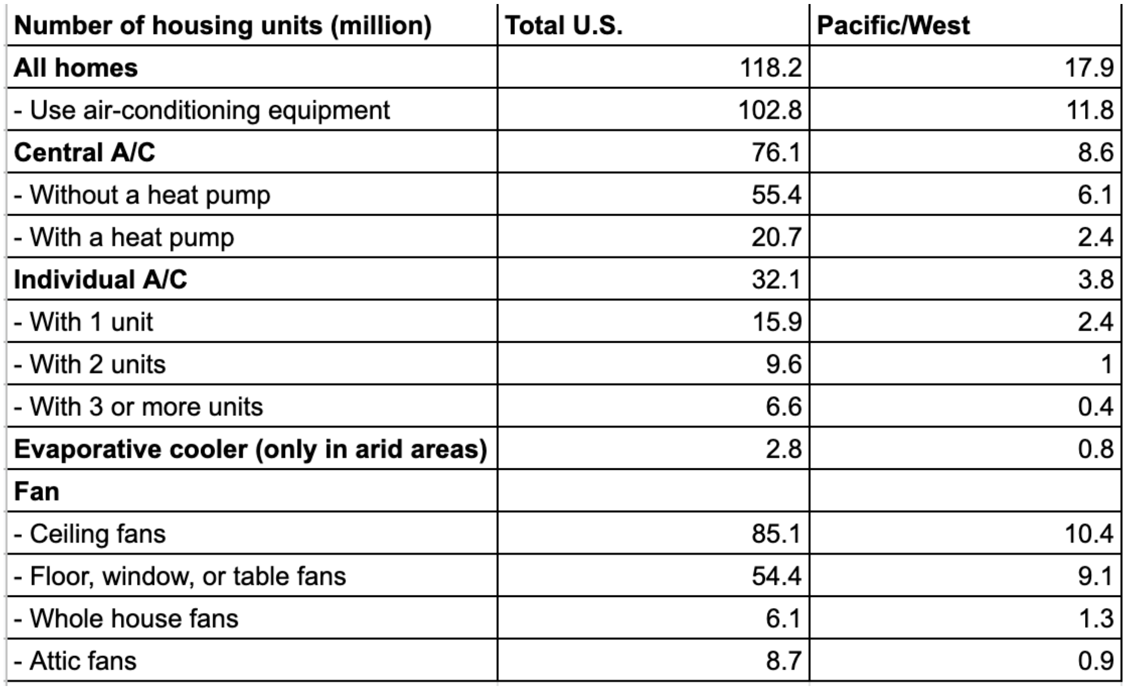
RECS2015

For all residential in United States	Annual Energy Use (Billion kWh)	% of Total
Space cooling	214	15
Space heating	207	14
Furnace fans and boiler circulation pumps	25	2

Air Conditioning

RECS2015 reports that in 2015, more than 76 million households (64%) used a central air-conditioning system, an increase from less than 66 million households (59%) in 2005.

Within the Pacific region:



Number of housing units (million)	Total U.S.	Pacific/West
All homes	118.2	17.9
- Use air-conditioning equipment	102.8	11.8
Central A/C	76.1	8.6
- Without a heat pump	55.4	6.1
- With a heat pump	20.7	2.4
Individual A/C	32.1	3.8
- With 1 unit	15.9	2.4
- With 2 units	9.6	1
- With 3 or more units	6.6	0.4
Evaporative cooler (only in arid areas)	2.8	0.8
Fan		
- Ceiling fans	85.1	10.4
- Floor, window, or table fans	54.4	9.1
- Whole house fans	6.1	1.3
- Attic fans	8.7	0.9

Space Heating

According to RECS2015, space heating accounts for 15% residential electric use of 22.2 billion kWh in Pacific/West, with 1.2 billion kWh for air handlers for heating:

- 5.6M homes have electric heating units vs. 8.6M homes using natural gas – here the statistics are likely misleading, as the Pacific Northwest portion of the Pacific designation are more likely to use electricity.

RASS - Space Conditioning

Although space cooling consumes only 7 percent of annual residential electricity consumption, it is “the main driver of residential peak load”, according to the 2010 California Residential Appliance Saturation Study. As noted above, natural gas provides the bulk of space heating, whereas electricity provides the bulk of space cooling:

Within SCE only	Average Annual Consumption per Household, kWh	Saturation (1.00= 100%)
Conventional electric heat	371	0.03
Heat pump	508	0.01
Auxiliary heat	141	0.01
Furnace fan	143	0.66
Attic ceiling fan	156	0.15
Central air conditioning	883	0.58
Room air conditioner	238	0.18
Evaporative cooler	716	0.07

Within SCE, air conditioning use varied by climate zone:

Energy Commission Climate Zone (Utility)	Central Air Conditioning kWh/Household	Cooling Degree Days
Zone 7 (SCE)	1,122	1,557
Zone 8 (SCE)	382	575
Zone 9 (SCE)	763	882
Zone 10 (SCE)	1,318	1,583

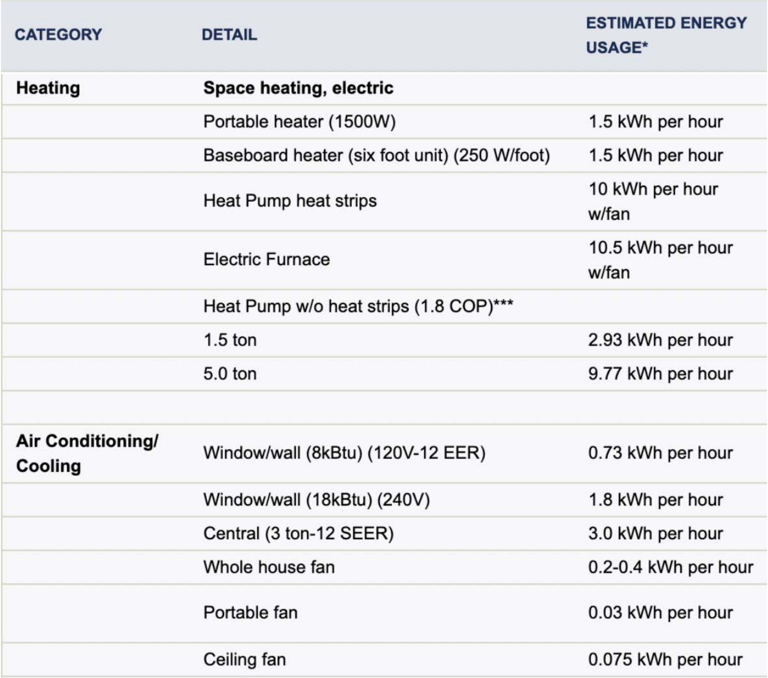
Power Consumed

Box fan	0.2 kW
Ceiling fan	0.120 kW
Central A/C 24000 BTU NA 10000 BTU NA	 kW 3.25 kW
Furnace fan blower	0.8 kW
Space Heater NA	1.5 KW
Window air conditioner 10000 BTU NA 12000 BTU NA	 0.900 kW 3.250 KW

Energy Consumption

Usage notes – users need comfortable space, but there is some flexibility. For space cooling, air movement is critical: ceiling fans (if available) can make a space more comfortable at a fraction of the energy and power of HVAC

- Spark Energy estimates 1450 kWh/month for 2T central air conditioning
- Energy estimates from Silicon Valley Power:



CATEGORY	DETAIL	ESTIMATED ENERGY USAGE*
Heating	**Space heating, electric**	
	Portable heater (1500W)	1.5 kWh per hour
	Baseboard heater (six foot unit) (250 W/foot)	1.5 kWh per hour
	Heat Pump heat strips	10 kWh per hour w/fan
	Electric Furnace	10.5 kWh per hour w/fan
	Heat Pump w/o heat strips (1.8 COP)***	
	1.5 ton	2.93 kWh per hour
	5.0 ton	9.77 kWh per hour
Air Conditioning/ Cooling	Window/wall (8kBtu) (120V-12 EER)	0.73 kWh per hour
	Window/wall (18kBtu) (240V)	1.8 kWh per hour
	Central (3 ton-12 SEER)	3.0 kWh per hour
	Whole house fan	0.2-0.4 kWh per hour
	Portable fan	0.03 kWh per hour
	Ceiling fan	0.075 kWh per hour

WATER HEATING (and Cooling)

RECS2015

Residential water heating for the entire US as an electrical end use consumes 174 Billion kWh or 12% of total residential energy. In the Pacific, this end use consumes 19.6 billion kWh, or 14% of residential energy use in the region.

- 5.7 M homes using electric water heaters – resistive and heat pump; as noted above, since RECS2015 includes Oregon and Washington in the Pacific category, much of the electric use for water heating is likely to arise from those states.
- 11.4 M homes using Natural gas water heaters
- 0.8 M homes using an alternate source

RASS 2010

Note: heat pump water heating not listed in this study.

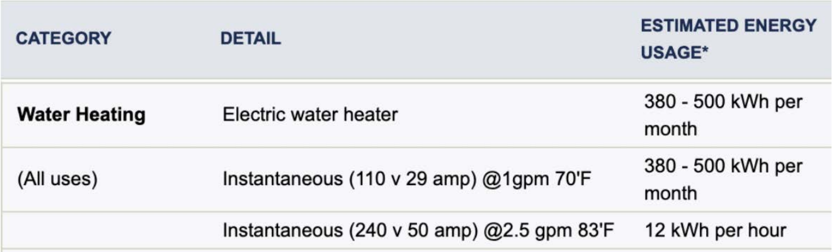
Within SCE only	Average annual consumption per household, kWh	Saturation (1.00= 100%)
Resistance water heating	2,143	0.05
Solar water heating	1,838	0.00

Power Consumed

Tankless water heater - electric	18 kW
Water heater - electric	4.5 kW
Electric kettle	1.2 kW

Energy Consumption

- Spark Energy estimates 310 kWh/month for water heating
- Silicon Valley power estimates are higher:



CATEGORY	DETAIL	ESTIMATED ENERGY USAGE*
Water Heating	Electric water heater	380 - 500 kWh per month
(All uses)	Instantaneous (110 v 29 amp) @1gpm 70'F	380 - 500 kWh per month
	Instantaneous (240 v 50 amp) @2.5 gpm 83'F	12 kWh per hour

Lighting

RECS2015

Within the entire US, electric lighting consumed 91 billion kWh each year, or 6% of the total residential energy consumption. Within the Pacific segment, 16.3 billion kWh was consumed annually for lighting

RASS 2010 – only outdoor lighting cited

Within SCE only	Average annual consumption per household, kWh	Saturation (1.00= 100%)
Outdoor lighting	348	0.66

Power Consumed

CFL Bulb	
40W equivalent	0.011 kW
60W equivalent	0.018 kW
75W equivalent	0.020 kW
100W equivalent	0.030 kW
Compact Fluorescent	
20 W	0.022 kW
25 W	0.028 kW
Halogen – 40 W	0.040 kW
Incandescent	
50W	0.050 kW
100W	0.100 kW
LED bulb	
40W equivalent	0.010 kW
60W equivalent	0.013 kW
75W equivalent	0.018 kW
100W equivalent	0.023 kW

Energy Consumption

- Spark Energy estimates 50 kWh/month for 4-5 room household
- Silicon Valley Power provides these more detailed values for each kind of light bulb (for reference, 50 kWh per month, assuming, 8 hours/day, 30 days/month, would be 0.21 kWh per hour):

CATEGORY	DETAIL	ESTIMATED ENERGY USAGE*
Lighting	**Incandescent bulbs**	
	Incandescent bulb (40 W)	0.04 kWh per hour
	Incandescent bulb (60 W)	0.06 kWh per hour
	Incandescent bulb (75 W)	0.08 kWh per hour
	Incandescent bulb (100 W)	0.1 kWh per hour
	Incandescent bulb (150 W)	0.15 kWh per hour
	Compact fluorescent (CFL)	
	Compact fluorescent (8 W) equivalent to 25 W incandescent	0.008 kWh per hour
	Compact fluorescent (11 W) equivalent to 40 W incandescent	0.01 kWh per hour
	Compact fluorescent (15 W) equivalent to 60 W incandescent	0.015 kWh per hour
	Compact fluorescent (20 W) equivalent to 75 W incandescent	0.02 kWh per hour
	Compact fluorescent (27 W) equivalent to 100 W incandescent	0.027 kWh per hour
	Compact fluorescent (38 W) equivalent to 150 W incandescent	0.038 kWh per hour
	Halogen	
	Halogen (300 W)	0.3 kWh per hour

Pool Pumps

RECS2015

Pool pump electricity use for the entire US was grouped into the “other uses” category (460 Billion kWh; 31% of total) with small electric devices, heating elements, exterior lights, outdoor grills, pool and spa heaters, backup electricity generators, and motors not listed [elsewhere].

In the Pacific region, RECS2015 notes that “only 7.9 million homes, or about 7% of the national total, reported using a pool pump. Nationwide, pool pumps consume 1% of the electricity used in homes, but among homes that have pool pumps, the equipment consumes 8% of total electricity used each year.”

Typical pool pump functions include water clarification and chemical treatment mixing.

RASS2010

Within SCE only	Average annual consumption per household, kWh	Saturation (1.00= 100%)
Pool pump	3,442	0.11
Spa	294	0.10
Spa electric heat	951	0.04

Power/Energy Consumed

Pool pumps are typically chosen by the user according to the available power (multiply HP of pump by 0.7457 to get kW). The key distinction with pumps is in the energy consumed at different speeds: for example, at high speed a pump might draw 7 amps but only needs to operate for 8 hours to filter the pool (11.27 kWh per day) versus 2.3 amps at low speed but takes 16 hours to filter the pool (8.464 kWh/day). Only Silicon Valley Energy provided estimated energy usage related to pool pumps:

CATEGORY	DETAIL	ESTIMATED ENERGY USAGE*
Swimming Pool	Sweep pump (3/4 hp)	0.56 kWh per hour
	Filter pump (1-1/2 hp)	1.12 kWh per hour
	Filter pump (2 hp)	1.5 kWh per hour
Spa/Hot Tub	Electric heater (1500 W)	1.5 kWh per hour
	Electric heater (5500 W)	5.5 kWh per hour

Notes:

Pump speed is the critical variable with pool pumps, as noted in the main text of this report. There are three key pump rules related to speed:

1. Flow is directly proportional to speed (e.g., a pump will pump half the water at 1740 RPM as it will at 3450 RPM)
2. Head (related to ability of pump to move water via pressure in the pump) varies as the square of the change in speed. A motor running at 1750 RPM versus 3450 RPM would only have 1/4th the head. For filtration, higher speeds are needed to provide sufficient agitation of the water.
3. Power required varies at the cube of the change in speed. It only takes 1/8th the HP to run at 1750 versus 3450.

Other Residential Appliances

RECS2015

Within the entire US

Appliance	Annual Energy use (Billion kWh)	% of total
Refrigerator	87	6%
Clothes Dryer	60	4%
Freezer	20	1%
Cooking	16	1%
Clothes washer (excludes water heating)	10	1%
Dishwasher	7	1%

In the Pacific sector, RECS2015 notes that average household energy consumption for refrigerators is 2.6 million BTU per household (762 kWh).

RASS 2009

Within SCE only	Average annual consumption per household, kWh	Saturation (1.00= 100%)
Dryer	693	0.19
Clothes washer	119	0.82
Dishwasher	77	0.68
First refrigerator	784	1.00
Second refrigerator	1,174	0.26
Freezer	914	0.16
Range/oven	282	0.32
Microwave	128	0.93

Power Consumed

Note: Refrigerators and freezers do not operate all the time – they cycle as needed to maintain pre-set interior temperature targets; in general, they operate at maximum power approximately 1/3 of the time.

Refrigerator	
20 cu. Ft.	1.411 kWh/day
16 cu. Ft.	1.200 kWh/day
Clothes Dryer – electric (gas is 1.8 kW)	3 kW
Freezer – 15 cu. Ft.	
Upright	1.240 kWh/day
Chest	1.080 kWh/day
Cooking	
Oven – electric	1.200 kW
Microwave	1.000 kW
Toaster	0.850 kW
Toaster oven	1.200 kW
Clothes washer (excludes water heating)	0.800 kW
Dishwasher	1.2 – 1.5 kW
Small kitchen appliances	
Blender	0.500 kW
Can opener	0.150 kW
Coffee machine	1.000 kW
Espresso machine	0.800 kW
Garbage disposal	0.450 kW

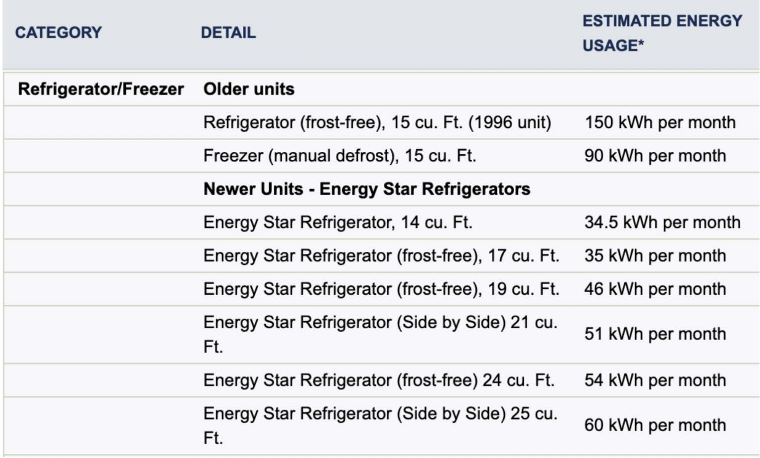
Iron	1.200 kW
Stand Mixer	0.300 kW
Tools	
Saws	--
Band saw 14”	1.100 kW
Chain saw 12”	1.100 kW
Circular saw 7-1/4”	0.900 kW
Circular saw 8-1/4”	1.400 kW
Belt Sander	1.000 kW
Drill	--
¼”	0.250 kW
½”	0.750 kW
1”	1.000 kW
Disc Sander	1.200 kW
Hedge Trimmer	0.450 kW
Weed eater	0.500 kW
Miscellaneous	
Clock radio	0.007 kW
Curling iron	0.150 kW
Dehumidifier	0.280 kW
Electric shaver	0.015 kW
Electric blanket	0.200 kW
Hair dryer	1.500 kW
Humidifier	0.200 kW
Paper shredder	0.150 kW
Radio-telephone send/receive	0.005 kW/0.075 kW
Sewing machine	0.100 kW
Vacuum	1.000 kW

Energy Consumption

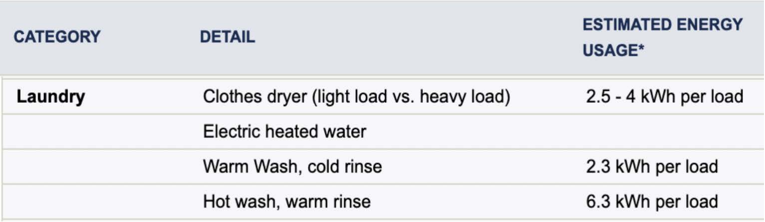
Spark Energy estimates:

Refrigerator (17-20 cubic foot	205 kWh/month
Clothes Dryer	75 kWh/month
Oven/Range (if electric)	58 kWh/month
Dishwasher	30 kWh/month
Microwave	16 kWh/month
Washing machine	9kWh/month

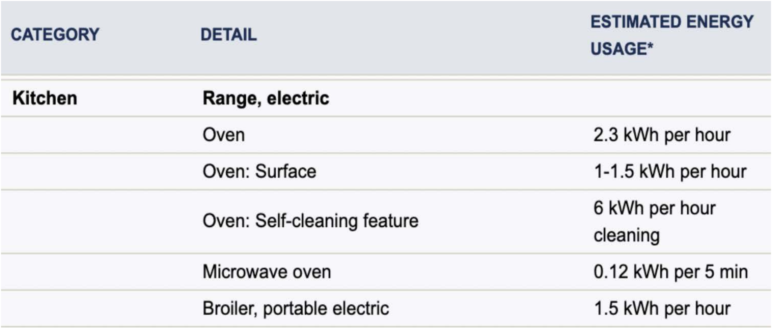
Silicon Valley Power estimates:



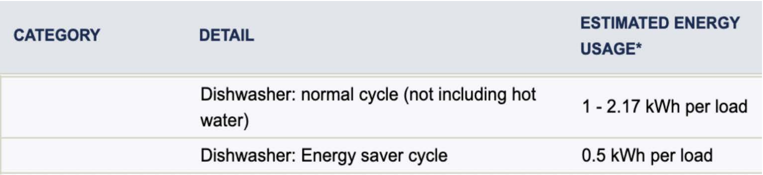
CATEGORY	DETAIL	ESTIMATED ENERGY USAGE*
Refrigerator/Freezer	**Older units**	
	Refrigerator (frost-free), 15 cu. Ft. (1996 unit)	150 kWh per month
	Freezer (manual defrost), 15 cu. Ft.	90 kWh per month
	Newer Units - Energy Star Refrigerators	
	Energy Star Refrigerator, 14 cu. Ft.	34.5 kWh per month
	Energy Star Refrigerator (frost-free), 17 cu. Ft.	35 kWh per month
	Energy Star Refrigerator (frost-free), 19 cu. Ft.	46 kWh per month
	Energy Star Refrigerator (Side by Side) 21 cu. Ft.	51 kWh per month
	Energy Star Refrigerator (frost-free) 24 cu. Ft.	54 kWh per month
	Energy Star Refrigerator (Side by Side) 25 cu. Ft.	60 kWh per month



CATEGORY	DETAIL	ESTIMATED ENERGY USAGE*
Laundry	Clothes dryer (light load vs. heavy load)	2.5 - 4 kWh per load
	Electric heated water	
	Warm Wash, cold rinse	2.3 kWh per load
	Hot wash, warm rinse	6.3 kWh per load



CATEGORY	DETAIL	ESTIMATED ENERGY USAGE*
Kitchen	**Range, electric**	
	Oven	2.3 kWh per hour
	Oven: Surface	1-1.5 kWh per hour
	Oven: Self-cleaning feature	6 kWh per hour cleaning
	Microwave oven	0.12 kWh per 5 min
	Broiler, portable electric	1.5 kWh per hour



CATEGORY	DETAIL	ESTIMATED ENERGY USAGE*
	Dishwasher: normal cycle (not including hot water)	1 - 2.17 kWh per load
	Dishwasher: Energy saver cycle	0.5 kWh per load

Electronics and TVs

RECS2015

Within the entire US:

Televisions and related equipment (set-top boxes, home theater systems, DVD players, video game consoles): 62 Billion kWh; 4% of total

Computers and related equipment (desktop and laptop computers, monitors, networking equipment): 26 Billion kWh; 2% of total

RECS2015 included 25 questions related to home electronics, up from only two questions in 1990. The survey notes that “The pace of computer saturation in the United States over the past 20 years has been dramatic. In 1990, just 16% of households owned a computer. In 2015, ninety percent of homes had at least one desktop, laptop, tablet, or smartphone, and 79% have more than one.” By contrast, RECS2015 reported that “more than twice as many households reported not using a television in 2015 compared to 2009.”

RASS 2009

Within SCE only	Average annual consumption per household, kWh	Saturation (1.00= 100%)
TV	735	1.00
Home office	80	0.21
PC	618	0.85

Power Consumption

TVs and computers continue to draw some power when plugged in but not turned on. Values below assume normal, not standby, operation.

Television and related	
DVD	0.015 kW
BluRay	0.015 kW
TV	--
LCD	0.150 kW
Plasma	0.200 kW
Stereo receiver	0.450 kW
Video Game Console	0.150 kW
Satellite Dish	0.025 kW
Cable box	0.035 kW
Computer and other electronics	
Computer	--
Desktop – computing	0.200 kW
Desktop – gaming	0.500 kW
Laptop	0.100 kW
LCD monitor	0.100 kW
Modem	0.007 kW
Printer	0.100 kW
Router	0.007 kW
Recharge smartphone	0.006 kW
Recharge tablet	0.008 kW

Spark Energy estimates 27 kWh/month for television

Silicon Valley Power estimates:

CATEGORY	DETAIL	ESTIMATED ENERGY USAGE*
Electronics	**Television**	
	> 50" Plasma	0.48 kWh per hour
	40" - 49" Plasma	0.4 kWh per hour
	> 50" LCD	0.016 kWh per hour
	40" - 49" LCD	0.012 kWh per hour
	> 50" DLP	0.24 kWh per hour
	40" - 49" DLP	0.2 kWh per hour
	30" - 36" Tube	0.12 kWh per hour
	25" - 27" Tube	0.09 kWh per hour
	Recording/Video Playing Devices	
	DVR (Tivo)	28.8 kWh per month
	VCR	0.02 kWh per hour
	DVD player	0.03 kWh per hour
	Gaming	
	Nintendo Wii	0.02 kWh per hour
	Xbox 360	0.15 kWh per hour
	Play Station 3	0.21 kWh per hour
	Computers	
	Desktop Computer	0.06 - 0.25 kWh per hour
	Desktop Computer on sleep/standby mode	0.001 - 0.006 kWh per hour
	Laptop	0.02 - 0.05 kWh per hour
	Monitor - 17" CRT	0.08 kWh per hour
	Monitor - 17" LCD	0.04 kWh per hour
	Other	
	Speakers (25 Watts x 2) normal volume	0.05 kWh per hour
	Stereo	0.05 kWh per hour
	Radio, CD player	0.02 kWh per hour

E

PREDICTED TRENDS IN RESIDENTIAL ELECTRICAL USE

Linvill and others [79] predict the following anticipated trends in California building electrical use to 2040. Looking forward, some of these loads are expected to remain fairly constant over the next twenty years, while others may grow, especially after 2025 when California regulations encourage a shift from gas to electricity as an energy source (State of California, Senate Bill No. 100, 2018). Note that lighting and cooking are not predicted to be shiftable, whereas heating, cooling, and ventilation show flexibility arising in part from internal thermal mass. Electric water heating loads are not predicted to become significant until there is sufficient market penetration following a legislative push to move traditional gas- powered heating to electrical:

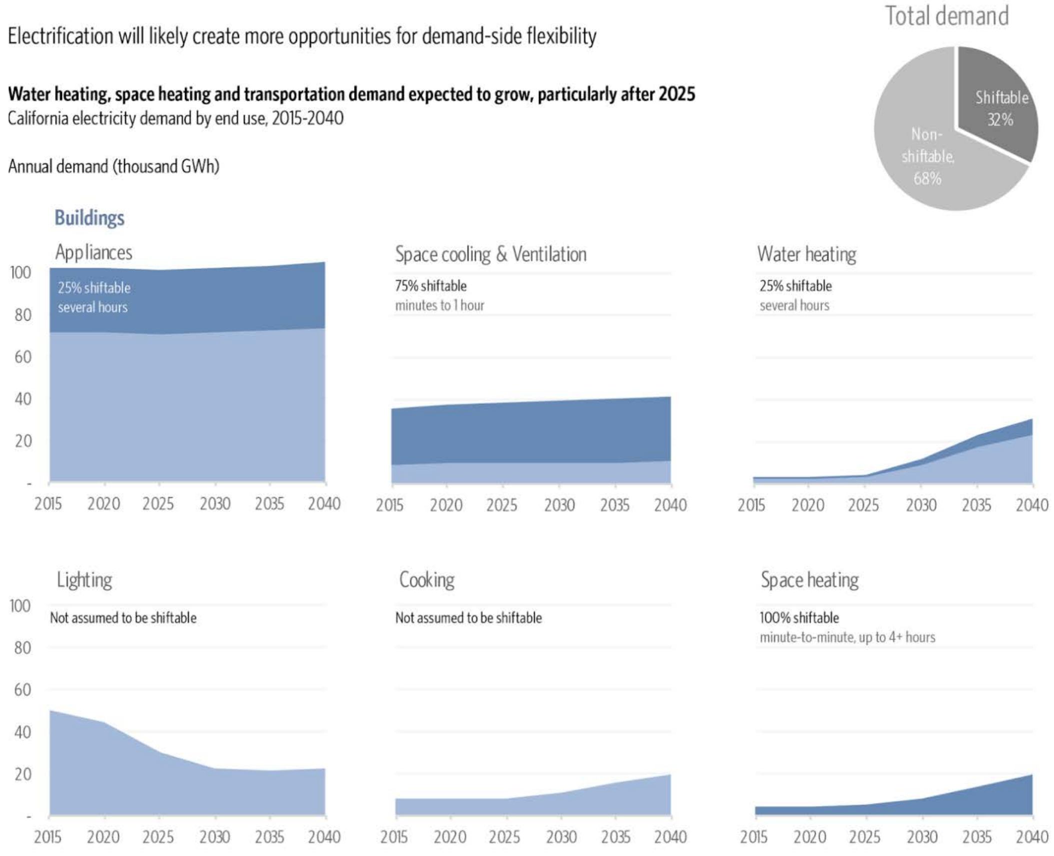


Figure E-1
Predicted growth of energy demand by end-use [79]

For completeness, the remaining part of the analysis presented by Linvill shows flexibility in industrial, agricultural, and transportation sectors as follows:

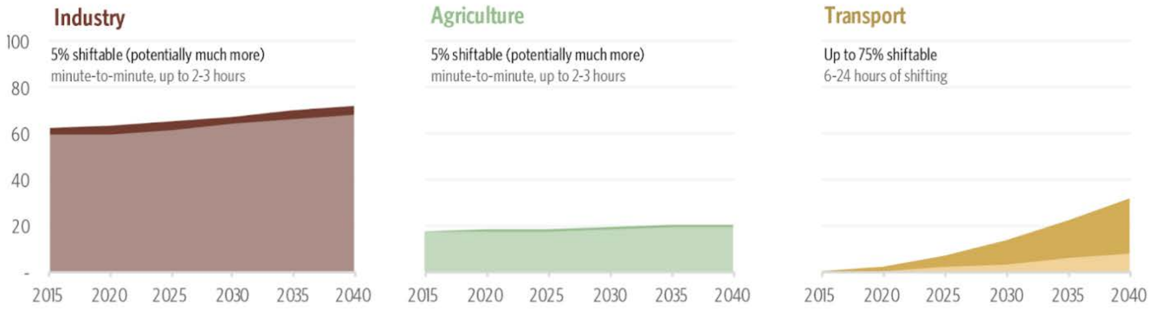


Figure E-2
Industrial, Agricultural, and Transport predicted energy use changes [79]

F

COMMUNITY CHOICE AGGREGATIONS IN SCE TERRITORY (JANUARY 2020)

- **Apple Valley Choice Energy Contact Information**
  - Website: https://avchoiceenergy.com/
  - Phone: 1-760-573-2823
- **Lancaster Choice Energy Contact Information**
  - Website: lancasterchoiceenergy.com
  - Phone: 1-844-288-4LCE
- **Clean Power Alliance Contact Information**
  - Website: cleanpoweralliance.org
  - Phone: 1-888-585-3788
- **Pico Rivera Innovation Municipal Energy**
  - Website: poweredbyprime.org
  - Phone: 1-800-GOPRIME or 1-800-467-7463
- **San Jacinto Power Information**
  - Website: sanjacintopower.com
  - Phone: 1-951-665-6812
- **Rancho Mirage Energy Authority Information**
  - Website: RanchoMirageEnergy.org
  - Phone: 1-760-578-6092

G

CALIFORNIA BUILDING CODE SECTIONS RELATED TO DR

Residential building construction codes in California are specified in:

- California State Laws: State Housing Law and Building Standards Law
- State Regulations: California Code of Regulations (CCR) Title 24, Parts 1-12, including building, residential, electrical, mechanical, plumbing, green building standards, etc., commonly called the California Building Standards Code and CCR, Title 25, Housing and Community Development regulations for implementation of State Housing Law
- Local Code Adoptions reflecting legally adopted local ordinances

CCR, Title 24 is divided into numerical segments called "Parts" identified as follows:

- Part 1. California Administrative Code
- Part 2. California Building Code, presently based on the most current edition of the International Building Code, published by the International Code Council
- Part 2.5. California Residential Code (developed in 2009 to provide building standards specifically for one and two-family dwellings and townhouses) presently based on the most current edition of the International Residential Code, published by the International Code Council
- Part 3. California Electrical Code, presently based on the most current edition of the National Electrical Code, published by the National Fire Protection Association
- Part 4. California Mechanical Code, presently based on the most current edition of the Uniform Mechanical Code, published by the International Association of Plumbing and Mechanical Officials
- Part 5. California Plumbing Code, presently based on the most current edition of the Uniform Plumbing Code, published by the International Association of Plumbing and Mechanical Officials
- **Part 6. California Energy Code**
- Part 7. Not defined (vacant)
- Part 8. California Historical Building Code
- Part 9. California Fire Code, presently based on the most current edition of the International Fire Code, published by the International Code Council
- Part 10. California Existing Building Code, presently based on the most current edition of the International Existing Building Code, published by the International Code Council
- Part 11. California Green Building Standards Code, developed in 2008 to underscore the need for increased building sustainability, to support conservation of resources and building materials, and to promote water efficiency and environmental air quality)
- Part 12. California Referenced Standards Code

H

SELECTED USEFUL APPS AND API

A wide variety of apps and APIs have appeared recently to facilitate residential DR. Not all of the apps listed below are available or useful to SCE customers at this time, nor is this an exhaustive list of what is available, but SCE customers can find out about these and may inquire as to their applicability. Those not currently usable in SCE territory at present are highlighted below but may provide guidance for future development of apps or APIs for future use in SCE territory.

WattTime's Automated Emissions Reduction API "provides an automated process for emissions reductions without impacting functionality" by optimizing the time of energy use to meet capacity, cost, comfort, carbon objectives. It syncs electricity consumption to cleaner times, within whatever limits are needed for a particular device (appliance, electronics, thermostats, electric vehicles) to operate as its designed.

UtilityAPI allows access to user data with explicit authorization from the utility account holder (mostly used by solar installations and energy efficiency evaluations). Begins with Green Button data and also includes total bill amount(s), TOU and tier information, demand charges, 15-min interval data (currently just for commercial and industrial customers; smart meter data if available). Data can be directly imported to software tools, including excel spreadsheets.

Some apps are directly related to particular equipment. For example, **ecobee API** provides an http-based interface for control and access to the ecobee thermostats to allow read, update and poll information about ecobee thermostat(s). This app includes a DR object containing information pertaining to a program change event for a set of thermostats. DR object is "only available to EMS and Utility accounts".

Separately, for users, ecobee calculates expected energy savings (ecobee believes these can be up to 23% of energy bill) using HomeIQ:

1. Energy savings as a percentage tied to equipment runtime and thermostat temperature setbacks used over the previous month, based on equipment runtime energy use compared to energy required if thermostat was set at a constant 72 degrees F for the month.
2. Measure of home envelope energy consistency based on data gathered by monitoring the floating temperature in the house when the equipment shuts off. The company notes it is "continuously trying to find innovative ways to make this calculation better."
3. A comparison of runtimes with other ecobee users by province or state.

The following apps facilitate specific device operation or coordination and could help support DR programs.

Table H-1
Device or manufacturer specific DR related apps

Name	What it does	Works with
Inspire	Energy use and device management	Inspire Eco, ecobee, and Nest smart thermostats; Sengled Element hub and light bulbs
Toon	Control and monitor energy use by appliance	Phillips Hue lighting and Fibaro smart plugs, review solar panel output, battery life of Fibaro smoke detectors
PeakShaver	Monitor and control	POMCube products
ThinkEco smartAC	Control and schedule window AC	ThinkEco Zigbee enabled units purchased 2012 or earlier
SmartAC GO	Control and schedule via WiFi	ThinkEco smartAC
Geo Tempo	See energy usage and costs from anywhere	Requires in home display Trio II with WiFi
GridRabbit	Home energy management system via preferences set for comfort, time of use, and if-then controls (allows user override).	GridRabbit controls, and sensors, thermostats, smart sockets, motion/temperature/humidity sensors, etc
SmartThings	Monitor and control connected devices; receive alerts of unexpected activity from connected devices; automate connected devices to turn on or off when doors are opened; create morning, departure, evening and other routines.	Samsung home devices Requires an Android device (6.0 or later) or iPhone (iOS 10.0 or later). Requires a SmartThings Hub or compatible device with SmartThings Hub functionality.

Often a first step towards DR involves becoming aware of the actual electricity used in a home. These apps provide insights about how and when energy is used in the home:

Table H-2
Apps that can support residential DR

Name	What it does	Notes
Evo Energy	Residential electricity usage calculator	
MES energy manager	Works via in-home Zigbee gateway to control HVAC, electric water heaters, refrigerators, pools, etc.	Ethernet, WiFi or Cellular
Geo Tempo	See energy usage and costs from anywhere	Requires in home display Trio II with WiFi
SparkChange	Energy usage for different appliances; visualize savings by turning off appliances at selected times	Focus on carbon reduction
Canari	Real time energy use (via data from energy provider) visualization.	Only for iphone.
Clariti	Insights on energy usage compared with historical use	
Prism by Freestyle	Visualize energy consumption; can be white labelled with client logo	
Direct Energy	Provides data on how much and when a home uses energy, compares it with historical energy usage, identifies the heavy energy users in your home are and creates estimates of upcoming power bills based on predicted weather (since heating and cooling is the single greatest factor in variable energy use in a home).	
Bidgely	Energy disaggregation via artificial intelligence algorithms that itemize customers' energy data into individual appliances. Uses this "deep analysis" of smart meter data to develop low cost options by which residential customers can get reliable bill savings.	Option available with at least 20 utilities around the world

For reference, this report also notes apps available for use in other locations or for other sectors, some of which could be adapted for use at SCE.

Table H-3
Outside apps adaptable to SCE's residential market

Name	Task	Location
Griddy	Real time wholesale prices for energy	Texas market App supports subscription program for energy purchase \$9.95/mo + wholesale costs of energy
nPower	Visualize energy usage and bill forecasts based on historical usage	UK
Powerwatch	Wholesale energy spot prices with alerts to reduce usage if spikes in price	Specific to Texas market
AutoDM	Enernoc's DR interface for aggregated residences.	Appears to be more business focused.
Kisense	Information on energy consumption and remote control of energy consuming equipment.	Business sector focus
Infinite Energy	Rewards program whereby customers earn points, later redeemable for gift cards, if they consistently check and improve their household's energy use.	Available in Florida, Georgia, New York, New Jersey and Texas

I

TECHNOLOGY FOR ENERGY CONTROL RELATED TO DR

iDevices: connected switches, outlets, and thermostat that can be coordinated via a single app. Light switch (Instinct) is Alexa enabled.

Uplight: combines continuous energy use analytics, customer interactions, and what is already known about available products and customer profile history, to identify products for which a customer did not previously qualify (reportedly used by more than 80 utilities around the globe to power their customer energy experience).

Glow: reminiscent of the orb, this device changes colors to alert homeowners to greater than usual amount of energy use (via information gained from a two inch high magneto-resistive sensor to measure current flow placed on a home's electricity meter, with "low power radio" conveying signals into the base unit in the home). Also comes with an app to let you track energy use from your phone and provides notifications if energy use appears out of the norm.

Energy efficiency focused technology with limited DR potential:

Nanolight: a crowdsourced effort to develop 12 W light bulbs that produce 1600 lumens, equivalent to a 100W incandescent lightbulb.

BeOn: plug-in microinverter solar panels would allow customers to plug in the output from panels (parallel connection) to reverse feed directly into the home wiring ("connect a power generating solar panel to any electric socket, just like a common electric appliance, in a safe, reliable and simple way"). Available from company based in Portugal, but advertising in English via internet.

TheGEN: a crowdsourced effort to build compact combined rooftop solar and wind units for residential use.

JuiceNet: cloud based IOT platform for EV load management that optimizes EV charging loads via a patented communication and control algorithm that dynamically matches drivers' historical charging patterns, real-time input and signals from grid operators and utilities to aggregate and manage charging station demand. It can control any WiFi connected charging station and coordinates periodic, changes in charge rate and timing, which the driver can override at any time. Works with Amazon Alexa and Google Home.

Brightbox: home solar system with a battery service to use stored energy instead of electricity from the grid during on-peak TOU hours in the summer (e.g. June 1 to September 30). Note that Tesla Powerwall has a higher capacity (13.5 kWh) than this system (9.3 kWh).

J

RECENT DR RELATED RESEARCH

Space Conditioning

EPRI (3002011045): Common Demand Response Functions for Heating, Ventilating, and Air Conditioning (HVAC): A Summary of Demand Response Functionality Discussed in the Industry to Date. Dec 13 2017

Comprehensive guide describing the utility-facing demand response (DR) functions related to residential heating, ventilating, and air-conditioning (HVAC) equipment

EPRI (3002009455): Evaluation of Residential Room Air Conditioner Control with Smart Plugs for Peak Load Reduction. Dec 30 2017

Work evaluated a sample of smart plug technologies with the potential for supporting peak load reduction via connected room air conditioner

Heating

Unico Cold Climate Heat Pump (CCHP): Residential Cold Climate Heat Pump with Variable-Speed Technology (ORNL, Purdue, Emerson Electric, Invention House)

Develop a residential split-system three-ton cold climate heat pump (CCHP) using boosted compression technology and variable speed motors.

Cooling

References	Year	Methods	Technologies	Communication and Control Architecture	Key Findings
Behboodi, S. et al.	2018	Modeling	Market-based control for flexible loads (thermostatically controlled loads) based on transactive paradigm	N/A	Consumer electricity costs reduced by over 10% compared to uncoordinated operation.
EPC-14-021, EPRI	2016	Development, laboratory and field Testing	Development and Testing of the Next Generation Residential Space Conditioning System for California	N/A	Demand-response interactivity to grid flexibility and reliability; Various advanced efficiency solutions integrated into the HVAC system.

References	Year	Methods	Technologies	Communication and Control Architecture	Key Findings
EPC-15-081, CEC	On-going	Modeling	Historical Insights for Technology Adoption Scenarios in California and Flexible Energy Demand Modeling for Residential Air Conditioning with Improved Behavioral Specificity	N/A	Develop a tool to enable exploration of impacts of a number of human dimensions (e.g., behavior, policy, trends in AC adoption) on residential air conditioning demand.
EPC-16-013, CEC	On-going	Laboratory testing and demonstration	Integrating Smart Ceiling Fans and Communicating Thermostats to Provide Energy-Efficient Comfort	Vendor Cloud (Tstat)	Demonstrate energy savings and improved comfort of the integrated system in retrofit applications; Develop standard rating methods, a design guide, and energy code language to facilitate more widespread implementation.
EPRI 3002009247	2016	Demonstration	BGE's Wi-Fi Thermostat Pilot: Smart thermostat or air conditioning device (cycle 50%, 75% or 100%)	Device (load control switch); Vendor Cloud (Tstat)	Receive between $50 to $200 in bill credits from June–September.
EPRI 1018895	2018	Assessment	Tests of four end-use vendor technologies in the residential, commercial, and industrial sectors, each configured to automatically receive real-time DR event notifications.	N/A	All four end-use technologies demonstrated that they could receive and interpret OpenADR messages to automatically shed loads.
EPRI					
3002008238	2018	Modeling	Mini-Split and Multi-Split Heat Pump Evaluation for Energy Efficiency and Demand Response	N/A	Mini-split and multi-split equipment was modeled under various DR scenarios, utilizing an indoor temperature setback approach.

References	Year	Methods	Technologies	Communication and Control Architecture	Key Findings
EPRI 3002011250	2017	Pilot study	DR pilot evaluation of Wi-Fi thermostat or a two-way communicating air conditioning (AC) load control switch	Device (load control switch); Vendor Cloud (Tstat)	Customers received their choice of either a free Wi-Fi thermostat or a two-way communicating air conditioning (AC) load control switch; Tests measured response compared against AC-level consumption estimates derived from the thermostat- and switch-generated data.
Lincoln Electric System, EPRI	2017	Pilot study	DR pilot evaluation of Wi-Fi thermostat or a two-way communicating air conditioning (AC) load control switch	Device (load control switch); Vendor Cloud (Tstat)	Events were generally conducted from 3:00 to 6:00 p.m (9 events in 2015 summer and 17 events in 2016 summer);AC units cycled using a 15/15 or 22.5/7.5 strategy, or thermostat setpoints increased by 3°F (with or without setpoints decreased by 3°F during a precooling period); Tstat offset strategies resulted in AC-level demand savings ranging from 1.20 to 1.22 kW (63 to 68% of AC-level baseload), without and with precooling, respectively; AC units cycled impacts ranged from 0.49 to 0.53 kW (34 to 42%) for 15/15 and 22.5/7.5 cycling, respectively.
EPRI 3002009414	2016	N/A	Meeting Residential and Small Commercial Customer Needs for Space Conditioning	N/A	Describe a project to be developed to determine various geographic trends for the effectiveness of the Next-gen HP for heating applications and assess/evaluate use cases for meeting overall project metrics

References	Year	Methods	Technologies	Communication and Control Architecture	Key Findings
EPRI 3002005241	2016	Pilot study	Smart Thermostat Collaborative Study by products and/or service vendors and other stakeholders	N/A	Defines methods to translate the value proposition from multiple utilities smart thermostat pilots to utility programs of the products and services; Understand all the costs and benefits from the various thermostat hardware and software offerings as well as the data streams that come from the products and services.

Ventilation

References	Methods	Technologies	Communication and Control Architecture	Key Findings
Sherman and Walker, 2011	Simulation and Field Study	Smart ventilation controller with a switch-off during a 4-h peak price period	N/A	Run of the ventilation fans reduced by 25%Estimated 1000 kWh of annual energy savings and a reduction of 71% of run time of the fans
Turner and Walker, 2012	Simulation	Same + Occupancy	N/A	Ventilation energy savings were typically 40% while maintaining the IAQ equivalence of ASHRAE 62.2.Energy savings from 500 to 7000 kWh/year per household. Peak power is also significantly reduced up to 2 kW for a typical house
Turner and Walker, 2013	Simulation	Same + Occupancy	N/A	Ventilation energy savings were about 25%.
Walker and Sherman, 2013	Simulation	Smart ventilation controller with a switch-off during a 4-h peak price period and ozone peak period	N/A	A reduction of 10-40% in ratios of indoor-to-outdoor ozone while continuous exhaust ventilation system gave around 20%
Turner, Walker, Sherman, 2014	Simulation	Same + Occupancy	N/A	Ventilation energy savings were typically 40% while maintaining the IAQ equivalence of ASHRAE 62.2.Energy savings from 500 to 7000 kWh/year per household. Peak power is also significantly reduced up to 2 kW for a typical house

Heat Pumps (Space Heating and Water Heating)

Heat Pump Water Heater / technology note

Heat pump water heaters use the refrigerant compression and expansion cycle (much like a refrigerator operating in reverse) to heat water. Heat is extracted from the air and transferred to water in an enclosed tank. A low-pressure liquid refrigerant is vaporized in the heat pump's evaporator and passed into the compressor. As the pressure of the refrigerant increases, so does its temperature. The heated refrigerant runs through a condenser coil within the storage tank, transferring heat to the water stored there. As the refrigerant delivers its heat to the water, it cools and condenses, and then passes through an expansion valve where the pressure is reduced and the cycle starts over. Experiments in the PNNL Lab Homes are investigating their use in utility DR programs (for managing energy loads). See https://www.pnnl.gov/main/publications/external/technical_reports/PNNL-22642.pdf

Brattle Group. Controllable hot water heaters: peak shave, thermal storage, fast response, uncontrolled vs controlled HPWH/Pilot Study. 2016.

EPRI: Draft Specification for Electric Water Heating with Demand Management for California Title 24 2019 Building Codes Standards (1/9/2019 revision of 2/21/2018 version submitted to Title 24 docket)

Defines requirements (user interface, hardware, communications, demand control, installation, field verification, and feedback functions) for an electric water heating system to qualify for a Water Heating Demand Management credit(s) in Title 24

DOE/GEB 2.3.1: Novel solar absorption cooling system to reduce peak loads

Examine heat pumps that use solar (prime driver) and electricity or natural gas (secondary) to provide space conditioning and water heating in residences. Does use of liquid desiccant as processor to remove latent heat loads, with AC focus on sensible loads, produce useful energy savings? (ORNL; FY18-20)

DOE/GEB 2.3.3 Thermoelectric Heat Pump Recovery System for Domestic Dishwashers

Develop and test prototypical heat recovery dishwasher for domestic use (extracts heat from rinse water and from drying process). Expected to provide up to 90TBtu annual energy savings once fully deployed across US. (ORNL; FY 17-19)

EPRI (members only): Peak Load Management of Thermal Loads: Laboratory Evaluation of Demand Response Capabilities for Residential HVAC Systems. December 13, 2018

Assessment of the advanced DR capabilities of a ductless, residential (mini-split) heat pump in a controlled environment, including a summary of available variable-capacity systems in the residential market, details of the experimental setup, and analysis of measured system performance

EPC-15-097

This project demonstrates the potential of breakthrough electric water heating and space conditioning technologies as a pathway to zero net energy. The project explores the complex, interdependent systems in multifamily buildings and how they work together to achieve zero net energy status for the buildings in a cost-effective manner. Four multifamily buildings, designed to be affordable, are to be evaluated in various stages of design and development. These buildings share a goal of all electric zero net energy construction with 100 percent renewable energy generation and utilize innovative new heat pump technologies to serve the buildings water heating and/or space conditioning needs. All monitoring equipment such as meters, data loggers and sensors are installed at the Calistoga and Cloverdale sites. Data on the performance, energy consumption, water usage, water temperature and other areas are being collected and analyzed. The research team is working on installing all monitoring devices needed at the other two project sites in Atascadero and Sunnyvale.

Southern Company subsidiaries Alabama Power and Georgia Power, sponsored by BTO: Smart Neighborhood (TM)

Creating state-of-the-art “smart” neighborhoods in partnership with local builders and Vivint Smart Home (e.g. Reynolds Landing, outside of Birmingham, AL) real-world research and development project(s) focused on how cutting-edge technologies can help homes function more efficiently while providing more convenience to homeowners, and how advanced communities will impact the electric grid (includes a microgrid (composed of solar panels, battery storage and back-up generation) with the capacity to generate more than 600,000 kWh annually).

PG&E: Water Saver Pilot

Goal is to encourage customers to replace existing propane and electric water heaters with heat pump water heaters (residential single and multi-family homes) and provide pay-for-performance incentive to operate electric water heaters in late evening, early morning, or afternoon (off-peak hours).

Phase 1 is lab test to evaluate two heat pump and two electric resistance water heaters on interface to user, platform functions on user and utility sides, CTA2045 control capabilities, and ability to get and respond to OpenADR signal. Phase 2 is a field test that examines customer willingness to adopt heat pump water heaters, and a multi-level study of incentives that those customers respond to. The study also looks at whether a daily send of OpenADR signal helps manage TOU responses. Phase 1 report has been issued in draft form. Phase 2 has been deployed with three heat pump water heaters as of 21 March 2019.

Additional heat pump studies

- Mitsubishi has developed a cloud application for several models and remotely controls air source heat pumps from a mobile app
- PNNL’s Heat Pump Water Heater Controls Studies found that heat pump water heaters could cover about 62 percent of energy shifting capabilities that an electric resistance tank could have
- Electrifying Boulder (CO) looking at incentives for residential air source heat pumps and heat pump water heaters and electric vehicles.

Water Heating, not Heat Pump Related

EPRI (3002011775): Flexible Demand Response: Evaluation of Water Preheaters to Support Grid Services at Sacramento Municipal Utility District

Report outlines EPRI laboratory and field testing of a water heater controller that can regulate the power of an electric resistance water heater for DR purposes. Tested functions of the load controller included ramping capabilities at various rates and response to PJM frequency regulation signals.

Vermont/Green Mountain Power: eSmartWater Program60

Project provides customers with an Aquanta hot water heater controller and a Nest smart thermostat with goal of coordination between the Nest and the Aquanta to optimize energy savings.

Lighting

References	Year	Methods	Technologies	Communication and Control Architecture	Key Findings
UC Davis	2019	Development and Laboratory Testing	A New Generation of LED Lighting Solutions	N/A	Design and develop innovative light-emitting diode lighting solutions for three key product categories: screw-base replacement lamp, linear tubular replacement lamps and spectrally optimized dedicated LED luminaires
LBNL	2018	Evaluation	Demand responsive (DR) lighting controls system	N/A	Identify, quantify and evaluate the incremental costs and benefits of demand responsive (DR) lighting controls system requirements in the California Energy Code

EPC-14-011

This project focuses on the design and development of innovative LED lighting solutions for three key general illumination product categories. These solutions are a best-in-class medium, screw-base replacement lamp, linear tubular light emitting diode (TLED) replacement lamps and spectrally optimized, dedicated LED luminaires. Product design requirements are based on consumer light quality and functional performance preferences determined through a series of unique laboratory-based consumer preference and product characterization studies. Preliminary results of the lamp characterization study and the performance and function experiment is posted on the California Lighting Technology Center website https://cltc.ucdavis.edu/. In addition, the research team is working with multiple lighting manufacturers interested in collaborating on new LED lamp development such as optics, quality and architecture.

EPC-15-051

Advanced lighting controls are among the rapidly evolving technologies that utilize wireless communications, embedded sensors, data analytics and controls to optimize building systems in real time. Energy benefits due to lighting controls are becoming a smaller piece of the technology overall value proposition. This project seeks to quantify the demand response (DR) value (energy and non-energy benefits/costs) for networked lighting systems in addition to their energy-efficiency benefits, and integrate this DR value into a broader advanced lighting controls value proposition framework that can be employed as a tool for the future. This project identifies, quantifies and evaluates the incremental costs and benefits of demand responsive (DR) lighting controls system requirements in the California Energy Code across existing, nonresidential building stock. The project focuses on the incremental costs and benefits associated with adding the DR functionality to enhance general lighting upgrades in existing, non-residential buildings to enable them to act as DR resources.

Pool Pumps

EPRI (3002008320): Demand Response-Ready Variable-Speed Pool Pump Specification: Preliminary Requirements for CEA-2045 Field Demonstration. May 24 2016.

Specification for variable-speed pool pumps with built-in demand response (DR) capabilities and a standard communication interface port.

Appliances

Refrigerators/Freezers

References	Year	Methods	Technologies	Communication and Control Architecture	Key Findings
NREL	2013	Laboratory Testing	DR Enabled Household Appliances - Refrigerator-Freezer: turn off defrost cycle	GE Nucleus	The High price controls reduce the peak energy consumption by 16% and the Critical price controls reduce peak load by 22%

Clothes Washers and Dryers

Condensing Clothes Dryer/ technology note:

Among the most efficient models are condensing dryers and heat pump dryers, which work like condensing dryers but replace the condenser with a heat pump for even greater efficiency (Figure 2). These condenser dryers and heat pump dryers can save 20% to 60% compared to conventional clothes dryers. Condenser dryers take in ambient air, heat it in a heat exchanger, circulate it in the drum to absorb moisture from the wet clothes, send it to the heat exchanger where the air is cooled, releasing the moisture to a condensate drain, then recirculate the air to the heat exchanger to repeat the process until the clothes are dry. However, there are some issues to consider when purchasing a condensing dryer. They can be more expensive to purchase and many of the models available are small or medium sized rather than large sized. They may also take longer to dry a load of clothes, potentially double the time of a conventional dryer.

References	Year	Methods	Technologies	Communication and Control Architecture	Key Findings
NREL	2013	Laboratory Testing	DR Enabled Household Appliances: both the washer and dryer automatically delay the cycles when the electricity price reaches the High or Critical level.	GE Nucleus	Turn off additional energy used by the water heater (~0.24 kWh);Economic cycle takes about 30 min longer than the standard cycle but it reduces the cycle energy use by 32%.

Other Residential Appliances

DOE/GEB: Reducing Plug-Load Electricity Footprint of Residential Buildings Through Low-Cost, Nonintrusive Submetering and Personalized Feedback Technology (Columbia University, Siemens, Lucid)

Leverage existing non-intrusive submetering in developing a human-in-the-loop approach and investigating occupant feedback strategies to change electricity use by reducing load or shifting usage to non-peak hours. Although the focus will be on multifamily dwellings, the technology can also be extended to single-family homes. A unique multiyear and anonymized dataset of residential electricity use, broken down by demographics and appliance end use, including which user types best respond to what type of feedback message (e.g., monetary saving, energy saving, environmental impacts), will be made publicly available to inform the research community, as well as utilities on their investment strategies.

PG&E: Expansion of the Deemed Auto-DR Express/Fast Track Solutions

In the past few years, PG&E and SCE have offered a more streamlined ADR incentive option to SMB customers: PG&E's SMB offering is the Fast Track ADR Program and SCE's SMB offering is the Express ADR Program. Since there were limited SMB customers enrolled in the Fast Track and Express ADR Programs, the objective of this DRET assessment is to increase ADR market penetration of SMB customers. Methods investigated to increase market penetration include expanding SMB eligible measures, adding additional facility types, and increasing customer and vendor awareness of the program.

- Preliminary results:
- Simplify the reservation process
- FastTrack form based on PG&E FastTrack program
- Increase eligibility of FastTrack/Express
- Facilities based on past participants and interviews with vendors
- Make Auto-DR easier for vendor sales staff to discuss during onsite meetings with customers
- Offline form, incentives and kW listed, uniform across utilities

PG&E: GHG Grid signal indicator lab test

Goal is to confirm that smart devices can be automatically controlled by a continuous/high frequency dispatch Demand Response (DR) signal (based on a combination of near-real-time GHG data from power grid operators and a forecast of grid conditions over a 30-day planning horizon) in a lab environment.

Contractor has completed testing with most of the appliances (EV, Smart Thermostat, refrigerator and water heater). Report in progress 2019.

PG&E: Integrated Energy Efficiency and Demand Response Programs: Breaking Down Silos

Goal is to assess promising opportunities, identify barriers, and recommend supportive policies for greater integration of utility EE and DR programs that yield greater benefits to customers at lower costs than would separate programs.

Study is in progress. Report expected end of August 2019.

PG&E, SCE, SDG&E: Automated Demand Response Collaborative Stakeholder Process

In order for the Residential ADR Program to provide ADR incentive to other residential ADR enabled end use devices (beyond Smart Thermostat), PG&E needs to develop average load impact and deemed incentive levels for these end-use devices. Stakeholder meetings held. Now added to the list of issues to be discussed in 2019 by stakeholders are (a) working on development of a list of residential Auto DR enabled end-use devices to be considered for eligibility for an Auto DR incentive from PG&E and (b) development of criteria to determine the order for PG&E to evaluate load impacts attributable to the devices.

PG&E: Connected Home Product Bundle Field Study

Goal is to explore the way that customers are currently interacting, and could interact, with new Energy Management Technologies (EMTs) for a variety of different energy management-related applications. The goals of the Field Study are to explore the EE, DR and Share My Data opportunities and customer satisfaction aspects of connected home product bundles that include smart thermostats, lights, switches, and Smart Plug devices. As of March 2019, this integrated emerging technology assessment has enrolled 158 participants. All participants have received connected control equipment such as smart plugs and smart lights by enrolling in this study.

Electronics and Miscellaneous Plug Loads

Low-Cost Identification and Monitoring of Diverse MELs in Residential and Commercial Buildings with PowerBlade (LBNL, NREL, Cubeworks, University of Michigan)

Address the challenge of identifying loads within the “long tail” of consumption which consists of devices less than 50 W that make up 75% of MELs devices and accounts for approximately 48% of their energy use using the previously developed PowerBlade wireless AC plug-through meters to measure real, reactive, and apparent power with load monitoring based on extracting high-fidelity electrical waveform features to capture power profiles and automatically identify and categorize MELs in a scalable manner (PowerBlade is currently the smallest, lowest cost, and lowest power AC plug-through meter)

Reducing Plug-Load Electricity Footprint of Residential Buildings Through Low-Cost, Nonintrusive Submetering and Personalized Feedback Technology (Columbia University, Siemens, Lucid)

Leverage existing non-intrusive submetering in developing a human-in-the-loop approach and investigating occupant feedback strategies to change electricity use by reducing load or shifting usage to non-peak hours.

Electric Energy Storage

Home Battery System: Homeowner-Centric Automation for Cyber secure Energy Efficiency and Demand Response (NREL, BPA, Bosch, Colorado State U)

Developing a residential automation solution for homeowners, utilities, and energy service aggregators. Goal is to increase residential energy efficiency by roughly 1 Quad and DR participation by 2KW+ firm resource per home, by easing consumer adoption of integrated solutions towards enabling >10% active devices to provide flexibility by 2035. So far in simulations, a highly-predictive preference elicitation method has been identified, 12% uncertainty in resource availability at 12-hour look-ahead, and minimum 5% energy savings has been demonstrated.

EPC-15-049

Electricity Pumped Storage Systems Using Underground Reservoirs: A Feasibility Study for the Antelope Valley Water Storage System (EPC-15-049). This study evaluated the potential to integrate pumped storage with groundwater banking operations for two types of pumped storage systems: peak-hour pumped storage, with all the components above ground, and aquifer-pumped hydropower, which uses the aquifer as the lower reservoir. The project team also assessed hydropower generation and DR potential of groundwater banking projects in addition to pumped storage. Properly configured, peak-hour pumped storage facilities at groundwater banks will increase the capability of the California electricity grid to integrate renewable energy and provide reliable energy to ratepayers. The study estimated that statewide peak-hour pumped storage potential of 44 megawatts (MW) could address up to 1 percent of California’s storage requirements and, on average, reduce annual GHG emissions by 44,000 metric tons of carbon dioxide equivalent (CO2e). The analytical tools and other results from this project are being used in a new project funded by the Energy Commission at the Willow Spring Water Bank to integrate onsite renewable energy generation to achieve energy neutrality at the facility.

SDG&E: Battery Powered Load Shedding System – Automated Demand Response (ADR) Evaluation

Project aims to evaluate the DR capability of an Energy Storage System (ESS). In addition to peak load shaving capability, the study will evaluate the impact of the ESS on the circuit and analyze customer bill/economic impacts.

Systems of Controlling End-Uses

GMLC 1.5.4: Integration of Responsive Residential Loads into Distribution Management Systems (Oak Ridge National Lab, Electric Power Research Institute, National Rural Electric Cooperative Association, Southern Company, Tennessee Valley Authority, Duke Energy, Con Edison, Electric Power Board, Jackson EMC)

Effort to develop and validate a home energy management system (HEMS) as a grid interface that also serves as a platform for deploying intelligent algorithms to execute grid-responsive functionality of a collection of residential devices. Effort uses hierarchical, decentralized control and optimization systems capable of providing the response needed to deliver guaranteed grid services to utilities from end uses including water heaters; HVAC; electric vehicle chargers; pool pumps, and residential photovoltaic inverters.

EPC-15-025

This project researches methods to reduce home idle loads by utilizing smart meter analytics, an engaging smart phone app, a new online crowd-sourced database of miscellaneous electric loads, and an online efficient product marketplace to educate California residents about the idle load of their home and ways to reduce it. The system is to be piloted within all three electric investor owned utility territories and measure actual energy savings through smart meter data. Idle load is a new concept to most residential energy users and includes appliances and equipment in the off or standby mode but still drawing power. The recipient has developed an innovative smart phone app called Dr. Power which provides residents with information about their idle loads, provides ideas and a plan to reduce the idle loads, and correlates any energy saving actions with smart meter data. This simple to use app tests the theory that if accurate information about energy use is provided to consumers, they will be more likely to engage and take action. The application, Dr. Power, was launched successfully for both Apple and Android mobile operating systems. Feedback on the application is being collected to ensure accuracy; early feedback is encouraging. Developed successfully for both Apple and Android mobile operating systems. Feedback on the application is being collected to ensure accuracy; early feedback is encouraging. The team is also working with Southern California Edison to resolve issues with the Green Button Connect features.

EPC-15-026

This project will develop an interoperable protocol that can be implemented in all plug-load devices, unhampered by proprietary restrictions which will implement energy reporting to enable plug-load devices to transmit operating information - such as identity, power consumption, and functional state - through a communications network to a central entity. After a communication infrastructure is established for plug-load devices, the data flow can be reversed to send control signals to individual devices. The central management system that this project will demonstrate is well positioned to provide comprehensive control over diverse plug-load devices.

SDG&E: Whole Connected Home

DR approach where multiple end use systems are triggered by a single DR signal delivered by the utility to either an in-home or a cloud gateway. The purpose of the project is to evaluate various emerging Internet of Things (IoT), connected device technologies, as one unified system for their capability to be developed and integrated into WHDR programs. The demonstration is done at three selected residences. The evaluation will consider both technologies and other program impact factors such as customer adoption, ease of recruitment, persistence, and data availability for M&V.

SDG&E: In-Home Display & Smart Phone Application (PEEK) Behavioral Conditioning with Time of Use Billing for Energy Efficiency & Demand Response

Test of Peek Smartphone App for iOS and Android for customer download, registration and activation. The application is complementary to the in-home device, enabling the customer to view TOU pricing periods and period prices via their smartphones. Project looking at the extent to which customers find this useful.

SDG&E: Voice Activated Assistant for Energy Savings (IDSM Project)

Test customer interest in using voice activated assistant with one or more pre-qualified appliances (thermostats, water heaters, batteries, and blinds) to facilitate participation in TOU program.

Electric Vehicles

EPC-14-056

The UCLA team developed EV charging algorithms with DR capability. The team also developed and tested a phone application and an EV user web application. The researchers are continuing development and integration of an IEC 61850 standard compliant gateway. Several EV chargers were installed in the City of Santa Monica Public Parking Building and on the UCLA campus. Possible solutions for control and V2G operations were explored, and the team also tested the bi-directional fast chargers during the past year.

EPC-14-057

This project is developing an aggregation system for smart charging PEVs to provide DR, mitigate demand charges, leverage time-of-use rates, and offer wholesale market services. The demonstration is tapping into the inherent flexibility in the time and rate of PEV charging to participate in PG&E's automated DR programs, and CAISO wholesale markets for DR and ancillary services. A charging control system is being applied to a fleet of vehicles owned by Alameda County and to charging stations that are used by both county vehicles and the public. The project is adding systems for intelligent prediction of PEV loads and control algorithms to create a flexible, modular, and scalable solution for smart charging county fleet and public PEVs.

EPC-15-015

The project enables the harmonization of V2G services, removing the communication barrier between PEVs of different standards and the grid. The communication interface enables Smart Demand Side Management with the possibility of using PEVs as distributed energy storage and controllable load. Local PEVs can be used to store onsite renewable energy and deliver to the grid on demand. The additional smart charging incentive can accelerate PEV adoption to achieve the targeted 1.5 million ZEVs on the road by 2025. Using PEVs as an energy storage resource can reduce energy demand and stress of the grid, making the load predictable and more manageable.

SDG&E (and others): Vehicle to Grid Integration Platform (VGIP)

Create requirements and use cases for a unified grid services platform that is secure, low cost, and an open source platform. It will also aide in the development of architecture and functionality of the VGIP including OpenADR2.0b, Smart Energy Profile (SEP), and Home Area Network (HAN). Additionally, this project will assess the performance of the VGIP against utility requirements through field tests and trials. BMW, Chrysler, Ford, GM, Honda, Mercedes, Mitsubishi, Nissan, and Toyota have agreed to be study participants.

Communication

EPRI (3002011409): Persistent Wi-Fi™ Platform for Connected Devices Demonstration. July 2017

Project to define and demonstrate a communications platform that can facilitate secure integration of customer systems with grid operations (both distribution and system operator) as well as enabling third parties, service providers and equipment manufacturers to maintain their own interfaces.

Other Related Research

GMLC Collaborative Demo for Secondary Use and Use Case Validation (Spiers New Technologies, Habitat for Humanity, Central Carolina Community College)

Develop and examine the business case for a residential based deployment of secondary use energy storage, deploy and commission a secondary use energy storage system to bring industry acceptance and validation of the business case, drive the future of secondary use energy storage systems with advanced supporting control algorithms, and disseminate information to stakeholders

DOE/GEB 1.1.1: End Use Load Shapes

Develop end-use profiles for US building stock (aggregate and building scale); calibrate with ability to estimate EE/DR savings profiles for existing and emerging technologies (LBNL, NREL; FY19-20)

DOE/GEB 1.1.2: Time Sensitive Valuation

Document studies of time-varying energy and demand impacts of EE measures in multiple geographic areas and summarize end-use load data that can be use in electricity resource planning to develop models of EE and DR effectiveness (LBNL; FY19-20)

DOE/GEB 1.2.2: National GEB Potential

Add EE and DR measures into Scout (a DOE tool for estimating the energy and carbon impacts of various energy conservation measures) to develop regional, sector, and national estimates of economic and energy impacts of program (LBNL, NREL; FY19)

DOE/GEB 1.2.3: System Level Assessment of EE&DR

Integrated valuation of EE and DR based on loadshapes and regionally representative electricity load features (LBNL; FY19-20)

DOE/GEB 3.2.1.4: Scalable Load Management Using Reinforcement Learning

Scalable load management system algorithm development: goals are ease of deployment, accurate algorithms to optimize loads to meet comfort and economic constraints. Test scalability, accuracy, performance at ORNL, then deploy at research house for demonstration of capabilities. (ORNL; FY19-21)

CEC Contract 300-15-009

This contract will provide market analysis that will address the barriers that hamper commercial development of emerging energy technologies. Tasks under this work authorization contract could include tracking past and current award EPIC technology solutions to monitor successes, more accurately consider future EPIC funding opportunities, inform technology gap analyses, and develop online resources. The deliverables from this project will help prioritize future Energy Commission funding towards technologies that solve the addressed issues. The project team has five work authorization projects:

1. Market Research on Microgrids - review commercial viability of microgrids in California without government support.
2. Benefits Methodology for the Regional Energy Innovation Clusters- evaluate the benefits accomplished by the Regional Energy Innovation Cluster agreements.
3. Needs Assessment for an online portal to support the Energy Innovation Ecosystem - define priorities for an online platform to support the Energy Innovation Ecosystem agreements.
4. Investing in DACs (in progress) - recommend strategies that have been piloted to overcome barriers to mass deployment of DER in existing buildings in DACs.
5. DER Innovations in California's Food Processing Industry - identify and recommend technologies that will reduce costs, increase efficiency, and reduce emissions for California’s food processing industry.

CEC Contract 300-15-011

Updates to Commercial End Use Survey from 2003: The contractor has had many challenges recruiting the California electric investor owned utilities' (IOUs) participation in providing customer billing data necessary to conduct the survey. The contractors began with an initial survey sample in the San Diego Gas & Electric service territory and expect to expand to the other IOU service territories.

EPC-14-072

Clean electricity generation technology adoption beyond the baseline used for the study does not necessarily provide the greatest improvement in local air quality and public health but this varies across the geographic area studied. The baseline used for this study included 50% zero carbon electricity in addition to large hydropower by 2030. However, to comply with the 40% GHG reduction 1 WECC is a non-profit corporation that exists to assure a reliable bulk electric system in the geographic area known as the Western Interconnection, which covers the 14 western states, 2 Canadian provinces, and the northern portion of Baja Mexico. Figure 5: Final Report for EPC-14-027 Source: California Energy Commission 12 mandate, higher levels of carbon free electricity are needed. For example, in the Central Valley, decarbonizing residential fuel combustion, including wood-burning stoves and fireplaces, and diesel-powered transportation are more beneficial than other options to reduce emissions from power plants.

EPRI 3002011500: National Renewable Energy Laboratory's (NREL's) Integrated Network Testbed for Energy Grid Research and Technology (INTEGRATE) initiative hosted at Energy Systems Integration Facility (ESIF), RFP Number RCS-4-42326, Topic 2, "End-to-End Communication and Control System to Support Clean Energy Technologies." August 4, 2017.

Final report of a two-year development, test, and demonstration project, "Cohesive Application of Standards-Based Connected Devices to Enable Clean Energy Technologies."

PG&E: Secured Data Sharing to improve residential DR programs' enrollment process.

Goal is to collect information in order to create a smooth and secure customer authentication, authorization, and enrollment framework for DR pilots and programs in the future. This project focuses on improving the residential customer experience with third party DR aggregators or DR program providers. Status: Draft report is being reviewed by PG&E. A public version of the final report will be posted to the ETCC website when it is finalized in the 2nd quarter of 2019.

Building-to-Grid

GMLC 1.2.4: Grid Services and Technologies Valuation Framework

Development of a comprehensive and transparent framework to value the services and impacts of grid-related technologies based on a systematic approach to the definition and documentation of scale, scope, and assumptions that define any valuation or modeling activity. Successful development of this framework would allow electricity-sector stakeholders to conduct, interpret—and most importantly, compare—valuation studies with high levels of transparency, repeatability, and extensibility.

Integrated Connected Homes (Oak Ridge National Laboratory, Emerson, Southern Company (GA), SkyCentrics, EPRI, AO Smith, PNNL, National Assoc. of Realtors, Haier)

Manufacturers of home appliances and related building products are increasing connectivity options for consumers. This project engages manufacturers in the development and deployment of residential end-use connectivity to validate how coordinated control of these technologies can provide novel grid services (e.g. balancing electricity demand and reliability with the variability of distributed energy sources). Through partnerships with utilities, equipment and appliance manufacturers, realtors, and national labs, the project develops new methods and applications of complex control to provide these resources to the grid. The project team leverages existing market solutions like home energy management system (HEMS), enables interoperability by developing multi-protocol device drivers, and facilitates validations using retrofit-compatible hardware/software as supervisory controllers.

DOE/GEB: Connected Neighborhood (SE-USA)

Validate a "smart," neighborhood-level, buildings-to-grid integration strategy utilizing the VOLTTRON platform. Screen reader support enabled.

Connected Buildings Innovator (Northwest U.S.)

Advance R&D in transactive buildings and complex control science by better integrating connected technologies to factors that motivate the market, validate the connected building technologies through proof of concept and field validations, and create a clear market channel for consumer and grid "friendly" technologies to facilitate market adoption of connected buildings and their associated products by consumers and utilities.

DOE/GEB 3.2.2.1: Transactive control based Connected Home Solution for Existing Residential Units and Communities

Goal is to overcome difficulty integrating new connected platform with existing homes and enhance quantification of benefits (e.g., improved comfort, grid services) from connected home solutions. Team will develop end-to-end solution that will be validated. Data expected to show how homes can be upgraded cost effectively to provide grid services. (PNNL; FY19-21)

CEC Report 300-15-008

Itron is working with Energy Commission staff to develop a gaps analysis that identifies, describes and prioritizes research, development, demonstration, and deployment (RDD&D) gaps that need to be addressed to achieve the state's goals for Zero-Net Energy (ZNE) buildings in a safe, equitable and cost-beneficial manner. The gaps analysis is being developed in consultation with stakeholders and subject matter experts through interviews, written comments, and public workshops. After completing a comprehensive literature review of zero net energy research, the recipient conducted a stakeholder survey designed to understand the research needs surrounding ZNE technology. The survey received over 550 responses the largest ZNE focused survey ever conducted. Stakeholders felt that technologies such as battery storage and grid integration merited technology research much more than lighting or appliance efficiency. As the project continues, more granular detail about the performance and cost targets will be identified. For more information, visit: http://zneroadmap.researchenergy.net/

Energy and Buildings 2017 pp 55-63 May 8, 2017 (DOI: https://doi.org/10.1016/j.enbuild.2016.08.009)

Mathematical model for the optimal energy management of a residential building and proposes a centralized energy management system (CEMS) framework for off-grid operation: Results show that the proposed CEMS can reduce the energy cost and energy consumption of the customers by approximately 17% and 8%, respectively, over a day (with 50% reduction of energy storage system use). Work by ORNL, University of TN at Knoxville, Georgia Institute of Technology.

EPC-15-053

The California retrofit goal is to reduce 50% of existing buildings' energy use by 2030. Disadvantaged, low-income, multifamily communities are one of the most important retrofit targets,yet have no cost-effective pathways to achieve these goals. Multifamily housing is a difficult market segment to address due to split incentives as retrofits are the responsibility of a property owner but he/she does not pay the energy bill. Limited technical and financial knowledge for owners also plays a role. This project develops and demonstrates an approach to scale residential retrofits for disadvantaged communities that will focus on customer-centric solutions. This project develops and demonstrates an innovative approach, focusing on energy efficient retrofit packages that are non-intrusive to occupants and have the potential of reducing energy use by 30 to 40 percent.

PG&E: Testing Statistical Sampling Methodologies and Alternative Baseline

The CAISO evaluates Proxy Demand Resource (PDR) and Reliability Demand Response Resource (RDRR) wholesale market performance using one of two North American Energy Standards Board (NAESB) measurement and verification standard baseline types (a.k.a. "Type-I" and "Type–II"), with Type–I being the default methodology. Under Type-I, a resource's performance is based on aggregated interval Revenue Quality Meter Data (RQMD) for all customer locations comprising that resource. However, Type-II is available for resources that do not have interval

RQMD available for all locations, which would meet the CAISO's required timelines. Using Type-II, performance evaluation uses statistical sampling to estimate the performance of the entire resource based on interval RQMD for a subset of the locations in that resource. In order to use the Type-II methodology, a proposal specific to the resource, which demonstrates 10% error at a 90% confidence interval must be submitted to and approved by the CAISO. The purpose of this project was to develop and analyze a Type-II methodology so that all residential customers may be able to participate in CAISO's wholesale markets.

Status: after getting CAISO approval for a sampling plan, the contractor planned to assess the accuracy of the plan by comparing the projected performance against actual available meter data. However, the particular Supply Side Pilot participant (for whom the plan was developed) proved unable to enroll a sufficient number of kWs to be able to participate in the pilot and therefore the remainder of the assessment could not be pursued. Meanwhile, PG&E's Measurement and Evaluation team conducted an assessment on the CAISO approved statistical sampling methodology by applying it to the Smart AC program's population and comparing it to the existing methodology, which requires a bigger population than the CAISO approved statistical sampling. Preliminary results indicate that PG&E's approach is more accurate than the CAISO approved methodology due to the large population RQMD customers already participating in the Smart AC Program. Subsequent work planned includes identification of methods for accurately quantifying load for each customer and supply side aggregations; exploration of the impacts of clustering on the accuracy and bias of the baseline models; and examination other methods for load forecasting (including machine learning) and calculating residential (and small/medium business) resource availability.

DER Integration

GM0204: Universal Hybrid Inverter Driver Interface for VOLTTRON Enabled DER Power Electronics Applications (PNNL, Agilestack)

Enable near real-time control and management of power electronics in buildings with distributed energy resources (DER) by developing a universal driver interface using VOLTTRON platform.

- GM0061: Virtual Battery-based Characterization and Control of Flexible Building Loads Using VOLTTRON
- Enable utilities to use flexible building loads as virtual storage resources to provide grid services, integrate more renewable generation such as wind and photovoltaics (PV), and

improve building (note this is also for commercial and other building types in addition to residential) operational efficiency: Understand capacity of virtual storage resources (e.g. residential loads), at a national scale, as a percentage of total system generation capacity akin to the analyses of Rosenfeld and colleagues of new efficiency opportunities;

- Develop methodology for characterizing the flexibility of building virtual storage at any scale from a single load in a building to the aggregate load of all buildings (or participating buildings) in a utility-service territory;
- Performing regional and national assessments to identify and quantify utility and building owner/occupant benefits for actual physical and virtual storage systems;
- Developing algorithms that optimally control building loads to behave as virtual storage and thereby provide grid services while meeting the needs of building occupants (e.g., comfort, health, and safety); and
- Implementing the control algorithms as applications in the VOLTTRON deployment platform and evaluating the performance of the control strategies in realistic environments using the PNNL, ORNL, NREL, Tennessee Valley Authority (TVA), Bosch and United Technologies Research Center (UTRC) building/grid test facilities.

DOE/GEB 3.2.2.2: AI driven Smart Community Control for Accelerating PV Adoption and Enhancing Grid Resilience

Goal is to reduce/eliminate PV curtailment in ZNE community by self consumption of generated solar energy via flexible building loads, and minimal battery storage. Results: advanced control method for improving load flexibility and identifying energy savings, cost effective analysis under different tariffs of sensing and control devices, report of regional distinctions. Testing to be done in 20 homes to demonstrate smart community control. (NREL, SETO, BTO; FY19-21)

DOE/GEB 4.2.1: Smart neighborhoods research and field verification

Scalable control framework to co-optimize energy cost, occupant comfort, grid reliability, and resilience in future neighborhoods (next generation: integrate renewables and storage). Two platforms: centralized microgrid gen/storage with controllable residential end uses AND integration of DERs with controllable end uses and BTM storage. Partnership with Alabama Power and Georgia Power. Outcome will be open architecture based transactive control algorithms to manage energy at building and community levels. (ORNL; FY19-21)

EPC-14-083

This project was initiated to demonstrate an integrated solar PV, energy storage, and advanced power electronics within a single module to significantly increase overall efficiencies by minimizing conversion losses. The demonstration was to include the integration of a 250 kW pre-commercial high-yield PV system from Flex, a 500 kWh stationary battery energy storage system, and advanced HVAC system and controls, with an advanced energy management system that uses the Internet of Energy concept to optimize performance of distributed energy resources and the local grid.

EPC-15-047

This project will further develop Powernet, a cloud-based method to manage energy resources in homes and businesses. Powernet will control and coordinate energy resources both behind the meter and at the distribution system for residential and commercial ratepayers to: (i) minimize costs, (ii) increase consumer quality of service, (iii) preserve grid stability and (iv) offer services to the grid. Several significant Powernet system innovations would be developed under this proposal: (i) the integration of control, optimization and power electronics would enable novel functionality – stable connect/disconnect from the grid, local and global power sharing and grid services including DR; (ii) the layered structure of the system will enable the operator to utilize Powernet for a variety of different grid purposes or service offerings with the assurance that those are always done on top of an economically optimal operating point every second; (iii) the system would be robust and secure by design; and (iv) the system would adopt open source standards and establish an open protocol (OpenDER) for the platform to enable scalable engagement of devices in the future.

EPC-15-048

Renewable energy generation, such as solar, creates a challenging situation for grid operators (e.g. CAISO) due to the steep ramp-up needed after the sun goes down. Until there is a better way to manage intermittent renewable resources and peak energy demand, a significant contribution from renewable energy cannot be realized. Intelligent building energy management systems that can shift energy loads and manage more complex and robust resources are needed to transition from a few centralized energy resources into millions of distributed energy resources (DER) such as rooftop solar, and energy storage. This project tests and validates an intelligent residential energy management system that communicates with a variety of DER such as solar PV, and energy storage in 100 residences in San Diego, CA.

EPC-15-094

Demonstration of cost-competitive ZNE design strategies that combine occupant needs with technology solutions to create new pathways for residential ZNE communities. The project's goals are cost effectiveness for the customer, affordability, overcoming customer apprehension, establishing a track record of new technology for builders, enabling distribution grid integration, creating a planning process for ZNE communities, evaluating community solar and evaluating the impact of future changes to ZNE cost effectiveness. This project also aims to understand the operation and energy use of the unregulated loads.

EPIC Highlights

Grid Flexibility and Resilience

Fostering transformation of the electricity grid to accept greater quantities of renewable generation and distributed energy resources. Research underway is focused on increasing the penetration of renewable energy resources such as solar and wind to benefit customers and the electric grid. This research includes testing DR with various end uses, developing and field testing smart inverters with communications capability to ensure proper operation with the electric grid, testing new energy storage technologies, and demonstrating the integration of distributed energy resources, control strategies, optimal designs, and best practices in microgrids. For instance, the community microgrid demonstration at the Blue Lake Rancheria in Humboldt County is demonstrating how to build and operate a low-carbon microgrid for resilience. The research involves demonstrating how such a microgrid can optimize the use of energy storage, DR, and renewables to provide resiliency and to document cost, performance, and benefits. The Blue Lake Rancheria microgrid leverages on-site generation and grid power to provide services at its Red Cross safety shelter-in-place facility in the event of an emergency. It also keeps electricity prices low for the tribe.

Customer Empowerment

Empowering customers with tools to manage their energy consumption efficiently and provide grid support when needed. 4 Research is underway to develop strategies and tools that help consumers respond to real-time signals for their benefit and the mutual benefit of the grid. The research aims to overcome technical, institutional, and regulatory barriers that prevent expansion of DR participation, energy efficiency, community solar and storage integration into advanced energy communities. Also, this research is developing consumer tools to increase customer procurement of distributed energy resources. One researcher has developed a social media platform and gamification strategy that includes game-like elements to encourage large numbers of small residential customers to engage and participate in real-time response to DR signals. The project engaged more than 15,000 California residential customers to cut load at critical times to support the grid and provides financial rewards for their actions. Another researcher has created a tool to reduce home idle loads using a smartphone application called “Dr. Power.” The application allows residents to know where energy is used in their homes so that they can take appropriate action. Preliminary results show a potential 10 percent reduction in idle loads energy use per home by residential users.

Disadvantaged Communities

Bringing the benefits of advanced technologies to those in disadvantaged communities. The Energy Commission advances energy equity for disadvantaged communities when considering the customers and benefits of EPIC research. The EPIC program prioritized disadvantaged communities in four of its 2017 solicitations by setting aside specific amounts for projects in disadvantaged communities or providing bonus points for demonstration or test sites in and benefitting disadvantaged communities. Two additional solicitations did not provide set aside or preference points for disadvantaged communities but emphasized tools to benefit or positively target customers in disadvantaged communities. As of December 30, 2017, 97 demonstration sites were within disadvantaged community. Furthermore, about 32 percent of total EPIC encumbrances for technology demonstration and deployment projects, to date, were located in a disadvantaged community. As an example, one of the funded projects benefits disadvantaged communities by providing training and apprenticeship programs for advanced technologies. This training program is recruiting 5 workers from disadvantaged communities into apprenticeship programs at California Joint Apprentice Training Centers. The program provides comprehensive classroom and on-the-job training on the installation and maintenance of automated DR communications equipment in buildings in disadvantaged communities across California. As of the end of 2017, 321 electricians and acceptance test technicians have successfully completed the automated DR training, with an additional 250 individuals undergoing training. The program also completed training for the International Brotherhood of Electrical Workers instructors. These instructors will be training apprentices from disadvantaged communities. Training of apprentices from disadvantaged communities will begin in the second quarter of 2018.

EPRI (3002013621): Protocol Reference Guide: Understanding the Characteristics of Communications with Distributed Energy Resources. December 2018.

Reference document for stakeholders working with distributed energy resources and DR technologies who want to learn more about the different options for application-layer protocols, created with the help of American Electric Power, Duke Energy, and Salt River Project.

EE & DR Market and Participation

Connected Buildings Innovator (Northwest U.S.: PNNL with Amazon, City of Seattle, BNIM, CleanTech Alliance, Emerson Climate Technologies, National Association of Realtors, Microsoft, and Smart Buildings Center)

Work aimed to better integrating connected technologies to factors that motivate the market, validate the connected building technologies through proof of concept and field validations, and create a clear market channel for consumer and grid "friendly" technologies to facilitate market adoption of connected buildings and their associated products by consumers and utilities.

2018 IEEE Power & Energy Society General Meeting (presentation supported by the Centre for Advanced Sustainable Energy, under the DINOSAURS project)

Analysis of a converged approach to the challenges of developing a domestic-level automated DR system to support smart scheduling of controllable loads such as EV charging and HVAC, and fast load-shedding to provide frequency stability during system faults using the development of a test-bed platform to highlight the physical-layer communications required.

Hierarchical control strategy for residential demand response considering time-varying aggregated capacity. International Journal of Electrical Power & Energy Systems, Volume 97, April 2018, Pages 165-173. (https://doi.org/10.1016/j.ijepes.2017.11.001)

An aggregate model is established to exploit the time-varying potential response capacity of a population of residential loads. In the upper strategy, an equivalent response potential (ERP) index is created to quantitatively calculate the aggregate capacity and utilized to guide the allocation of total response demand to each LA. In the lower strategy, an optimal allocation model is built to determine the response status of each residential load per minute, ensuring end-user satisfaction and DR requirements. The aggregate model and control strategy are verified valid through case studies.

EPC-15-045

Demand response (DR) has substantial potential to act as either a demand-side or a supply-side resource. However, existing programs and rates do not provide a participation incentive structure that accurately reflects system conditions or system costs, a suboptimal situation that results in higher ratepayer costs, low DR participation and an inability for system operators to regularly utilize demand-side resources. As the state moves toward more distributed generation and intermittent renewable energy generation, integration of those generation resources will further increase costs in the absence of significantly expanded DR resources responding to actual system needs in real time. This project develops Transactive Load Management (TLM) signals, expressed in the form of proxy prices reflective of current and future grid conditions, and develops and implements software to calculate such signals. These signals are being designed to provide customers sufficient information to optimize their energy costs by managing their demand in response to system needs. The signals are transported via proven and available protocols and networks for use by projects that will test the efficacy of the TLM signals using the DR projects awarded under GFO-15-311, Advancing Solutions that allow Customers to Manage Their Energy Demand. The reference design for the TLM signal was being finalized for implementation in early 2018. EPRI/Greenlots

EPC-15-073

The end-use loads enrolled in Existing Demand Response (DR) programs have high opportunity costs and participation is low. Some newly-developed market options, such as aggregation programs, could enable large numbers of small loads across multiple customers to participate in wholesale markets. However, participation logistics, including metering, verification and settlement, are barriers to wider participation. This project is testing the effectiveness of innovative designs for DR programs for residential customers using a behind-the-meter customer engagement platform developed by Chai Energy. Each of these innovative DR strategies integrates a recent approach that energy researchers have shown to be effective in reducing customer consumption. These strategies include providing households with a) tailored energy-analytic feedback, b) aggregated versus single-period incentive information, c) non-financial environmental health benefit frames and d) social comparisons. An additional strategy is exploring how the timing of the delivered DR information affects the magnitude of household participation and response. About 3,200 customers have been signed up for participating in the project which is less than the ultimate target of at least 7,000. A video has recently been produced, and supplemented strategies to enhance recruitment are being considered. UCLA has randomly assigned participants to one of 6 test groups to compare with the control group. 6 treatments have been delivered to the 3,200 customers based on the assigned group they are in and the data is being analyzed.

EPC-15-083

The market for third-party demand response (DR) is constrained, severely limiting non-utility resources from contributing to the electricity grid. Although a bi-directional grid is now technically possible, neither prosumers (customers who both draw from and contribute to the grid) nor their devices can be integrated into the energy markets. A chicken and egg situation exists where policymakers and regulators will not open up the market for non-utility energy sources, citing a lack of customer interest, while customers remain unaware of how to contribute to the grid. This project contains three elements to provide data for policymakers and businesses to explore this new market. First, this project determines prosumer (producer/consumer) interest in a third-party DR market by testing user acquisition via direct and non-direct engagement strategies. Second, experimentation with behavioral and automated users allows analysis of user yield under a variety of conditions and extract a set of shadow curves that can inform how much energy load shifting can be expected under various price incentives. Finally, this project creates a novel solution for using residential telemetry to connect prosumers and their Internet of Things (IoT) devices to the market operators. (OhmConnect) The recipient completed the work to incorporate numerous different transactive signals, including the utility, the CAISO, and EPRI. The recipient has completed the preliminary data modeling process to be used for testing and has successfully completed testing the transmission of telemetry data to EPRI’s ftp site at 5-minute intervals. The team also began building the automation required to participate in the CAISO’s day-ahead markets. UC Berkeley, the evaluation subcontractor, published results of their initial analysis of customer participation showing that reductions in the program were reliable, had little rebound effect, and were greater for participants using automation than those not using automation. A separate listing described OhmComment social media platform and gamification strategy to encourage real-time response to DR signals from large numbers of small residential customers. The project provides policy makers and regulators with information to develop policies and limitations for a third-party DR market. A method for residential telemetry is also proposed, to empower prosumers (producer/consumer) to interact effectively with the grid market operators, via their Internet of Things (IoT) devices, allowing them to supply electricity and save money. Preliminary results show 8 to 35 percent lower energy consumption for program participants. There appears to be high participation in homes in disadvantaged communities. Participation in OhmConnect's DR program has grown from about 15,000 when the grant was awarded in 2015 to about 300,000 in all three IOU service territories as of the beginning of 2018. Of those, a sample of over 15,000 users has been included in the EPIC-funded experiment to assess different user engagement strategies for impact and persistence. The program bids 1-hour load reductions from the entire user base into CAISO markets through the Demand Response Auction Mechanism (DRAM), rewarding participating customers who are able to reduce their consumption for those hours with "points" that can be redeemed for cash or energy savings devices such as smart thermostats or automated plug strips, or donated to charities or local projects such as school PTA fundraisers.

EPRI (1020871): Results of a study to assess the achievable potential for electricity energy savings and peak demand reductions for the Tennessee Valley Authority (TVA) for 2010-2030. March 10, 2010

EPRI (1016987): Assessment of Achievable Potential from Energy Efficiency and Demand Response Programs in the U.S. (2010 - 2030). Jan 14 2009

EPRI (3002008225): Demand Response Landscape and Best Practices: Driving Towards Fast and Flexible DR. June 2017

Highlights key trends in market and policy development impacting current DR; assessment of resulting implications for DR and enabling technology alternatives.

EPRI (3002010195): Driving Towards Fast and Flexible DR Leveraging Distributed Resources. December 2017

Distills literature reviews and industry interviews to identify promising DR strategies for providing fast and flexible services in select industrial customer sectors, including refrigerated warehouse and data centers.

EPRI (3002006187): Multi-Year Study of the Impacts of OG&E's SmartHours Residential Electric Service. May 2017

Goal was to quantify the extended subscription (three years) customer response of SmartHours Variable Peak Pricing (VPP) and VPP Plus (same as VPP base service except that customers received a Programmable Communicating Thermostat (PCT) upon enrollment) participants. The study investigated the effect of price, temperature impacts, persistence and other influences. Data for 13,220 customers on 259 weekdays in the summer months of 2012, 2013, and 2014, resulted in 3.423 million observations

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